AQUATECTURE:

UNDERWATER DWELLINGS AND SEA BORN STRUCTURES

AS PARADIGMS OF DESIGN

by

RICARDO GUILLERMO

B. Arch., The Cooper Union, School of Architecture

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ABSTRACT

There are many reasons for undertaking a work such as this. Among them are the benefits offered to society when we acknowledge the potential of submersible structures. The provision of habitable underwater space remains an unexploited resource of great potential. Hopefully, it will be utilized in an ethically intelligent manner. Perhaps, the spiritual qualities of water will foster peace engendering or life sustaining pursuits resulting in paradigms of new urban forms and ideals.

Herein, a broad view is offered of inspirations and ideologies leading towards a conceptual basis for sea dwellings. Developed from an ontogenesis into criteria for environmental design, siting, energy options and program ethics, a platform for establishing a sea utilization framework is imparted.

The structural design development incorporates fundamental considerations for aqueous habitats. Reinforced concrete for sea use is discussed in depth including expositions on hydraulic cements and construction techniques.

A basic sea structure design/analysis method which uses thin shell theory to reliably approximate the behavior of thick shells is presented through both simple and complex examples. The volume concludes with a metamorphosis of sea dwelling concepts in the form of original sketches, technical drawings and tone paintings.

This thesis attempts to broaden the scope of knowledge of the architectural designer and planner through an effort to bridge ocean sciences, ocean engineering and architectural concerns. With the knowledge thus gained, it may be possible to project further into civilization's potential for cultural development within the limited context of the sea as a dwelling place.

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Thanks especially to Waclaw Zalewski and Ellen.

DEDICATION

To, Gregory Victor, Garlic, and the rest of the next generation.

CONTENTS

SOCIAL BENEFITS

There are many reasons for undertaking a work such as this. Among them are the benefits offered to society by the proposals which follow. First, acknowledge the potential of a submersible dwelling structure to meet human needs under the following conditions:

1) EMERGENCY Habitat Possibilities: In the event of natural emergency, there could be some Habitat possibility. Whether due to natural or man-made catastrophes, submersion in the sea would impart a buffering effect due to the sea's mass inertia. Natural catastrophes include earthquakes, tidal waves, monsoons, cyclones, hurricanes, floods and drought. Man-made catastrophe's include war, nuclear, chemical or biological fallout, calamitous noise, breakdown of the economic systems and increased ultra violet radiation. An increase in ultra violet radiation is due to the systematic depletion of the ozone layer by the environmental pollutants of society. Our planet is fragile. An increase of 1 to 2° Farenheit of the Earth's average temperature would melt

the icecaps, flooding most of the earth's major metropolitan regions, from 60 to 300 feet, according to various estimates.

2) CLIMATIC COMFORT Possibilities: Climatic comfort in inclement regions, whether due to heat or cold, could be efficiently achieved within a submarine structure.

3) HEALTH TREATMENT Possibilities: The thermal stability of the inner sea could provide some unforseen health treatment, either mental or physiological. A consequence of undersea dwelling is the relatively high ambient pressures which may bear alleviation for sufferers of pneumopulmonary diseases. Another benefit accrues from the rapidity with which open wounds heal in subsea dwellings. As an example of benefits for the mentally infirm, consider the delight imparted by the aqueous medium upon autistic children. In fact, water has a tranquilizing effect upon those receptive to it.

4) RECREATIONAL and EDUCATIONAL Possibilities: Recreational and educational possibilities are inherent in the development of underwater dwellings. Shelters for water sport enthusiasts and natural underwater reserves would increase popular

knowledge of the marine environment and could serve as bases for development of a meaningful science education program. Basic scuba diving incorporates a useful knowledge of gas laws, concepts of vision, navigation, hydrodynamics, water safety and lifesaving techniques, human physiognomy, marine ecology as well as coordination, training, exercise and the application of economy and grace in movement.

5) SCIENTIFIC RESEARCH POTENTIAL: Scientific research potential could further advance our understanding of the sea. Sea dwellings could enhance our ability to fruitfully manage our marine resources.

6) INDUSTRIAL and COMMERCIAL Possibilities: Industrial and commercial possibilities could also be examined. For example, the provision of usable space by and for developments of sea energy conversion. Seabased energy conversion sources could form nuclei for many types of developments from industries to residences.

7) MARICULTURE Possibilities: Mariculture could provide large, predictable crops, grown or raised in seawater. Traditional sea crops and traditional fresh water crops,

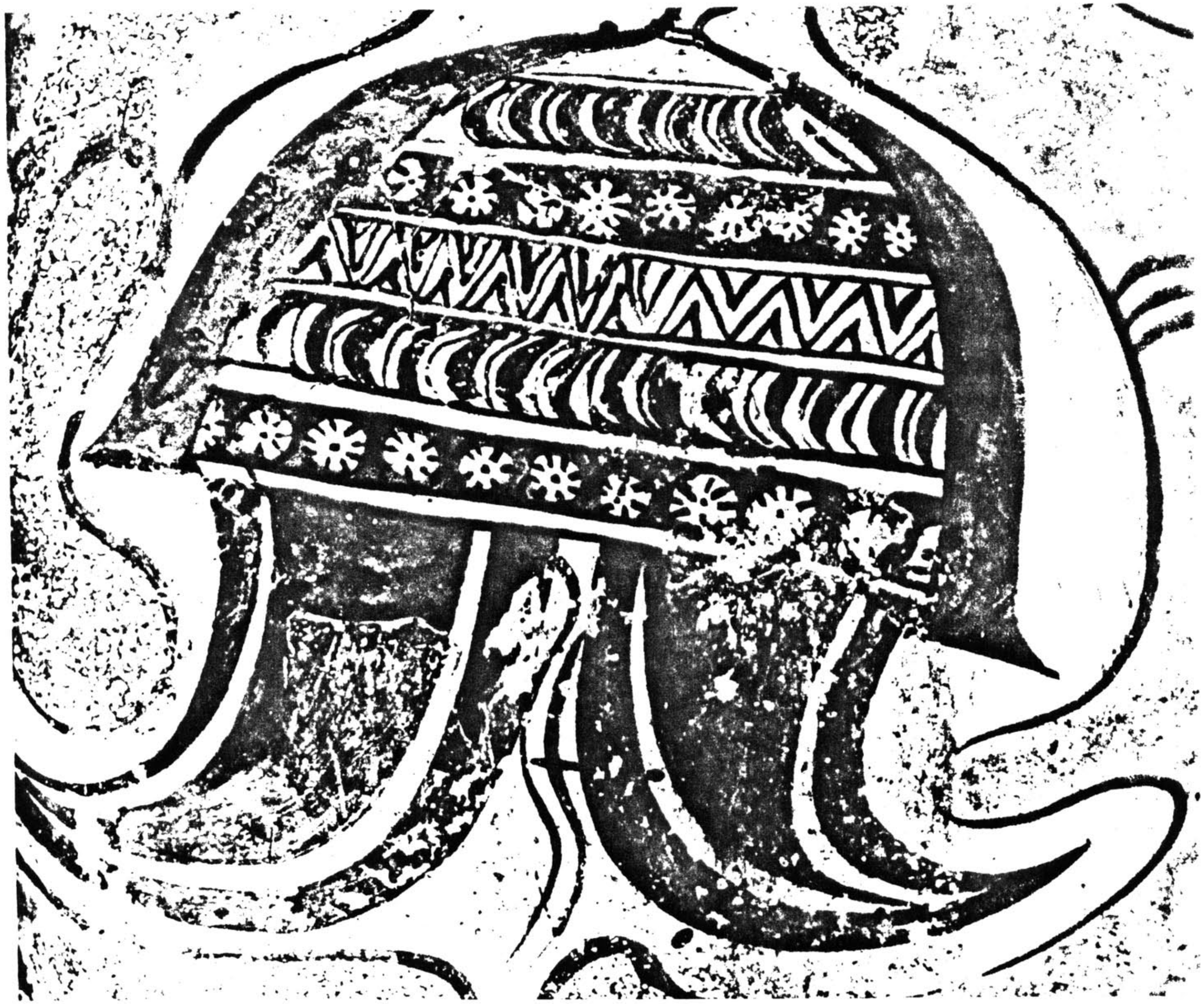
such as tomatoes can be cultivated in sea water. Mariculture farms could benefit from structural solutions for improving yields. Many marine organisms, such as seaweeds, shrimp, oysters, as well as a multitude of fish species have been cultivated commercially in the U.S., although not on such a great scale as in the orient, where seafood forms the protein and mineral base of sustenance.

8) LIFE UNDERWATER: Life underwater, the provision of habitable underwater space for large populations remains a resource of undetermined potential. The sea covers 3/4 of the earth's surface; man concentrates about the shores of bodies of water. Biologically, ecological edges bear a greater vitality of living organisms. Man has in his capacity, the ability to create new edges as do the coral. In doing so, a microecological system is established in which living organisms can thrive.

9) CULTURAL PARADIGM Possibility: As a cultural paradigm, the potential of new urban forms are inherent, including the full score of civic pursuits. As we revere the artifacts of the Minoan culture, we confront a culture born of the

sea. The legend of Atlantis and all the wishful thinking it has engendered bear testament to the associations society places on utopian models.

10) SPIRITUAL ORIENTATION: A spiritual orientation is also possible for man/woman kind as creative faculties could foster peace engendering i.e., life sustaining pursuits. The sea must not become the fodder of despots, as falling short of spiritual alignment would allow. For the majority of the earth's inhabitants who rely on the coastal zone, caring for it is a process of building knowledge and cultivating discipline. We must refrain from doing harm to the sea, such as dumping wastes or ignoring cycles. More than this, we must work constructively to enhance sea life as with all life on earth; to preserve it in its natural state, being free of society's materialistic toxins. This is the fundamental character of dwelling as mortals on the Earth.—This sparing and preserving by which we might "live in peace".



ILLUUSTRIOUS SEQUENCEES: ACTCYCLE CODEX

Animatica cosmologoloque della sforza attractione y
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Osiris genasio.
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Remembemammaillemberthesea.
Encyclica evolutionario.
Dedeluge buffetus arkus noahnna.
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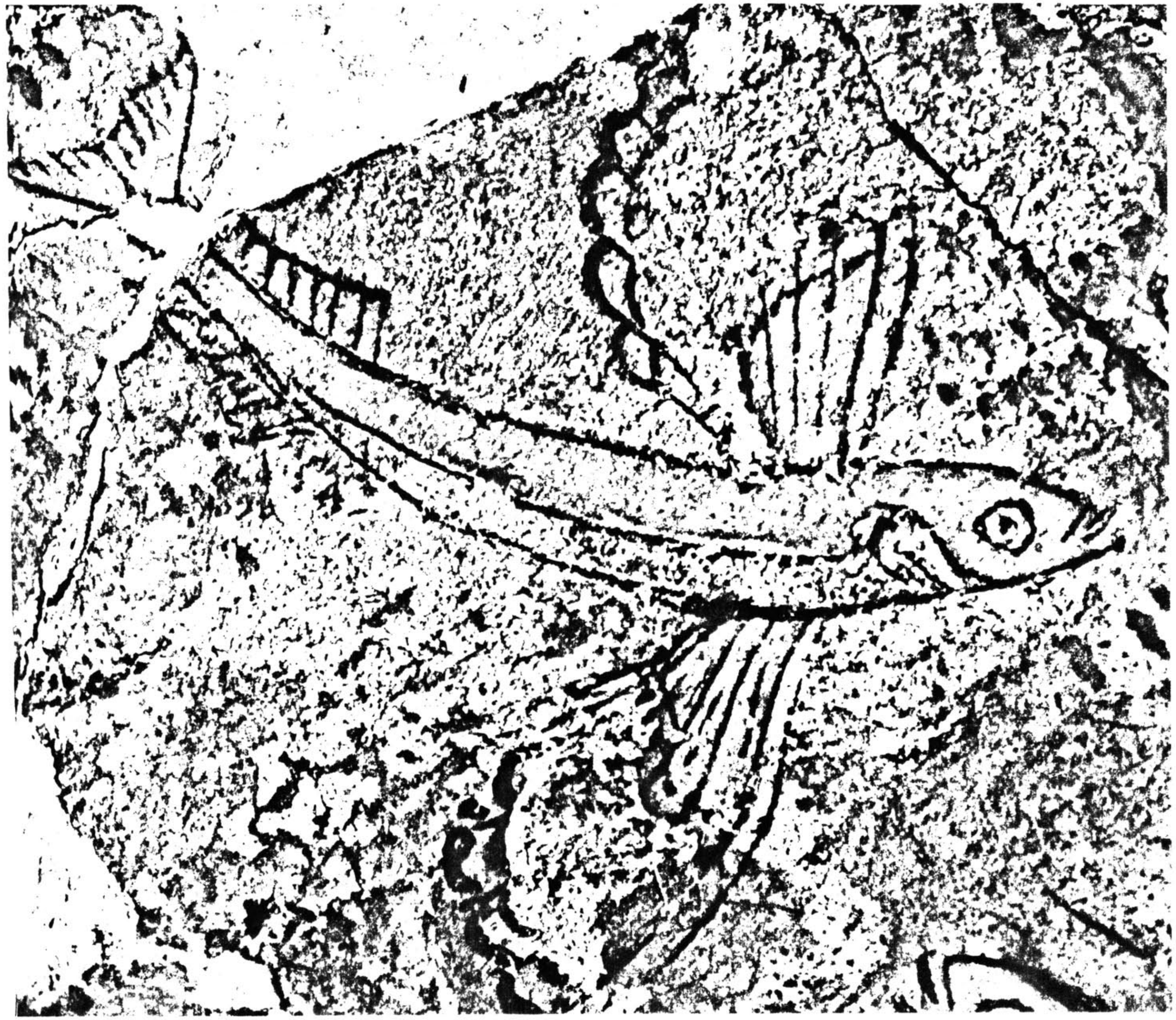
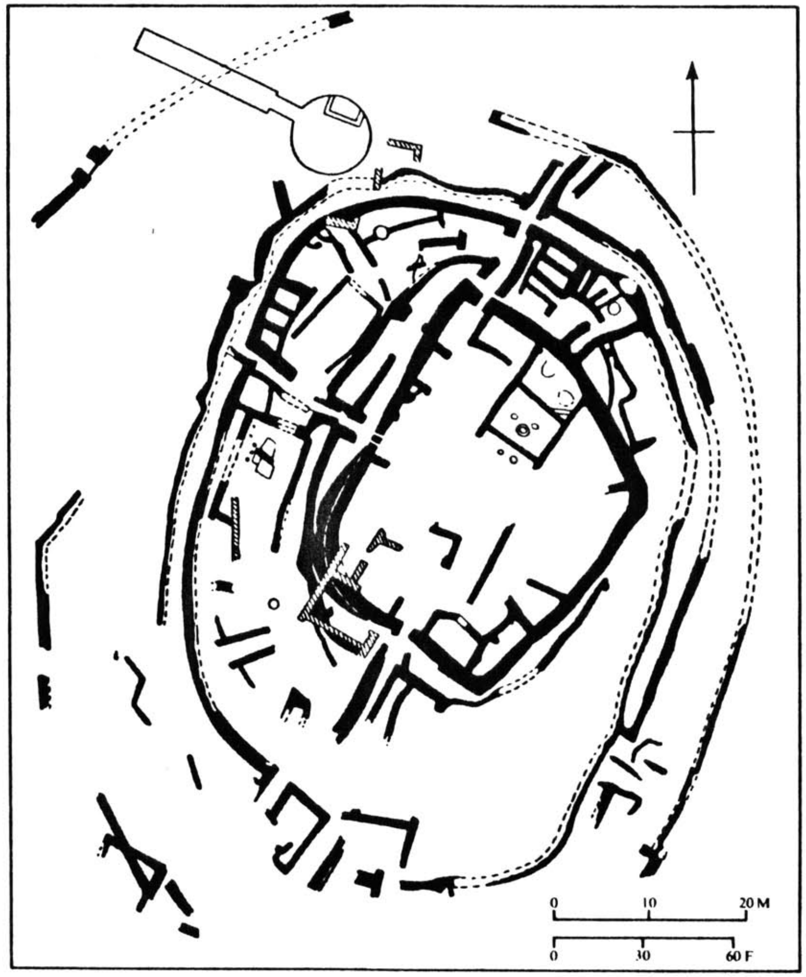
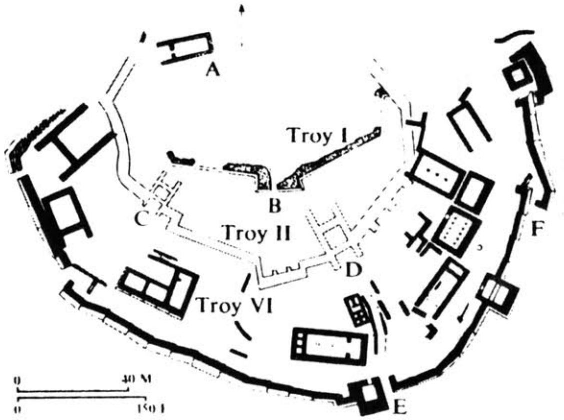




Dimini (Thessaly). *Plan of the Site.*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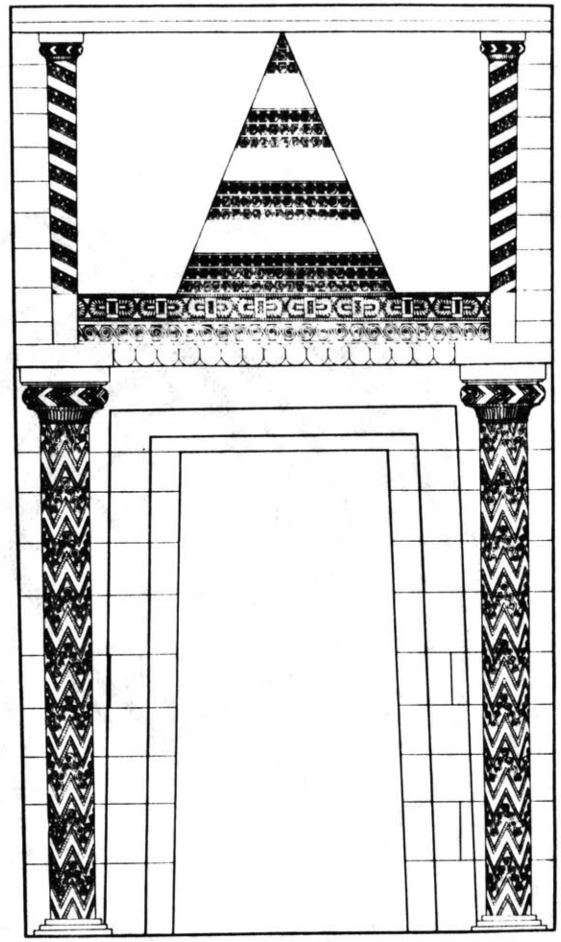
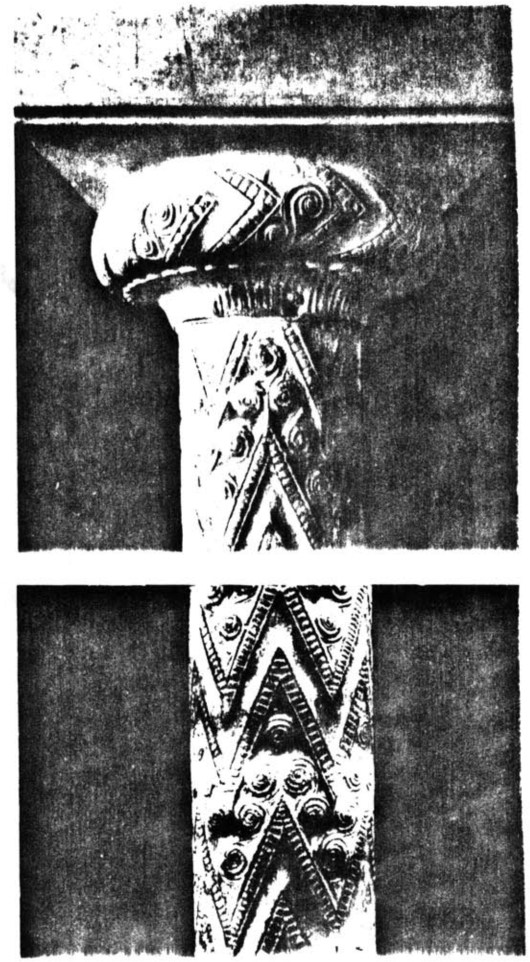
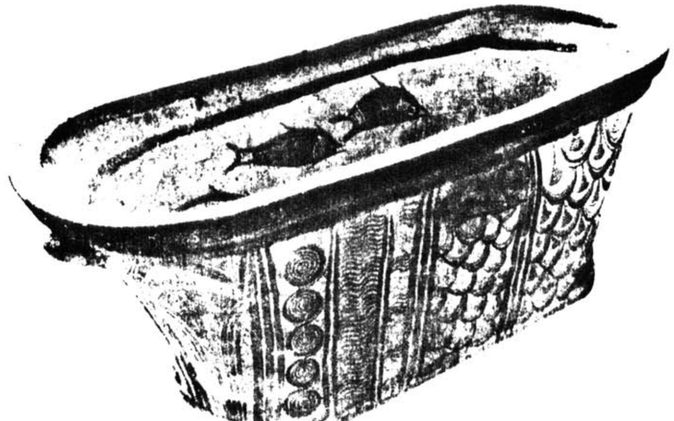
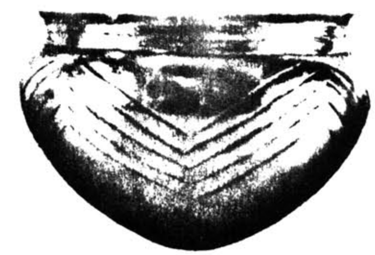
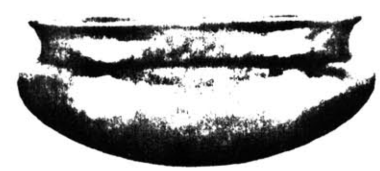


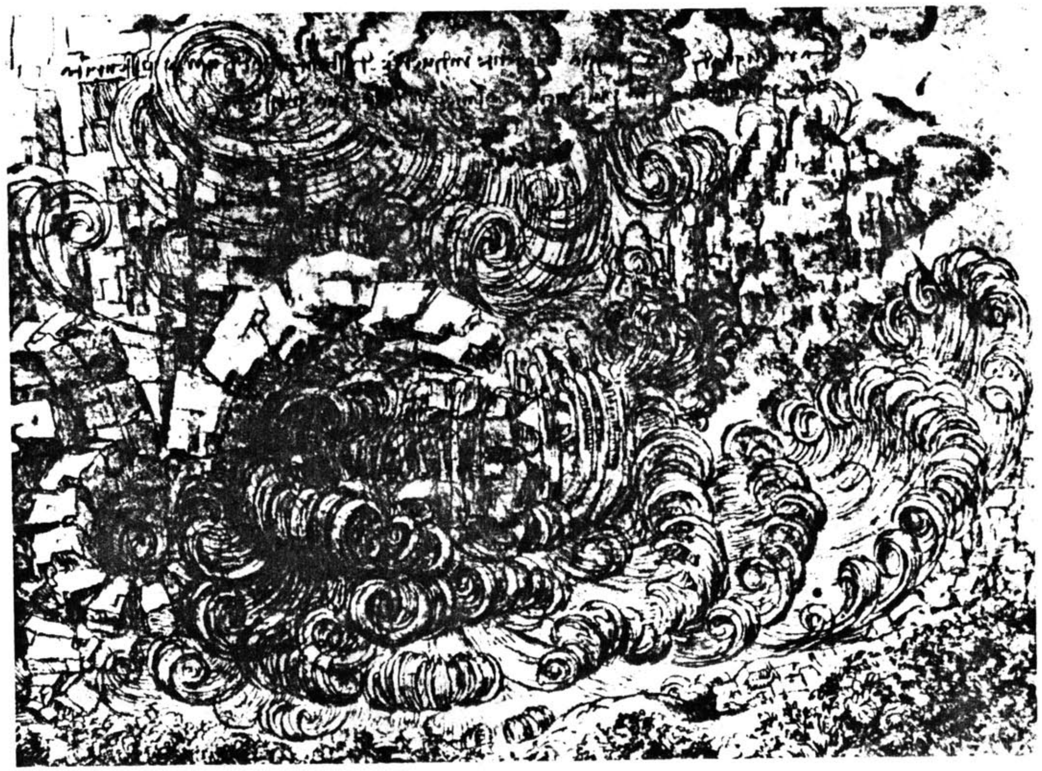








A drawing for the Deluge c. 1515 by Leonardo DaVinci.



The ideologic foundation of sea dwelling is a systematic body of concepts underlying the idea of sea dwelling. In founding such a conceptual basis, we must rely on the existing meanings of language, just as when we materially build such dwellings, utilization of grounded technology is necessitated.

Idea, the root of ideology, comes from the Greek, idein, to see. It means here, the visible representation of a conception, an entity actually or potentially present to consciousness. It is what exists in the mind as something represented. Synonymous with idea, thought suggests the result of reflection, meditation or reasoning, while conception stresses the process of imagining and formulating. On one hand, we have the conception of the sea, and on the other, we have the thought of dwelling. We must consider both and establish how they may belong together. In putting this forth, will the origin of the work be found.

The thesis put forward here is the origins of sea dwelling as a significant phenomenon. The concept of dwelling is bound with the concept of being and the process of coming to be, that is, the origin of being. Historically, being and art are analagous as the origin of both the creators and the preservers, a people's historical existence, is art. "Art is by nature an origin, a distinctive way in which truth comes into being, that is, becomes historical." The sea signifies origin as well. On a bio-evolutionary level, life began in the sea. Human blood maintains the memory of this origin as its chemical composition is similar to sea water. On a metaphysical level as well, the sea, in psychology, for example, is a metaphor for the unconscious, the psychic realm of the unknown in which imagination and creativity are borne.

Thus the origin of dwellings are to be found in art. This thought generates a series of concepts which will benefit the understanding of how this work relates to

Heidegger, M. <u>Poetry</u>, <u>Language</u>, <u>Thought</u>. (Harper and Row, 1971.)

culture.

The generating concepts are dwelling, sea and gathering. **Abstraction** of the facets of culture and their implementation as analytic deconstructors of the meaning of culture, dwelling, sea and gathering follow

IDEOLOGY CULTURE

Culture[1] is the integrated pattern of human behavior that includes speech, thought, action and artifacts and depends upon man's capacity for learning and transmitting a knowledge[2] to succeeding generations.

The voice is produced by our ability to inspire[3], that is, breathe, by virtue of our lungs and larynx. Thought is reasoning power. Conception, the power to imagine. Action is found in the figure, that is, in the graphic representation of a form, expecially of a person.

1 Webster's New Collegiate Dictionary (W.D.)

2 Knowledge can be thought of as nourishment by which succeeding generations can form culture. Nourishment is denoted by opening of the mouth by the chinese character symbol.

3 in + spirare (latin), to breathe.

IDEOLOGY/CULTURE/VOICE

The voice and speech, conception and thought, action[1] in the design[2] of figures and the resultant artifacts[3] are facets of culture. We can examine culture by the paradigm of voice, concept and figure.

Culture unfolds in the voice, especially in poetry and drama, song and discourse.

These derive from the epics through which the ethics and technology of Greek culture was diseminated. Often about the journeys of man, his capacity for life and death beneath the divinities, epics imparted upon the seafaring nations' astronomy and the power of celestial orientation and identification which is navigation.

The epics in turn are vestiges of the oral incantations and rituals which were the upwellings of ancient humanity's theological nature and need to apportion time.

1 Action is an act of will or a thing accomplished in time with the possibility of repetition, the unfolding of events or an operating mechanism.

2 Design: to mark out: to have as a purpose. Intend: to create or construct according to plan.

3 Artifacts are the products of civilization revealing the level of cultural and technological development.

"Language itself is poetry in the essential sense." Heidegger.

Rituals invoke the spring rains and return of the of the sun, the sowing and the harvest. The hunter vocally invokes the spirit of his prey in the mimetic dance. Marking the seasons thus, civilization and the earth weld their regenerating cycle. This is the origin of theatre. The aspect of rhythm and repetition of ritual are maintained in the matinee, evening and day to day performance of the theatrical play.

<u>ENTHUSIASM</u>

When, at the beginning of summer, thunder--electrical energy--comes rushing forth from the earth again, and the first thunderstorm refreshes nature, a prolonged state of tension is resolved. Joy and relief make themselves felt. So too, music has power to ease tension within the heart and to loosen the grip of obscure emotions. The enthusiasm of the heart expresses itself involuntarily in a burst of song, in dance and rhythmic movement of the body. From immemorial times the inspiring effect of the invisible sound that moves all hearts, and draws them together, has mystified mankind.[1]

[1] Wilhelm, R., Translator, <u>The I Ching</u>, (Princeton University Press, 1970)

Rulers have made use of this natural taste for music; they elevated and regulated it. Music was looked upon as something serious and holy, designed to purify the feelings of men. It fell to music to glorify the virtues of heroes and thus to construct a bridge to the world of the unseen. In the temple men drew near to God with music and pantomimes(out of this later the theater developed). Religious feeling for the Creator of the world was united with the most sacred of human feelings, that of reverence for the ancestors. The ancestors were invited to these divine services as guests of the Ruler of Heaven and as representatives of humanity in the higher regions. This uniting of the human past with the Divinity in solemn moments of religious inspiration established the bond between God and man.[1]

[1] Wilhelm, R., Translator, The I Ching. (Princeton University Press, 1970)

Incantation and invocation are the bringing forth through voice, the act of calling or summoning. The repetition of sounds, words, names. Symbolization of concepts or ideas by representations are formed with the flowing breath. This is the origin of poetry.[1] This breath itself is spirit, an animating or vital principle which gives life to physical organisms. The word spiritus is of Latin derivation and means literally, breath. Respire, to blow, breathe, has the same root and inspire, of archaic origin, means to blow into or upon, to infuse with life by breathing, to impel, motivate, affect, to draw forth or bring out, to incite. Inspiration is the action or power of moving the intellect or emotions as well as the act of drawing air into the lungs. Breathe means to take in oxygen and give out carbon dioxide as well as to make manifest to utter or express.

> "...in naming a thing, man, through his speech, creates it anew as a form in the space of air, insofar as his words still partake of the living origin of language. Everything surrounding us in nature has a part in the original gestures, but only a part. Man, uniting all nature, has at his disposal the whole - a whole alphabet ... The spoken word is more than the intellectual naming of a thing, more than a "nomen", it is form - creating, spiritual reality.[2]"

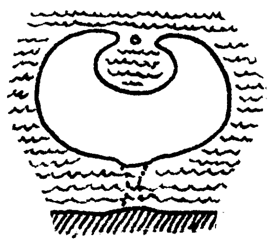
1 Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

2 Schwenk, T. Sensitive Chaos. (Schocken Books, 1976.)

CONCEPT

The concept of culture includes the ideal culture concept, the non extant or utopian culture, i.e., the culture existing nowhere. The concept of Utopia comes from Sir Thomas Moore's book bearing the same name. It brought him persecution as his free thought wrought a biting political satire of this culture. It forms his model for social scholars who have further developed the theme through the philanthropic development and the introduction of worker's housing and model cities.

Every act of building is initiated with the idea of an ideal outcome. Ideal cities are planned and built in that each planned city fits the criteria or attributes of the ideal in its time. Usually, cities do not maintain their character of ideal through time and so the ideal remains a concept.



Moore's Utopia, reconstructed from his writings, is a civil society of city-states equally spaced over a crescent shaped island, with a light-tower separating the shipping lanes of its circular harboring bay. It was severed from the mainland by its founder, Utopus, a military tactic which helped to resist attack and led to prosperity.

Island cultures of city-states occur throughout the globe in a multitude of forms and scales. (See chapter 4) The isolation thus engendered is equally represented by the moat surrounded castle or even the mass of the circumferential masonry wall of many inland cities of Europe. In that time, the landscape of the forest was as unknown and ominous as the sea is today to contemporary culture. What better example of medieval society than the cloud swept tower ideal. The final isolation from the threats of the earth was evinced by the masonic constructions of the crusades, culminating in the Gothic cathedrals. They embodied the concept of eternal life in the kingdom of God.

Throughout the Mediterranean Region, the seat of Western culture, from which most of our languages and customs derive, the cycles of conquests and trade have fertilized the different societies with culture along the route; the transference and transformation of technology.

Plato's Timeaus was spared from the fire at the great Library of Alexandria in Egypt. It recounts the legend of Atlantis, an ideal island culture. The builders of concentric canals with canals radiating to the four quarters of the earth from the inner sanctum. The circle concept is a common and recurrent attribute within a majority of the formulations of ideal cultures, as is the grid crossing of the cardo and the decumanus. Together they constitute the oldest representation of the concept city.

IDEOLOGY/CULTURE/FIGURE

Homer describes the concentric masonry walls of the Cyclopean dwelling place visited in the epic The Odyssey. They are to be found in Mycenae. The Labyrinth of the Minotaur may refer to the tile work of the court and plan of the Palace at Knossos. (Graves, Robert, The Greek Myths.) What remains of these legendary island cultures are the figures of artifacts in which they were manifest.

> "Whenever art happens - that is, whenever there is a beginning - a thrust enters history, history either begins or starts over again. History means here not a sequence in time of events of whatever sort, however important. History is the transporting of a people into its appointed task as entrance into that people's endowment ... Art is historical, and as historical it is the creative preserving of truth in the work ... Art is history in the essential sense that it grounds history." [1]

[1] Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

Some of the earliest egrarian cultures dwelt upon their bundled reed boats in the ancient Nile Valley. The earliest of the masonry buildings are derived from techniques and forms developed with the bundled reeds. (See Thor Hegerahl's Early Man and the Ocean.)

> "Art lets truth originate. Art, founding, preserving, is the spring that leaps to the truth of what is, in the work. To originate something by a leap, to bring something into being from out of the source of its nature in a founding leap - this is what the origin (German: Ursprung, literally, primal leap) means."
>
> "The origin of the work of art - that is, the origin of both the creators and the preservers, which is to say of a people's historical existence, is art. This is so because art is by nature an origin: a distinctive way in which truth comes into being, that is, becomes historical."[1]

[1] Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

"...art is or is not an origin in our historical existence." Under what conditions can it and must it be an origin? "Only such knowledge prepares its space for art, their way for the creators, their location for the preservers."

Can art be an "origin" and "head start" or does it "remain a mere appendix" only "carried along as a routine cultural phenomenon?"

"Are we in our existence historically at the origin? Do we know, which means, do we give heed to, the nature of the origin? Or, in our relation to art, do we still merely make appeal to a cultivated acquaintance with the past? For this either-or and its decision, there is an infallible sign. Holderlin, the poet ... named it in saying:

Schwer verlasst was nahe dem Ursprun wohnet, den Ort.
(Reluctantly, that which dwells near its origin departs) -

"The task is to see the riddle." [1]

IDEOLOGY/DWELLING: Voice/Language/Dwell

Being, building, growing and dwelling are the same thing in language.

"Dwelling and building are related as ends and means ... building is not merely a means and a way toward dwelling - to build is in itself already to dwell..."

"The Old English and High German word for building, buan means to dwell. This signifies: to remain, to stay in a place." [2]

1,2 Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

"... bauen, buan, bhu, beo are our word bin in the versions: ich bin, I am, du bist, you are, the imperative form bis, be ... ich bin, du bist mean: I dwell, you dwell ... The manner in which we humans are on the earth, is buan, dwelling. To be a human being means to be on the earth as a mortal. It means to dwell ... This word bauen, however, also means at the same time to cherish and protect, to preserve and care for, specifically, to till the soil, to cultivate the vine ... Both modes of building - building as cultivating, Latin colere, cultura, and building as the raising up of edifices, aedificare - are comprised with genuine building, that is, dwelling. Building as dwelling, that is as being on the earth, however, remains for man's everyday experience that which is from the outset "habitual" - we inhabit it, as our language says so beautifully: it is the Gewhonte. For this reason it recedes behind the manifold ways in which dwelling is accomplished, the activities of cultivation and construction. These activities later claim the name of bauen, building, and with it the fact of building, exclusively for themselves. The real sense of bauen namely dwelling, falls into oblivion.

"1. Building is really dwelling.
2. Dwelling is the manner in which mortals are on the earth.
3. Building as dwelling unfolds growing things and the building that erects buildings.

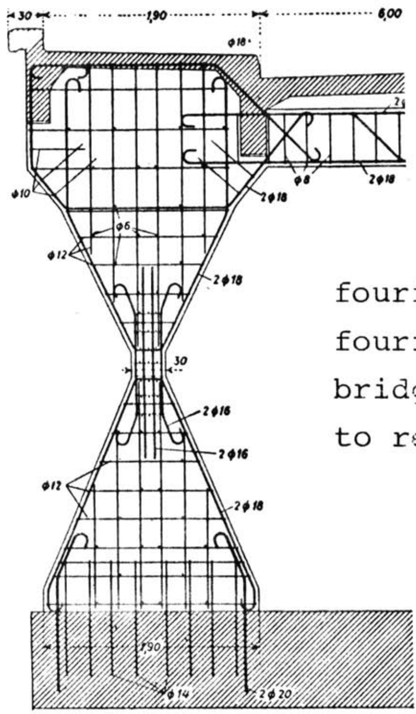
'...We do not dwell because we have built, but we build and have built because we dwell, that is, because we are dwellers.[1]"

1 Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

IDEOLOGY/DWELLING/CONCEPT: METAPHYSICS

"The bridge swings over the stream with ease and power." It does not just connect banks that are already there. The banks emerge as banks only as the bridge crosses the stream ... The bridge gathers the earth as landscape around the stream... "The bridge gathers to itself in its own way, earth and sky, divinities and mortals."

