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Aquatecture. Macro-design Projects on the Theme "Water": *CrossRoads in the Sea*

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Three additional **Aquatecture** project reports are available under the subtitles:

Floating Fields
Patterned Energy
Mobile Offshore Industry

Detailed information on the Structured Planning process used for this project can be found in papers by Prof. Charles Owen on the Institute of Design web site: www.id.iit.edu

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Preface

Mankind is inextricably bound to the water. Beyond our own obvious physiological needs, there are its associations with other life forms of concern to us, its importance as a medium for transportation and commerce and, above all, its very omnipresence. Three quarters of the Earth's surface is covered by water, and a great percentage of the world's population lives close to large bodies of water.

The contrast between development of the resources of land and sea, however, is sharp. The disparity suggests that, as we near the new millennium, we consider thoughtfully how to extend to the seas the understanding we have gained in developing the land for human habitation and support of our societies. Activities that were conceived for and evolved on land might now be better conducted on the waters, given the maturation of our technological knowledge and the crowding of our land base.

Aquatecture is a conceptual systems design project. Drawing on the computer-supported techniques of Structured Planning, it explores possibilities for uses of water resources for food production, transportation, energy development and manufacturing. Four subprojects: **Floating Fields, CrossRoads in the Sea, Patterned Energy** and **Mobile Offshore Industry**, deal individually with these subjects. In separate project reports, each speculates on how a "macrodesigned" environment might be developed using known technology to expand the uses of the seas, lakes and rivers as space, media and sources of energy, food and raw materials. This report describes **CrossRoads in the Sea.**

All four projects were done in the Fall 1986 Systems and Systematic Design course at the Institute of Design. This course is the final course in a three-course sequence for product design students beginning with Product Design, continuing with Environmental Design, and ending with the Systems and Systematic Design course. The Systems course is concerned with products working in concert to achieve goals; the development of comprehensive design concepts; the problems of teamwork in design; and the use of systematic, computer-supported design techniques (Structured Planning) for handling complex problems.

The topic for the fall 1986 course was the Japan Design Foundation's Third International Design Competition. Within the competition theme of "water", four study areas were set out: food production, transportation, energy and materials processing. Research in these areas evolved projects, collectively entitled "Aquatecture", which explore visions for uses of the oceans, lakes and rivers.

The projects were completed in four months and submitted to the competition in January, 1987. From a field of 2,281 entries representing 58 countries, 1,144 projects were actually submitted from professionals and students in 48 countries. All four of the Institute of Design projects survived the first round to be among 59 finalists. After another month of work to prepare final presentations, a second submission was made in June. Final competition results were announced in August: the four Aquatecture projects were together awarded the Grand Prize of 10,000,000 yen ($78,500). The award, made in Osaka on October 30, 1987, marked the second time in three competitions that Institute of Design students had won the Grand Prize.

The projects received considerable attention in the world press. Perhaps the best presentation of them was in the Italian international magazine of architecture: ***L'ARCA***. Its April 1988 issue (No. 15) contains a ten page article with a number of drawings and color photographs.

Charles L. Owen, Advisor and Editor

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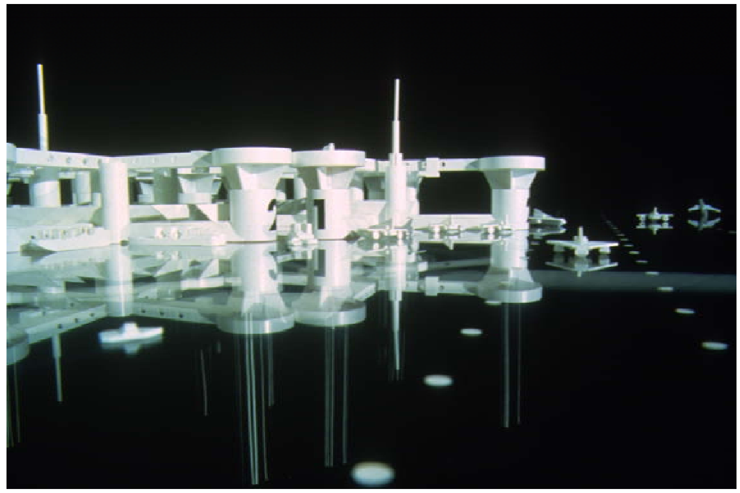

Figure 1 **CrossRoads in the Sea**
A system of floating aquatectural megastructures can be assembled into air/land/sea transportation interchanges that take advantage of the seas and lakes adjoining many of the world's major cities.

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CrossRoads in the Sea

Overview

Transportation in a world of growing population and denser population centers faces dilemmas of space and location. Trends are to larger and larger "regional" interchanges for intermodal transportation, but these, because of their size and activity, must increasingly be located at inconvenient distances from the urban centers they serve. "CrossRoads in the Sea" examines the potential for floating "aquatectural" structures of great size to take advantage of the nearness of the great majority of large urban centers to large bodies of water.

The aquatectural Interchange structures of the CrossRoads system are approximately 400 meters square and rise 60 meters above the water surface. Elements of the structures above the surface serve shipping and air traffic. Large seaplanes use water lanes marked with lighted buoys as runways; vertical and short-take-off-and-landing aircraft (VTOL and STOL) operate from the topmost level of the structures. Below the water level, Submarine Connection tubes 20 meters in diameter connect units of the system, conveying people and cargo, and providing channels for utilities and telecommunications. Where feasible, these also connect the system to land with multiple lanes of rail traffic. All structures (including the Submarine Connections tubes to land) are buoyant and are held below the surface with cables tensioned dynamically to adjust to tidal and weather conditions.

An important concept of the CrossRoads in the Sea is that it places the connections between major modes of transportation within a concentrated area—a multi-modal interchange. This has readily apparent value for air and rail traffic, and will become increasingly important for sea transport as shipping becomes more highly integrated with delivery service transport and additional destinations, such as aquatectural industrial centers, begin to appear. Passengers are also turning to the sea in numbers as the cruise ship industry has seen, and high-speed passenger ships are

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becoming more important in local transportation. It is not improbable that water-based transport will be a major factor in the transportation industry of the next century.

General Description

The CrossRoads system is made up of one or more Interchange Units anchored to the sea floor, connected to each other and, in some locations, connected to land by a submerged vehicular passageway. Each Interchange Unit is in its own right a complete terminal; larger installations of multiple Interchange Units allow greater amounts of traffic to be handled or specializations to be made to take advantage of transportation modes feasible at a particular geographic location.

Each Interchange Unit has four Arms arranged in an "x" pattern around a Central Core (where most services are located) and terminated by vertical Cylindrical Buoys topped with Landing Pads. An Arm has a number of operating levels, or decks, which are functionally different depending on whether they are above or below the waterline. For identification, decks are numbered according to their distance in meters above or below the waterline; the waterline deck is the 0 deck; decks above the waterline are +; those below are -.

From the 0 deck upward in the Arms, there are three main levels. At the +2.5 level general loading and unloading of cargo takes place. Component parts for the Interchange Units and major equipment is also stored here. In essence, it is a cargo bay. At the +10 level, embarkation and disembarkation of passengers takes place from both ships and sea planes. Gates are located here, along with processing counters and waiting areas, much as is seen in conventional air terminals. The +14 deck contains general circulation passages from and to the gates. Mechanical walkways assist travelers here, as it can be expected that people will be walking with hand luggage or carry-on bags. Passengers disembarking at a gate reach the walkway on the +14 level by escalators and pass along it to the Central Core.

Below the waterline, there are four main levels in the Arms. Decks -9, -11 and -14 each have two central conveyor belts with storage areas alongside them throughout the length of each Arm. Deck -18.5 contains the main conveyor belts for heavy cargo. All cargo handling decks are connected vertically by freight elevators, and all operate in both directions; that is, they move cargo to the gates or to central storage and claim areas.