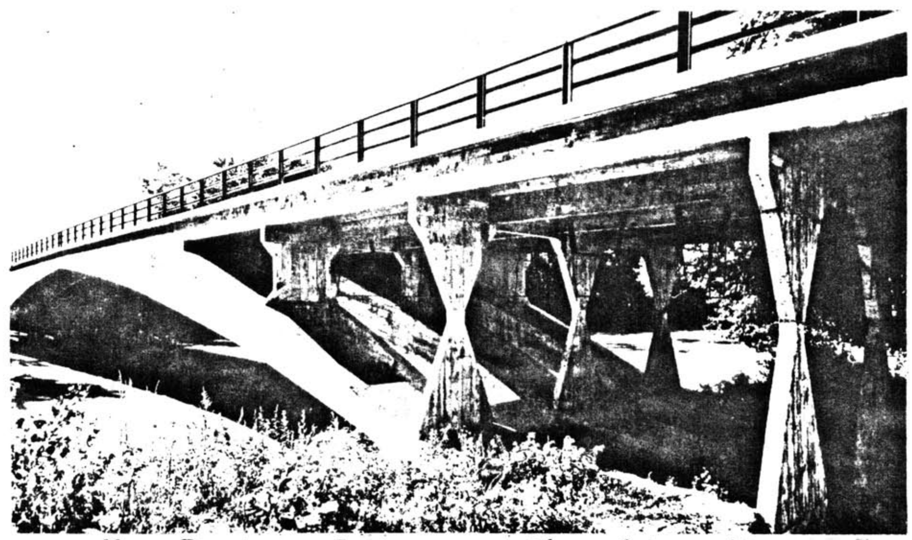
Gathering or assembly, by an ancient word of our language, is called "thing". The bridge is a thing - and indeed, it is such as the gathering of the fourfold..."[1]



Maillart.

Arve Bridge, 1936-37

The bridge is a thing in that it gathers the fourfold about it. As dwellers we too gather the fourfold in the naming and making of things. We create bridges of time. Dwelling is being when we are free to remain in a place.



1 Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

The Gothic wunian, like bauen, means to remain, to stay in a place ... "more distinctly how this remaining is experienced. Wunian means: to be at peace, to be brought to peace, to remain in peace. The word for peace, Fried, means free, das Frye, and fry mean: preserved from harm and danger, preserved from something, safeguarded. To free really means to spare. The sparing itself consists not only in the fact that we do not harm the one whom we spare. Real sparing is something positive and takes place when we leave something beforehand in its own nature, when we return it specifically to its being, when we "free" it in the real sense of the word into a preserve of peace. To dwell, to be set at peace, means to remain at peace within, the free, the preserve, the free sphere that safeguardes each thing in its nature. The fundamental character of dwelling is this sparing and preserving. It pervades dwelling in its whole range. That range reveals itself to us as soon as we reflect that human being consists in dwelling and indeed dwelling in the sense of the 'stay of mortals on the earth.'

"But 'on the earth' already means, 'under the sky'. Both of these also mean 'remaining before the divinities' and include a 'belonging to men's being with one another.' By a primal oneness, the fourfold earth and sky, divinities and mortals - belong together in one."

"For here the dreamer has entered into the domain in which convictions that originate beyond what we see and touch, are formed."

1 Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

2 Bachelard, G. The Poetics of Space. (Beacon Press, 1969.)

"Characteristic of the process of differentiation in childhood is the loss and renunciation of all the elements of perfection and wholeness, which are inherent in the psychology of the child so far as this is determined by the pleroma, the uroboros. The very things which the child has in common with the man of genius, the creative artist, and the primitive, and which constitute the magic and charm of his existence, must be sacrificed. The aim of all education, and not in our culture alone, is to expel the child from the paradise of his native genius and, through differentiation and the renunciation of wholeness, to constrain the Old Adam into the paths of collective usefulness.

"From the pleasure principle to the reality principle as we have defined it, from the mother's darling to the schoolboy, from uroboros to hero, such is the normal course of childhood development. The drying up of imagination and of creative ability, which the child naturally possesses in high degree, is one of the typical symptoms of impoverishment that growing up entails. A steady loss of the vitality of feeling and of spontaneous reactions in the interests of "sensibleness" and "good behavior" is the operative factor in the conduct now demanded of the child in relation to the collective. Increase in efficiency at the cost of depth and intensity is the hallmark of this process." [1]

[1] Neumann, E. The Origins and History of Consciousness. (Harper Torchbooks, 1962.)

From creations of culture, as ideas are built and works are made and the earth is sown and reaps its harvest, there is culture. From the seed of ideas, the fruit of discovery, disclosure, the opening and awakening of consciousness; from the miasma of the depths of non-reason, the dreams we negate we pass off as sleeping self as unaware and innocent we are.

The Malayalay tribe of the south seas turns dreams into culture. They travel the spirit lanes at night, drawing from that state their songs, stories and recipies. Taking oracle of these travels, they bear gifts and givings to friends in the day who were enemies at night; if they see harm come to one in the tribe, they forewarn him of the treacherous points.

"The visible world was made to correspond to the world invisible and there is nothing in this world but is a symbol of something in that world." (Al-Ghazzali, The Mystic, 11th century).

IDEOLOGY/DWELLING/LIFE

DWELLING ART/THE BIOLOGICAL SEA MODEL DWELLING

"Only if we are capable of dwelling, only then can we build."[1]

Life exists as interdependent ecological cycles with organisms from the full spectrum of the evolutionary scale. Our nourishment and sustenance is as reliant upon the plankton of the sea as on the grass of the meadow. The sea is a living soup and all life derives from it. Water is the major constituent of the sea, with salt next in line, with from 32 to 35 parts per thousand. All the other elements are present in miniscule quantities.

In the late 1950's, life's building blocks, diribonucleaic acid (DNA) and ribonucleaic acid (RNA) were recreated in a simulated primal earth sea atmosphere charged with electricity. The bi-helexial form of these molecules recapitulate the recurrent pattern of fluid motion as the girdle of life.

> "Water that has seeped into the nooks and crannies of the cliffs expands as it freezes, thus cracking the hardest rocks. In this way, it starts off the dead, hard element on the way back to life. As through the action of water, in the course of time, the rocks crumble to a finer and finer consistency, they become the basis for plant growth and are again received into the great cycle of living nature."[2]

2 Schwenk, T. Sensitive Chaos. (Schocken Books, 1976.)

The sea uses and reuses the elements of life, conserving and recycling its water and nutrients. Life has been built up by the sea and to the sea will it return.

> "...water flows and streams on the earth as ceaselessly as the stream of time itself. It is the fundamental melody that forever accompanies life in all its variations. Unremittingly, it belabors the solid earth, grinding, milling, destroying, levelling out, and at the same time elsewhere building up again, creating anew, preparing for life. As the life blood of the earth, in the great network of veins, it shifts unbelievable amounts of substance, which everywhere accompanies the life process it transforms the hardest rocks and the highest mountains into a flowing, finely ground stream of substance, and it dissolves finished forms, preparing them for new creation. Water is thus the great exchanger and transformer of substances in all forms of metabolism... In the passage of the earth around the sun, the stream of time divides itself rhythmically into years and days, through planets. So, too, the waters of the earth rhythmically work upon the material world."[1]

[1] Schwenk, T. Sensitive Chaos. (Schocken Books, 1976.)

IDEOLOGY/SEA/SOUND

Sound propogates spherically from its source. This sphericity is the ideal form for the concept of wholeness. The earth's oceans are a unified body of water. H_2O is the only element found naturally in the 3 phases of matter, its metabolism includes the sensitive air streams carrying water vapor in clouds (gas), the frozen ice caps (solid) and the underground streams and springs of the earth (liquid). The oceans and atmosphere are driven by a) the thermal difference between day and night, north and south; b) the rotation of the earth, and c) the gravity of the earth and moon.

The expansion and depletion of sound in air is a wave, a rhythm of expansions and contractions, tens, hundreds or thousands of them in a second as sound waves travel at 360 feet per second; in water, the speed of sound is 4754 feet per second.

What gives sound its being is our capacity to hear it. Composed of sensibly present micro-osilations in air or water, our ears are the receptors of the phenomenon. In examining the human ear's structure we find they develop with the pattern of water impressed in their form and are formed for sound by sound:

"The membranous cochlea of the internal ear, a tube filled and surrounded with fluid and having a blind extremity, combines the spiralling surface - an archetypal form of flowing movement - with the spiral twisting of a vortex. The vortex, which otherwise appears in a liquid, is here moulded into a perfect, most delicately differentiated sense organ. The formative principle of the curling, rolled in surface of contact between different regions of liquid permeates the whole ear. It is as though in the embryonic development of the human ear the sacculus were drawn with a force of mighty suction into a liquid vortex, its surface rolled up to form the sensitive boundary membrane and at the same time twisted through 90 degrees.

"Thus in the internal ear the two scalae are like the two regions of liquid, on either side of a boundary layer; they hold the really sensitive organ between them and develop it further. It must be realized that in the phylogenetic development of the organ of hearing there is no actual occurrence of circulating liquids - apart from what we have already described regarding the vortex cavities in the labyrinth of the river-lamprey. It is rather as though the rotating principle as a force were invisibly to permeate and guide the embryonic intucking. A time-lapse photograph of the development of the cochlea would certainly reveal a movement like that of a vortex in a liquid. Vortices with a distinct spiral twist may also arise when rhythmical impulses influence a fluid at rest, for instance the movement to and fro of an object on the surface of water. A system of adjacent vortices - for example, four lying side by side - results from movements of this kind.

"Taking into account that in the process of hearing, incessant rhythmical impulses are inflicted from without upon the fenestra ovalis - a delicate membrane leading to the fluid in the internal ear - one can understand how this vortex-like organ might develop out of the world of rhythmical sounds; it is formed by sound for sound." [1]

[1] Schwenk, T. Sensitive Chaos. (Schocken Books, 1976.)

"In the world of living creatures [the] principle of repetition appears in great variety, e.g., in the formation of segments, vertebrae, metameric organs, for instance in the primative kidney and in many other examples. Reproduction, repetition in propagation, appears in the organic world as well as in the flowing of water and in the spiritual life of the human being. When learning something by heart, the more often we repeat it rhythmically, again and again, the better it impresses itself upon us and becomes a permanent memory and ability. But also it is all the easier to understand something the more it is examined, felt and grasped from all sides. This spiritual activity too has its expression in the liquid element, which envelopes objects from all sides, grasps and feels and goes thoroughly into every detail of a form."[1]

Rotation, the sun and the moon are the movers of the sea. The sea catches most of the sun's radiation. It is converted to heat, to which the cool winds come from above as warm winds drive the water vapor in clouds to thirsty and cooler parts of the earth and sea with warming rains. The sound of rain brings comfort to many a farmer and city dweller alike. Streams and fountains have a soothing effect. The sound of the sea annually draws millions to the shores, if not for the sun, the sand and the salt sea air.

1 Schwenk, T. Sensitive Chaos. (Schocken Books, 1976.)

ALL IS ONE

"One of the earliest symbols of the alchemists: the serpent biting its own tail. In Egypt, it represented the circle of the Universe or the path of the sun god. The Greek inscription ἓν τὸ πᾶν (all is one) is often found in the center of the uroboric circle. To the alchemist, the uroboros symbolized the mysterious circulation of chemical substances in the hermetic vessel during distillation. Drawing from a Greek ms. of the Alexandrian period, containing the "Chrysopoeia" (Gold-making), a work attributed to the woman alchemist "Cleopatra".

" Every dream is a statement of the psyche about itself. That the psyche should reveal itself to a child shortly before her death, in this profound way, is an amazing fact - one might call it the miracle of the helpful collaboration of the unconscious. The answer to the secrets of the day and the solutions to the riddles of the future are all contained in its primordial womb. That is why there is always something fateful about the images and symbols that arise from it. "Perhaps - who knows? - these eternal images are what men mean by fate."[1]

1 Jacobi, J. Complex Archetype Symbol in the Psychology of C. G. Jung. (Princeton University Press, 1972.)

IDEOLOGY/SEA/ALCHEMY

As the medieval alchemists were aware, the fire of the sun, the earth of soil and stone, the water of life and the air of the atmosphere are the elements of which our universe is materially composed.

> "In alchemy the "One" is the "quintessence", the result of the process whose purpose it is to produce it, to extract it from the four elements."
>
> "The five, or in other words, the quaternity united in the quintessence, is not a derivative, however, but an independent whole that is more than the sum of its parts. It is the superessential that transcends all the rest."
>
> "Jung has found the quaternity to be the archetypal foundation of the human psyche. And with the theory of the four functions, i.e., with the discovery of the significant role of the quaternity in the human psyche, whose archetypal basis he found it to be, Jung clarified a vast number of relationships and symbols. We know, for example, from Jung's researches and observations, that mandalas, those remarkable images for meditation found in oriental religions and also occurring frequently in the psychic development of the modern occidental, are based on the quaternity principle and may be regarded as symbols of the "primordial order" of the psyche. Both the production of mandalas and meditative immersion in them can awaken or express this "original order" that is potentially present in every psyche." [1]

Thus the elements have metaphysical meanings.

1 Jacobi, J. _Complex Archetype Symbol in the Psychology of C. G. Jung_. (Princeton University Press, 1972.)

"The ancients describe the psyche as a 'damp, cool breath', resembling in essence the living breath of God, which he breathed into the body of man, that had been formed of clay."

This statement gathers the coolness of absence of fire, the damp of water, the breath of air and the earth of clay to represent the greater whole, inspired life.

> "We know perfectly well that to inhabit a shell we must be alone. By living this image, one knows that one has accepted solitude.
>
> "To live alone; there's a great dream! The most lifeless, the most physically absurd image, such as that of living in a shell, can serve as origin of such a dream. For it is a dream that, in life's moments of great sadness, is shared by every body, both weak and strong, in revolt against the injustices of men and of fate."[1]

> "'I can only stop and gaze with admiration and awe,' writes Jung, 'at the depths and heights of our psychic nature. Its nonspatial world conceals an untold abundance of images that have been amassed and organically consolidated during millions of years of development. My consciousness is like an eye that contains in itself the most distant spaces, yet it is the psychic nonego that fills them non-spatially. And these images are not pale shadows, but tremendously powerful psychic factors. The most we may be able to do is to misunderstand them, but we can never rob them of their power by denying them. Beside this picture I would like to place that of the starry vistas of the heavens at night, for the only equivalent of the world within is the world without, and just as I reach this world through the medium of the body, so I reach that world through the medium of the psyche."[2]

1 Bachelard, G. The Poetics of Space. (Beacon Press, 1969.)

2 Jacobi, J. Complex Archetype Symbol in the Psychology of C. G. Jung. (Princeton University Press, 1972.)

NIGHT SEA JOURNEY

"Jung draws an analogy between the "way of individuation" and the archetypal image of the night sea journey. Once the psyche reaches the midpoint of life, the process of development demands a return to the beginning, a decent into the dark, hot depths of the unconscious. To sojourn in these depths, to withstand their dangers, is a journey to hell and "death". But he who comes through safe and sound, who is "reborn", will return full of knowledge and wisdom, equipped for the outward and inward demands of life. He has pressed forward to his limits and has taken his destiny upon himself. This "great Nekyia", which usually leads to the very threshold of the beyond, is interwoven with innumerable lesser Nekyia experiences, all the many psychic sufferings, upheavals, darknesses, that run through every life. To endure and withstand these experiences helps the individual to great insight and security. The great arc of the night sea journey comprises many lesser rhythms, lesser arcs on the same "primordial pattern". Here again there is a close connection between the unique event and cyclic recurrence. To this extent, whose meaning remains the same, mankind has given ever new norms, which rise up from the depths of the psyche in the veriegated richness of eternally renewed archetypal images. Birth, life, death and rebirth belong together; they are a totality; they represent a "primordial pattern" which finds its expression in symbols either reflecting it as a round unity or disclosing it as separate links in an endless chain, as "a moment of eternity in time."

Jacobi, J. Complex Archetype Symbol in the Psychology of C. G. Jung. (Princeton University Press, 1972.)

"The content of an archetypal image is always over determined; it can be interpreted and understood on different levels; seen in several aspects. It preserves the same meaning. The "Night Sea Journey", as a unique event or as a link in a chain of many repetitions has left its deposits in the myths. There are whale-dragon myths in which the dragon spews out what it swallowed, then goes on living, devours new victims, and vomits them up again, etc.; and others in which the victims are reborn but the dragon meets its death - as in our dream.
"Does the dream of the "Bad Animal" taken as a paradigm, represent a single "link" in a chain of recurrent dreams, as a kind of model for the archetype of the "Night Sea Journey", without regard to the dreamer. Both interpretations are possible, but if we take the dreamer into consideration - and without doing so it is impossible to do justice to the dream - we should not overlook the fact that the scene of the great conflict between the two worlds of the animal and the divine is the unconscious psyche...and that all our analogies are merely a metaphorical expression of this event."

Jacobi, J. Complex Archetype Symbol in the Psychology of C. G. Jung. (Princeton University Press, 1972.)

IDEOLOGY/SEA/MOVEMENT

We have started with the examination of culture to arrive at the meanings of sea and dwelling and shown how they belong to each other on many levels. History shows this as archeology gives new meaning to myth and legend. It has been suggested that the Minotaur's Labyrinth of King Minos was a tile pattern upon the court of the palace at Knossos (Graves) upon which a dance was performed. What is dance, but another form of rhythmic movement, another expression of fluidity?

The horns of the minotaur, scepters of power, embody the principle of growth inherent in life.[1]

Horns are crescents, denotive of the director of the tides, the moon. The labyrinth came to mean the pilgrim's journey in medieval time, losing its association with the sea culture of Mycenae. Now it symbolizes the troubled maze of the mind puzzled because of humanity's plight which is the plight of dwelling.

1 Thompson, D'Arcy, On Growth and Form.

"Whether we speak of streaming water or moving air, of the formation of organs or the movements of the human form, of speech, of eury-thmy, [the whole human forming, the basic gestures of the physical larynx], or of the regulating movements of the stars, it is all one: the archetypal gesture of the cosmic alphabet, the word of the uni-verse, which uses the element of movement in order to bring forth nature and man."

This bringing forth, as we know, is dwelling on the earth, the gathering of the fourfold. The water is gathered by the vortex as the fourfold is gathered by the mind. Being made of elements, we move as they do.

"The elements of the earth are arranged in a certain order; it is the same order as that in which the spirit descends into matter and can clothe itself in a body. Out of the world of the celestial laws of the eternal mathematical ordering of the stars, which makes itself manifest in the audible harmony of numbers in the world of sound, the spirit descends into the silence of water, there to be revealed in the ordering of number and substance in organic form. The laws of the stars descend and, through the mediating elements of air and water, impress themselves upon the earth."

"... to movement ... we must ascribe these forms ... They are movements of a spiritually living being descending from the world of cosmic laws to take on bodily form, through the circulations of air and water."

Schwenk, T. Sensitive Chaos. (Schocken Books, 1976.)

Thinking of the sea and the cycle in which it dwells draws us to numbers and harmony, conceptions of the micro and macrocosmos. Such thoughts return us to considering the origin of things.

Life begins in rhythm; the earth began in the poundings of the deluge upon non-existent shores. No being exists of these occurrences; nothing to differentiate a surface to the sea. Only fishtails and the legend of the Ark. This is our common heritage which unites us all as mankind; only on this stoney planet, born of the sun and the sea and their love for the earth child.

— its creatures receiving the radiant wishes from all the uncle and aunt stars in the nether heavens.

And the earth was born of the sea; a mountain surrounded by water; an island in the sea.

Under the sky is 'on the earth.' Without earth there is no sky and without sky there is no earth. Together they are touched by the sea. — Not only on the shores but in the currents of air which circulate earth and water from place to place in storms or simple evaporation carrying warm or cool rains to wet or thirsty climates. With the heat of the sun the currents of the sea run at a steady heartbeat carrying warmth to the cold and nourishment to the feeding.

— Not only the sea, but the streams of clouds and underground springs which support the earth as the sap of the tree or the water in the mortar of the house. We dwell with and in water and water dwells in us.

In each is a rhythm which reacts to the stars, the moon, the earth and the sun. That which binds them is the ether. Its form is movement; repetition its motif. We are of water, but we are also of earth, air and fire which are sensitive to sound. We can see how fire and water hear, i.e., react to sound, and air is our happy medium for speech. If the air was dry it would soon deprive us of our capacity to speak. Drinking a glass of water relieves this thirst.

Some people cannot speak nor listen nor touch nor see and find not consolation, but compensation in our abilities to adapt to the most adverse or hostile conditions as tenacious human beings.

In our dwellings, from day to day in our habits of washing and showering, bathing and cooking, cleansing and watering, and in our crafts, whether printmaker artist, window washer, car mechanic, farmer, priest, indian chief, mula, tea maker or mason, we handle water and control its course, sending our shower songs, work whistles and wastes along with it.

In each case, a posture is held, a gesture is made in space. In the orient, such bowing or supplications are not reserved for the serving-bearer who bows the gracious bow of humility.

Each change in the figure of the human form is a transformation of the life force, the chi, in us. These changes of life energy affect our thought, speech and actions; interact with our surrounding environment and our perception of it. As such, each figural posturing in relation to water acknowledges water's characteristics and properties which forms with us a living alphabet. "All things were made by the Word, and without the Word, was not anything made that was made."[1]

		Gathering		
		Culture	Dwelling	Sea
Ideology	Voice	Poems	Language	Sound
	Concept	Ideal	Metaphysics	Alchemy
	Figure	Art	Life	Movement

1 A Prophet whose name remains unknown

Introduction to Development of the Objects of Underwater Technology.

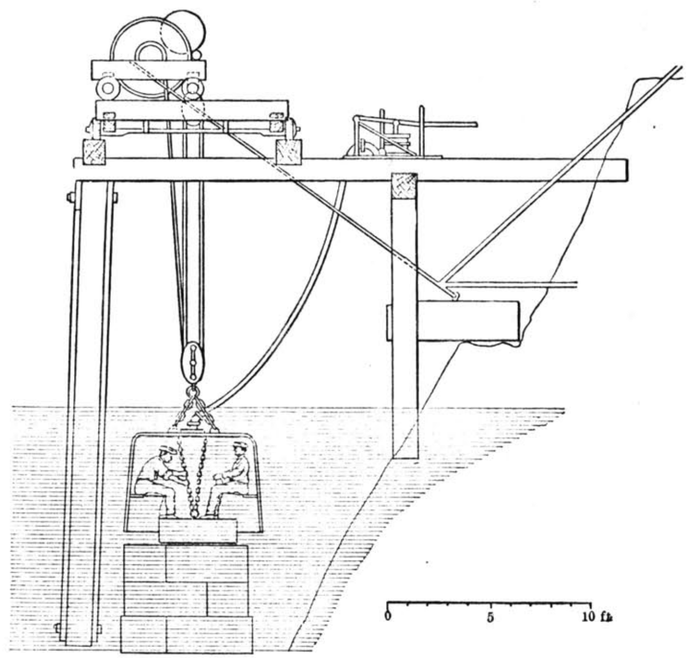
The scope of Underwater Technology ranges from breath hold diving to surface supported or self-sustaining submersible dwellings. What follows is a brief survey of the development of this technology. It is organized into three broad areas.

First is the development of diving in which the diver is sensually in contact with the water environment. Advancing technology increases his temporal range and mobility. The diver, appends apparatus to his body. He can still feel the water, although contained by a membranous (diving suit) structure. Recent developments promise freedom underwater heretofore thought impossible.

The second area of development is what I call techno-structural diving. The diver is completely or partially contained within a rigid or flexible structure which does not conform to his body and limits his capacity for autonomous movement, yet increases his range and ability for performing useful work while submerged.

The third area of development has origins which differ from the other two, but logically evolves into a joining with them in its final development. This is the area of settlements and the building of cities which use underwater technology in the process of becoming. Beginning with floating boats and dwellings of early history, structural types evolve into the historically imminent underwater dwellings.

Inadvertently, this ontogenetic framework develops in parallel and overlaps of the three broad areas. Together they form the basis for further developments bearing historic continuity.



—Rennie's Diving Bell.

DIVING DEVELOPMENT

Biologically, humanity maintains an evolutionary memory of amphibious origins in the fetal development within the amniotic fluid of the mother. The African Lungfish which annually burrows into the moisture retaining mud before the parching droughts, evinces an ambirespiratory propensity. While in water it breaths through gills, as the early human fetus does. When the droughts come, its metabolism slowed, it maintains a breathing tube of earth from its moist burrow dwelling to the dry surface above. It becomes a lung powered air breather.

The religious vein originates humanity at the coast, the interface of the sun, sea, air and water. Adam was made of water and earth. His first choice occurred when he stood up and walked onto the land. He might have easily swam into the sea as the dolphin and other sea mammals have done on the evolutionary plane. With his downfall from paradise, humanity has become the cultivator and caretaker of the earth. Now threatened with failure in an industrially synthesized and polluted environment, he returns to the sea for solace and protection. Alternatives to self-genocide confront him.

Cultures the world over have sustained a grasp of a symbiotic relationship with the sea. We find man's early relationship with the sea in considering his efforts to penetrate the surface. The breath hold diver originates this attempt. The breath hold dive (limits submersion to two minutes at most.) The diver's harvest of mature oysters in the lagoons of the south seas assists the younger oysters to flourish, ensuring the perpetuation of this resource.

Humanity's ingenuity overcomes the biological inability to breath while submerged. The water has been a protector of men, shielding him from his greatest predator, the hostility of other men. We find in the history of the Middle East many examples of escape from death by using a simple reed, a hollow tube, through which the breath is taken by the submerged (and concealed) diver. Such is the origin of the snorkel.

The human eye has been designed to see clearly in air, not in water. By maintaining a pocket of air between the eye and water, the problem of blurred vision in water is overcome. The containment of this air pocket is the purpose of the diving mask. It has transparent glass on its face, through which the diver is able to see into the water. In earlier examples, the glass is held in by glue to a handmade wooden frame which closely follows the contours of the diver's eye sockets.

The pearl diver, sailing across the wind swept water, knows to see the sea bottom clearly, he need only place a square wooden box, with glass bottom and open top, into the surface of the sea. Thus is the sea bed rendered clearly with its cache of oysters.

Upon sighting a rich bed, hibiscus wood floats are thrown overboard, followed by a team of three masked divers. They will be picked up by the captain later in the day along with the oysters, which are supported by the floats upon which the divers may also rest.

The mask, the snorkel and the float have continued, since ancient times, to be indespensible equipment for the diver. They are the diver's apparel which allow him to dwell a semi-submersible life for considerable amounts of time. With centuries, this equipment has evolved with the technology of their constituting materials. Wood has been replaced by rubber and metal.

Human beings, 98% composed of water, are approximately as dense as sea water. With lungs full of air, we are lighter than sea water and float. Therefore considerable energy is expended in overcoming this natural bouyancy.

In order to increase the efficiency of the dives, the Ceylon pearl divers learned to minimize descent time and energy by riding down astride a stone which is hauled back to the surface by co-workers. This method allows for more productive time at the bottom. This is the origin of the counter-weight.

A small amount of weight tied about the diver's waist makes him heavier than water. Early military divers learned by blowing into a collapsed membrane structure, such as a wineskin sewn of greased leather or the sealed stomach of a cow, the breath would displace more water than when contained in the diver's lungs. Thus, overall, the diver and his appliances being again lighter than the water could ascend effortlessly to the surface with his counter-weights. Such is the predecessor of the modern bouyancy compensator by which the diver can maintain neutral bouyancy at any depth of water.

Membranes could also be used to maintain an air reserve supplying the diver with air of nearly equal pressure as the water about his chest. This allows him to breathe while submerged, thus increasing temporal duration under water.

Once diving technology reached this point, it could be used to salvage sunken wrecks or to carry out military suprises in war.

"Do not impart your knowledge and you will excel alone. Choose a simple youth and have the dress stitched at home. Stop the galleys of the captains and afterwards sink the others and fire with the cannon on the fort."
"Everything under water, that is all the fastenings. Here stands the man. Doublet. Hose. Level frame."
"When the watch has gone its round, bring a small skiff under the poop and set fire to the whole all of a sudden."
"To fasten a galley to the bottom "m" on the side opposite the anchor."
"A breastplate of armour together with hood, doublet and hose, and a small wine-skin for use in passing water, a dress for the armour, and the wine-skin to contain the breath, with half a hoop of iron to keep it away from the chest. If you have a whole wine-skin with a valve from the ball, when you deflate it, you will go to the bottom, dragged down by the sacks of sand; when you inflate it, you will come back to the surface of the water.

A mask with the eyes protruding made of glass, but let its weight be such that you raise it as you swim.

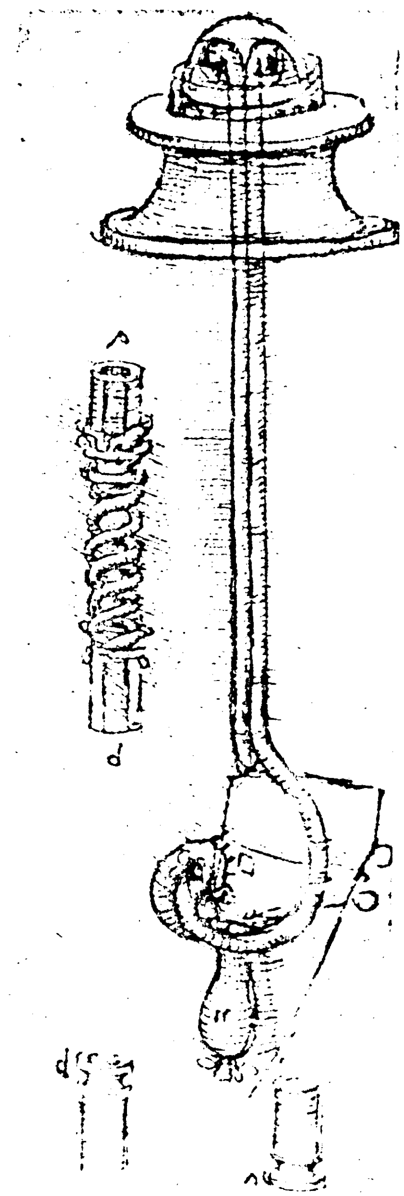
Carry a knife which cuts well so that a net does not hold you prisoner.

Carry with you two or three small wine-skins, deflated, and capable of being inflated like balls in case of need.

Take provisions as you need them, and having carefully wrapped them up hide them on the bank. But first have an understanding about the agreement, how the half of the ransom is to be yours without deduction; and the store-room of the prisons is near to Manetti, and payment may be made into the hand of Manetti, that is, of the said ransom.

Carry a horn in order to give a signal whether or no the attempt has been successful."

DaVinci, Leonardo



PARTIAL CONTAINMENT

Leonardo DaVinci is among the early innovators of diving technology, depicting diving helmets supplied with air through a long leather tube. He pedagogically instructed the means of military diving. His drawings appear naive because of the length of the breathing tube, which couldn't work beyond a depth of 18 inches to two feet at the most. Such designs require air pumped from the surface to a pressure equal to that exerted by the water upon the diver's chest.

The earliest example of the diving helmet and suit dates from 1415 and is to be found in the Munich Library. Presumably, made of stitched and greased leather, it combines mask and snorkel in the helmet with the open end of the snorkel supported at the surface by two air bladder floats. This early diving dress was tied just below the waist.

The German instrument maker and gunsmith, Augustus Siebe, having emigrated to England, by 1819 developed the open diving dress consisting of a metal helmet, canvas suit extending below the diver's waist, weighted belt and shoes. The diver was indeed supplied pressurized air by means of an efficient pump. By 1837, Siebe had perfected the closed diving suit which was full length and contained the diver completely and offered great freedom of mobility

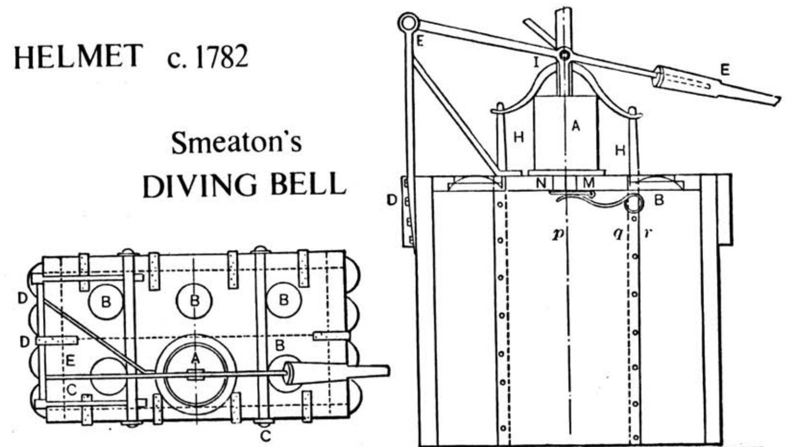
Made possible by the

AIR PUMP

DIVING SUIT c. 1837 copper; glass; oiled leather.

HELMET c. 1782

Smeaton's
DIVING BELL

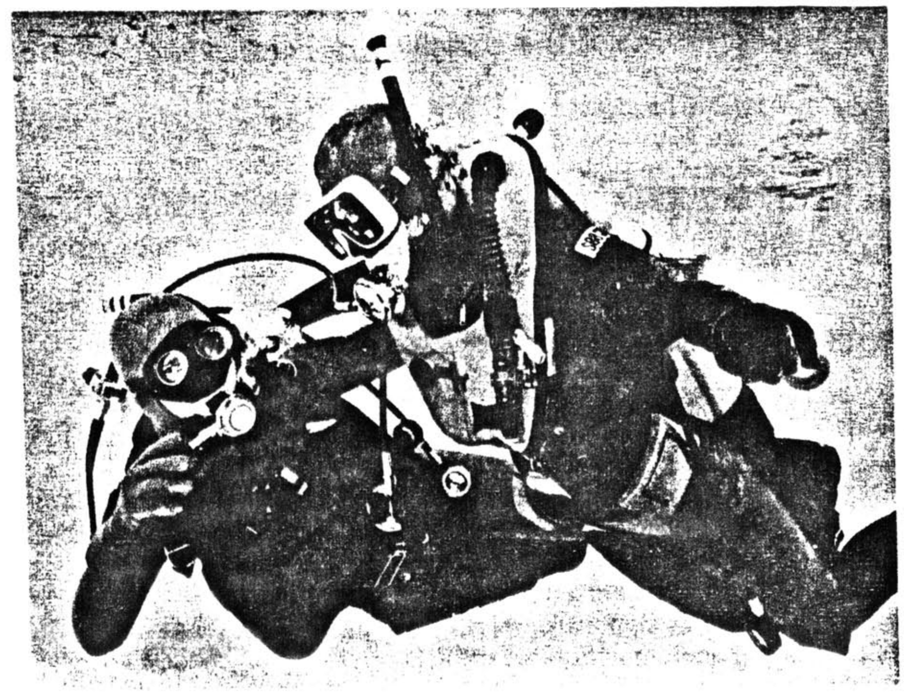


on the sea bed. These inventions were employed in the salvage of the Royal George, which had sunk in 1782 in Portsmouth Harbor. The hulk of the Royal George, a menace to navigation, was destroyed following the salvage of its 108 guns.

The modern wet and drysuit evolved from these early origins. Today, they are made of neoprene rubber which has air bubbles entrained in it, which insulates the diver from cold water. The wet suit allows a small amount of water to seep between it and the diver's skin through the openings at the wrists, neck, waist and ankles. This water is heated by the diver's metabolism, thus insulating him from the colder water outside the diving suit skin. The dry suit is water tight but similar in concept allowing air between skin and suit to serve as insulation.

The mining engineer, Benoit Rouquayrol, and the naval officer, August Denayrouze, invented and utilized a tank strapped to the back with air supplied to the diver by a demand valve which equalized the air pressure with the diver's surroundings. The tank was replenished frequently by an air hose delivering the compressed air by pump from the surface, while the diver remained submerged.

Employed until WWII, its principles led to the development of the aqualung.



The development of fins, the rubber appendages attached to the feet which increase the swim surface and length of the diver's kick increased his mobility and speed. The frog foot embodies the prototype of this apparatus which combined with mask, snorkel and bouyancy compensator, forms the basic equipment of the modern sport skin diver.

The increased mobility in water naturally led to Commandant Jacques-Yves Cousteau and Emile Gagnan's invention, the aqualung. It is a metal tank of compressed air supplied by a demand regulator. The aqualung allows commercial or military descents of up to two hours in shallow water or much less time to a depth of two hundred feet. Sport divers are restricted by safety precautions to 100 feet in the United States.

With the advent of the space age, self-contained, back mounted, closed circuit rebreathers have been developed which recycle a helium nitrogen mixture which is replenished with oxygen from a compressed tank upon inhalation. Excess carbon dioxide is extracted from the gas mixture upon exhalation as the recycled gas passes through a filter. The rebreather extends the time and distance a diver may travel from the diving station, whether surface or submerged craft.

The breath of total freedom is within sight of our technological age. A super thin, super strong membrane of silicone has been used as a selective membrane extracting oxygen directly from water. The process of osmosis through a semi-permeable membrane mimics the gill lamella's functioning. In an age of synthetic mimicry of human tissue, the possibility of artificial gill grafting presents itself.

TECHNO-STRUCTURAL DIVING

The solutions to the problems of dwelling in the sea have evolved through a series of technical innovations arising from the ingenuity and industry of many individuals since ancient times. Impetus can be gained through an understanding of the historic course of the objects of technological development manifest in the diversity of structural forms and apparatus, artifacts which predispose a sea dwelling culture. Such a perspective begins in unverifiable and remote legends and historic declarations of antiquity.

AIR RESERVES AND DIVING BELLS:

Early BC Greek divers used huge pottery jars for storing air while seeking sponge. Air could be drawn from a thin-necked amphora by using a hollow reed. It is possible that wide necked pots were early forms of diving bells. Dio Cassius has reported of Pompey's son Gnaeus, whose divers performed an early salvage operation by refloating ships which had been sunk by Romans, thus blocking the port of Oricus in Greece, resulting in the town's capture. Another underwater
480 BC military exploit occurred in 480B.C. outside Salamis which was besieged by Xerxes' ships. The night before

the battle, the Greek Scyllis and his daughter Cyane cut the enemy's anchor cables contributing to Salamis' victory over Xerxes.

425 BC In 425B.C., Spartans, besieged by the Athenians on the Isle of Spacteria, were kept supplied by divers dragging wineskins full of provisions through the water. It is simple to surmise how the divers, concealed beneath the enemy's hulls, could replenish their breath from similar wineskins full of air which could also serve to neutrally bouy the weight of the provisions.

332 BC An account by Aristotle of 332B.C. indicates the use of a diving bell by Alexander the Great at the battle of Tyre. Alexander is commonly considered the father of the diving bell due to his descent in a glass barrel in

330 BC 330B.C. He was appalled by what he saw, which was how the fish, having swallowed smaller fish were soon swallowed by those still larger.

GLASS DIVING
c. 330 B.C.

Little survives of the developments underwater technology incurred during the dark and middle ages, if any.

c. 1460 AD By 1460A.D., Prince Henry the Navigator had charted the winds and currents of the Atlantic Ocean for Portugal, conquering western man's fear of the earth's ocean edge. In light of Thor Heyerdahl's findings of our century, it is extremely probable that humanity's quest upon the high seas has much older precedents.

c. 1550 Charles V of Spain, in the mid 1500's, received a proposal for a submersible to be used against the English fleet, although whether the plan was employed remains unverified. Of the same period, water craft which skimmed just below the water's surface are reported to have been employed by pirates in European waters.

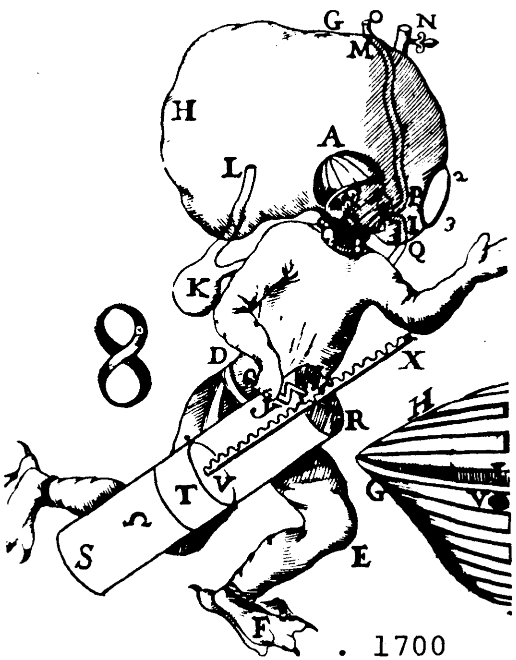
SUBMARINES: PROPULSION AND REFRESHED AIR:

Submarine development has mostly been the fruit of military necessity, although the first verified documentation of such a vessel served no military purpose at all. Cornelius Van Drebble's heavily ballasted twelve person submarine, made of wood and able to travel awash or just below the surface was observed by England's King

1624 James in the Thames River in 1624. It was propelled by oars fit through watertight greased leather casings. Van Drebble, a physician, refreshed the air in the submarine by unstopping a vial of an undisclosed chemical liquor.

c. 1650

In the mid 1600's, Father Schott designed an "aquatic corselet", an early diving suit adapted from the diving bell concept. An inverted leather pail, braced by iron supports and strapped to the shoulders of the diver, had small circular glass windows set at eye level. Maneuvers required balance as the contrivance was bulky and cumbersome. Among the numerous plans of this period is that of Buonaiuto Lorini who drew the diver sitting upon a platform suspended by cable from a surface tending ship. Over the diver's head was a rawhide tube; the diving bell concept. Borelli, another Italian, surrounded the diver's head with large bladders inset with a transparent occullus (view port). He also indicated fins for the swimmer's feet. The intended use of these devices is probably salvage.



. 1700

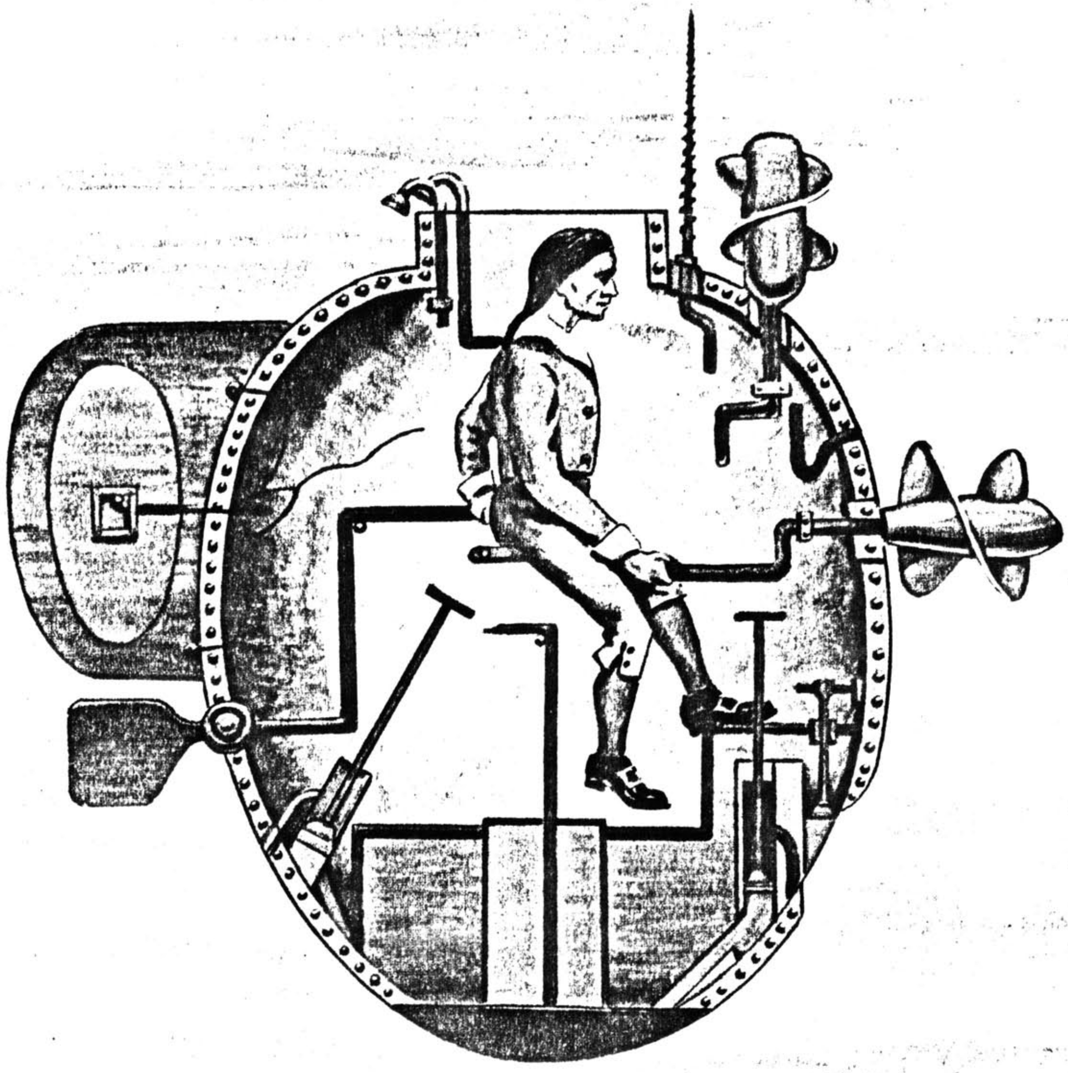
During the 1700's, an English shipwright, Day, successfully dived in 30 feet of water in his wooden vessel ballasted down by weights which were released to ascend. Unaware of water pressure's increase with depth, his second attempt, in 132 feet of water, was unsuccessful; the hull collapsed.

c. 1725

Also in the early 1700's, Sir Edmund Halley innovated a technique for freshening the air in his diving bell. Using hose of leather "liquored" with beeswax and oil, he transferred fresh air, brought down in weighted barrels, into the bell as the heated air escaped from a small valve at the top. As a depleted barrel ascended to the surface, another, full of air, descended from the support ship.

The bell carried Halley, together with four other divers, to nine or ten fathoms for an hour and a half at a time without ill consequences. In clear waters on sunny days, a glass window admitted enough light into the bell to read or write by, let alone salvage goods from the sea bed. He communicated orders to the surface with a lead slate and iron pen giving directions for the movements he desired the support ship to take. In dark waters, he kept a candle flame ignited to light the underwater work.

1775 The first truly operational one man submarine was
the Turtle designed and built by David Bushnell. It
was eggshaped and driven by two hand cranked screw
propellers; one for vertical propulsion and another
for the horizontal maneuver. A 700 pound lead keel
1776 kept the iron hulled Turtle upright. In 1776, the
Turtle was deployed against the 64 gun British flag-
ship under commander-in-chief Lord Howe. The H.M.S.
Eagle, anchored off Governor's Island in New York Harbor,



THE TURTLE

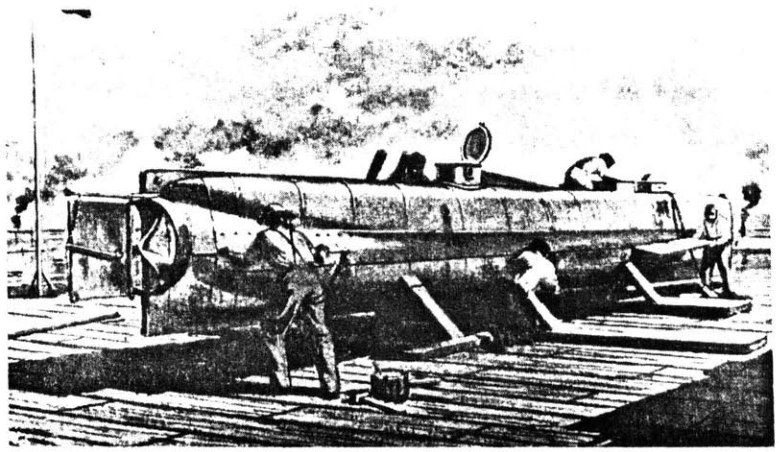
was attacked by the Turtle's first trained military submariner, Ezra Lee. He attempted to attach 150 pounds of gunpowder to the submerged portion of the flag ship's hull. The hardwood screw, meant to attach the charge, could not pierce the heavy copper sheathing of the warship. Ezra Lee made his escape with the returning tide. No casualties occurred with the Turtle's use. She was sunk by the British while docked and unoccupied.

1798 In 1798, Kleingert of Beslau designed a system for forcing air from the surface down to a diver introducing the utility of the air pump concept. The diver took breath by way of an ivory mouthpiece fed by flexible pipe into a tin helmet which resembled a hot water boiler. A second flexible pipe carried out the nasally expelled air. A pair of bellows were employed to force the air. Heavy weights were required to overcome the bouyancy of this structure. Leather sleeves and pants kept the diver dry from the waist up, depending on the fit. Augustus Siebe's "open dress" diving suit also employed an air pump and an improved (less cumbersome) helmet.

Robert Fulton's motive intent in designing his Nautilus, a twenty-one foot by seven foot submarine, was the obsolecence of the world's navies and the invocation of universal disarmament. His innovations included two options for propulsion; a deployable mast and rigging for setting sail upon the surface and a hand cranked propeller for submerged thrust. He also introduced horizontal rudders (predecessor of the hydroplane) for maintaining steady depths and compressed air for hull ventilation on long dives.

Fulton's submarine project was supported by the Emperor Napoleon who, from the quay nearest the Hotel des Invalides on the Seine, watched Fulton man the
1801 Nautilus in 1801, remaining indifferent to his dreams of disarmament. Soon after, at Brest, using the Turtle's method of deploying a charge, Fulton utterly destroyed a target schooner so completely, the shocked French Admirals would have nothing to do with the awesome
1809 power displayed by the weapon. Similarly, in 1809, at the request of Britain's Prime Minister, William Pitt, Fulton's submarine demolished the target brig Dorothy so quickly and easily that the British Admiralty, terrified, refused to use the devilishly devastating war engine. Disillusioned, Fulton returned to America to develop his famous steam boat.

1863-64 During the Civil War, the Confederacy built three "Little David" submarines in Mobile, Alabama. One of these, the twenty-five foot iron boiler plate hulled Henley, sank the Union's Sloop-of-war Housatonic with a demolition charge carried at the end of a long spar. The Henley's propeller was manually crankshafted by her



crew of eight. All eight were drowned as the Henley also sank in the backwash of the explosion.

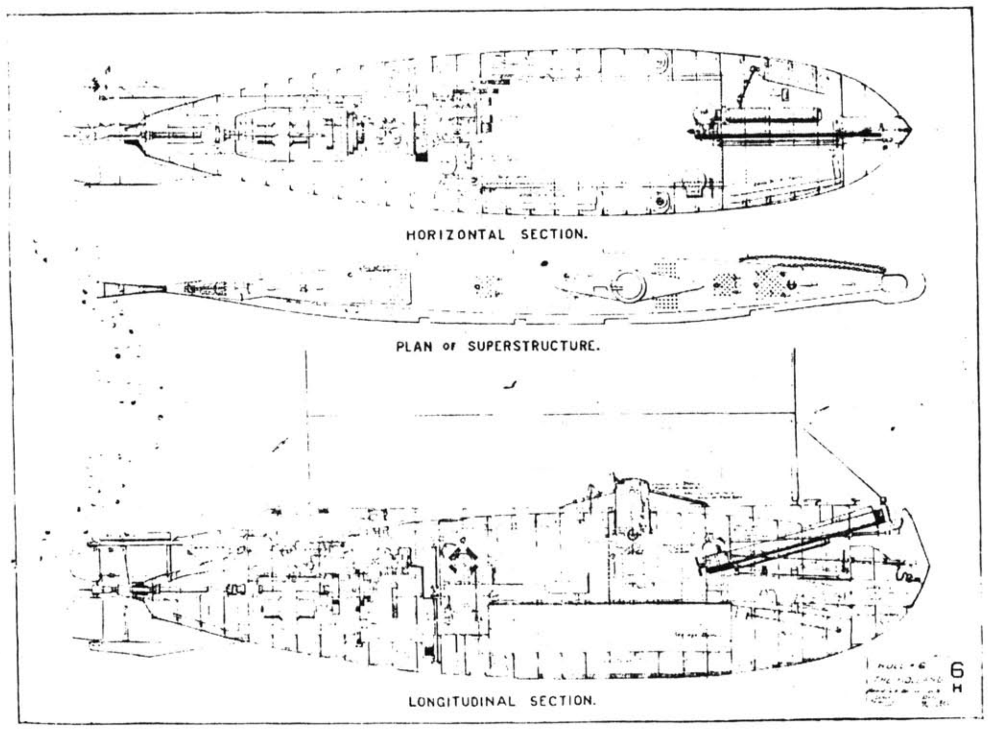
1872 By 1872, Augustus Siebe had perfected his closed type diving dress. The incorporation of rubber in the suit made this possible. Surface to undersea contact was accomplished through telephonic communication.

The trolley car, the electric automobile and the submarine all came to be with the advent of the electric storage battery and the electric motor which, unlike the steam boiler and internal-combustion engines, required no oxygen to operate. Lieutenant Isaac Peral
c. 1880 of the Spanish Navy was first in the 1880's to install electric lighting and propulsion on board a submarine by using batteries. Methods for controlled vertical movement and horizontal trimming remained unresolved until the innovations of John Holland and Simon Lake.

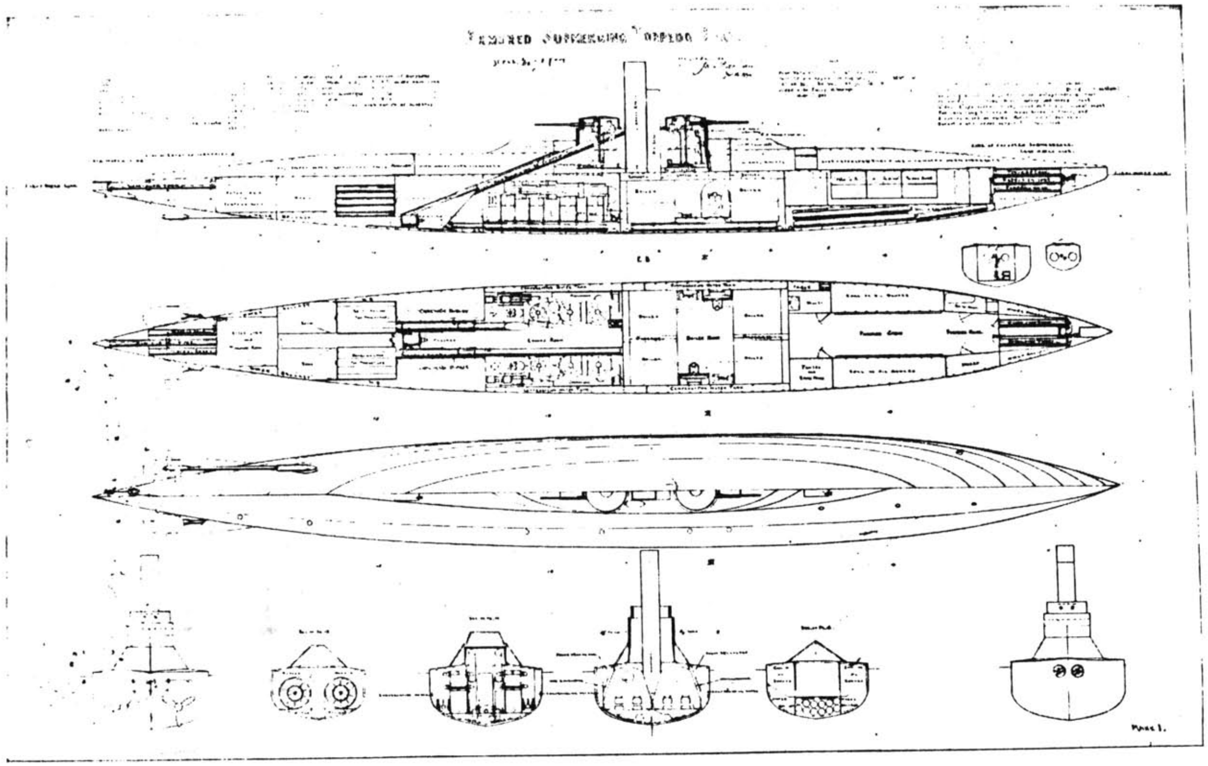
The young American, Simon Lake, inspired by Jules Verne's "Twenty Thousand Leagues Under the Sea", began
1897 experimenting in a nearby river at the age of ten. By 1897, Lake's Argonaut was installed with a four-cylinder gasoline engine, a dynomo, an air compressor, a search-light, a crew of five, geared wheels for rolling on the bottom and a propeller for surface and submerged propulsion. He cruised 2000 miles down Chesapeake Bay and into the ocean. His fore and aft hydroplane innovation allowed even keel diving. Lake also innovated the rotating periscope, a salvage tube, a mine laying submarine and an undersea cargo boat. Furthermore, he demonstrated how helmeted divers could operate from submarines. (B)

John Holland, an independent contractor commissioned by the U.S. Navy, took twenty five years to perfect the modern submarine. In his Plunger I, surface propelled by steam power, his crew nearly roasted. In his 30 foot Fenian Ram, propelled by a 17 horsepower gasoline engine, his crew was nearly asphixiated. Finally, in
1898 1898, he launched the father of the modern submarine, the Holland No. 9, from a private shipyard in Elizabeth, NJ. The English, French and Russian Navies, having added submarines to their fleets, incited the U.S. Navy to order six of the new Holland 9 subs to be built in two different locations; the Grampus and the Pike in

California; and the Moccasin, the Porpoise, the Adder
1900 and the Shark in Elizabeth. By 1900, they formed the U.S. Navy's class "A" submarines. Each carried an officer and a crew of eight. The "Hollands" were 63 feet long with a 12 foot beam and were armed with Whitehead torpedoes ejected from a single bow tube. On the surface, they achieved a speed of 6 knots propelled by a 50-horsepower gasoline engine. Submerged, 5 knots were achieved with an electric motor powered by a 120 cell battery.



SECTIONS SHOWING GENERAL ARRANGEMENT PLAN OF ORIGINAL HOLLAND SUBMARINE



SKETCH OF ARMORED SUBMARINE TORPEDO BOAT DESIGNED BY JOHN P. HOLLAND, 1894. AT THAT TIME SUBMARINES WERE HARDLY THOUGHT OF. NOTE FORESIGHT OF MR. HOLLAND IN DESIGNING THIS BOAT. AT THE TIME THIS PLAN WAS DRAWN HOLLAND'S ASSOCIATES CONSIDERED IT WHOLLY VISIONARY AND IT WAS NOT UNTIL 1917 UNDER PRESSURE OF THE GREAT WAR THAT CONSTRUCTION OF THIS TYPE WAS UNDERTAKEN.

1900-1920 Between 1900 and the end of WWI, the U.S. Navy developed submarines from the "A" class to the "S" class. They became her most effective secret weapon.

1911 In 1911, introduction of the Diesel engine for surface propulsion increased their cruising range.

By 1900, an efficient diving dress had been developed but was used unsafely. Penetrations to depths greater than 30 or 40 fathoms increased the mortality rate. Deadly physiological changes occurred in the body exposed to an increase or decrease in pressure over even short periods of time.

1886 Before his death in 1886, French physicist, Paul Bert had systematically studied and formulated basic rules of decompression which concern the oxygen and nitrogen dissolved in the diver's blood. He found these elements under pressure regassify upon quick ascent causing gaseous embolism, a decompression sickness. Nitrogen bubbles can form stoppages in the joints, lungs, spinal cord and brain.

c. early 1900's In the early 1900's, Professor John S. Haldane, Sir Robert Davis and Admiral Momsen, continuing the work of Paul Bert, began unravelling the time, depth and pressure relationship; their effect upon animals and then, upon humans. Dr. J.S. Haldane of England developed a method for predicting the saturation of various tissue compartments with gas under pressure relative to time. Accurate decompression tables were the result. They indicated various stages (sea or pressure levels) and durations for ascending decompression stops depending on the maximum depth and time of any dive. The decompression schedule allowed for the release of gas from the various tissue compartments and blood stream. Proper use of the decompression tables greatly reduced the occurrence of mortality due to the bends, often called compressed-air illness or caisson disease because of its occurrence among caisson workers who descend through pressure locks of chambers within caissons used in the underwater construction of foundations for structures such as bridges.

Nitrogen narcosis, the saturation of nitrogen (an anasthetic) in the bloodstream, was prevented by using helium as an inert breathing medium in mixture with the essential oxygen. Helium could be expelled from the tissue faster and more completely than nitrogen, reducing decompression from deep dives or dives of long duration.

Salvage and rescue operations have continued to utilize the advancing underwater technology. For instance,
1917 in 1917, a German U-boat sank the S.S. Laurentic with its cargo of gold bullion bound for the United States. Only after great difficulties and many years of work was the cargo completely recovered. Salvage operations have pushed the limits of depth and duration of dives in quests for sunken fortunes leading to further technical innovations and knowledge.

1934 In 1934, curiosity drove Dr. William Beebe and Otis Barton to a depth of 3,028 feet off Bermuda in a bathysphere suspended by a cable from a surface support ship.

Their mission was one of biological inquiry as they sought the living habits of organisms which had been dredged from the depths.

1939 In May of 1939, 33 men were rescued from the sunken S.S. Squalus. The rescue employed an oxygen-helium diving suit and the McCann Rescue Chamber, a diving bell which mated to the submarine escape hatch which became a standard submarine feature.

Universal acceptance of the self contained underwater breathing apparatus (scuba) was helped by Jacques-Yves
1943 Cousteau and Emile Gagnan who in 1943 advanced the work of Yves Le Prieur whose perfected equipment had been adopted by the French Navy.

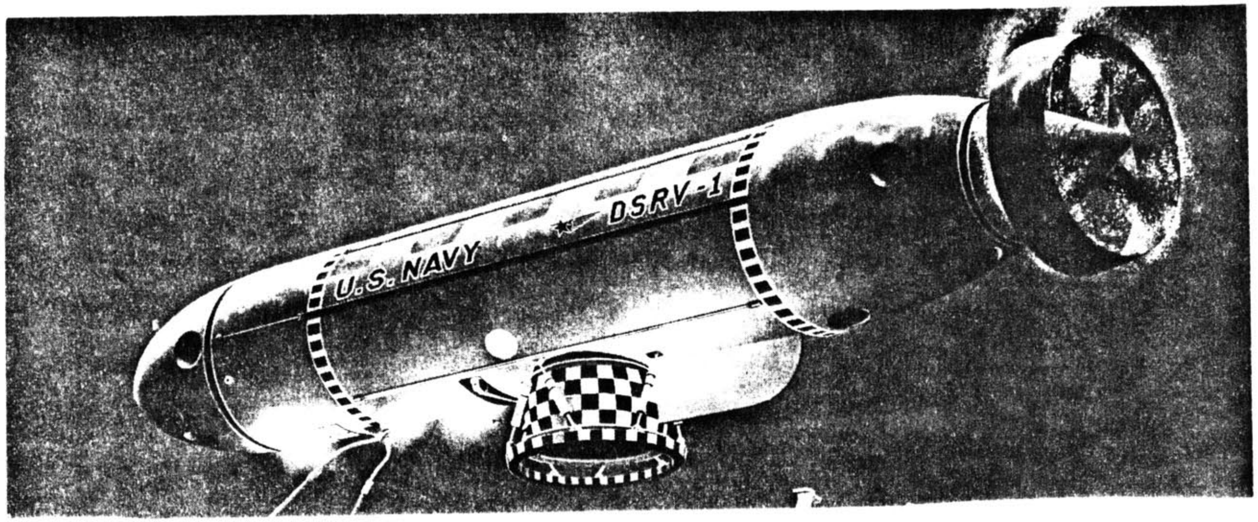
WWII The Englishman Davis' submarine escape apparatus, an early form of self-contained underwater breathing apparatus (scuba) was first employed as a safety device. The U.S. Momsen Rescue Lung soon followed. The Italian and British Navies developed them further for underwater demolition work. The french aqualung is an open circuit breathing apparatus, meaning exhausted air is expelled into the open water. The closed circuit apparatus recycles most of the inert gas by filtering out the carbon-dioxide through a soda-lime canister with which it reacts. Advances in air compression techniques and mixtures, gaskets (o - rings), rubber, plastics and sea knowledge have led to modern techniques.

The aqualung's technical innovation was the design of a foolproof demand valve which equalized air pressure delivered to the diver with the surrounding water pressure. Jacques-Yves Cousteau and Emile Gagnan popularized the aqualung which had been adopted by the French Navy following the work Yves Le Prieur performed to perfect it.

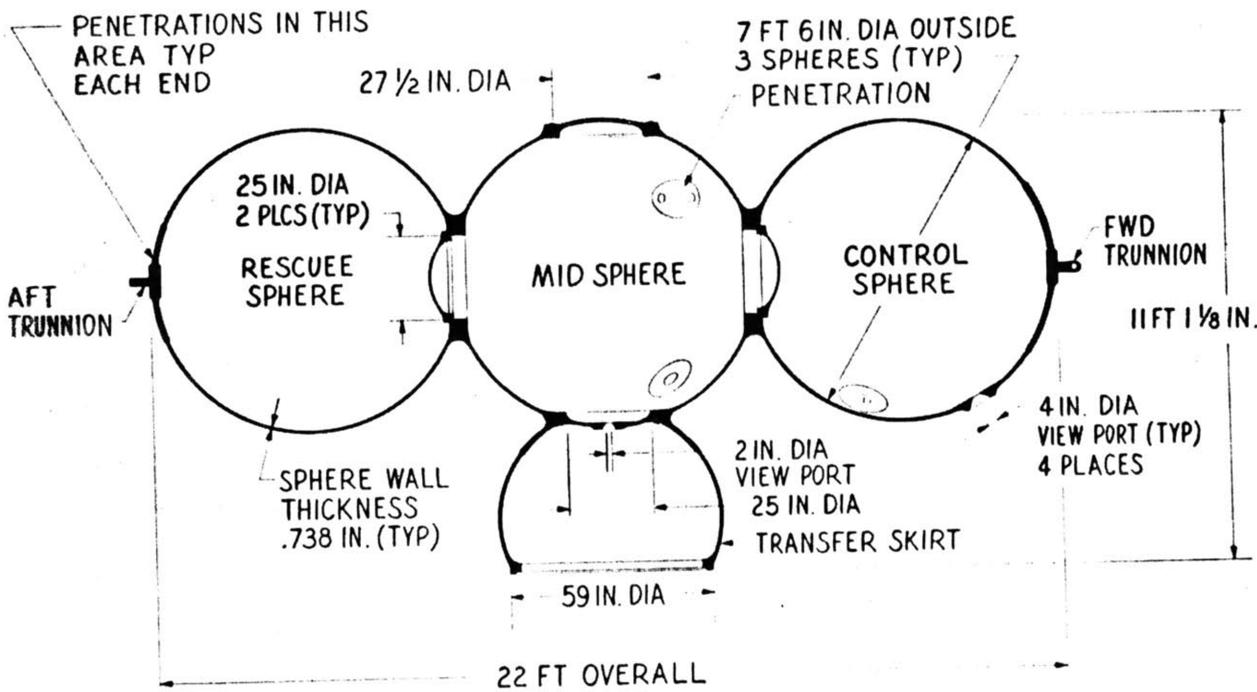
The development of radar during WWII spurred the German invention of the water stopping snorkel which could ventilate their diesel powered U-boats from 50 feet below the surface, avoiding detection by the allies' radar. Propulsion innovations and greater depth capabilities enhanced the world navies which to this day remain in a shroud of secrecy. The most recent U.S. products of General Dynamics Inc., Electric Boat Division based in Groton, Connecticut incorporate nuclear propulsion, are in excess of 600 feet in length, and can circumnavigate the globe submerged while producing oxygen from water through electro-dialysis.

The historic development of underwater technology's structural manifestations broadened drastically after WWI as the increased miliary utility became evident. After WWII, following Beebe's historic descent of biological inquiry, the commercial uses of submersible vehicles for science and industry flourished in multitudes of forms and material applications. The specifics of penetrations to greater depths and the solutions to technical problems thus engendered are directly related to the knowledge humanity has acquired for accomplishing the objective proposed by this initiative, the inhabiting of the shallower regions over the continental shelves. To verbally detail each innovation which resulted from these efforts would surpass the needs of this framework. A pictorial survey is provided, indicating the useful range and variety of structural form submersibles have taken over the years. The interested reader may avail of the references cited in the bibliography for in depth treatments of this topic. Categorical analysis of a few recent underwater habitats form the basis for the development of environmental design criteria established in the following chapter.

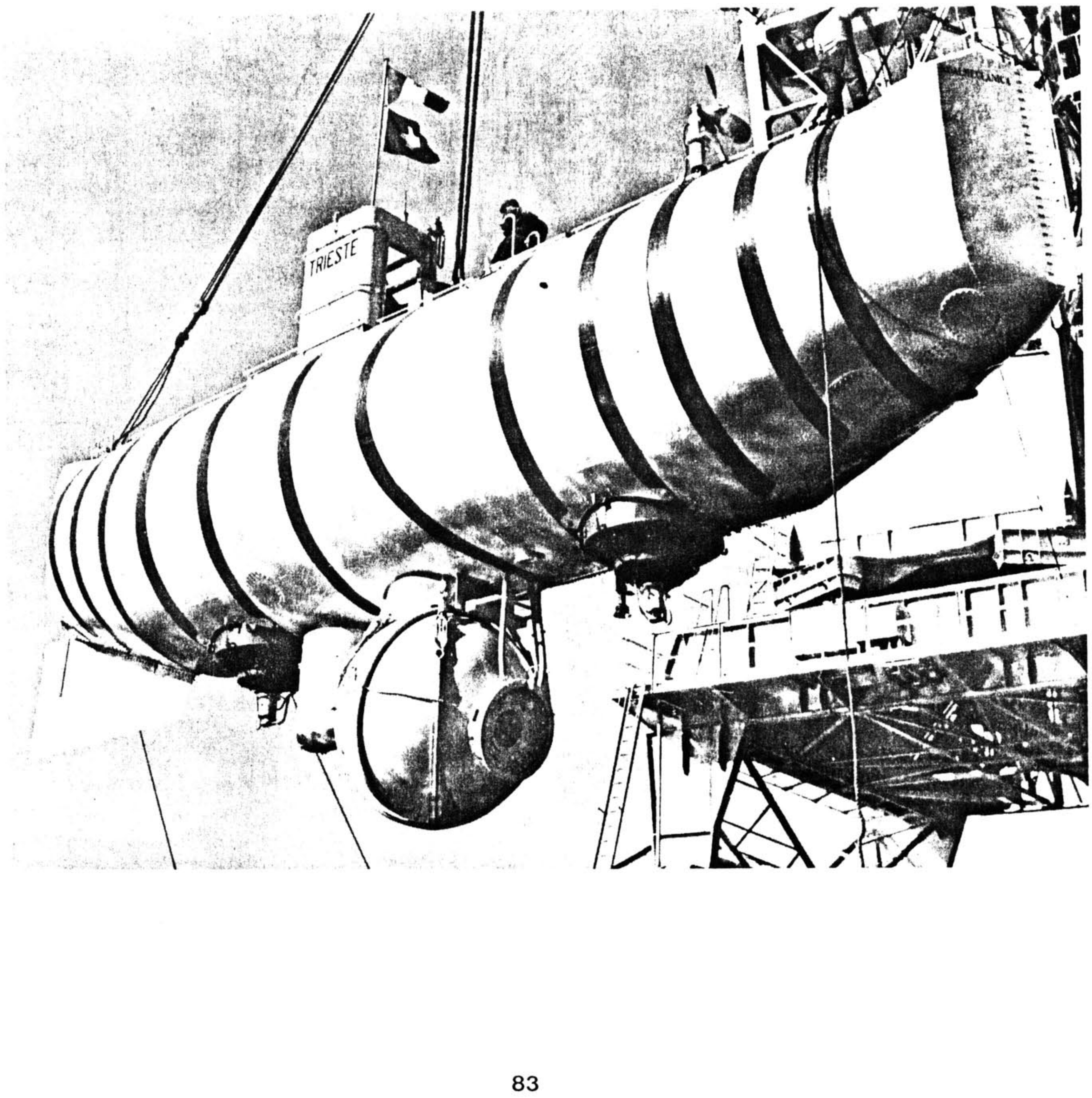
1956 Edward A. Link, the inventor of the simulated flight trainers, engaged in underwater archaeology, in 1956, built a vertical transport vehicle which could function as a diving bell and submersible decompression chamber (SDC). The aluminum cylinder is 3 feet in diameter and 11 feet long. It has a double seal entry lock so food or supplies can be delivered to a decompressing diver.