In the Cylindrical Buoys at the ends of each Arm are additional facilities. At the top of each (level +55), is a Landing Pad with hydraulically operated platform elevators capable of bringing large helicopters or VTOL/STOL aircraft down into the shelter of the Interchange Unit for loading, unloading, fueling and maintenance. The hangar level is the +21 deck. This deck is connected with passageway and cargo handling decks in the Arm by elevators. Below the hangar deck is the buoyancy chamber level. The buoyancy chamber is divided into four compartments which may be ballasted with water or pumped dry to adjust the Interchange Unit's trim and height in the water. Under the buoyancy chamber are fuel tanks for refueling planes and ships. These contain relatively small amounts of fuel (a week's supply), but are refilled from a major fuel supply center maintained at a safe distance from the CrossRoads installation. Finally, machinery for maintaining tension in the anchoring cables is located at the lowest level of the Cylindrical Buoy, and the anchoring cables themselves descend to the conical Bottom Anchors set in the sea floor (unless a section of the submerged vehicular tube is installed below the Buoy—in that case, the anchoring cables run from the control machinery around the tubular structure to the sea bottom).

On the top surfaces of the Interchange Unit are the control tower for air and sea control and masts for telecommunications. Two systems of cranes along the Arms are positioned to reach all locations—one system is specifically used to transport parts where needed when structural changes or repairs are made; the other performs the routine tasks of loading and unloading cargo.

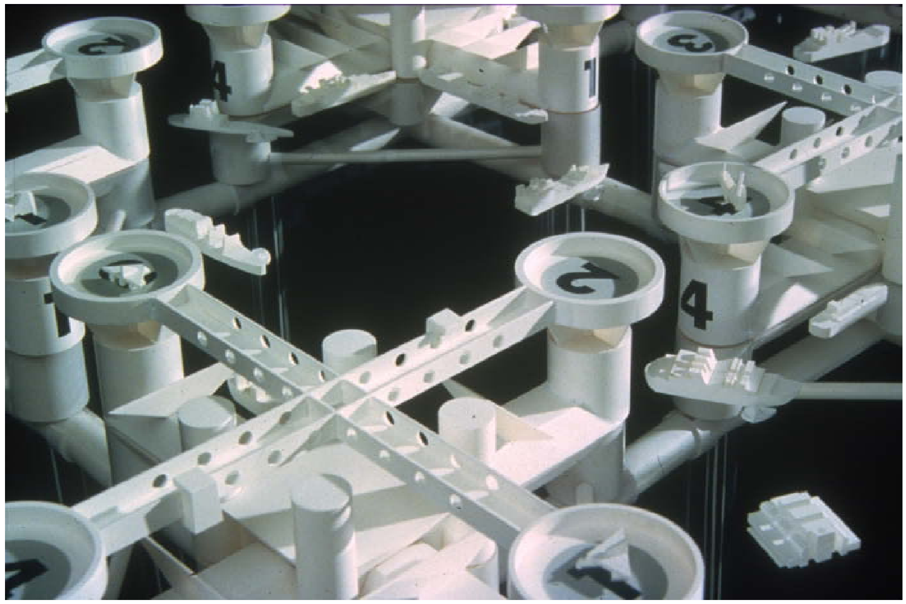

Figure 2 **Modular Segments**
Massive floating modules can be assembled into large or small arrangements to suit the kind of regional or local transportation interchange requirements. Parts of four "x" shaped modules can be seen in this abstracted model.

All structures and processes converge on the Central Core. From top to bottom, the Central Core has the following organization. At the top, in addition to the communication and control centers, there are: a terrace for outdoor sports, a solarium, a pool, gardens and a green house. From levels +35 to +22, five decks house crew quarters, a hotel, shops, entertainment areas, restaurants, bars, cinemas and areas for the support of other social functions. Management offices and the offices of airline and shipping line firms are also located on these levels. In total the five levels cover 16,000 square meters. The next three levels continue functions from the Arms into the Central Core. Levels +14 and +10 converge over a central lobby at the +2.5 level. Here are offices for customs and police, baggage claim areas, duty-free shops and counters for airlines and shipping firms covering a total floor space of 11,200 square meters. Levels in the Central Core are accessed by a battery of elevators at each of the four corners of the space, in between the Arms. Below the waterline, Central Core decks from -9 to -18.5 are devoted to processing cargo and luggage destined for land or other Interchange Units by way of the submerged vehicular tube called the Submarine Connection. Cargo and luggage are passed down by conveyors and automatically directed to their destination by a computer system that reads processing tags attached to each piece or package. From levels -20.5 to -38.5 are five decks of machinery, service and control offices, and specialized facilities for crew operations. The lowest level houses the entrance to the train station for rapid transit vehicles using the Submarine Connection. Rapid transit trains travel in a circuit around all Interchange Units before returning to land.

The Submarine Connection is a submerged tunnel connecting Interchange Units and, where viable, connecting the CrossRoads facility to land. It is suspended below the Interchange Units in the CrossRoads installation, and is anchored to the sea floor by Bottom Anchors along its path to land. Within a tube 20 meters in diameter, are five functional decks. One is for a rapid transit train system, the others convey cargo and luggage or contain piping and cables for utilities and telecommunications.

Movement of People

Three kinds of passengers can be distinguished:

A

Passengers who have arrived from land (urban environment) to initiate a trip, or have completed a trip and are departing for land. In this case, the modes of arrival or departure are: Ferry, in the case where the CrossRoads system is in relatively close neighborhood to land (less than 15 kilometers) and travel time is not a major consideration; Helicopter (or VTOL aircraft), where the offshore distance is greater or time of travel is important; and Rapid Transit, where the CrossRoads system is close to an urban center and a Submarine Connection tunnel can be economically routed from the city center.

In each of these cases, the traveler arrives at a designated entry port on an Interchange Unit, and then travels by internal transportation to the designated departure terminal (each Interchange Unit is a terminal). At the terminal, the internal trip continues down one of the four Arms to a departure gate on either side, or to elevators leading to the Landing Pads on the top deck. In the case of the traveler returning to land, destination may also be the terminus for the rapid transit system in the Submarine Connection beneath the terminal.

B

People who are changing from one mode of transportation to another, or who are changing vehicles (and/or carriers) between legs of a multi-stop journey. Possible combinations are: airplane to airplane, ship to ship, intermodal transfers and transfers between long distance transport modes and local modes (VTOL aircraft, helicopters, ferries and rail transit).

In all cases, luggage and cargo can be passed from one mode of transport or particular vehicle to another. The passenger has alternatives for how to spend time between trips, ranging from waiting halls to sleeping "capsules", and including entertainment and dining centers, and—if the delay is sufficiently long—hotel quarters with full facilities. Supplementing these, are shopping facilities, duty-free shops and many of the amenities of a small city.

C

People who have arrived at the CrossRoads facility as a port of entry to the country. In this case, there is a requirement for additional facilities specifically to handle customs, immigration and security.

Structural Component Elements

The structure of an Interchange Unit uses, for much of its volume, four basic, repetitive elements.

Structural Platform

This structure acts as a Service Deck (housing shafts, pipes, ducts and pumps for electrical, heating, ventilation, air conditioning and water systems), and as a Technical Equipment Deck for the location of heavy equipment. The basic construction element is a perforated structural steel beam in the shape of an "I", high enough in cross section to permit human movement through its perforations for inspection and maintenance operations within the platform it encloses. Forming a square grid 20 meters on a side in plan, the Structural Platform plays its structural role in closing and completing an element of the three-dimensional space grid, giving it strength and solidity in the horizontal plane.

Tetrahedral Spatial Module

Formed from perforated structural steel beams rising or descending to a vertex from a Structural Platform, this element is the spatial module for the Interchange Unit.

Design of its connections is guided by how loads are transferred within the structure. Loads are carried by the beams of the Tetrahedral Spatial Module down to the square frame of the Structural Platform. Large in-plane gusset plates welded in the corners of the Platform strengthen the joints at the points of greatest stress.