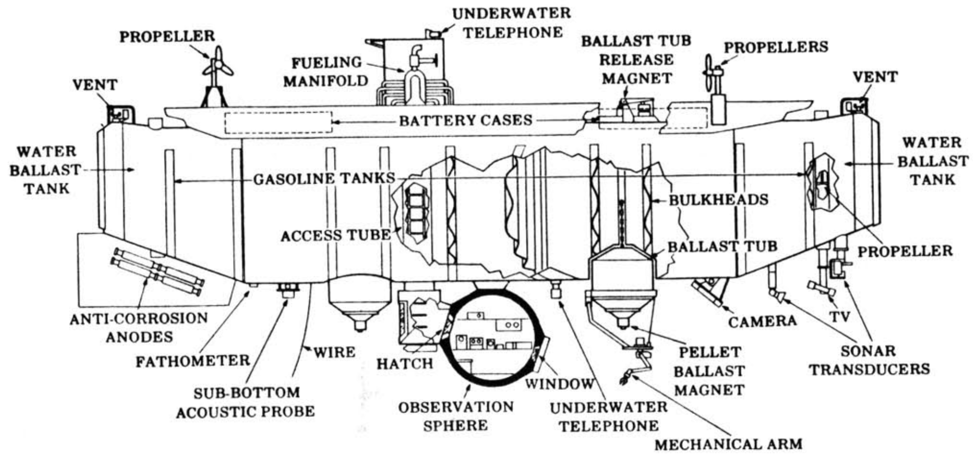


U.S. NAVY
DSRV-1

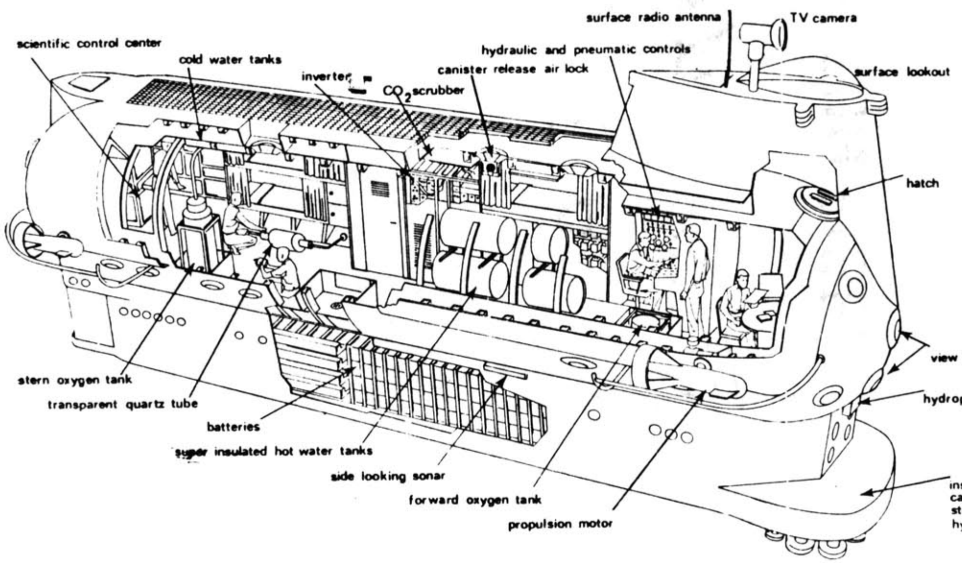


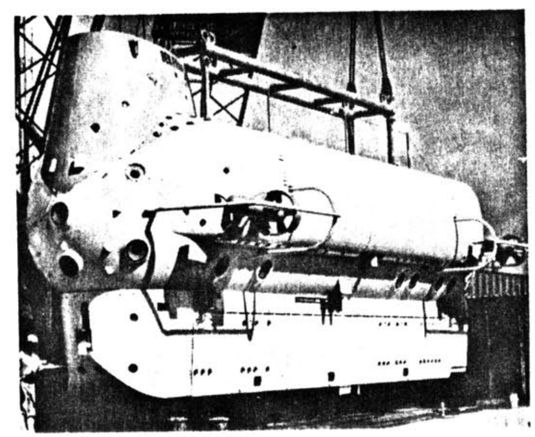
PENETRATIONS IN THIS AREA TYP EACH END
27 1/2 IN. DIA
7 FT 6 IN. DIA OUTSIDE 3 SPHERES (TYP)
PENETRATION
25 IN. DIA 2 PLCS (TYP)
RESCUEE SPHERE
MID SPHERE
CONTROL SPHERE
FWD TRUNNION
AFT TRUNNION
11 FT 1 1/8 IN.
4 IN. DIA VIEW PORT (TYP) 4 PLACES
SPHERE WALL THICKNESS .738 IN. (TYP)
2 IN. DIA VIEW PORT
25 IN. DIA
TRANSFER SKIRT
59 IN. DIA
22 FT OVERALL


TRIESTE

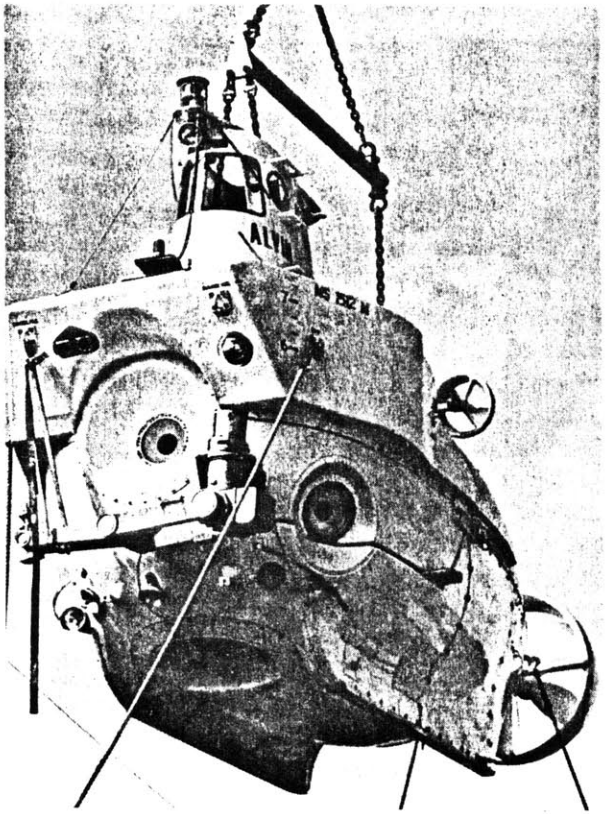


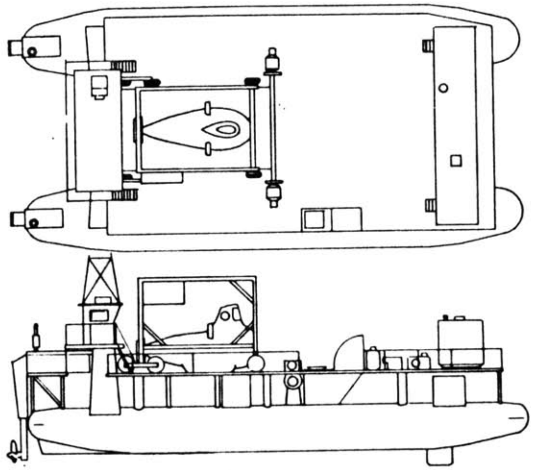
Trieste

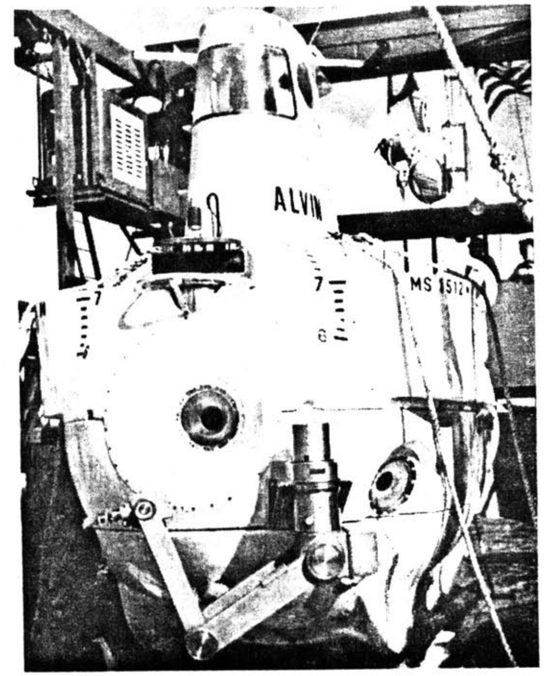


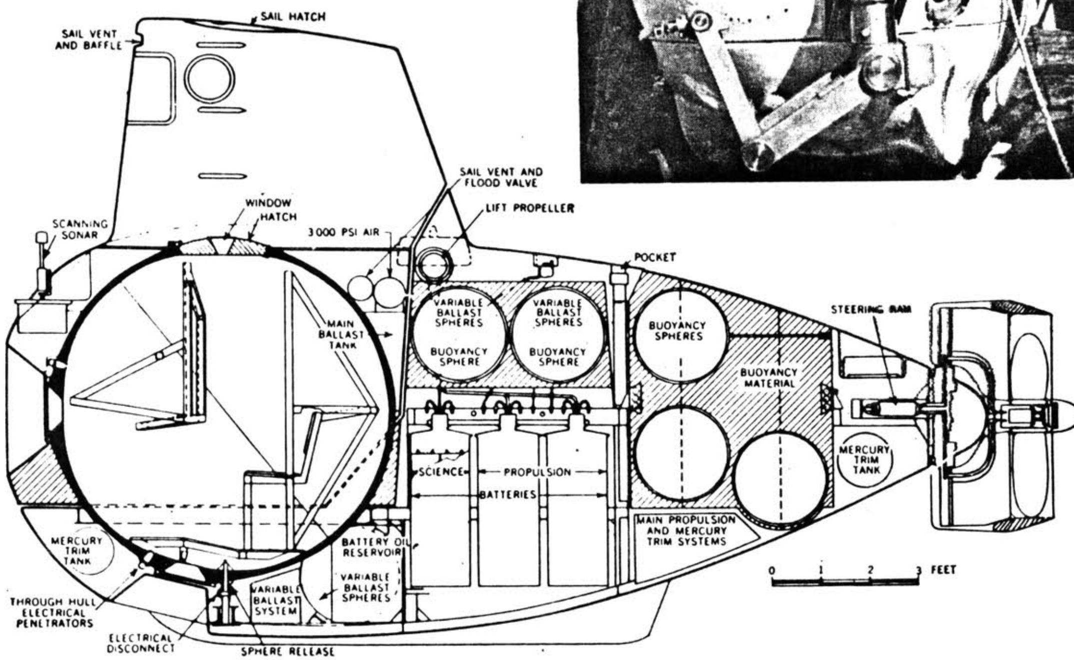


PX-15

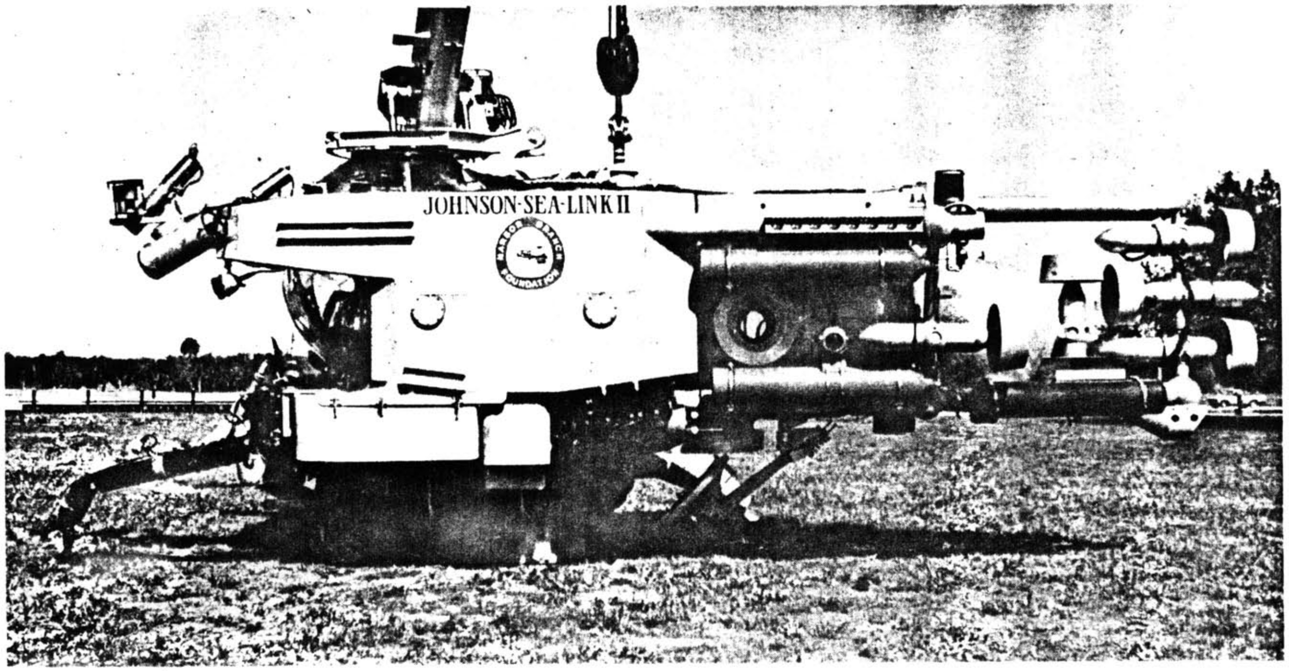




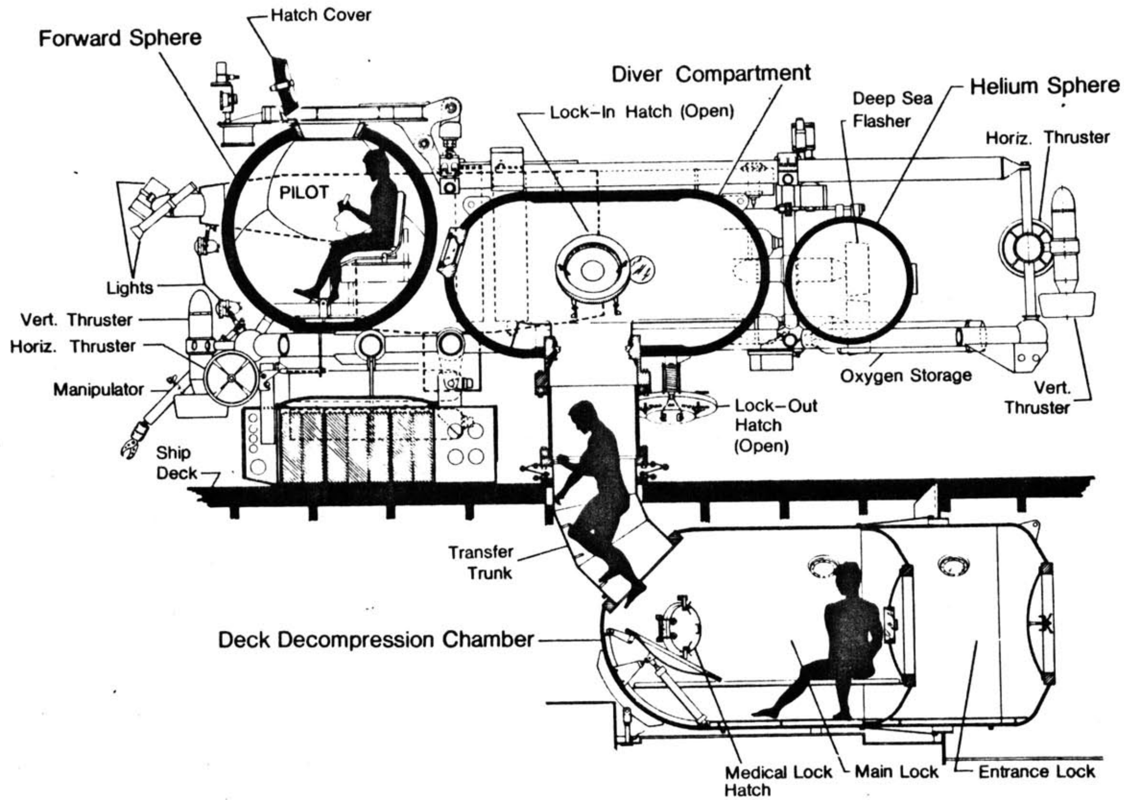

ALVIN


SAIL HATCH
SAIL VENT AND BAFFLE
SAIL VENT AND FLOOD VALVE
LIFT PROPELLER
WINDOW
HATCH
SCANNING SONAR
3000 PSI AIR
POCKET
MAIN BALLAST TANK
VARIABLE BALLAST SPHERES
BUOYANCY SPHERE
VARIABLE BALLAST SPHERES
BUOYANCY SPHERE
BUOYANCY SPHERES
STEERING RAM
BUOYANCY MATERIAL
MERCURY TRIM TANK
SCIENCE
PROPULSION
BATTERIES
MAIN PROPULSION AND MERCURY TRIM SYSTEMS
MERCURY TRIM TANK
BATTERY OIL RESERVOIR
VARIABLE BALLAST SPHERES
VARIABLE BALLAST SYSTEM
THROUGH HULL ELECTRICAL PENETRATORS
ELECTRICAL DISCONNECT
SPHERE RELEASE
0 1 2 3 FEET

Diver Lockout Submersible



Cutaway Showing Mating Position with
Deck Decompression Chamber



INBOARD PROFILE

Johnson–Sea–Link I & II Submersible & Ship Decompression Chamber

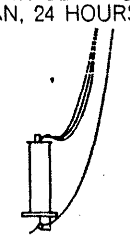
Scale In Feet

1957

In 1957, U.S. Navy Physician, Captain George F. Bond conceived and carried out a series of simulated dives at the Naval Medical Research Laboratory, first on small animals, then volunteer navy divers, to pressure equivalents of 200 feet depth of water. Pressure, temperature and humidity were controlled carefully. Helium was found to have no ill effects after long durations of use as a breathing medium.

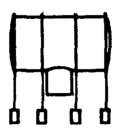
1962

MAN IN SEA SEPTEMBER, 1962
1 MAN, 24 HOURS (200 FEET)



In September, 1962, Belgian diver, Robert Stenuit descended to 200 feet for 24 hours off Villefranche on the French Riviera in the Link SDC. He worked in the water and rested in the vessel. His decompression occurred onboard Link's support ship, Sea Diver, in relative, though cramped, comfort.

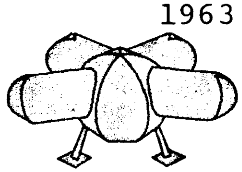
1962



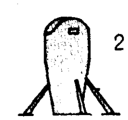
CONSHELF 1 SEPTEMBER, 1962
2 MEN, 7 DAYS (35 FEET)

That same month, Jacques-Yves Cousteau placed 2 men to live and work at 35 feet depth of water for one week, near Marseilles as part one of his Conshelf experiments. Conshelf was aimed at establishing undersea stations on the Continental Shelf.

1963



CONSHELF 2 JULY, 1963
5 MEN, 1 MONTH (33 FEET)



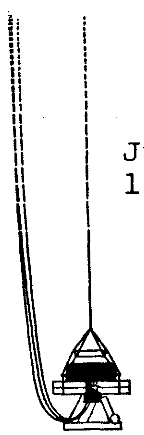
2 MEN,
7 DAYS (85 FEET)

During the Summer of 1963, Conshelf II was a multi-structural settlement at Sha'ab Rumi Reef in the Red Sea. "Starfish House", an assembly of cylindrical chambers in 33 feet of water was the hub of the settlement. In it, 5 men ate, slept and worked in the undersea laboratory for a month. There was also an undersea hanger for the diving saucer which explored and sampled to depths of 1000 feet with a crew of two. At a depth of 85 feet, down the coral slope, the deep cabin housed two men for seven days in an oxygen-helium-nitrogen environment. The two made short free dive excursions to 360 feet.

The divers of Conshelf II were mostly inexperienced divers from a wide age group and included one woman. Vocation, rather than physical condition was the prime determinant of the crew. Conshelf II showed biological investigations and submarine operations can be carried out from submerged stations.

Late 1963 - March, 1964 — Captain R.D. Workman, beginning in late 1963, at the Navy's Experimental Diving Unit in Washington, showed through simulation tests that divers suffered no harmful effects when exposed to 400 feet depth pressure for 24 hours and proved a linear decompression schedule.

1964 — Link's "Man in Sea" project, attempting to demonstrate man's work effectiveness at 400 feet for several days, established a life-support team under Christian J. Lambertsen of the University of Pennsylvania School of Medicine to do preliminary research and supervise the medical aspects of the dive. James G. Dickson and Joseph B. MacInnis evaluated the accuracy and reliabi-



MAN IN SEA JUNE, 1964
2 MEN, 49 HOURS (432 FEET)

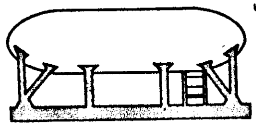
lity of gas analyzers that would monitor the divers' environment. It was discovered mice could be decompressed after surviving pressures of 4000 feet depth.

A larger "dwelling" was required for the 400 foot dive; one which would provide shelter, have easy access underwater, operate simply and resist seawater corrosion. Link's solution was an underwater tent of rubber, four feet in diameter and eight feet long mounted on a rigid steel frame.

Dubbed SPID, "submerged, portable, inflatable dwelling", and easily handled, internal gas pressure was kept equal to the ambient water pressure by inflating it from compressed gas tanks. There were no hatches. The SDC served as vertical transport to an eight by five foot decompression chamber with four foot air lock on board the support ship, Sea Diver, to which it could be mated for pressurized personnel transfer. The two man 49 hour dive in June, 1964, required 92 hours of decompression. The same amount of decompression would be required for much longer saturation dives. Humidity control was a big problem in the dive. The water temperature was 72°F, inside the SPID, it was 4° higher. The divers would have preferred 82-86° in the high helium environment because of its thermal conductivity.

SPID

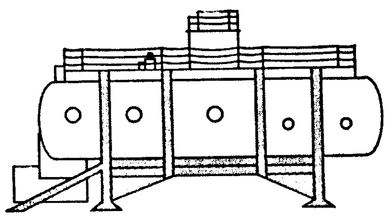
July, 1964



SEALAB I JULY, 1964
4 MEN, 11 DAYS (192 FEET)

Captain Bond's Navy group conducted Sealab I off Bermuda in July, 1964. Four men lived 10 days in a large cylindrical chamber at 192 feet. Man's ability to work underwater was tested.

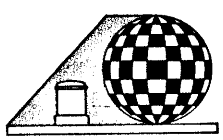
Summer, 1965



SEALAB II SEPTEMBER, 1965
28 MEN, 15 OR 30 DAYS
EACH (205 FEET)

In the Summer of 1965, Sealab II, a 45 day mission, saturated three 10 man teams for 15 days each. The astronaut, Scott Carpenter, stayed down 30 consecutive days. The cabin was 57 by 12 feet submerged in 205 feet of water near Scripps Institution of Oceanography at La Jolla, California. The mission objectives included salvage, biological and oceanographic research, as well as the conducting of physiological and psychological tests. Electrically heated suits allowed work in 55°F water.

Fall, 1965



CONSHELF 3 SEPTEMBER, 1965
6 MEN, 22 DAYS (330 FEET)

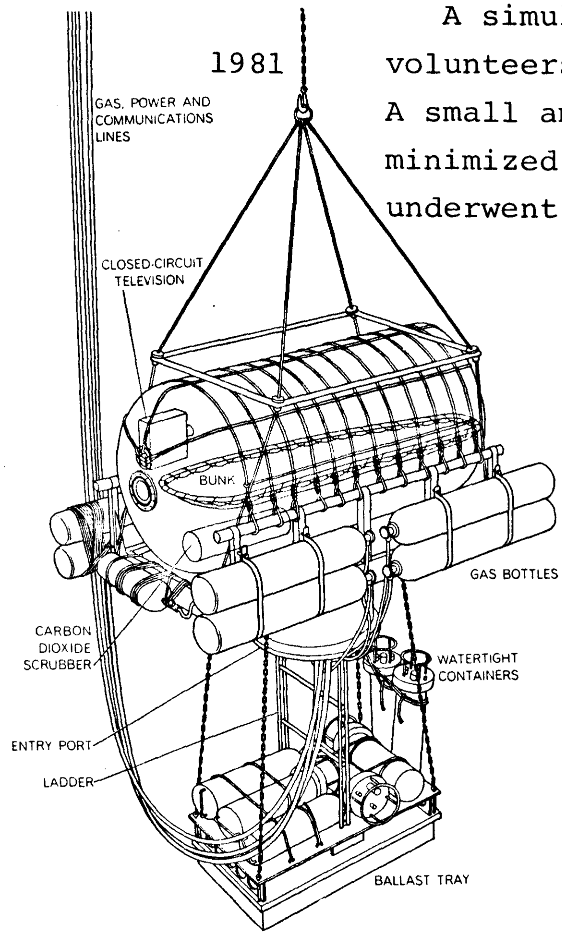
In the Fall of 1965, six of Cousteau's men lived in a spherical dwelling 330 feet below the surface for nearly 22 days, linked to the surface by only an electrical communication cable. The mission, off Cap Ferrat in the Mediterranean, concentrated on difficult underwater work, including a simulated 5 ton oilhead emplacement at 370 feet.

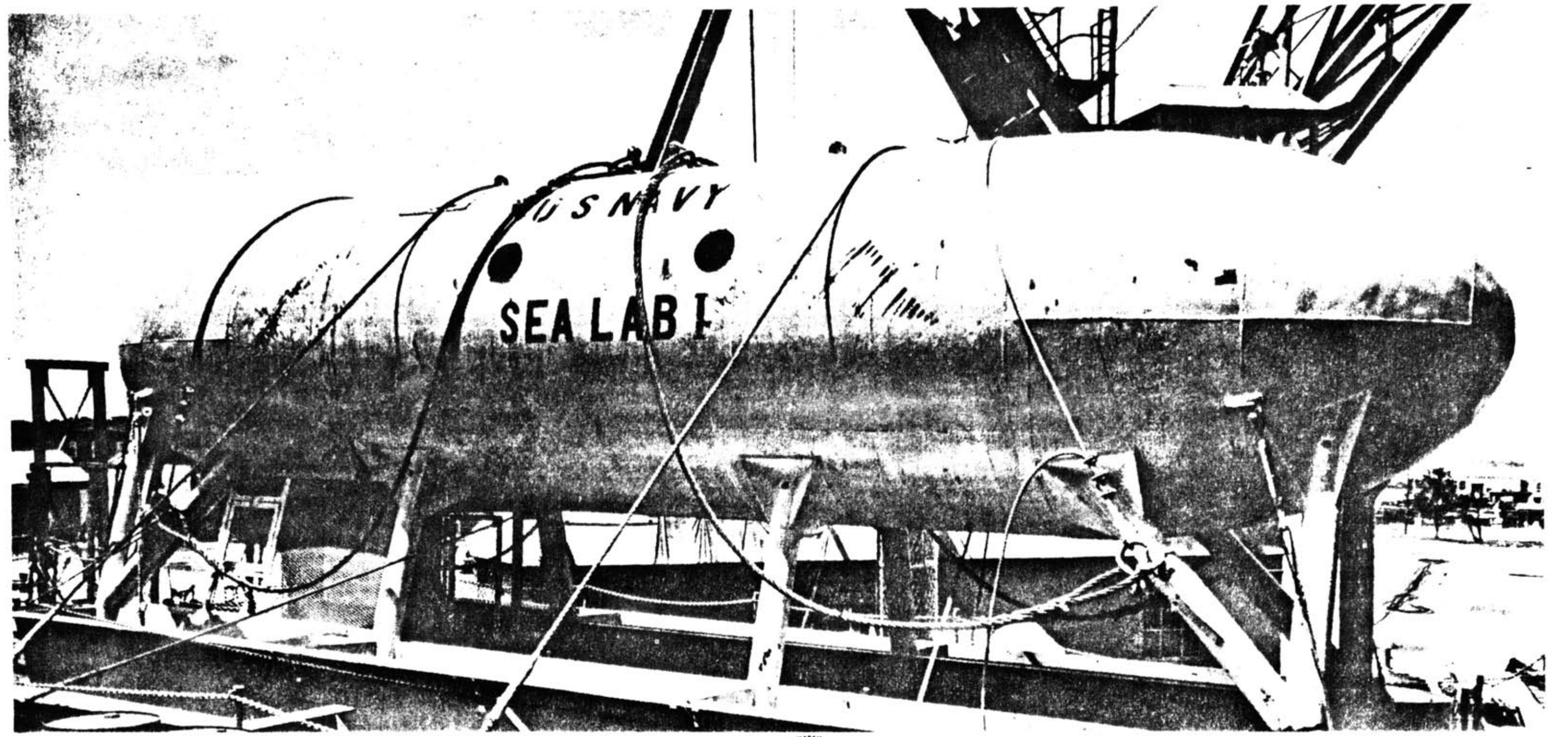
Fall, 1965

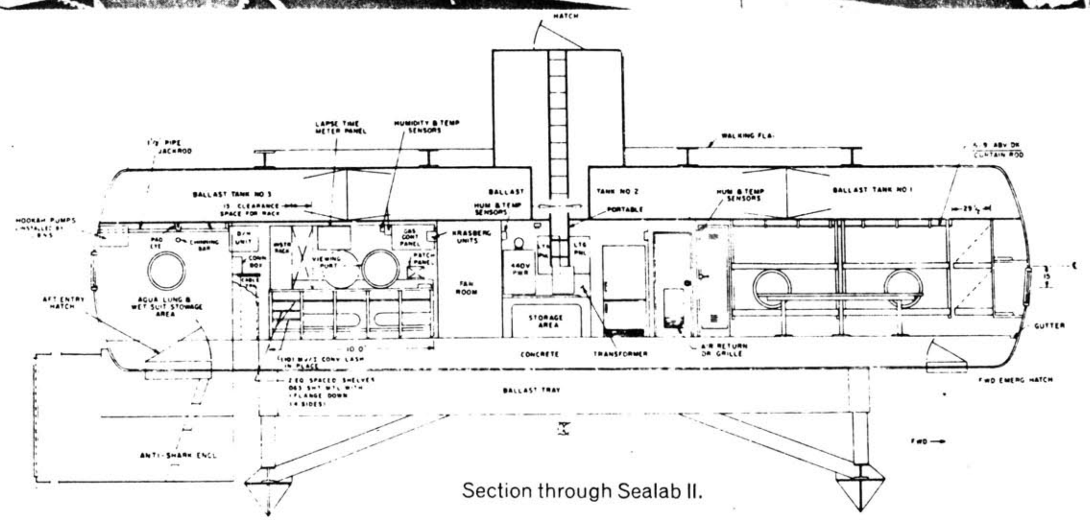
Ocean systems divers simulated a 650 foot saturation in a test chamber for 48 hours. The helium gas mixture used had no adverse effects. An oxygen-neon mixture enhanced voice quality in 30 minute testing without detrimental effect. The experiment showed work performance at 650 feet as effective as on the surface with medical reactions in the normal range.

1968 Sealab III was built in 1968. It was to house larger navy crews at greater depths but the mission was scrubbed following the death of a diver due to CO^2 poisoning.

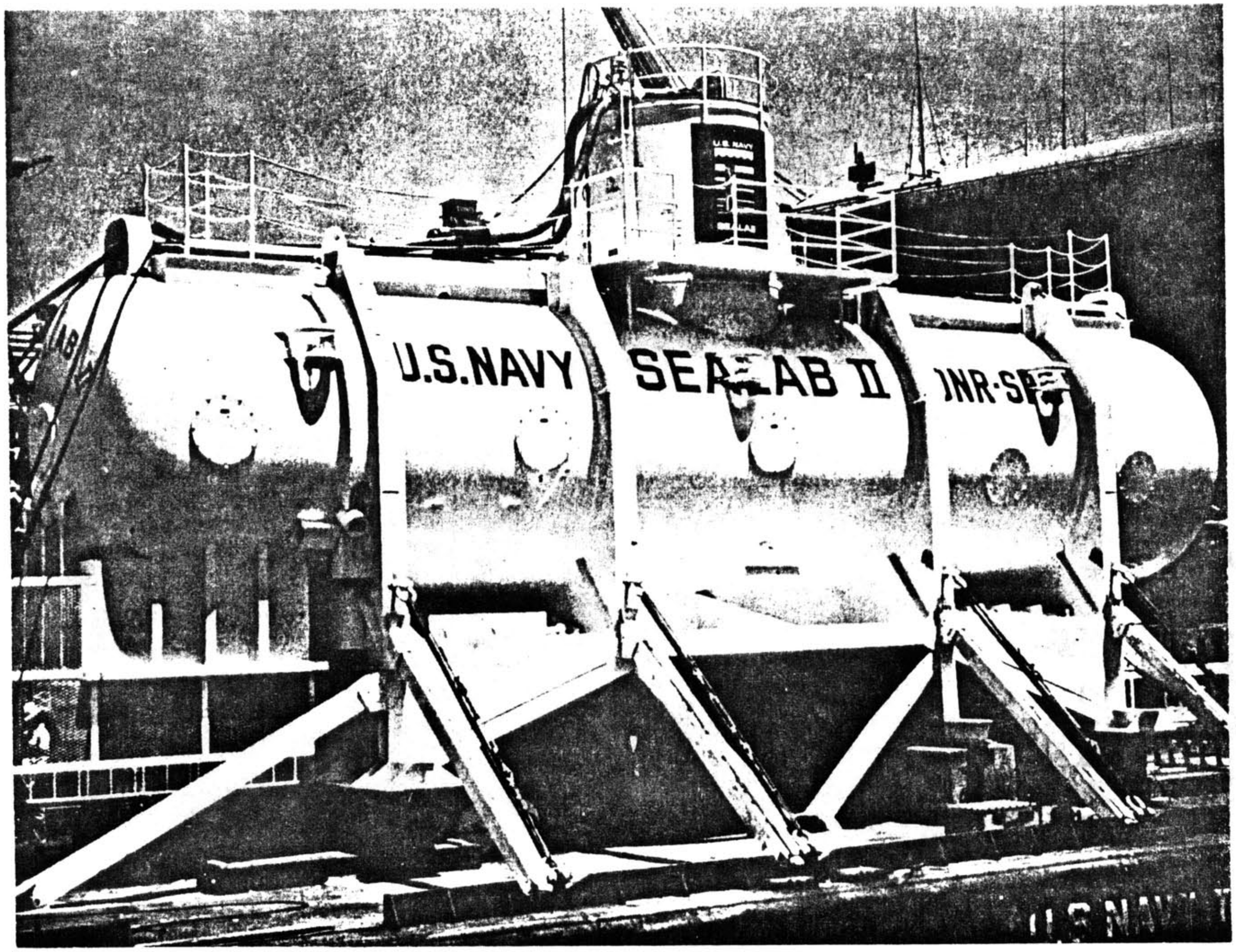
A simulated dive to 2,250 feet was survived by
1981 volunteers at Duke University Medical Center in 1981. A small amount of nitrogen in the helium-oxygen mixture minimized tremors, nausea and fatigue while the subjects underwent physiological and psychological testing.