Repetition of the Tetrahedral Spatial Module with its integrated Structural Platform creates the primary structural unit of the Interchange megastructure and configures it as a kind of gigantic Viereendel beam.

Intermediate Floor

Not a structural element, an Intermediate Floor has only to support its own weight plus the static loads of equipment and the active loads of the movement of people. An Intermediate Floor is modularly designed in a rectangular format and is easy to install or remove (plug-on). Light concrete is used for construction (8-12 cm. thickness); connections between Floors establish a structural continuum. The design treats floors as movable elements in a kit of parts that makes it possible to place decks inexpensively where needed.

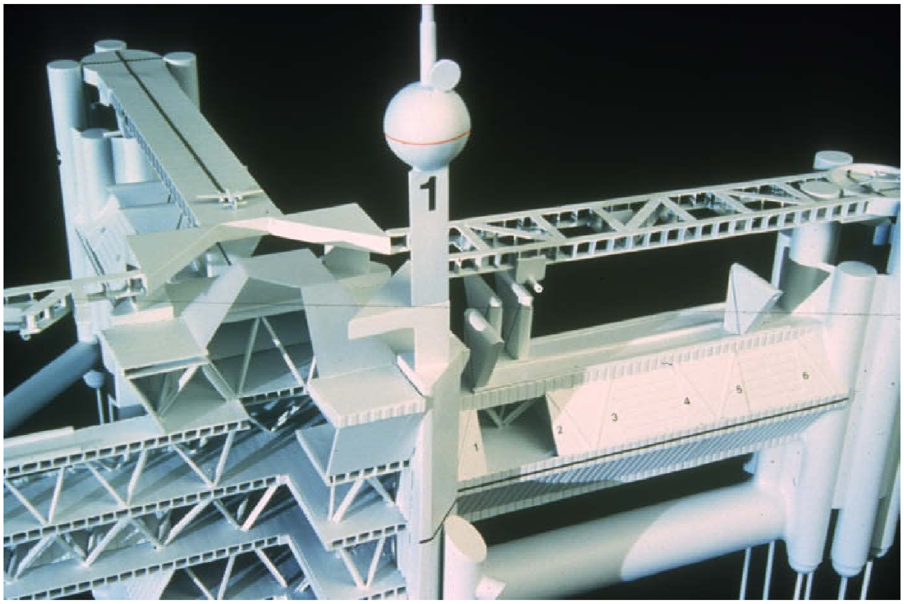

Figure 3 **Module Construction**

A cut-away view shows elements of the "x" module's construction. Cylindrical Buoys at the ends of the arms are the flotation elements. Connecting them to the central core below water are large-diameter Submarine Connections. Above water, Structural Platforms are connected above an below each other with Tetrahedral Spatial Modules, and external Shells above and below water are added for covering. Landing Pads on the top of the arms provide special runways for helicopters, STOL and VTOL aircraft.

Shells
Two kinds of Shells are used in the Interchange system.

Upper Deck Shell
This is a weather shell for use above water. Typically used for such purposes as hangar doors, and sometimes having transparent elements, Upper Deck shells are constructed of syntactic foam sandwiched between light steel surfaces.

Lower Deck Shell
Made of reinforced concrete and syntactic foam in a sandwich construction, this shell is waterproof and capable of sustaining the high levels of hydraulic pressure to be found at the deepest submerged levels of the Interchange Unit.

Other Elements

Cylindrical Buoy
Cylindrical Buoys 50 meters in diameter are the main flotation control structures of an Interchange Unit. Constructed with sealed compartments for ballasting and flotation, a Buoy mixes open compartments for controlled water ballasting with air-filled compartments and filled compartments for permanent buoyancy. Buoys are constructed of reinforced concrete, with syntactic foam used to fill voids designated for permanent buoyancy. A fuel tank (serving the associated Arm of the Interchange Unit) is located in one of the lower voids of each Buoy; cable control equipment for positioning occupies the lowest compartment.

Landing Pad
On the top deck, over each Cylindrical Buoy, is a Landing Pad for VTOL aircraft, STOL aircraft and helicopters. The Landing Pad is articulated in sections and is reachable by hydraulic elevator that can move aircraft for embarkation, disembarkation or maintenance from the Pad to a hangar located below. Other elevators connect the Landing Pad and hangar to people-moving and cargo handling passages in the Arm below.

Bottom Anchor
Below the fuel tank at the bottom of each Cylindrical Buoy is the machinery and cable control equipment for positioning the Interchange Unit. Spherical attachment points with two degrees of freedom guide the cables toward the bottom. On the sea floor, conical foundations with similar movable attachment points receive the cables and anchor the Interchange Units. Computer control of tensioning machinery maintains the Units in position over the Bottom Anchors.

Central Core
The four Arms of the Interchange Unit meet at the Central Core, which holds most of the amenities for crew and passengers and performs all of the central functions for the Interchange Unit.

Submarine Connection
Tubular elements 20 meters in diameter connect Cylindrical Buoys with the Central Core in each Interchange Unit and join Interchange Units to each other in larger CrossRoads installations. Submarine Connections may also extend to land, in which case they serve as channels for utilities and rail traffic between the CrossRoads Interchange and land facilities. Well below the surface, where they are beneath the keels of the deepest draft ships, Submarine Connections are

constructed in long sections from reinforced concrete and syntactic foam. Towed into place along with other elements of individual Interchange Units, they are either assembled into the Interchange Units or, in the case of the specialized connections to land, are winched down to their submerged positions over a line of Anchor Buoys along the path to land. A Submarine Connection can handle four tracks of rail transportation in addition to conduits for utilities and telecommunications.

Cranes

20-Ton Upper Deck Cranes load and unload materials and equipment from ships and aircraft. These cranes are extendible and move horizontally along a rail system at the upper deck level. They are manned.

30-Ton Sky Cranes hang at the highest level of an Interchange Unit from a specialized truss and beam system, using the lower I beam as a rail. Designed to be used in construction, these cranes can move the heaviest equipment and component parts of the CrossRoads system. They are used primarily for assembly and remodeling as an Interchange Unit is modified over its lifespan.

Lateral Flotation Chamber

Connecting the Cylindrical Buoys, in the bottom of the Arms, are Lateral Flotation Chambers constructed of reinforced concrete and syntactic foam. These add additional flotation capacity and help, in the case of storm, to increase the stability of the overall Unit—essentially bringing the center of gravity and the center of buoyancy into coincidence.

Flotation Control System

Flotation control is handled by a central computer which takes into consideration all the variable sea and air conditions. Instructions from the Flotation Control Center are executed by the machinery in the Cylindrical Buoys, which make the actual corrections needed. Most corrections are made by taking in or letting out