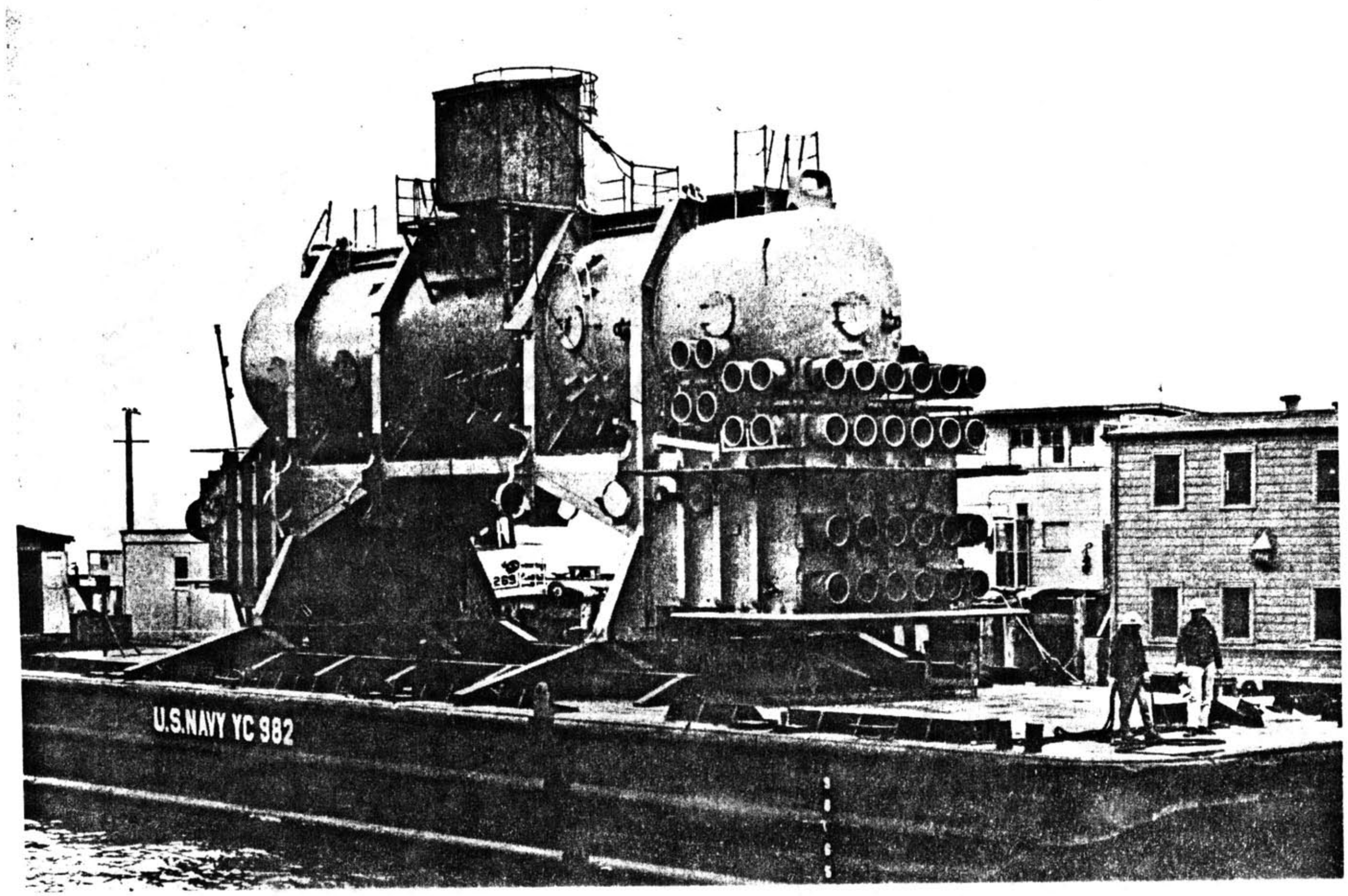




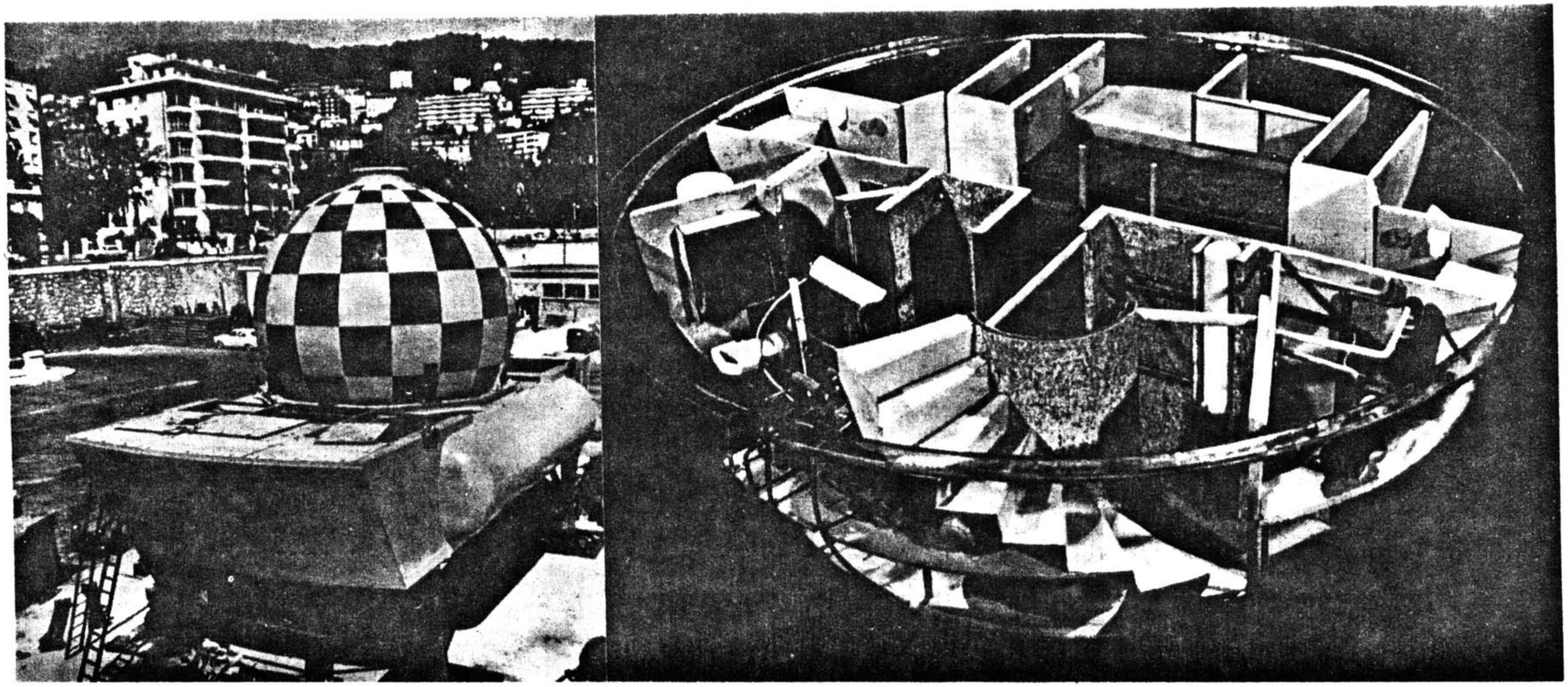


Section through Sealab II.


U.S.NAVY
SEALAB II



Sealab III



Conshelf III

Classification of Underwater Habitats

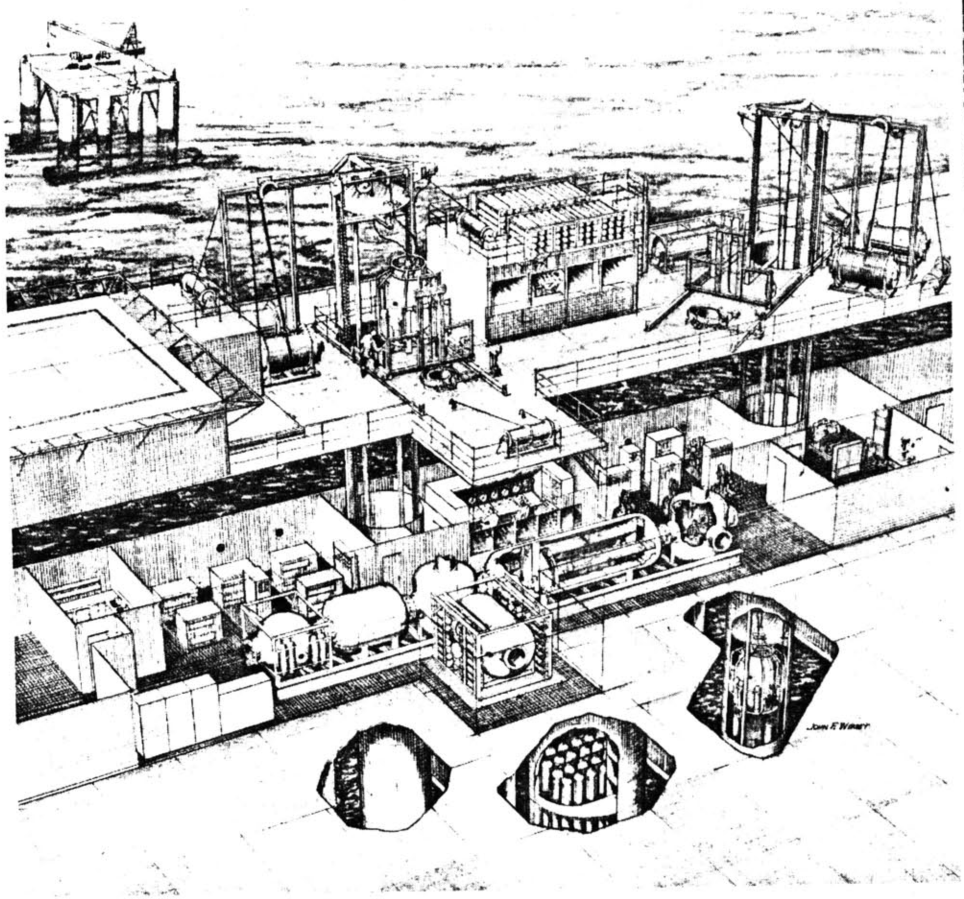
(from NOAA)

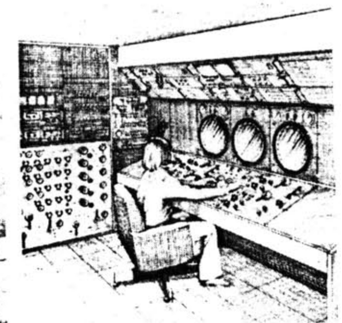
Program or Habitat Name	Operator and Country	Weight	Dimensions	Ballast	Fixed	Readily Movable	Mobile	Operations	Crew	Depth	Duration	Atmosphere	Mode of Supply: Power	Mode of Supply: Gas	Comments
MEDUSA I	Poland	3t	L=2.2m			•		Lake Klodno July 1967	2	24m	3 days	37%O_2 63%N_2	Land		
MEDUSA II	Poland		L=3.6m W=2.2m H=1.8m Total H=2.5m			•		Baltic Sea July 1968	3	30m	14 days	Air	Ship		Autonomous operation up to 50 hrs.
MINITAT	Department of the Interior, USA	4.5t	H=3.5m D=2.4m			• •		Design	3 2	26m 50m	7 days 14 days	N_2-O_2	Surface		4 view ports not used
OKTOPUS	USSR					•		Crimean Coast Black Sea July 1967	3	10m	Several weeks	Air			
PERMON II	Czechoslovakia		L=2m W=2m			•		Split, Yugoslavia Adriatic Sea July '66	2	3m	Discont.		Autonomous		Displacement = 5m³ Discontinued Decompression within habitat possible
PERMON III	Czechoslovakia	1.5t		5t		•		Czech. Lake March '67	2	10m	4 days		Land	Autonomous	
PRECONTINENT I (CONSHELF I) (DIOGENE)	Jacques Costeau France		L=5.2m D=2.5m			•		Marseille, Mediterranean Sept. '62	2	10m	1 week	Air			
PRECONTINENT II (CONSHELF II) "STAR HOUSE" "DEEP HOUSE"	Jacques Costeau France					•		Shaab Rumi Reef, Red Sea July '63	5 2	11m 27m	30 days, 1 week	Air 5%O_2 20%N_2 75%He	Ship		
PRECONTINENT III (CONSHELF III)	Jacques Costeau France	130t	L=14m Sphere D=7.5m H=8m	70t		•		France, Mediterranean Sept. '65	6	100m	22 days	1.9-2.3% O_2 1%N_2 Balance He	Surface	Autonomous	
ROBIN II	Italy					•		Genoa, Mediterranean March '69	1	17m	7 days				Light, permeable plastic hull
ROBINSUB I	Italy		L=2.5m W=1.5m H=2m			•		Ustica Is. Mediterranean July '68	1	10m		Air	Land		Wire cage, plastic tent, Vol. = 5m³
ROMANIA LSI	Romania							Bicaz Lake 1968	2				Ship		
SADKO I	USSR		Sphere D=3m	8.5t		•		Caucasian Coast, Black Sea Oct. '66	2	45m 40m 25m	6 days 6 hours 1 month		(Capable of Volume = 14m³ ship or land)		
SADKO II	USSR		Twin spheres D=3m	21t		•		Caucasian Coast, Black Sea, Summer 1967	2	25m (50-60m)	6 days		Land/ ship	Autonomous	Buoyancy = 12t
SADKO III	USSR							Zukhumy Bay, Black Sea	6	25m	6 days				
SD—M/1	UK		L=2.7m W=1.5m H=2.1m			•		Malta Mediterranean		9.1m		Air	Autonomous	Resupply tanks from surface	Discontinued
SD—M/2	UK					•		Malta Mediterranean	1-2	6.1m	10 man-days	Air	Autonomous	Resupply tanks from surface	
SEALAB I	US Navy USA		L=12.2m D=2.7m H=4.5m		•			Argus Is., Bermudas July '64	4	59m	11 days	4%O_2 17%N_2 79%He	Ship		Double chamber
SEALAB II	US Navy USA	200t	L=17.4m D=3.7m H=4.5m		•			La Jolla, California Pacific Ocean Sept. '65	10	60m	15-30 days	4%O_2 25%N_2 71%He	Ship	Autonomous	3 teams, 15 days ea. plus 1 man 29 days
SEALAB III	US Navy USA		L=2.4m D=3.7m H=4.5m		•			Planned for San Clemente Island, California	5-12	200m		2%O_2 6%N_2 92%He			Suspended

SHELF I	Bulgaria		L=6m D=2.5m			Cape Maslenos 1970		20m	6 days	Air	Surface Ship		
SUBIGLOO	Canada		2.5m sphere		•	Dec. '72 May '74	2	13m	up to 24 hours	Air	Surface		Designed as acrylic work station
SUBLIMNOS	Canada		H=2.7m D=2.4m	9t	•	Little Dunks Bay, Tobermory, Lake Ontario installed June '69 to date	2-4	10m	up to 24 hours	Air	Land		Designed for "day long" occupation— overnight accommo- dations feasible for short periods.
TEKTITE I	US Navy USA		Twin cylinders H=5.5m D=3.8m	79t	•	Lameshur Bay, US Virgin Is. 1969	4	12.7m	59 days	N_2-O_2	Ship		
TEKTITE II	Department of the Interior, USA		Twin cylinders H=5.5m D=3.8m	79t	•	Lameshur Bay. April- Nov. '70	5	12.7m	11-30 days	N_2-O_2	Land		11 crews 5 each
ADELAIDE	Australia					1967-68					Pontoon Barge		
AEGIR (Habitat II)	Makai Range Inc. USA	200t	L=2x4.6m D=2.8m Ball D=3m Total L=15.2m		•	Hawaii, '69	4-6	147m	14 days	Variable	Ship	Autono- mous	Can ascend and descend by com- pletely internal control
AQUATAT I **AQUATAT II**	Technautics Corp. USA				•		3-5						6 viewports 1.8m² viewing area (shallow water)
BACCHUS **BAH I**	Germany		L=6m D=2m		•	Baltic Sea Sept. '68 Ost Sea June '70	2	10m 10m	11 days 14 days 2.5 mo.	Air	Ship	Ship	
CARIBE I	Cuba		L=3m D=15m			1966	2	15m	3 days		Ship	Partly autonomous	
CHERNOMOR I	USSR		L=8m D=3m			Gelendehuk, Black Sea	4	5m 14m	30 days				
CHERNOMOR II	USSR	70t				Design 1967-73	4	25m 35m	4 weeks				
EDALHAB	Univ. of New Hampshire USA		L=3.7m D=2.4m	5.5t	•	Alton Bay, New Hamps. 1970-71	4	7.6m	36 hours	Air	Land	Land	
GLAUCUS	UK					1965		9m	1 week				
HEAVY DUTY **SEA BED VEHICLE**	Cammell-Laird Ltd., UK	65t	L=12m W=7m H=4.2m		•	Design	4+	180m	5 days		Surface		
HEBROS I (KHEBROS I)	Bulgaria		L=5.5m D=2m			Bay of Varna July 67	2	10m					
HELGOLAND	Germany	75t	L=9.0m D=2.5m H=6m		•	North Sea 1969-74	4	23m	10 days	Air	buoy		(About 64 tons) Capable of depths to 100m)
HUNUC	Union S. Africa				•	1971							Discontinued
HYDRO-LAB	Perry Foundation, Inc., USA NOAA		L=4.9m D=2.4m	40t	•	1966 continuous		20m	14 days	Air	Surface buoy		Numerous occupa- tions since '66. Transfer from sub- mersible at either ambient or atmos- pheric pressure possible

Program or Habitat Name	Operator and Country	Weight	Dimensions	Ballast	Fixed	Readily Movable	Mobile	Operations	Crew	Depth	Duration	Atmosphere	Mode of Supply: Power	Mode of Supply: Gas	Comments
ICHTHYANDR 66 (Idhtiandr) (Ikhtiandr)	USSR	600kg	L=22m W=1.6m H=2m			•		Crimean Coast Black Sea August 1966	1-2	11m	7 days	Air	Land		Single chambered lab. 6.8m³ 4 viewports
67	USSR	4.5t	W=8.6m H=7.0m	27t		•		Crimean Coast Black Sea August 1967	2-5	12m	2 weeks each	Air	Surface		3 Chambers
68	USSR					•		Crimean Coast Black Sea Sept. 1968	Several crew	20m	8 days total		Land		15m³ displ.
69	USSR					•		Design		20m					
KARNOLA	Czechoslovakia							1968	5	8-15m					
KITJESCH	USSR		L=5.6m D=2.6m			•		Crimean Coast Summer '68	4	15m			Shore		Volume = 30m³ 3 chambers (converted railway tank car)
KOCKELBOCKEL	Netherlands		D=1.9m H=4.6m	9.5t		•		Sloterplas 1967	2-4	15m	Short period	Air	Autonomous		
KRAKEN	UK		L=2.6m W=1m H=2.3m					Firth of Lorne, Oban Argyle, Scotland	2	30m	Several weeks	7% O_2 93% N_2			(Proposed) 2 compartments
LA CHALUPA	Puerto Rico, USA	133t	L=5.8m W=2.4m H=2.4m	22t		•		Caribbean 1972-74	5	33m	2 weeks	N_2-O_2	Surface buoy		Autonomous operation up to 48 hr. On board cumputer
LAKE LAB	Univ. of Michigan, USA		W=3.0m H=2.1m	24t		•		Grand Traverse Bay, Lake Michigan	2	10m	48 hrs.	Air	Shore		
LORA	Canada					•		Newfoundland 1974	3	8m	24 hrs.	Air	Surface		
MALTHER I	East Germany	14t	L=4.2m D=1.8m H=3.5m	(1.4m³ of iron) 11 mp		•		Malther Dam Nov.-Dec. '68	2	8m	2 days	Air	Land	Autonomous	Volume = 10m³
MAN-IN-SEA I	Edwin A. Link USA	19t	L=3.2m D=0.9m			•		Villefranche Mediterranean, Sept. 1962	1	61m	1 day	3% O_2 97% He	Ship		Aluminum cylinder
MAN-IN-SEA II (SPID)	Edwin A. Link USA		L=2.4m D=1.2m			•		Great Stirrup Cay, Bahamas June 1964	2	142m	2 days	4% O_2 96% He	Ship		Flexible rubber tent (submersible, portable, inflatable dwelling)

Saturation Diving Complex

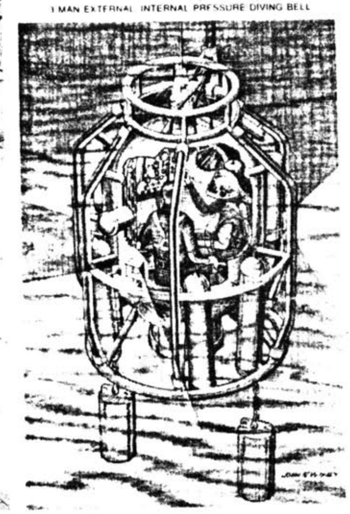


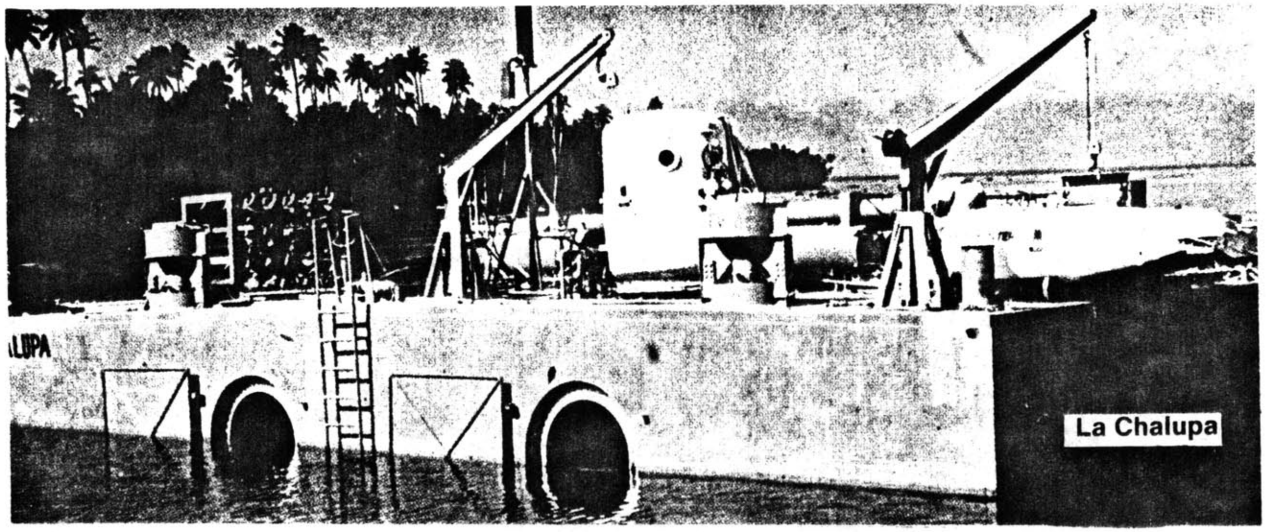


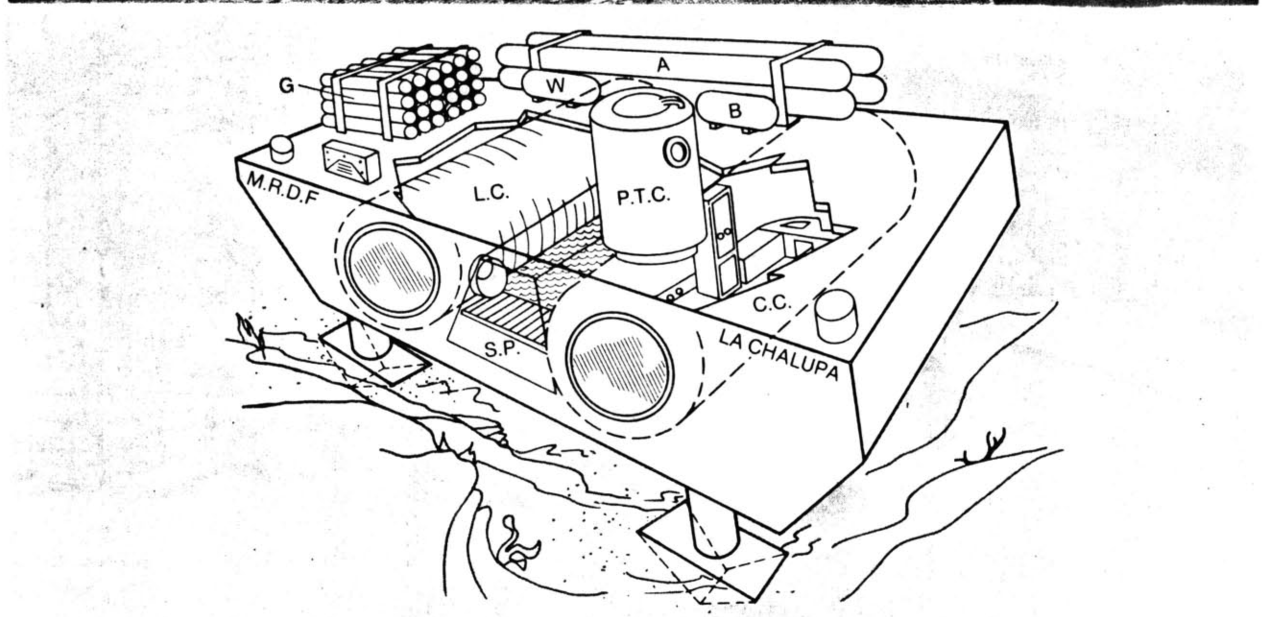
MODULAR BELL CONTROL CONSOLE

THE SATURATION DIVING SYSTEM INCLUDES TWO DIVING BELLS, SIX CHAMBERS, TWO CONTROL CENTERS, AND RELATED EQUIPMENT TO ACCOMMODATE A SIXTEEN MAN DIVING TEAM AT DEPTHS TO 1650 FEET

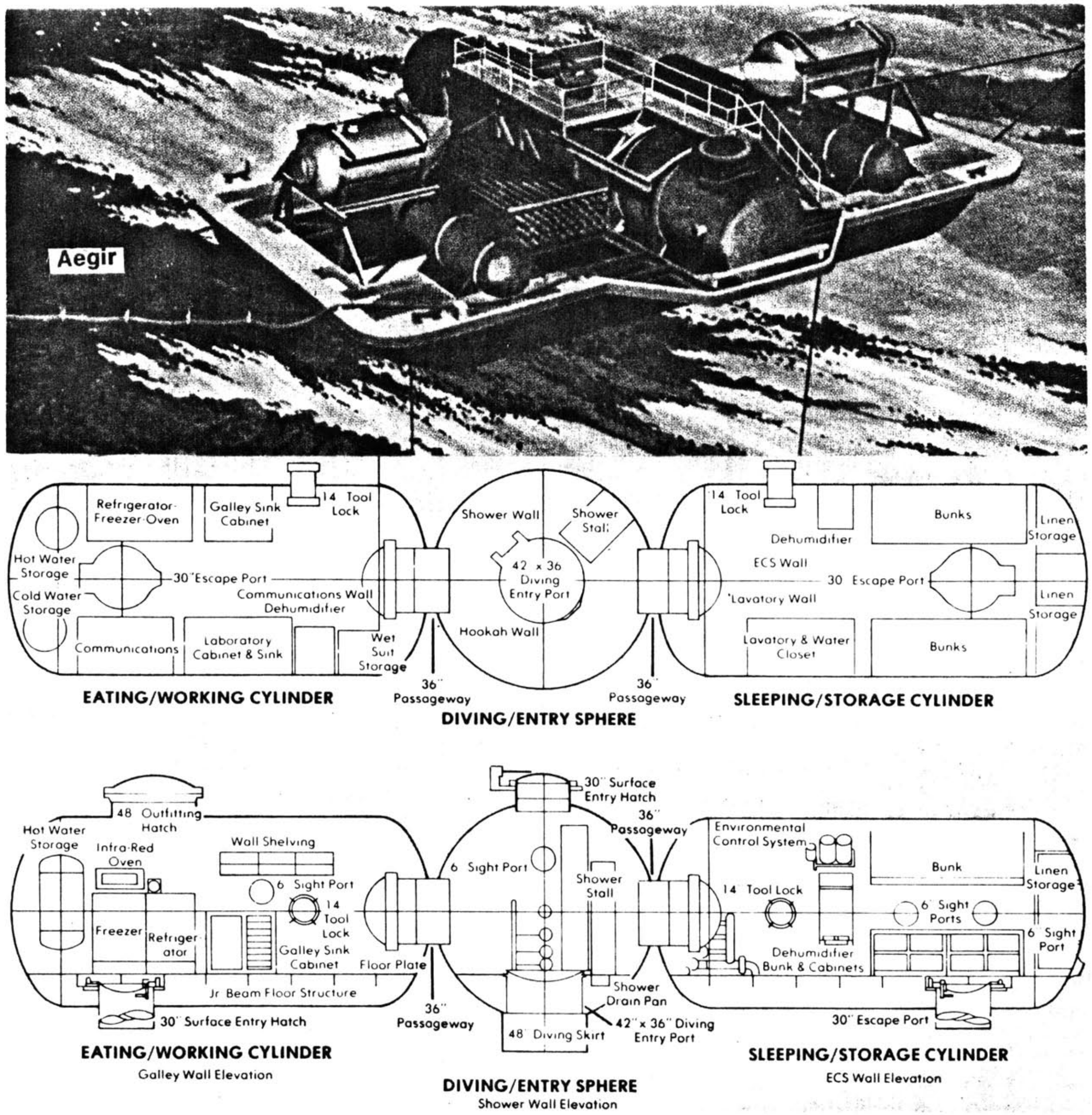
3 MAN EXTERNAL INTERNAL PRESSURE DIVING BELL







Living compartment (LC), control compartment (CC) and subport (SP) within the barge structure. On deck the high-pressure air (A), reserve water (W) and battery power (B), and two personnel transfer capsules (PTC) take up the remaining deck space. The whole structure is supported by four adjustable pneumatic legs..

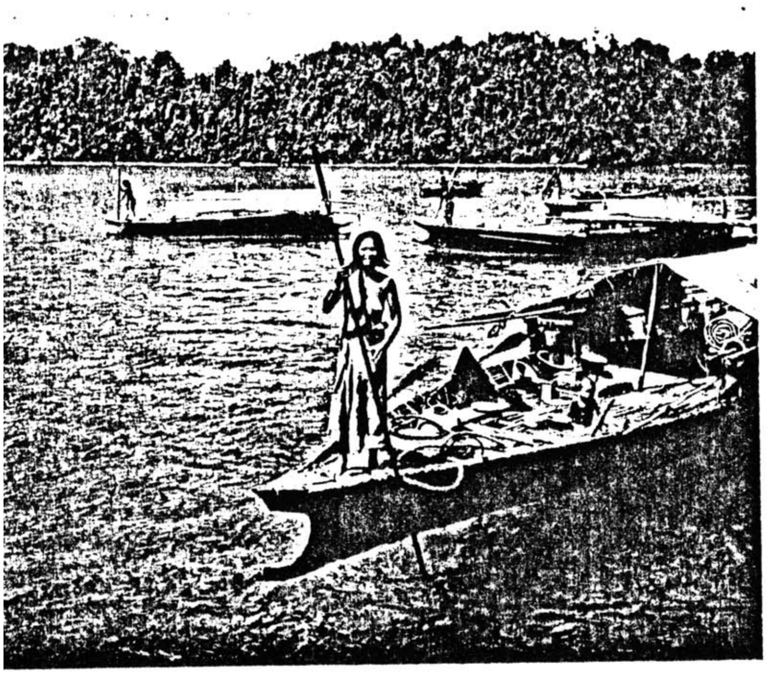

Aegir
Refrigerator-Freezer-Oven
Galley Sink Cabinet
14 Tool Lock
Hot Water Storage
30"Escape Port
Cold Water Storage
Communications Wall
Dehumidifier
Communications
Laboratory Cabinet & Sink
Wet Suit Storage
36" Passageway
EATING/WORKING CYLINDER
Shower Wall
Shower Stall
42 x 36 Diving Entry Port
Hookah Wall
36" Passageway
DIVING/ENTRY SPHERE
14 Tool Lock
Dehumidifier
Bunks
Linen Storage
ECS Wall
30 Escape Port
Lavatory Wall
Linen Storage
Lavatory & Water Closet
Bunks
SLEEPING/STORAGE CYLINDER
48 Outfitting Hatch
Hot Water Storage
Infra-Red Oven
Wall Shelving
6 Sight Port
14 Tool Lock
Freezer
Refriger ator
Galley Sink Cabinet
Floor Plate
Jr Beam Floor Structure
30" Surface Entry Hatch
36" Passageway
EATING/WORKING CYLINDER
Galley Wall Elevation
30" Surface Entry Hatch
36" Passageway
6 Sight Port
Shower Stall
Shower Drain Pan
48" Diving Skirt
42" x 36" Diving Entry Port
DIVING/ENTRY SPHERE
Shower Wall Elevation
Environmental Control System
Bunk
Linen Storage
14 Tool Lock
6 Sight Ports
6 Sight Port
Dehumidifier
Bunk & Cabinets
30" Escape Port
SLEEPING/STORAGE CYLINDER
ECS Wall Elevation

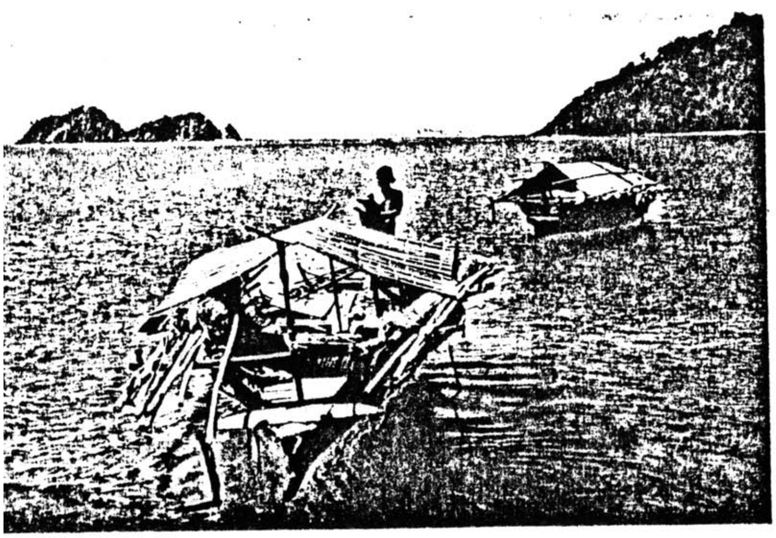
STRUCTURAL UNDERWATER TECHNOLOGY OF DWELLINGS, SETTLEMENTS AND CITIES

Early in humanity's existence, he and she learned where and how to dwell in relation to the water. The gathering of human beings is expressed in the binding of things, whether the leaves of a book or the stalks of reeds which are tied into rafts. What began as the mastery of the physical concept of bouyancy, the floating of dwellings in water, has evolved to the concepts of compression, as in Beebe's steel bathysphere, or tension as in Link's rubber submerged portable inflatable dwelling. The knowledge which goes into these artifacts includes the methods of planning, design, fabrication and deployment of these structures. Aside from the primary necessity of understanding the medium of breath underwater, structural consideration of the interface of water and usable space are of fundamental importance.

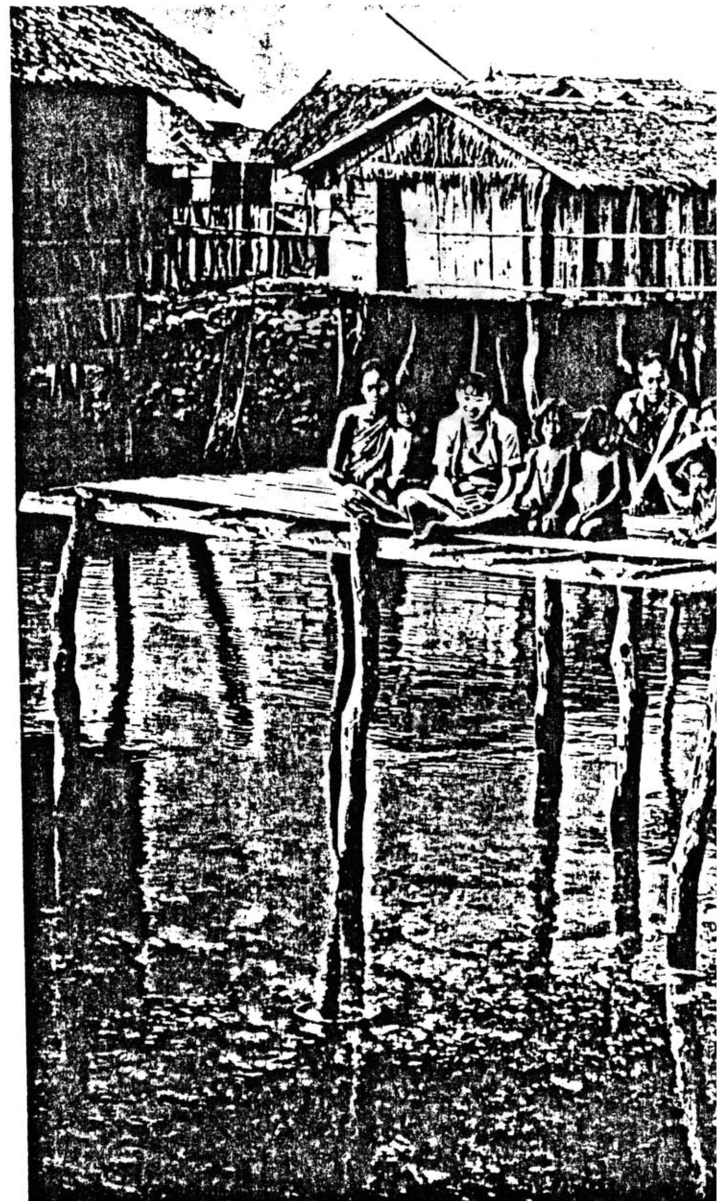
FLOATING DWELLINGS:

The Mokens of the Mergui Islands dwell in groups of six or seven boats called kabangs. Living on the waters of the Andaman Sea, south of Birmania, they trade fish, seafood, coral, pearls and shells with merchants from Burma.