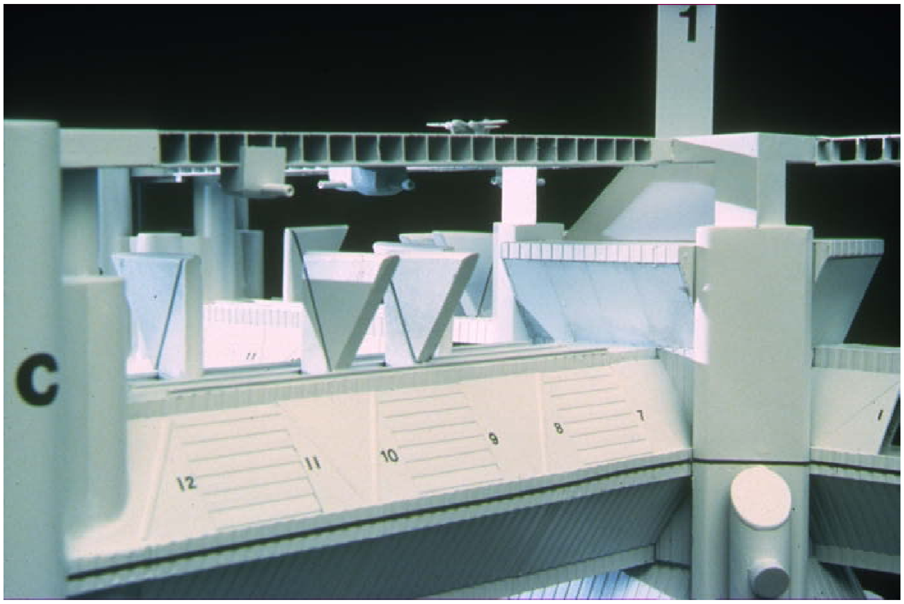

Figure 4 **Operations**

Ships dock along the cargo transfer positions numbered in the photograph. Massive cranes in the triangular-shaped housings move laterally to conduct loading and unloading. Cranes hanging from the highest level structures are used for construction and repair. On the Landing Pad, a STOL aircraft prepares to depart.

the anchoring cables to maintain proper tension. Special adjustments for the height of an Interchange Unit in the water can be made by adding or removing water ballast in the ballasting tanks of the Cylindrical Buoys.

Basic Structural Concept

To avoid excessive stresses, the high cost of maintenance, and a troublesome process of installation, the conventional technology of oil platforms was rejected. FTLP technology (Floating Tension Leg Platform), instead, offers very interesting opportunities for fast assembly, few on-site operations (especially desirable in deep waters), and mobility in the case of a need to reposition the whole structure.

FTLP describes a concept for a partially submerged floating structure held in place by cables anchored to concrete foundations at the bottom of the sea. As a positioning system, it takes advantage of the tremendous traction forces induced by the reaction of a large buoyant mass against tensioned anchoring cables.

On the bottom, some freedom in the tensioning system is provided by spherical joints in the foundation elements; at the surface, tensioning is controlled by taking up slack in the cables depending on the condition of the seas (winds, waves, tides, currents) and the proximity of other Interchange Units in the vicinity. Particularly in the case of major storms, this control of tension is a critical feature in the continual adjustment of position. Operations are entirely controlled by computer from each Interchange Unit in cooperation with others.

Structural Design

In addition to supporting dead and live loads, the structure of an Interchange Unit must resist waves, storms, wind and ice loads. The unit must be designed to withstand the conditions associated with severe hurricanes as well as the usual loads imposed by wave motions. Simultaneously, it must be able to support the heavy loads required for its operation and the changing loads of vehicles, supplies, shipments and crews.

The geometry of the Interchange Unit structure takes into consideration: (a) the complexity and magnitude of onboard equipment and transitional loads, (b) the severe stresses imposed by storms, wave motion and water pressure, (c) the number, sizes, capacities, maneuvering capabilities and support requirements for the kinds of vehicles that will use the Interchange (seaplanes, VTOL and STOL aircraft, helicopters, passenger ships, freighters, tankers, ferries and railroad vehicles), and (d) the variable conditions of sea environment in terms of currents, depth, adjacency to coastal lines and different climates that may be encountered in places of potentially important location. Because many of these factors are difficult to predict in advance, and the combinations of possibilities are astronomical, the system was designed from the outset for multipurpose use.

Fabrication

Interchange Units are prefabricated in component sections towed separately to a location site for final assembly. Central Cores, Cylindrical Buoys and complete Arms with their buoyant underbodies are thus floated and augmented on site with smaller components shipped by barge. Foundations installed previously on the sea or lake bottom are used immediately to anchor the sections during the assembly process. The cabling system used becomes the dynamic positioning system after installation.

Accessory work includes the separate construction of central fuel storage facilities. Major fuel resources (for ship, aircraft and wheeled vehicle refueling) are kept at a distance to reduce the hazards of explosion in the case of accidental or natural disaster. Relatively small amounts of fuel in the form of weekly supplies are retained in the Interchange Units.