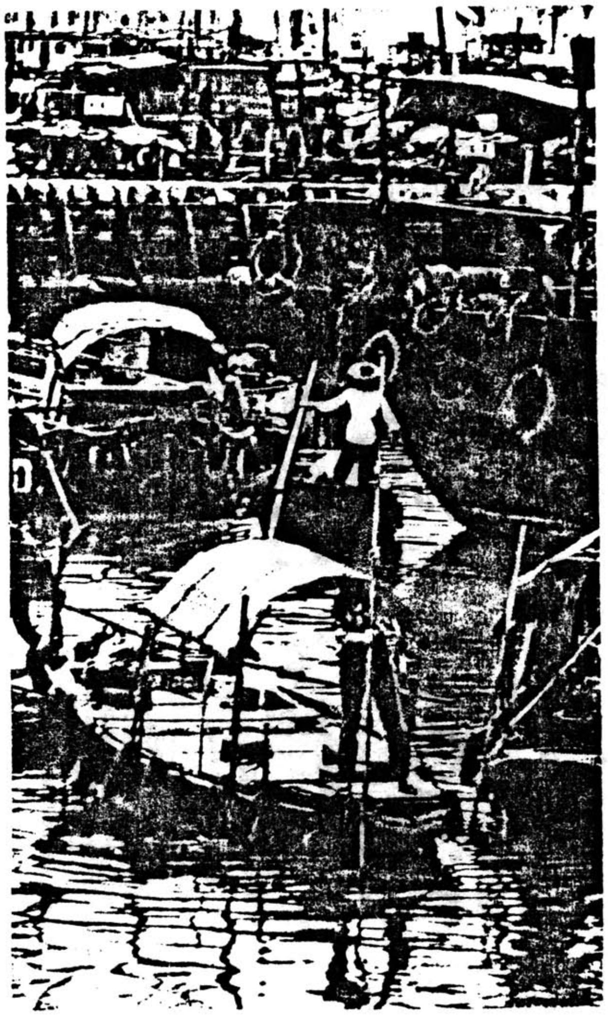




Nomads of Mergui Islands



Sulu Islands



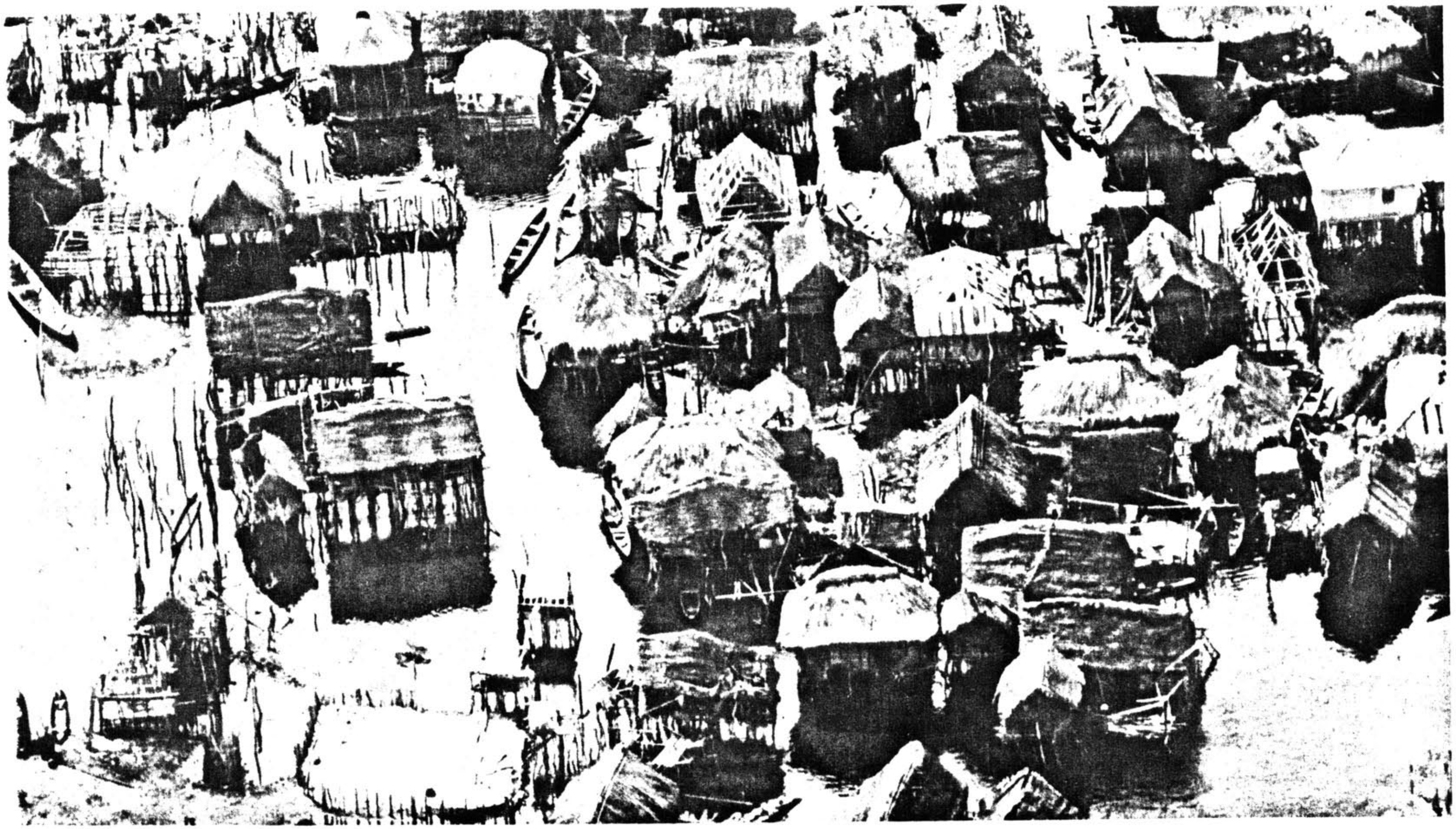
Aberdeen

The older Anuit of the arctic region spent much of their lives hunting and fishing upon the frigid waters. The frozen water itself formed their dwellings when combined with animal skins. Much of the hunting season was spent in kayaks.

Actual settlements extend over the water forming existing cities in many parts of the world. The single houseboat is a ready example. Dwellers of houseboats form an extended culture in Amsterdam New York, Hong Kong, Shanghai and Bangkok. The Indochinese dwellings of rafts, sampans or junks tied together, often with walkways and bridges, are in fact floating villages, such as Hong Kong's Aberdeen. The structural ability of resisting water pressure upon these floating bodies make these phenomenal settlements possible.

PILE DWELLINGS:

Pile dwellings, another form of dwelling in relation to water, date back to the Neolithic period. The floating markets of Bangkok are supplied by the pile house dwellers of the Menam River who fish and grow vegetables. The inhabitants of Tofinnu on the Ganvie lakes and lagoons, near Cotonou, dwell in carefully organized societal villages clustered in relation to lineage and family units. The Bayaiaos, in the Sulu Islands near Borneo, live in wood pile huts on the shoreline when not



Bayaiaos

threatened by the socially discriminating Taosung during the fishing season; during which time they dwell on their long canoes.

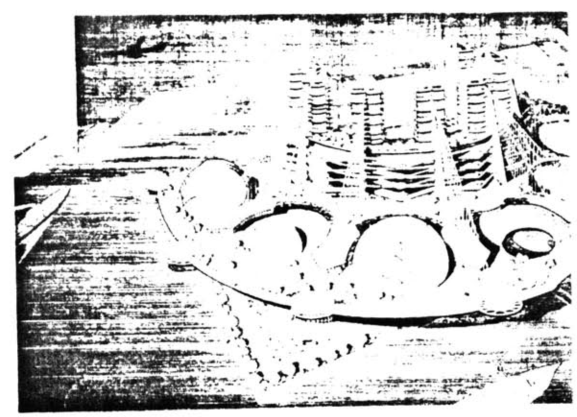
Venice, Italy is a complete city built on wooden piles in its lagoon. First, piles were driven for the perimetal foundation walls of the Venitian dwellings, forming, in essence, a caisson from which the water was pumped. Then, starting in the center of the site, piles were driven down in a spiralling pattern out towards the perimetal foundation. Thus, a solid wood substructure underpins the heavy masonry dwellings. Tromsoe, Norway is a site of continuing use of the pile dwelling technology. In lower Manhattan, the Waterside Complex, designed by Davis and Brody Associates, Architects and Planners, opened in the late 1960's; four forty-story towers of luxury housing built of reinforced concrete, brick and glass upon a field of concrete piles over the murky East River.

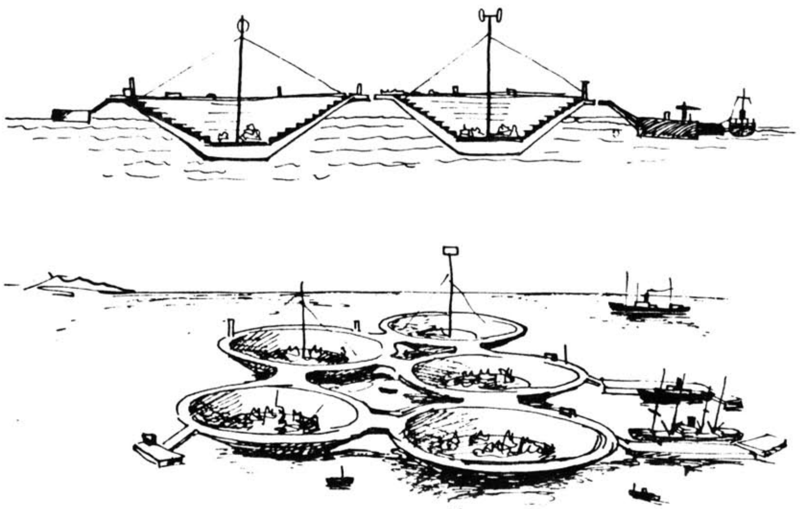
LAND FILL, DIKES, ISLANDS AND CANALS:

Currently, a multi-million dollar project in lower Manhattan, Battery Park City, is being constructed on a land filled area which extends to the bulkhead in the Hudson River. This is the third category of dwelling relative to the sea after floating dwellings and pile structures. Amsterdam is the classic example of this technology which has been used extensively throughout the Netherlands for centuries. The Perad papuan tribe of New Guinea and the inhabitants of Mala Island in the Solomon Group dwell on islands of their own manufacture. The lower part of Beacon Hill in Boston is the earliest example on our continent of dwelling lands wrested from the sea. To accomplish this, 60 feet of Beacon Hill was transported to extend the shore. The dredging of canals has also provided land fill matter while integrating the sea with the land. Water Street and Canal Street are vestiges of the Dutch tradition on the island of Manhattan.

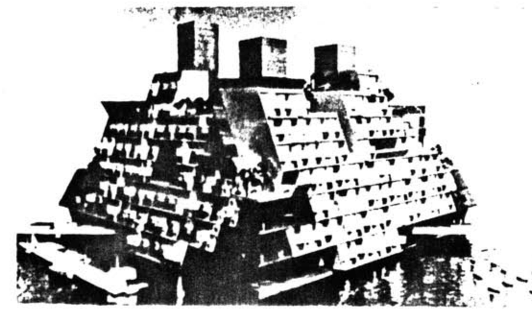
AQUATECTURE:

During the early 1960's, the Metabolist Group's projections of technological utopias, evolutions of social planning intent or parodies of the space age social condition left us with fleeting images of megastructural anachronisms. Among them is the highway ribboned extension of Tokyo onto its bay designed by Kenso Tange in 1959. That same year, before he died, Frank Lloyd Wright issued his proposal for a residence in New York Harbor. Walter Jonas also produced a proposal for Intrapolis, a clustering of floating dish shaped shell structures for dwelling, commerce and

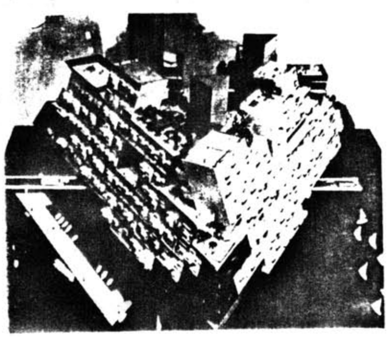

Frank Lloyd Wright



Jonas



Fuller

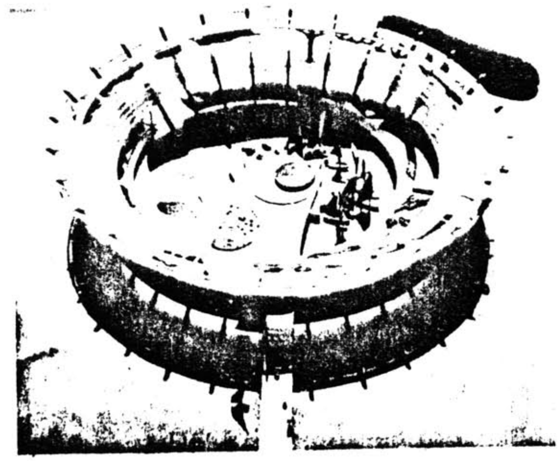


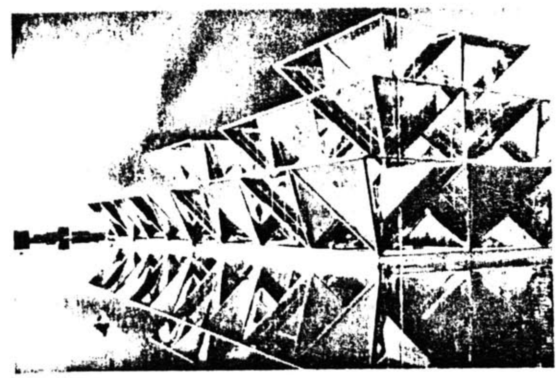
industry.

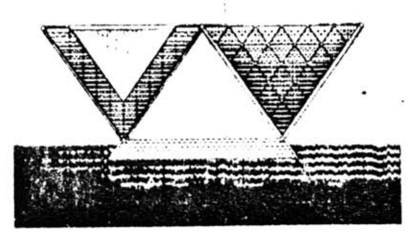
R. Buckminster Fuller's floating Triton City employed the tetrahedron's stability and prefabrication in its formation. An advocate of inventiveness and ecology, Fuller continues to seek ways for humanity to conserve and share the resources of our spaceship Earth.

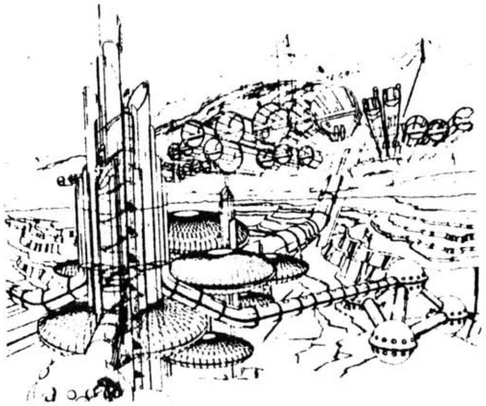
William Katavolos' Marine Urbàne structure, proposed in 1960, utilizes chemical processes in its formation, integrating clusters of surface and submerged dwellings. The membrane structures of Frei Otto, based on observation of soap film bubbles and water drops, have a wealth of pragmatic uses. Wolfgang Hibertz envisions growing structures through the process of mineral accretions in the ocean. He has successfully employed this concept in the manufactureof breakwaters and artificial reefs and advocates the process' use for storage vessels and dwellings.

In 1966, Paul Maymont proposed a floating village for Monaco. Resembling a huge stadium, the terraced dwellings step down the interior of the dished structure. Stanley Tigerman exploited the geometric hemi-octet spaceframe concept in his 1968 U.S.A. Urban Matrix. Jacques Covell and Damaz et Weigel imply a biological model in their amorphic dwellings clustered about courts and tied by bridges in their 1970 Floating Village for San Martin. Luigi Roselli-Lorenzini's 1971 Experimental Center for Volcanic Research is truly futuristic. Sergio Zampichelli in his 1973 Submarine Research Station design employed the space-frame concept and space age imagery in ellipsoidal shell pods linked by tubular bridges and tensile connectors. Aquapolis, 1975, by Kiyonori Kikutake displays in its design a knowledge of Louis Khan in plan and the technology of the oil industry's semi-submersible drilling platforms in elevation. The spaceframe concept is again employed for structural stability.


Maymont

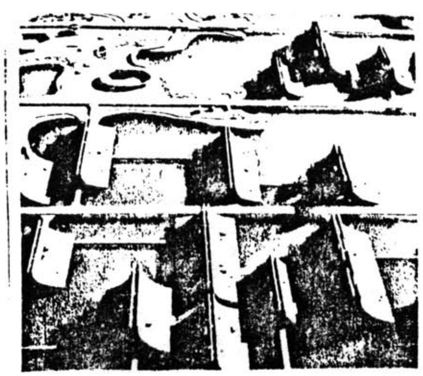

Tigerman





Lorenzini

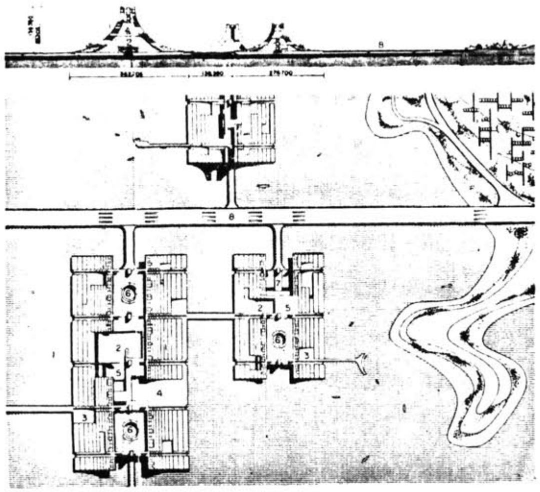
Tange

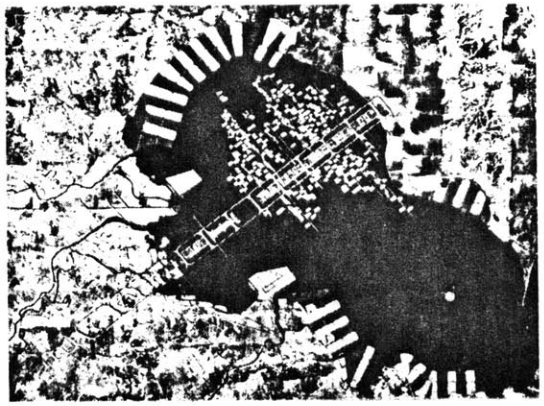


The work of Dr. John Craven, Hugh Burgess and Kiyonori Kikutake produced a model for a floating village for an exhibition in Hawaii in 1976. Prefabrication technology was proposed for construction of the complex which included a hotel, plaza, underwater exhibition rooms and an underwater laboratory. The form of the project employed two twenty-five story structural and vertical circulation cores with another nine or ten storys submerged. The towers were linked by and supported the horizontal dwelling space high above the water. Tensile cables stabilized the proposed structure.

Of large scale proposals, Sea City by the Pilkington Glass group is highly developed. A high perimetal wall opens to a harbor. A surrounding floating break-water shelters the structure. Within the walls are floating dwellings bearing triangular interlinked geometries. As with Noriaki Kurokawa's elegant Cite Lacustre design for a floating city, the gentle curvature of Sea City's primary structure reveals an aesthetic concern for its appearance.

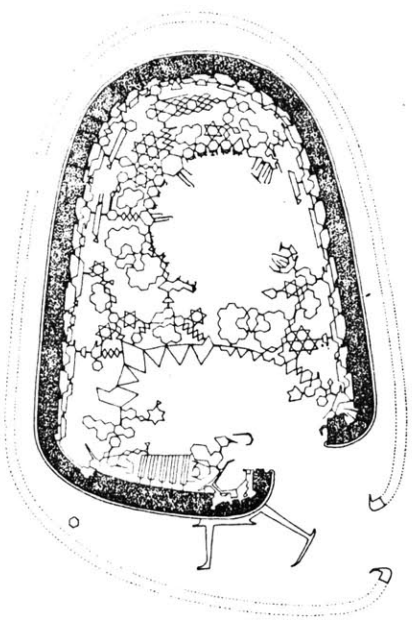
By far the most diligent proponent of underwater habitats has been Cousteau who has successfully manned the Conshelf dwellings. Yet, the American Hydrolab is the only underwater habitat in constant use over the past decade.

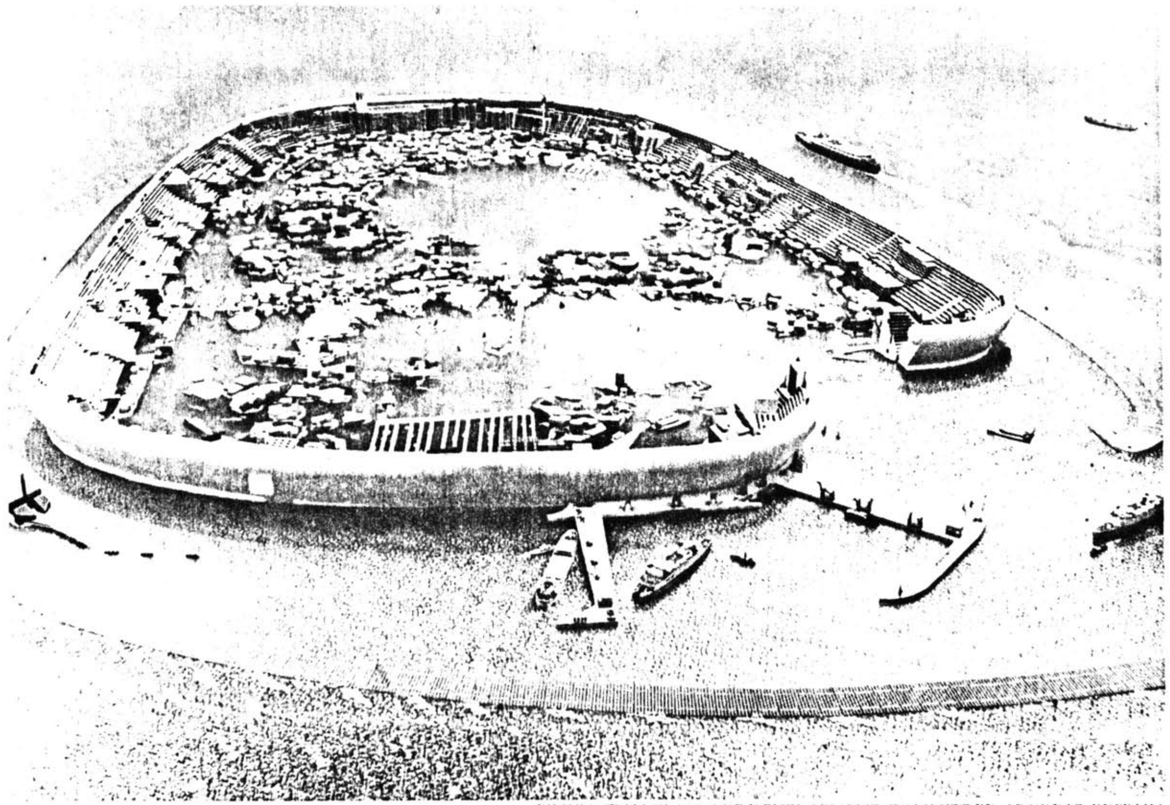




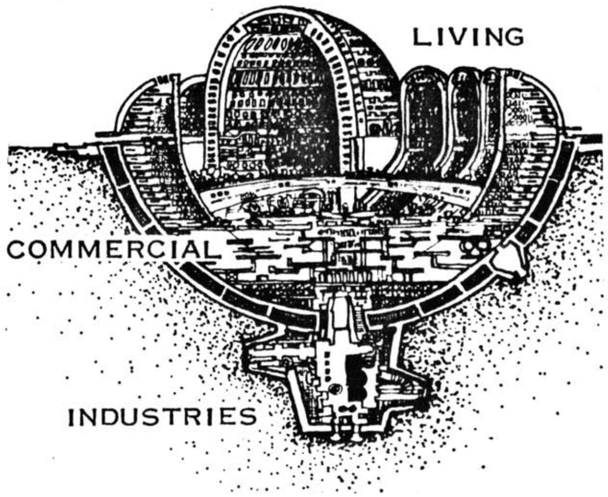
Tange

SEA CITY
A concrete and glass city at sea, housing 30,000 people in terraced apartments, could be a realistic solution to problems of living space, according to the Pilkington Glass Age Development Committee of Great Britain.



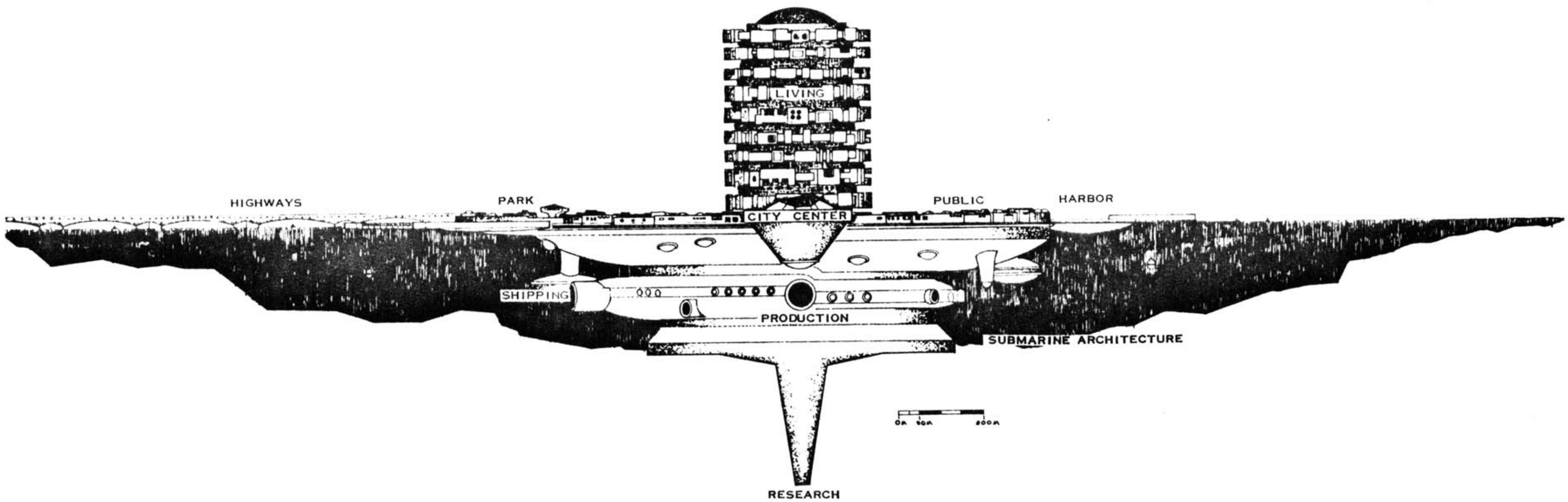


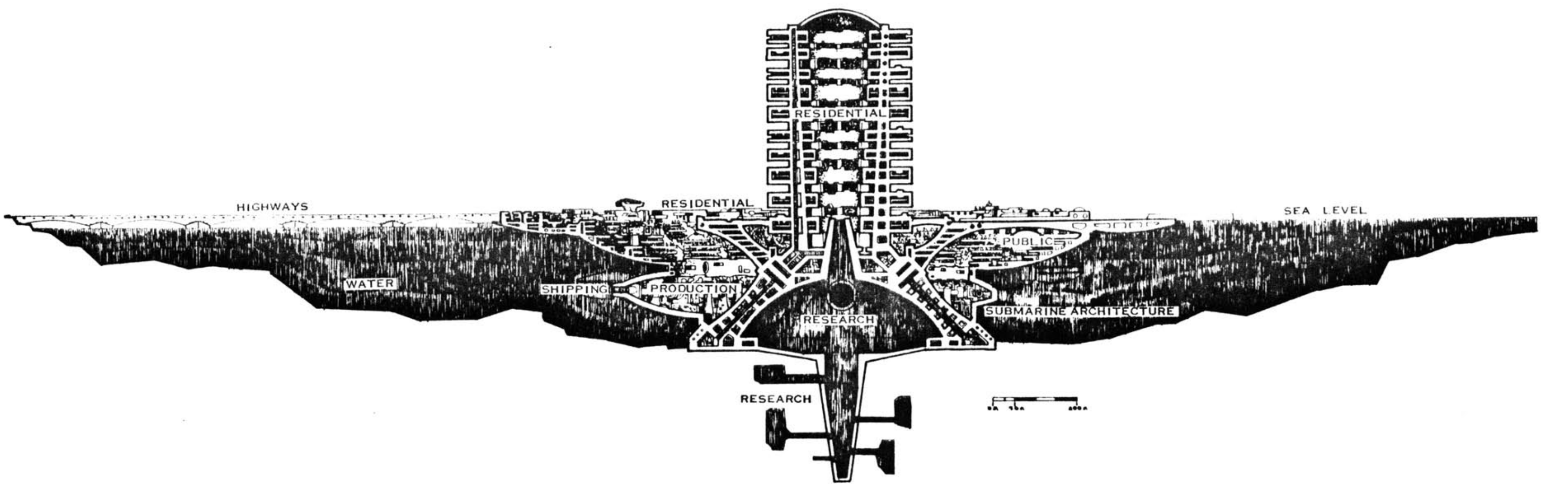
PILKINGTON GLASS AGE DEVELOPMENT COMMITTEE OF GREAT BRITAIN



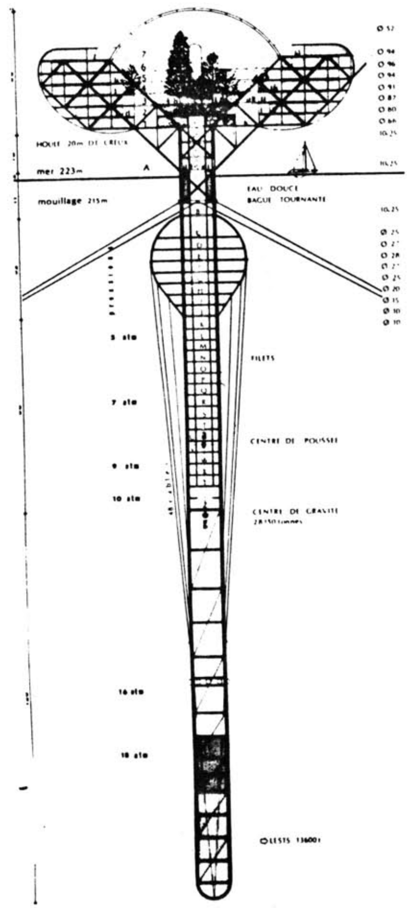
The architect with the most far reaching vision of sea cities is Paolo Soleri. His Arkologies, classified into types of terrain locating the megastructural communities, begin with the Novanoah projects, immense sea born dwellings. He employs the 3 dimensional mobility of the underwater medium in reaction to his view of contemporary culture dwelling on a two dimensional pancake-like existance. Research is only one link in the chain of the establishment of a fully rounded cultural organism. His vision is biologically founded and his pedagogy is comprehensive.

Most architectural proposals have concentrated upon dwellings upon the sea. Few seriously invest interest in the undersea realm. The oil industry also concentrates its manpower on the surface, subjected to storming seas and gale-force winds without the necessary concern for the lives of the workers as depicted by the recurrent catastrophies. The safety precautions which are available, deployable emergency escape submersibles, for example, are never employed. Loss of lives and equipment are common. These losses are included in the prices consumers must pay in order to insure profit to the oil industry. The huge Ecofisk complex in the North Sea has been plagued with the problem of scouring of the sand underpinning its foundations. The same lack of foresight in design


LIVING
HIGHWAYS
PARK
PUBLIC
HARBOR
CITY CENTER
SHIPPING
PRODUCTION
SUBMARINE ARCHITECTURE
RESEARCH


RESIDENTIAL
HIGHWAYS
RESIDENTIAL
SEA LEVEL
PUBLIC
WATER
SHIPPING
PRODUCTION
RESEARCH
SUBMARINE ARCHITECTURE
RESEARCH

Soleri



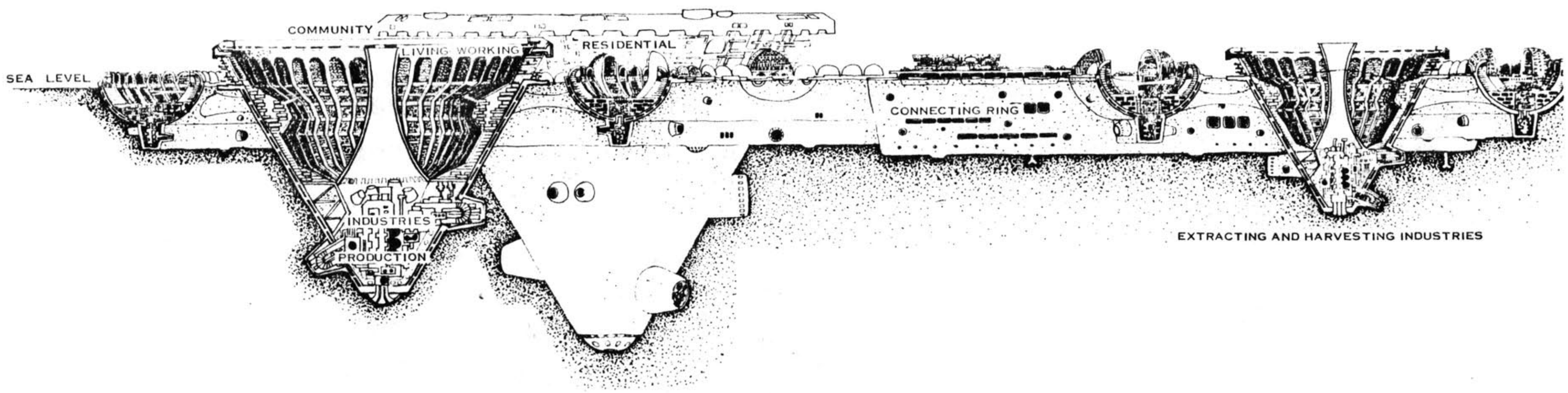
J.M. Cousteau

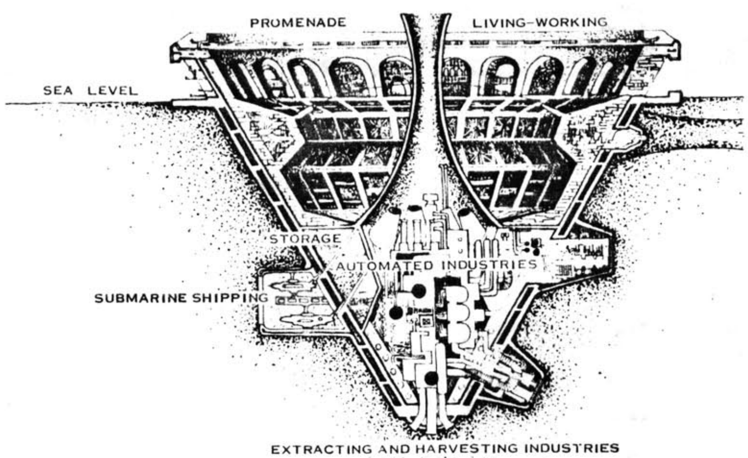
F. Marotti

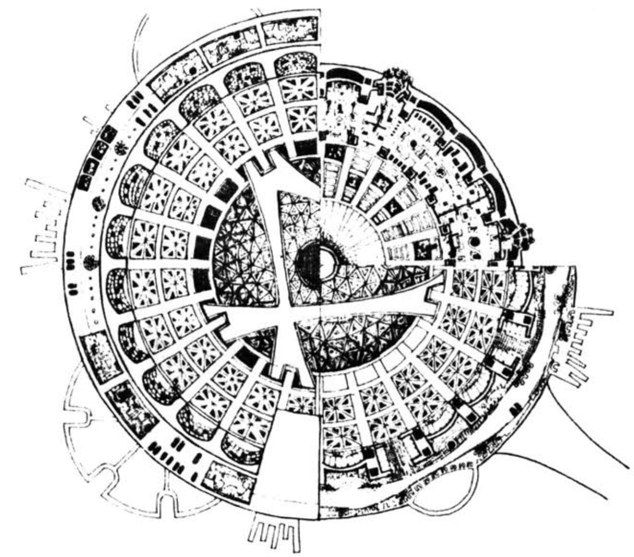
D. Auderie

plagues city dwellers subjected to gale force winds by high rise designers who ignore environmental impact assessments.

The design of submarine dwellings offers examples of solutions to problems outside the field of such dwellings. Similarly, NASA's interest in space simulations has furthered our understanding of the oceans and the technology now available for inhabiting it. The Tektite and Sealab projects are examples of this bond. Humanity has a long history of relating to the ocean and has depended upon its wealth for its sustenance. Only in this century has the ocean been threatened with such a degree of despoilation. In seeking a solution to this threat, which is a threat of manking upon mankind, dwelling in the sea offers the possiblity of monitoring, first hand, the changes as well as the option of seeking a solution.


COMMUNITY
LIVING WORKING
RESIDENTIAL
SEA LEVEL
CONNECTING RING
INDUSTRIES
PRODUCTION
EXTRACTING AND HARVESTING INDUSTRIES


PROMENADE
LIVING-WORKING
SEA LEVEL
STORAGE
AUTOMATED INDUSTRIES
SUBMARINE SHIPPING
EXTRACTING AND HARVESTING INDUSTRIES



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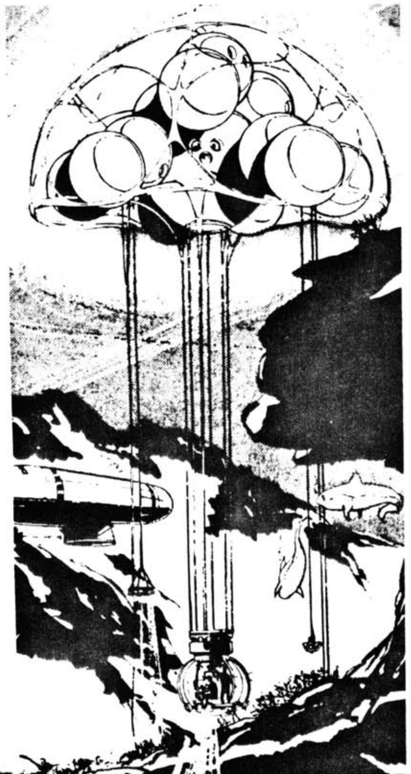

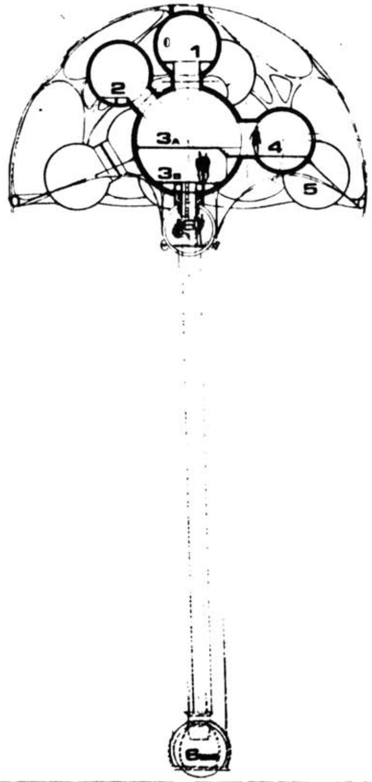

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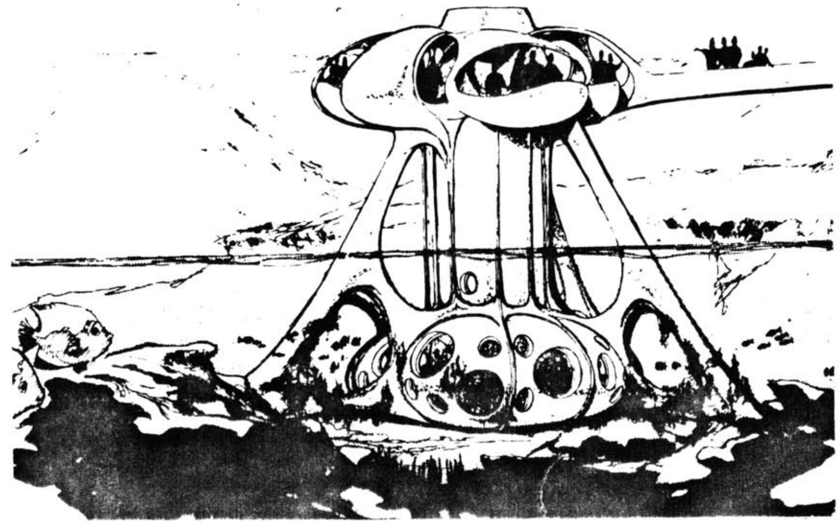
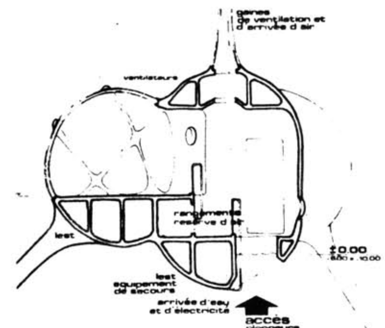
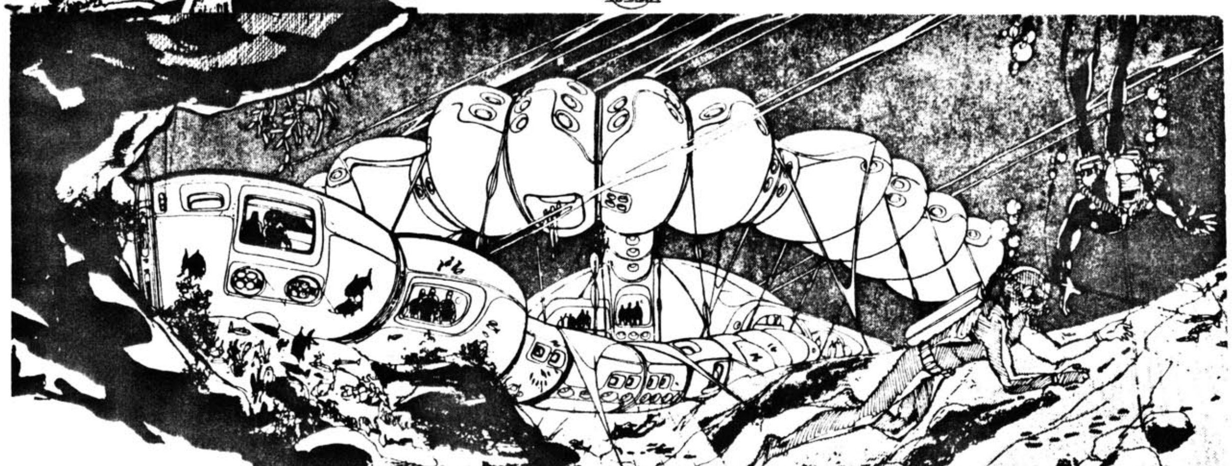
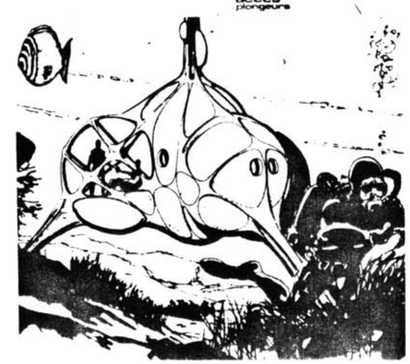


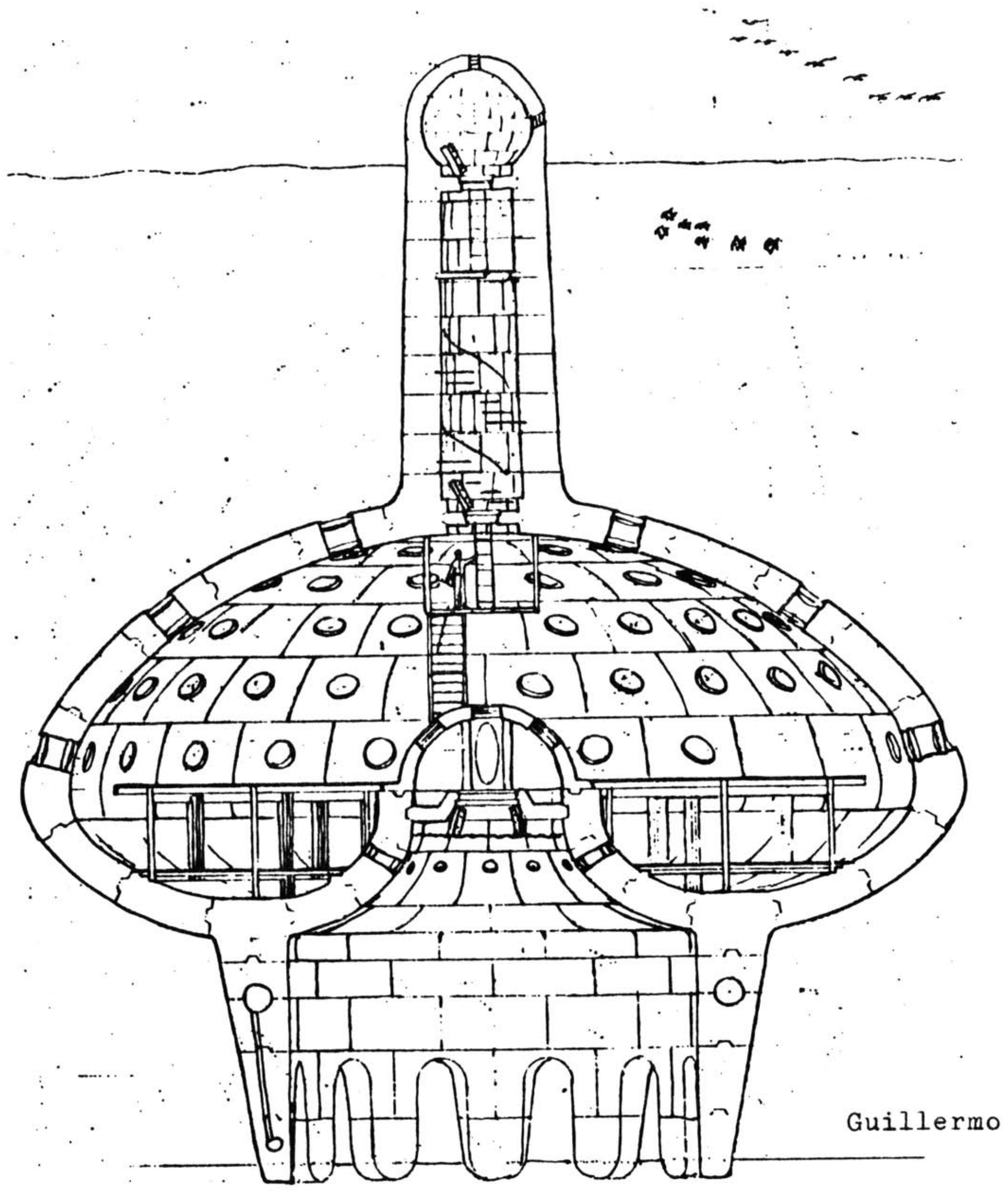
Rougerie



gaines de ventilation et d'arrivée d'air
ventilateurs
lest
±0.00
lest équipement de secours
arrivée d'eau et d'électricité
accès plongeurs






Guillermo

ENVIRONMENTAL CRITERIA

Desirable Features for Underwater Habitats (from NOAA)

Overall Size About 8′ × 38′

Separate Wet Room:	**Living Room:**
Large entry trunk	Bunks
Wet suit rack	Quick-cook oven
Hot shower	Food freezer and refrigerator
Hookah and BIBS	Water heater
Scuba charging	Toilet
Wet lab bench	Individual desk and storage
Specimen freezer	Dry lab bench
Clothes dryer	Compactor
Diving equipment storage	Library
Rebreathers	Tapes, TV, radio
	Emergency breathing system
	Computer terminal

- Hemispherical windows
- Temperature and humidity control
- Separate double chambers
- On-bottom and surface decompression capability
- Suitable entry height off bottom
- Submersible decompression chamber for emergency escape
- External survival shelter
- External lights at trunk and viewports
- External bottle storage and charging
- Habitat to diver communication
- Diver to diver communication
- Adjustable legs
- Mobility
- External or protected internal chemical hood

Before beginning this thesis, I took part in an open water scuba diving course with a National Association of Underwater Instructor (NAUI). The information and experience conveyed in ten lectures, ten pool sessions, and four open water training dives formed a basis for understanding the human and environmental constraints of designing for underwater dwelling. I would recommend such a course to anyone interested in such pursuits. A second hand understanding of diving knowledge would not be sufficient to insure proper design considerations.

To develop environmental criteria for designing underwater dwellings would comprise another volume. Therefore, the purpose of this chapter is to introduce the inherent problems and offer established guidance for resolution. The National Oceanic and Atmospheric Administration (NOAA) Diving Manual contains a list of desirable features for underwater habitats.

Basic to living underwater is breathing underwater. At 68°F standard atmospheric pressure, we breathe approximately 1 cubic foot of air per minute, which is triggered by the CO_2 content in our lungs. At 33 feet seawater pressure we breathe twice as much because the air has been compressed to half the volume it had at the surface. It is important to understand the behavior of gases which respond to temperature, pressure and volume. The relationships have been defined in the following five Gas Laws.

Dalton's Law states: "The total pressure exerted by a mixture of gases is the sum of the pressure that would be exerted by each of the gases if it alone were present and occupied the total volume." The expression of Dalton's Law for air is tabulated **(right)** at standard atmospheric pressure (14.7 psi) and at 2,000 psi.

Percent of Component × Total Pressure (Absolute) = Partial Pressure

Gas	Percent of component	Atmospheres partial pressure
N_2	78.08	0.7808
O_2	20.95	.2095
CO_2	.03	.0003
Other	.94	.0094
Total	100.00	1.0000

Gas	Percent of component	Atmospheres partial pressure
N_2	78.08	106.97
O_2	20.95	28.70
CO_2	.03	.04
Other	.94	1.29
Total	100.00	137.00

Boyle's Law states: "For any gas at a constant temperature, the volume will vary inversely with the absolute pressure while the density will vary directly with the absolute pressure."

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad P = \frac{F}{A}$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad D = \frac{M}{V}$$

where P = absolute pressure

V = volume

K = constant

$$PV = K$$

Absolute pressure is the sum of the atmospheric pressure and the hydrostatic pressure exerted on a submerged body measured in pounds per square inch absolute (psia).

Charles' Law states: "For any gas at a constant pressure, the volume of the gas will vary directly with the absolute temperature. For any gas at a constant volume, the pressure of the gas will vary directly with the absolute temperature."

where P_1 = initial pressure (absolute)
P_2 = final pressure (absolute)
T_1 = initial temperature (absolute)
T_2 = final temperature (absolute)
V_1 = initial volume
V_2 = final volume

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \quad \text{(volume constant)}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{(pressure constant)}$$

Henry's Law states: "The amount of any given gas that will dissolve in a liquid at a given temperature is a function of the partial pressure of that gas in contact with the liquid and the solubility coefficient of the gas in the particular liquid." This concerns gases dissolved in human tissue under hydrostatic pressure which must be released through decompression.

where VG = volume of gas dissolved at Standard Temperature Pressure Dry

P_1 = partial pressure in atmosphere of that gas above the liquid

VL = volume of the liquid

a = Bunson solubility coefficient at specified temperatures

$$\frac{VG}{VL} = a\ P_1$$

The General Gas Law is a combination of Boyle's and Charles' Law.

P_1 = initial pressure (absolute)

V_1 = initial volume

T_1 = initial temperature (absolute)

P_2 = final pressure (absolute)

V_2 = final volume

T_2 = final temperature (absolute)

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Useful in determining the rate of gas flow through orifices, as is necessary for providing sufficient air and ventilation in sea dwellings is Poiseville's Law of Laminar Flow:

where V = gas flow, in $cm^3\text{-}sec^{-1}$

P = pressure gradient between two ends of tube, in dynes - cm^{-2}

r = radius of tube, in cm

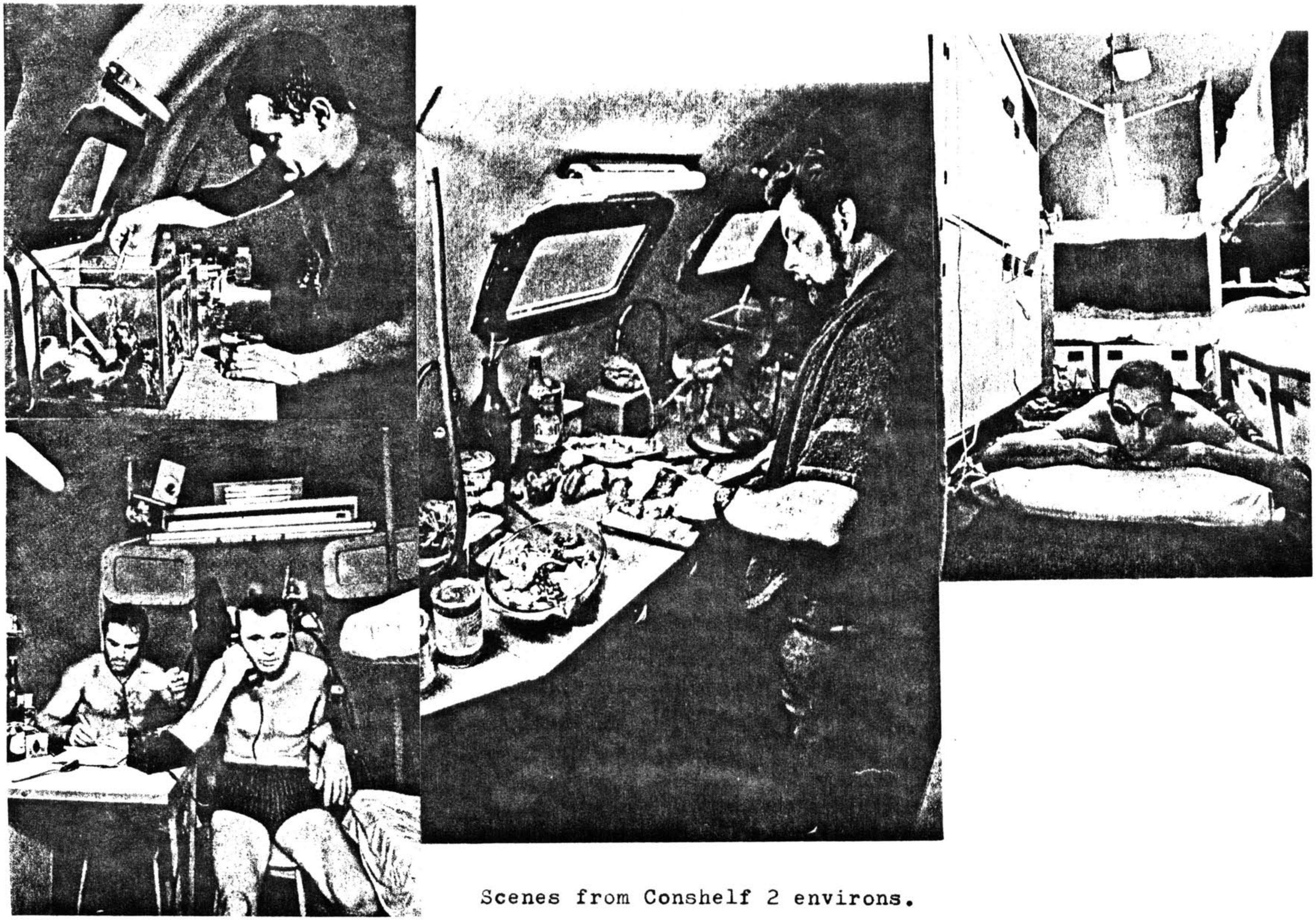
L = length of tube, in cm

n = viscosity, in poise

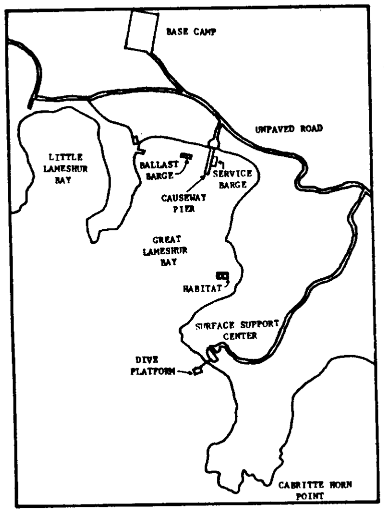
$$V = \frac{Pr^2}{8Ln}$$

We discover flow is reduced in direct proportion with the increase in resistance.

Besides the supply of air, underwater dwellers require other life supports such as fresh water and electricity. Toxic gases from cooking, expiration and other chemical and biological reactions must be collected and exhausted from the dwelling. Safety precautions on all levels must be rigidly adhered to. Redundancy of life support systems is required.



Scenes from Conshelf 2 environs.



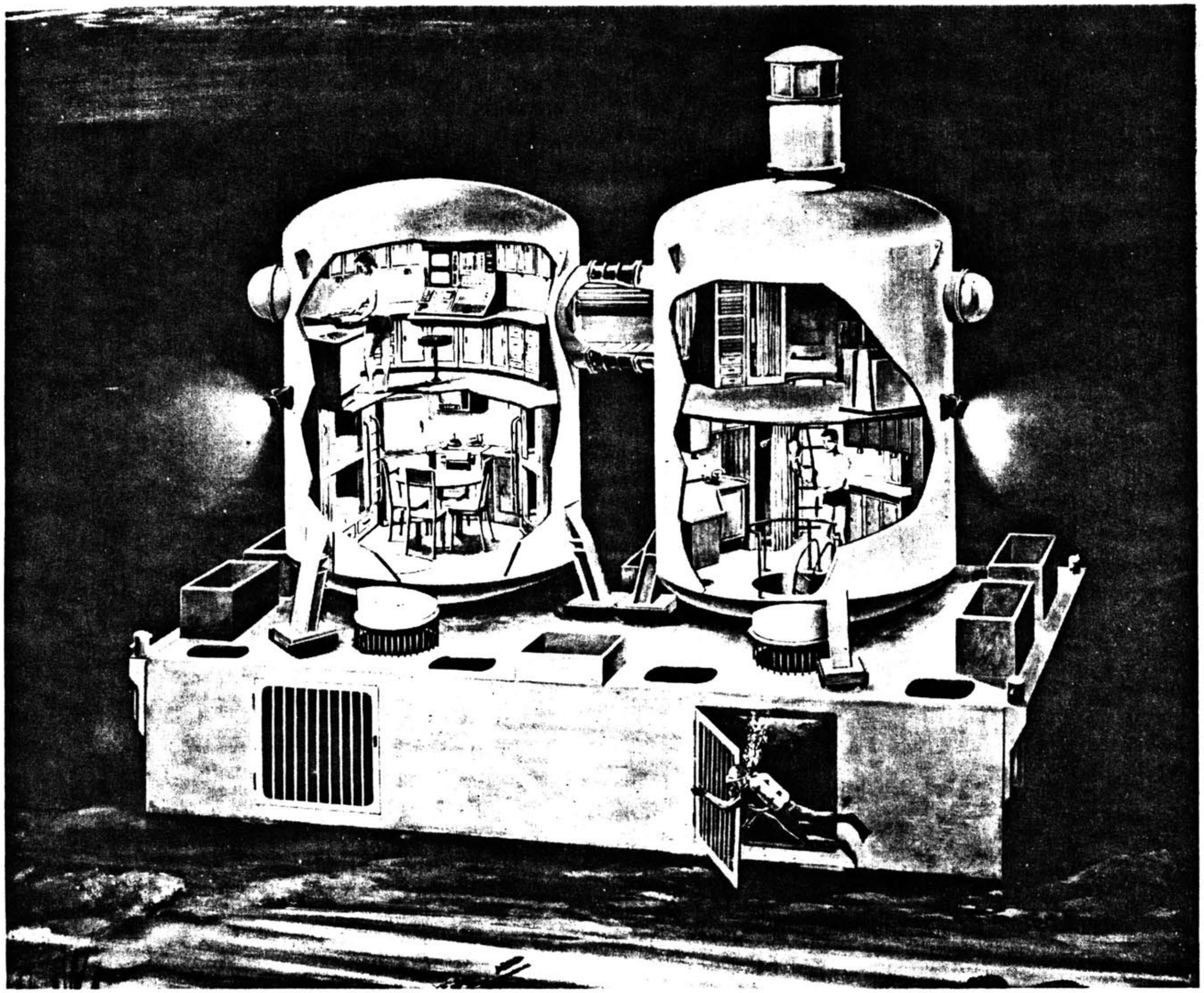
Pre-Mission Sites

St. John, V.I.

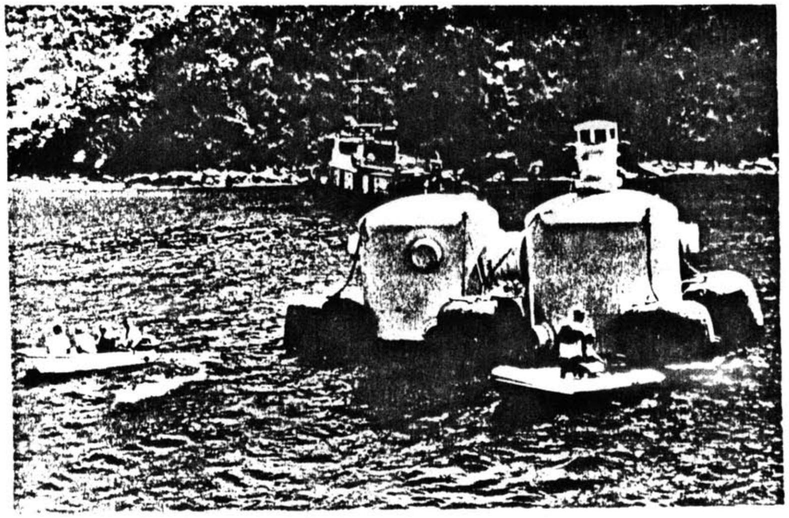
A study of thoroughly documented operating habitats will yield vital data for the design of underwater dwellings. The Scientists-in-the-Sea programs of Tektite 2, run by a host of Federal agencies and academic and industrial institutions between July 1969 and July 1971, produced a wealth of information covering the full spectrum of concerns. Through the testing of apparatus and techniques, surveys and experiments, information was gathered about underwater social behavior, psychology, physiology, bacteriology, biology, geology, ecology, logistics, meterology, oceanography, and ocean systems. Included was a habibility assessment program, a self-administered mood survey by the inhabitants and a tabulation of habitat inadequacies.

Social cohesion among the sea dwellers was very high, topside support personnel being regarded as separate from the group. Resolution of deficiencies attributable to habitat design would further the potentials of discovery through sea dwelling.

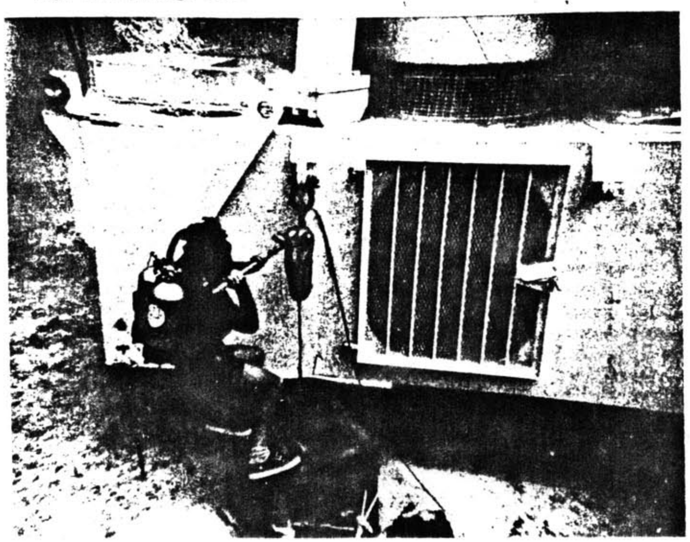
Prior to the construction and installation of the Tektite 2 the Minitat habitat helped solve problems of engineering and logistics as a lead project. I have included diagrams of its life support systems as a guide to the designer who must integrate the work of engineers.



Tecktite 2

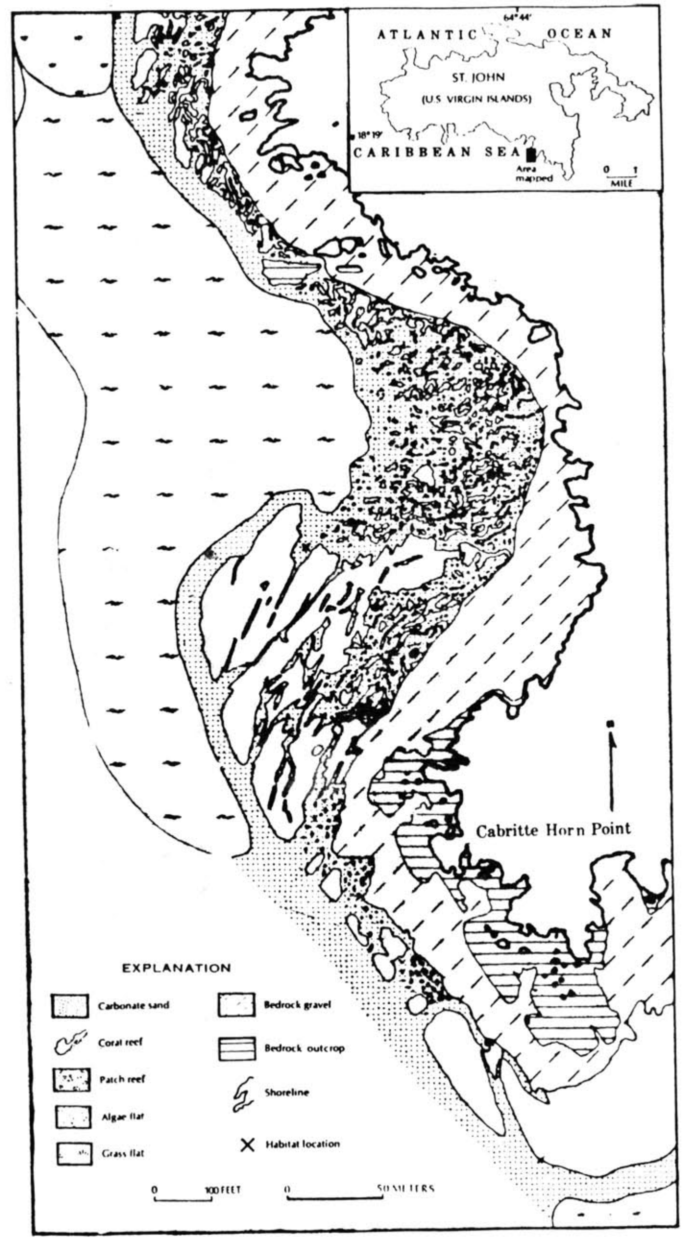


Habitat Moored at Ballasting Site Being Supported by Six 8.8 Ton Salvage Pontoons

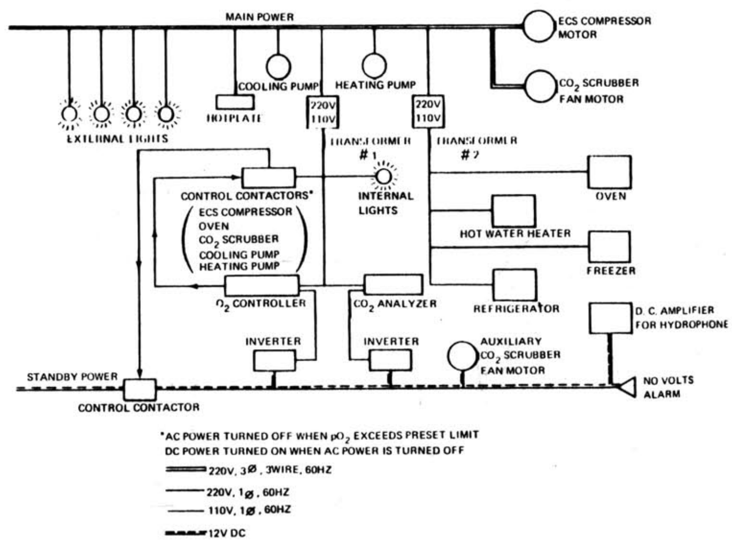


Final Stage of Hauldown

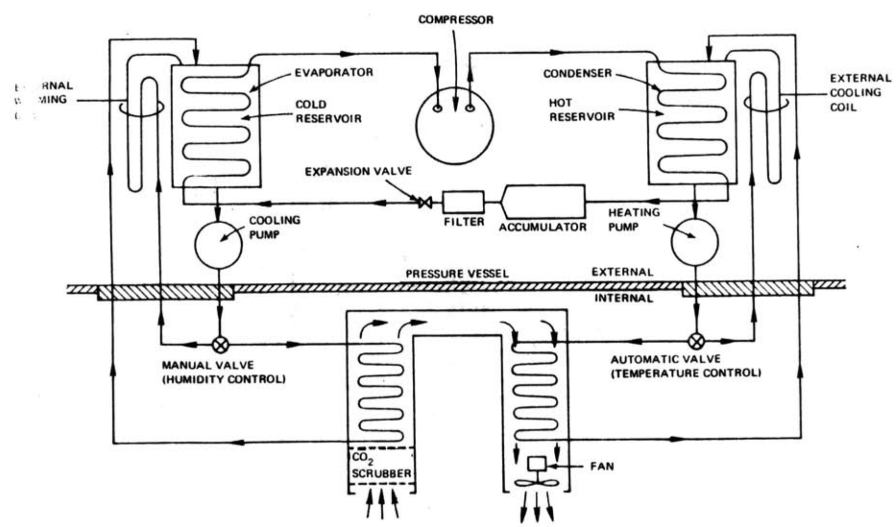
The various umbilicals were laid and hooked up individually. The small high pressure air line was completed first in order to maintain the internal pressure of the sealed habitat had it become necessary.



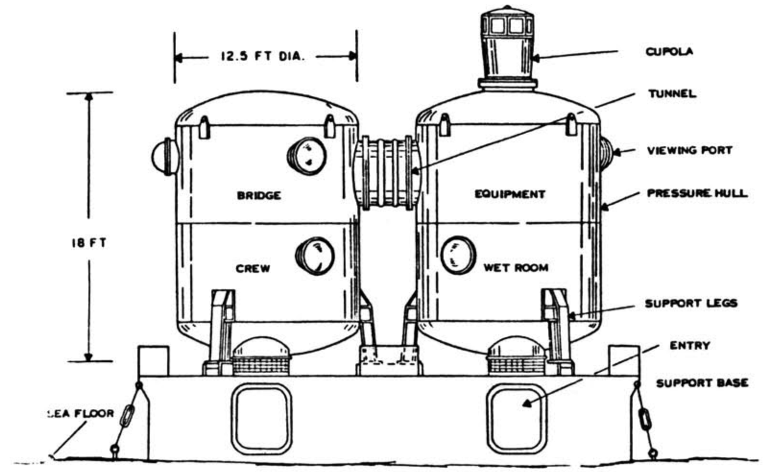
Map of Beehive Cove showing bottom types.



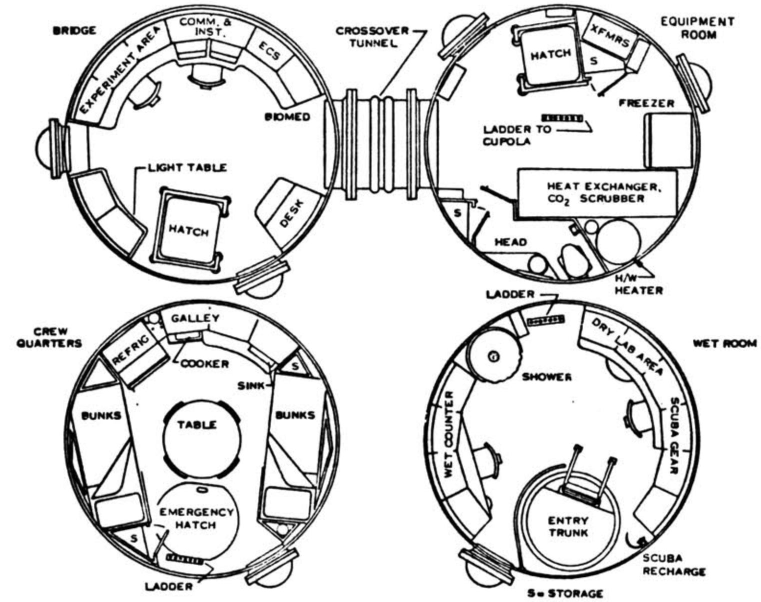
ELECTRICAL SYSTEM BLOCK DIAGRAM



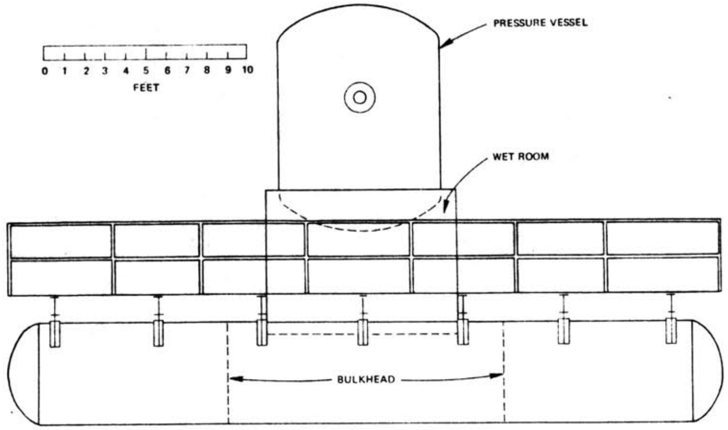
THERMAL CONTROL SUBSYSTEM SCHEMATIC



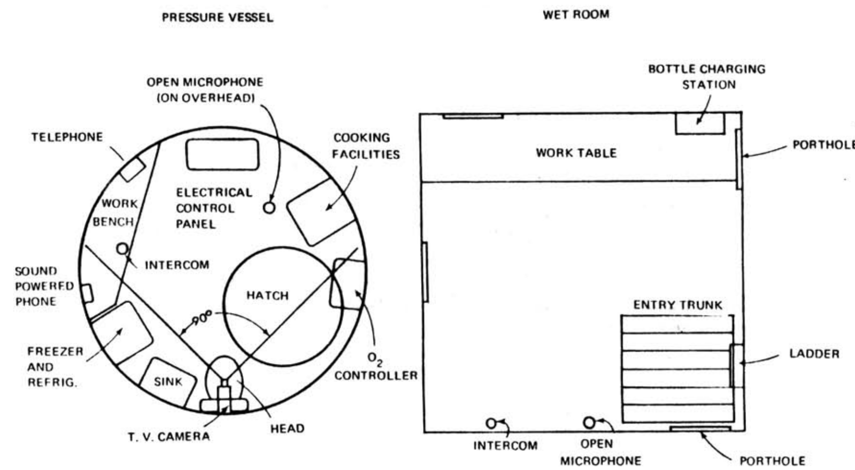
Side view of the TEKTITE II habitat



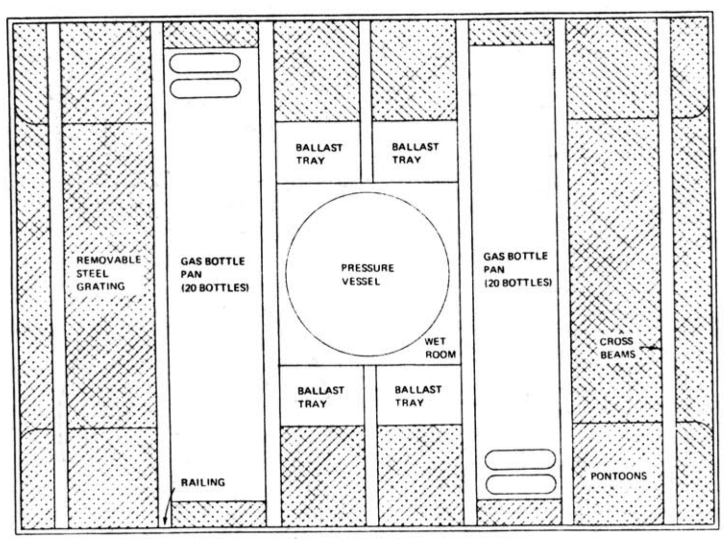
Plan views of the habitat compartments



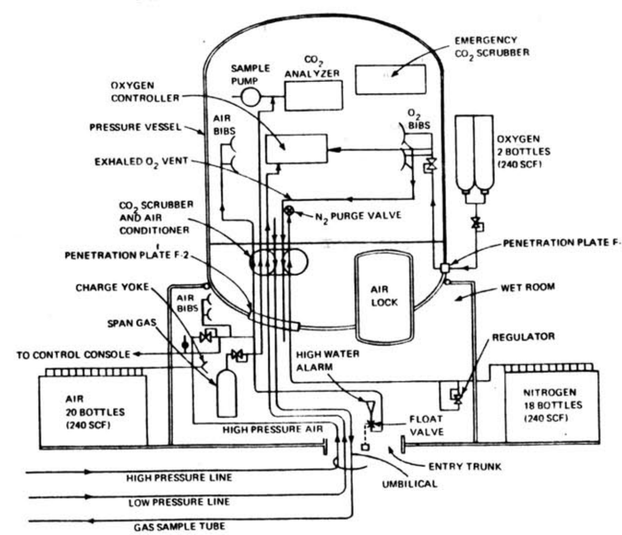
MINITAT PORT SIDE ELEVATION.