Materials

Principal construction materials and the relevant considerations for their use in the CrossRoads system:

Concrete. Concrete responds favorably to the sea environment and resists abrasion and buckling. High pressures and low temperatures enhance its basic properties, resulting in increases in strength and modulus of elasticity. It has the additional attractive advantage of being very economically molded into desired shapes. Well made structural concrete is highly resistant to the attack of micro-organisms, but permeability can be a problem if salt cells are allowed to form where they can corrode steel reinforcement materials. Waterproofing, accordingly, is commonly used in the form or epoxy paints or bitumastic resins, and cathodic protection may be applied where there is penetration by metals in such a way that the metals are directly exposed to the water environment.

Metals. Metals corrode quickly in sea water, less quickly in fresh water, to form metal compounds such as oxides, hydroxides and chlorides.

Cathodic protection prevents corrosion by inducing an electrical current flow in a local environment so that metal components to be protected are turned into cathodes instead of anodes. By this process, a sacrificial metal, like zinc, is allowed to "corrode" in place of the protected component. Most practical cathodic protection methods involve using magnesium or galvanic surfaces, using sacrificial anodes or impressing permanent currents (12 volts) on structures likely to corrode.

Where exposed steel is unavoidable, low carbon and stainless steels are recommended, especially for equipment such as piping, tanks and heat exchangers. Another solution for corrosion is the use of organic coatings like alkyds, chlorinated rubber, phenolics and vinyls. These can be used as paints or primers. There are also special cases where corrosion-resistant metal coatings can be applied, by electroplating or other technique, to components which must be exposed to a corrosive environment, but require construction from otherwise corrodible materials.

Syntactic Foam. Syntactic foam is a light-weight, composite material consisting of a low-density, hollow-microsphere filler embedded in a resin matrix. The resulting cured material is a solid which can be machined to desired shape. It has wide application for buoyancy and structural applications. Some general properties are: low density (weight saving), low maintenance requirements (because of its high resistance to corrosion), low water absorption (if Leakage occurs), low cost, sufficient strength, and good acoustic and thermal insulation.

In the construction of Interchange elements, syntactic foam has several important applications. Voids filled with syntactic foam ensure fail-safe flotation. Interior panels of syntactic foam faced with other materials are good thermal insulators, eliminating problems of sweating inherent where heat transfer between warm interior and cold exterior environments is a problem (typically, underwater). Sandwich construction, generally, with syntactic foam providing strength, rigidity and buoyancy is a low-cost technology important in projects the size of the CrossRoads system.

OTEC

Ocean Thermal Energy Conversion. More than 70% of the surface of the planet is covered by oceans. Of the total solar energy that reaches the earth's surface, approximately 45% is absorbed by the surface layers of the seas, especially in tropical and subtroplcal areas. Because of the difference in density between the warmer surface layers and colder water masses below, very little mixing occurs between them.

The power plant for each Interchange Unit is dispersed among four independent corner columns surrounding the Central Core. Each 80-meter high column houses a turbogenerator, an evaporator a condenser, pumps and water intakes for both cold and warm water.

The power cycle proceeds as follows: Warm surface water is first pumped through the evaporators in the top of each power column module. Each evaporator is, in essence, an enormous heat exchanger transferring heat from the warm water to liquid ammonia and, in the process, evaporating it. As the ammonia vapor expands, it is channeled past the wheels of the turbine; the pressure of the expanding vapor against the blades of the turbine wheels turns the turbine producing mechanical energy as shaft rotation, which is converted to electricity by the generator directly coupled to it. The relatively cool ammonia vapor then flows to the condenser where it is condensed back into liquid form by cold water pumped up from the lower water levels. As liquid ammonia, it is returned to the evaporator to renew the cycle.

An OTEC heat engine is expected to supply significant amounts of electric power at very competitive cost. Each one of the Interchange Units is in this way can be relatively independent in its use of energy. In some locations, where temperature differentials are great enough, there is an additional gain possible. Under these conditions the heat exchange fluid can be sea water itself. In this case, there is a significant byproduct: fresh water—which can be used as an auxiliary supply for human consumption.