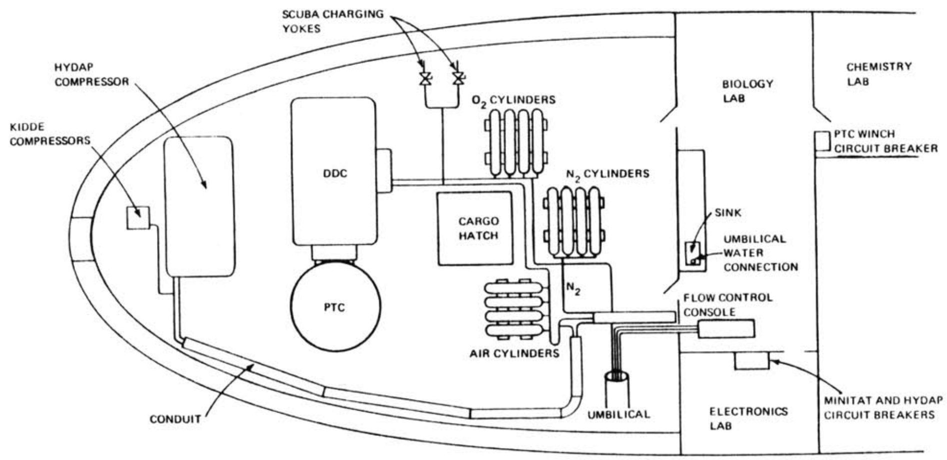
LOCATION OF MINITAT COMMUNICATIONS



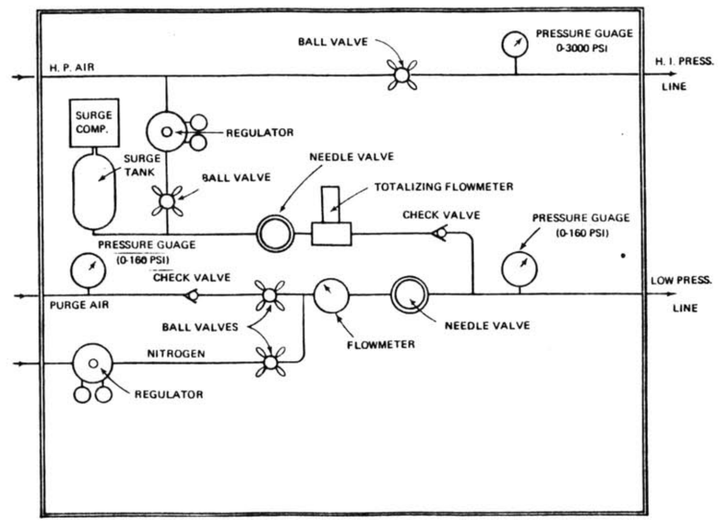
MINITAT PLAN VIEW.



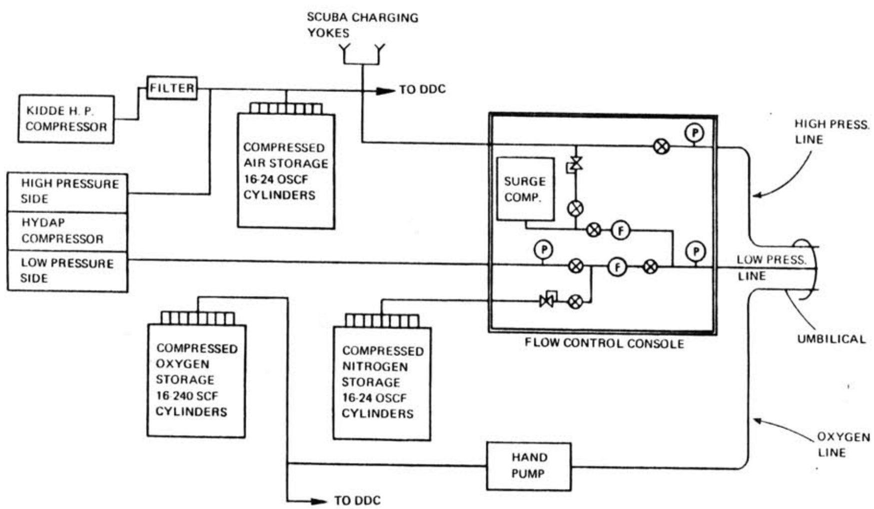
BREATHING GAS SUBSYSTEM SCHEMATIC



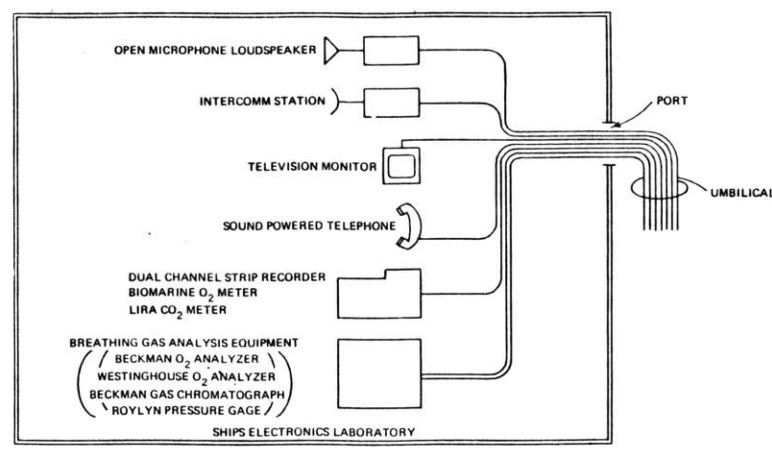
SUPPORT EQUIPMENT ARRANGEMENT



GAS FLOW CONTROL CONSOLE



BREATHING GAS SUPPLY SYSTEM



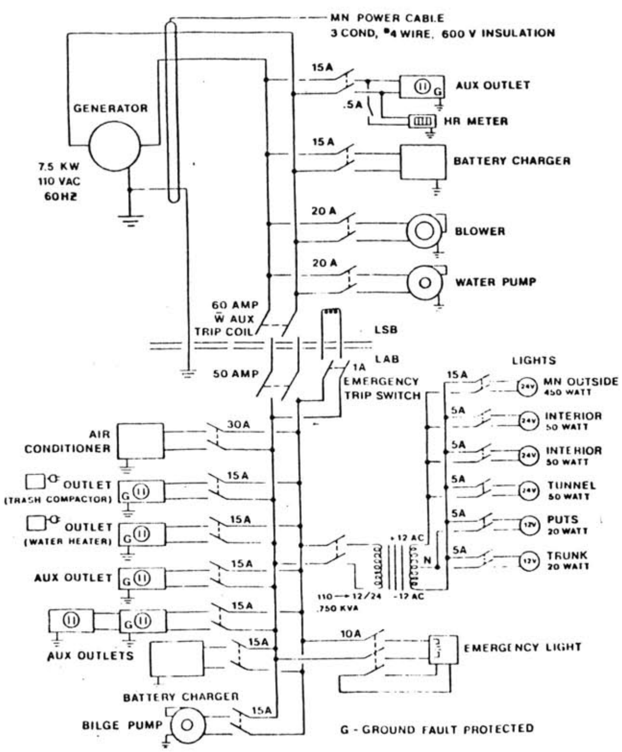
MINITAT CONTROL CENTER COMMUNICATIONS

Hydrolab is the only continuously functioning research laboratory underwater. Located in St. Croix in the U.S. Virgin Islands, it houses teams of four scientists for seven day missions. Operated under the auspices of NOAA, Hydrolab, originally designed and used by the Florida-based Perry Company for pressure testing small submersible research vehicles, has been converted into an underwater laboratory. A large hemispheric porthole has been added to one end and numerous smaller portholes admit natural light. The structure is located at 50 feet seawater depth amidst an array of encoded guide ropes which form underwater paths for research excursions. Surface personnel provide testing, training and life support for the researchers who are chosen by NOAA on the merits of their research proposals.

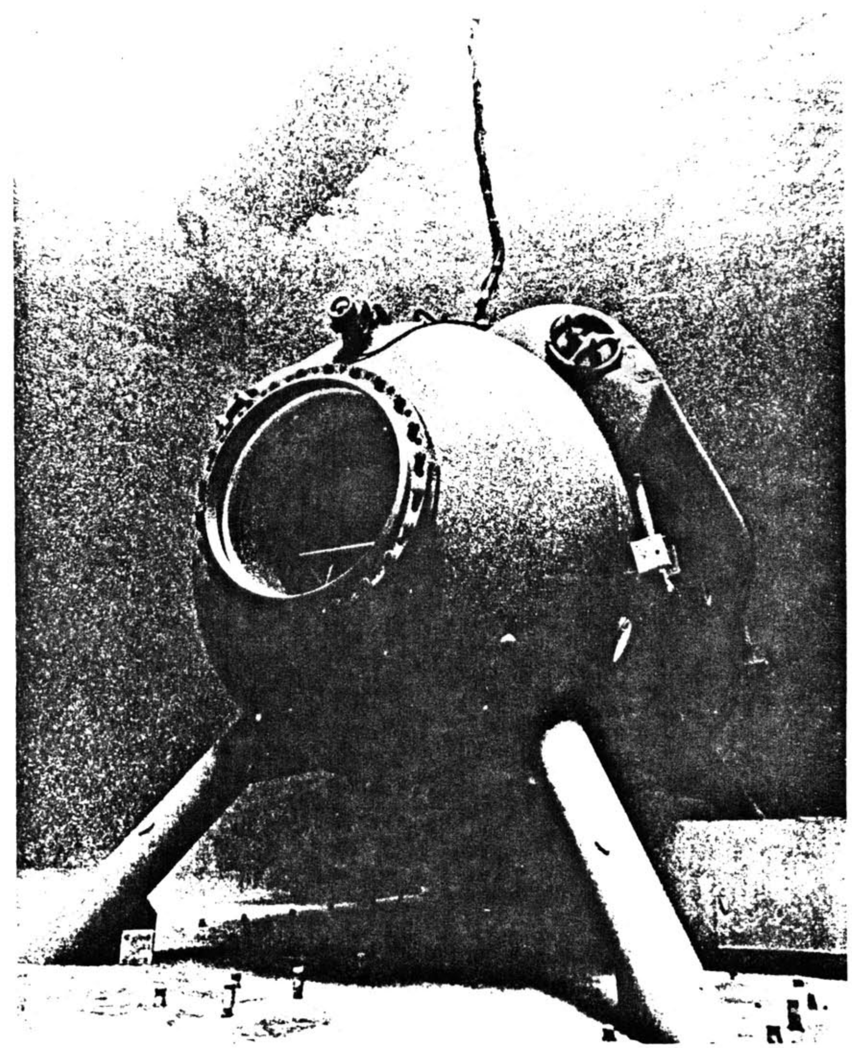
The researchers decompress while within Hydrolab, as it has been fitted with a double lock entry chamber. For the main duration of each mission, the hatches remain open with the internal pressure of the habitat holding water out.

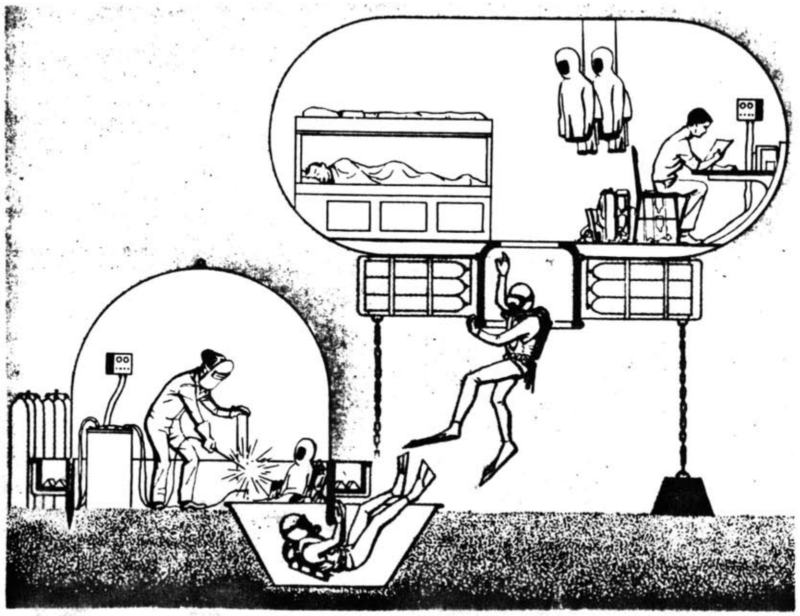
Upon visiting Hydrolab's shore support base in January 1982, Hydrolab's major problems were discussed. They included the high cost of air conditioning required to dehumidify the laboratory and the lack of a separate wet area for diving gear. It became evident that the design of such structures embodied unexpected problems for the designers were disassociated from the potential users of the facility. Future designs should grow from first hand experience of underwater dwellings and close association with the potential users.

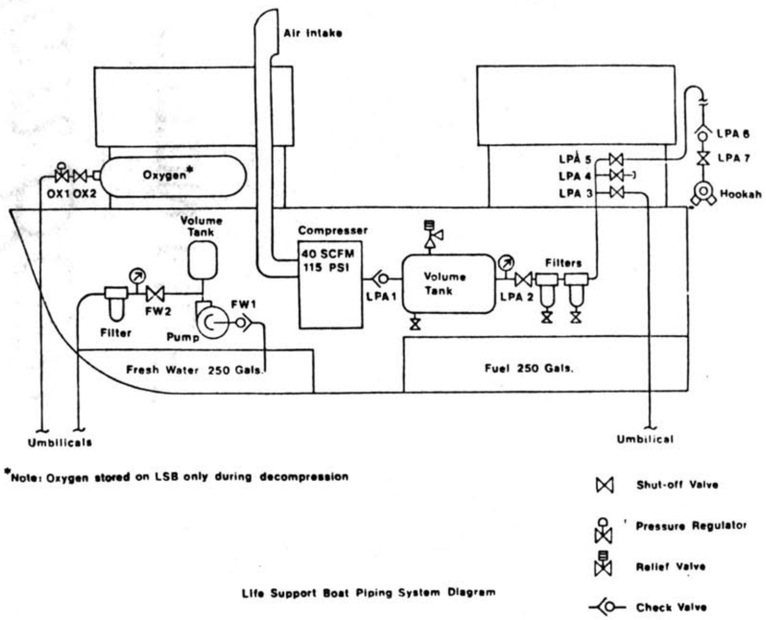
For comparison with Minitat, diagrams of Hydrolab's electrical, life support, and piping systems are displayed:



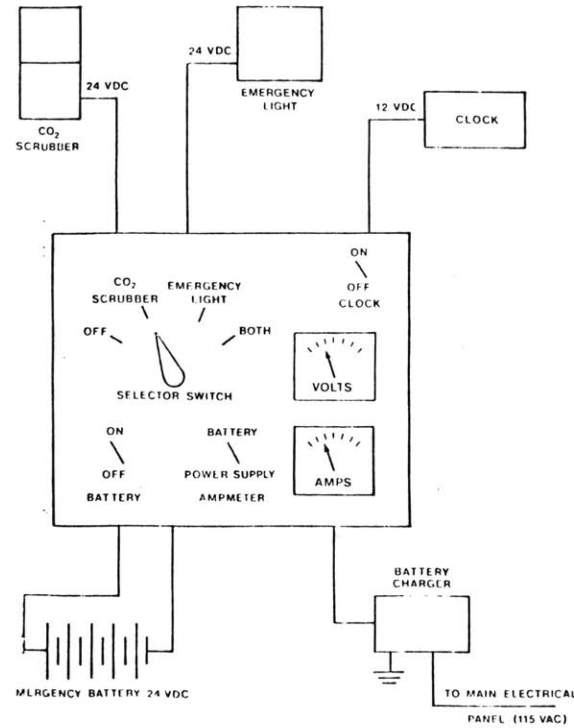
PRIMARY ELECTRICAL SYSTEM







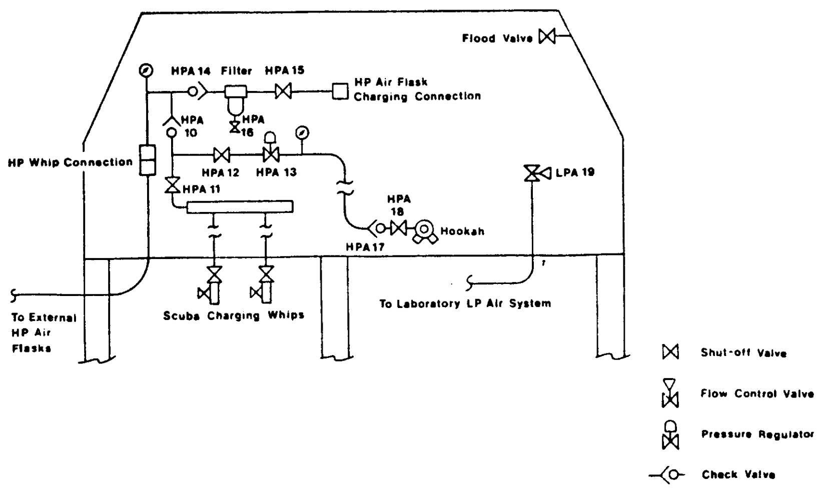
Life Support Boat Piping System Diagram



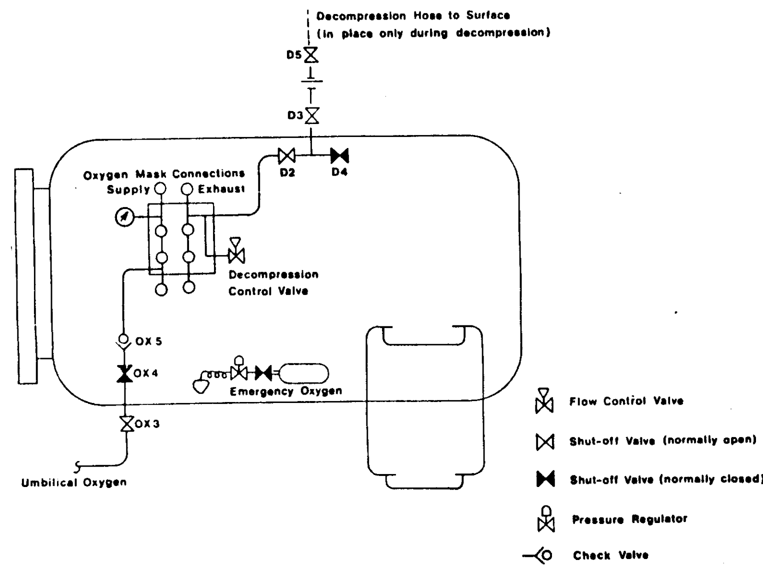
EMERGENCY ELECTRICAL SYSTEM

Hydrolab is similar to habitat designed by Link, above left.

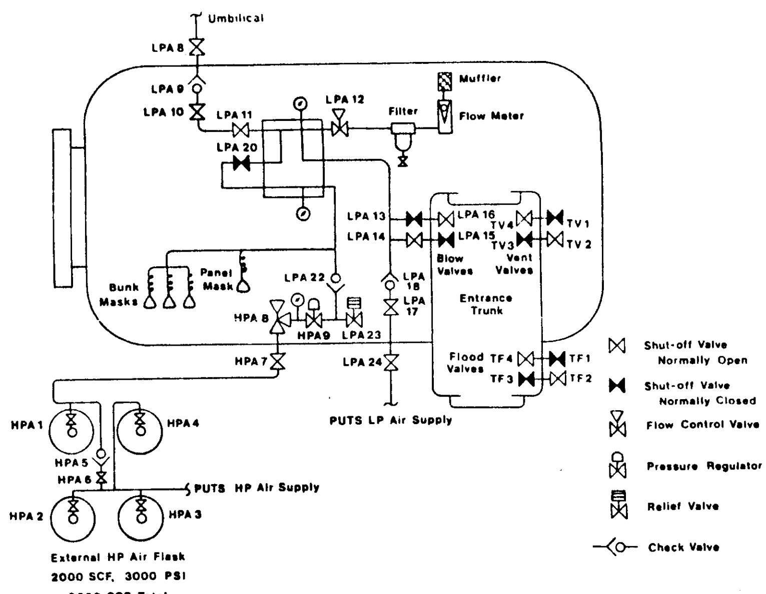
Hydrolab



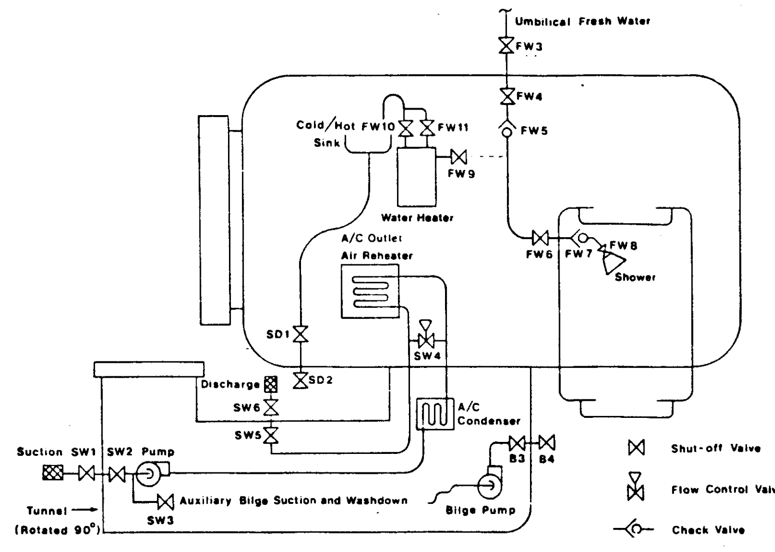
External Air Station (PUTS) Piping Systems Diagram



Laboratory Oxygen and Decompression Piping Systems Diagram



Laboratory Air Piping Systems Diagram



Laboratory Water Systems Diagram

When I inquired about a consensus of the sea dweller's subjective reaction to the Hydrolab environment, it came as an indication that it is often difficult to persuade the researchers to return to the surface and the terrestrial world. Of course, at those levels, due to the partial pressure of nitrogen, the inhabitants are slightly narced.

NOAA has developed evaluation criteria for habitat systems as listed below:

Habitat System Evaluation Criteria

(from NOAA)

1. Mission Adequacy
   - A. Habitability
     - Functional arrangement
     - Ease of operating and housekeeping
     - Motion stability
     - Bottom stay and visibility
     - Ease of access to water
     - Psychological environment for research
   - B. Degree of Meeting Mission Requirements
     - Site selection survey capability
     - Availability of required outside scientific support
     - Availability of required outside functional support
     - Training time
     - Depth, bottom type, slope, currents
     - Adequacy of adverse weather capability
     - Effect of premature storm termination
     - Minimum disturbance to environment

2. Operational Adequacy
   - A. Weatherability
   - B. Operating Complexity
     - Preparation and checkout
     - Transit
     - Site preparation, mooring, emplacement, startup, recovery
     - Operations, logistics support, communication, safety support
   - C. Upkeep – Surface and Subsurface Equipment
     - Simplicity
     - Reliability
     - Redundancy
     - Maintainability
     - Repairability
   - D. Other
     - Adequacy of surface accommodations
     - Availability of special tow boats and personnel when required
     - Need for special logistics services
     - Shore logistics base requirements
     - Training program complexity

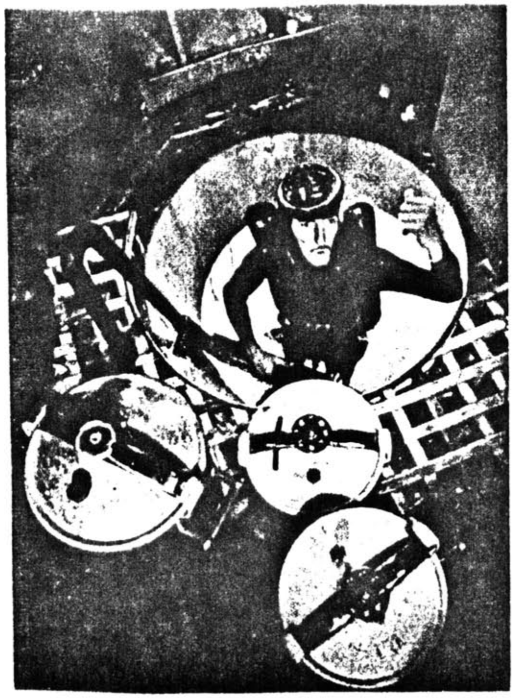
3. Flexibility
   - A. Changing Requirements Within Region
     - Greater depth – bounce dive
     - Longer missions
     - Fixed site
     - Smaller crew
     - Larger crew – modularity
     - Outfitting for different experiments
   - B. Meeting Requirements from Other Regions
     - Transportability
     - Other environmental conditions
   - C. Future Growth to All-Weather Capability
   - D. Utilization of Elements for Other Than Habitat Programs

4. Technical Confidence
   - A. Effect of Technical Uncertainty
     - Mission adequacy
     - Operational adequacy
     - Safety
     - Cost – schedule

5. Safety
   - A. Consider Following Hazards for Probability of Happening, Detection Capability, Availability of Standard Safety Devices, Backup Actions Available:
     - Lack of endurance of primary utilities
     - Failure of primary utilities
     - Failure of umbilical
     - Failure of surface communications
     - Contaminated atmosphere
     - Fire
     - Flooding
     - Diver incapacitated in habitat
     - Diver incapacitated in water
     - Hazard requiring evacuation
     - Inoperative primary decompression facility
     - One diver bent
     - Adverse weather
     - Loss of air while diving
     - Accidental diver surfacing
     - Exceeding excursion limits
     - Diver lost
     - Predator hazard
     - Failure of swimmer vehicle while remote
     - Entanglement of diver or equipment with lines, moorings
     - Surface support diver accidents
     - Object dropped on habitat or diver
     - Vessel moor shifting
     - Surface crewman incapacitated
     - Failure in emplacement/recovery system
     - Failure in PTC-DDC mating system

6. Cost
   - A. Cost Per Day
     - Development cost amortization
     - Manufacturing cost amortization
     - Operating costs – personnel, consumables, lease costs
     - Maintenance costs – preventive maintenance, spares, repair
     - Insurance, port and dock charges
   - B. Development Time Required
   - C. Funding Increments Required
   - D. Utilization of Existing Hardware
   - E. Savings if Several Identical Systems Used

| as in Nitrogen Narcosis



KEY
N=41
1=POOR
2=FAIR
3=VERY GOOD
4=EXCELLENT
X = NOT APPLICABLE

MEAN ENVIRONMENTAL ASSESSMENT SCORES

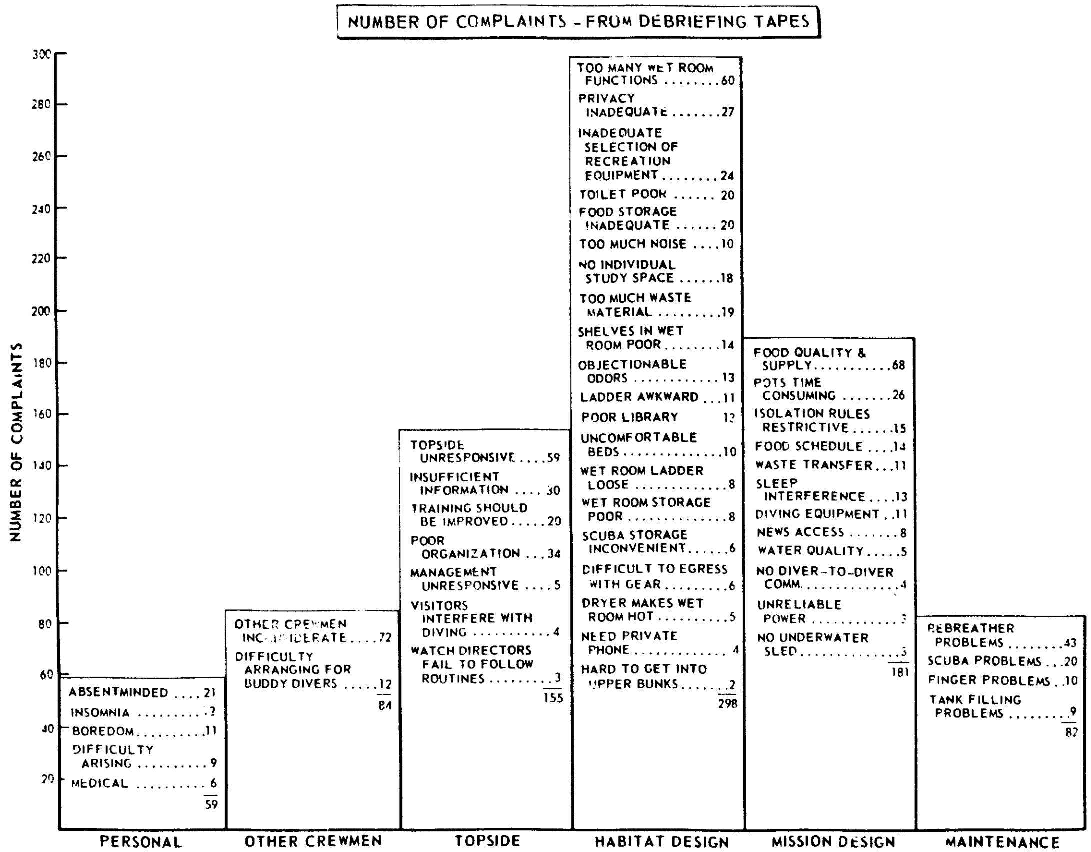
	SLEEP	FOOD		RECREATION		SOCIAL INTER-ACTION	WORK				HYGIENE		OVER ALL	AVER AGE
		EATING	PREPA-RATION	EXER-CIZE & ACTIVE REC'N	GAMES BOOKS ENTER TAINMENT		SCIENCE INSIDE	MAINTE-NANCE INSIDE	ACCESS TO OUTSIDE	WORK OUTSIDE	WASTE ELIM.	WASHING SHOWER-ING		
IS THERE ENOUGH ROOM?	3.12	2.76	2.46	2.32	2.83	2.80	1.69	2.15	2.51	X	2.61	3.12	2.98	2.62
IS THE LIGHTING OF THE AREA SATISFACTORY?	3.27	3.41	3.20	3.26	3.34	3.16	2.72	3.08	3.08	2.77	3.30	3.32	3.18	3.16
IS THE LOCATION OF THE AREA SATISFACTORY?	3.12	2.98	2.90	2.67	2.89	3.00	1.95	2.31	2.71	3.06	2.79	3.18	X	2.82
IS THE LAYOUT OF THE AREA SATISFACTORY?	3.03	2.78	2.63	2.50	2.77	2.89	1.86	2.07	2.49	X	2.81	2.97	2.87	2.66
IS IT QUIET ENOUGH?	2.22	2.59	2.63	2.38	2.37	2.38	2.20	2.34	2.24	X	2.47	2.62	2.31	2.40
IS THERE A LACK OF ODOR?	3.15	3.00	2.83	3.18	3.19	3.11	2.73	3.14	2.68	X	2.38	2.83	2.90	2.92
IS THE TEMPERATURE SATISFACTORY?	3.48	3.59	3.35	3.37	3.45	3.63	3.37	3.45	3.34	3.56	3.57	3.63	3.59	3.49
IS THE HUMIDITY SATISFACTORY?	3.60	3.66	3.62	3.47	3.57	3.66	3.51	3.61	3.47	X	3.61	3.62	3.68	3.59
IS ENOUGH TIME ALLOWED?	2.80	3.32	3.24	2.86	2.86	3.25	2.88	2.64	3.19	3.26	3.21	3.38	X	3.07
ARE THE TIMES AVAILABLE OK?	3.36	3.24	3.24	3.21	3.00	3.06	3.21	2.84	3.57	3.60	3.37	3.42	X	3.26
IS THERE GOOD SELECTION & VARIETY?	X	2.75	X	2.30	2.67	X	2.48	X	X	X	X	X	X	2.58
HOW DOES THE HIBITAT EFFECT THE ACTIVITY IN GENERAL?	3.16	3.10	2.79	2.47	2.75	2.97	2.32	2.55	3.20	3.46	2.66	3.27	X	2.90
AVERAGE	3.12	3.08	2.95	2.82	2.98	3.07	2.54	2.74	2.91	3.26	2.94	3.18	3.07	2.96

MEAN SCORES ON THE MOOD ADJECTIVE CHECK LIST
(SELF-ADMINISTERED DAILY IN THE HABITAT)

Mood	Mean Score*	Mood	Mean Score
Concentration	3.81	Deactivation	1.81
Activation	3.81	Aggression	0.51
Social affection	2.80	Egotism	0.51
Pleasantness	2.78	Skepticism	0.44
Nonchalance	2.10	Depression	0.33
		Anxiety	0.25

*The lower the score, the less common was the feeling in day-to-day life in the habitat.

(Tektite 2 surveys)

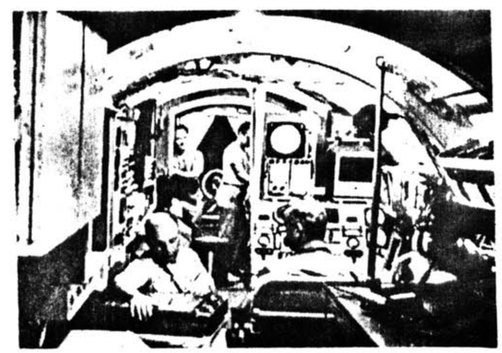


(Tektite 2 surveys)

Number of Complaints (From Debriefing Tapes)

It can be noted in this evaluation guide and in the Tektite 2 surveys, consideration of environmental quality is conspicuously absent. It appears as a calousness among technical personnel that finishes and treatment of interior surfaces, acoustics, lighting and the like are not programmed to provide a pleasing environment. Functional suitability to the mission plan and safety criteria manifest an environment which is hard and metallic in contrast to the soft nature of the external environment. While such environments have supported technicians and scientists, there is much to be desired in the area of environmental comfort and stimulus which go beyond the pragmatic utility of space. The question remains open as to how sea dwellings can be attractive environments which enliven the presence of sea dwellers. How is the apportionment of space for the provision of privacy to be accomplished? The solution is to be found in the design of architectural interiors which integrate the knowledge of materials and natural laws. Through the consideration of sensory determinants of space we might approach concepts by which the phenomenal perception of space is predictably pleasing.

Visually, lighting and color of the habitat must be considered. Raw flourescent tubes are no more pleasing underwater than above. Because of the absorption of light in sea water, only the cooler portions of the visible spectrum of natural sunlight penetrate beyond two meters of sea water. Therefore, artificial light is necessary to augment light intensity in the areas of specific tasks within the dwelling structure. In clear waters on a sunny day, the sea bottom 200 feet below the surface is visible. Lights with colder spectral temperatures penetrate sea water more effectively than tungsten lights. Colors on surfaces can be used to effect moods of the inhabitants and to complement or contrast the cool spectrum of light entering through the port holes.



Light tones should be used to increase light intensity due to reflectance.

The refractory index of water is 1.33 as compared to that of air, 1.0, for which our eyes are designed. Therefore, objects appear either 1/3 larger or 1/3 closer underwater than they are in reality. The hemishperical portholes could be designed to give a fisheye view of the surroundings thus admitting more of the visual field and intensifying the light passing through the porthole orifice. Unless high tolerances are adhered to, the view through a plexiglass hemisphere will be distorted which is not of ill consequence as brightly colored fish and other sea life would appear as impressionistic and kinetic hues. Where clear vision is required, the portholes could be designed to meet that criteria.

A finished glass hemisphere blank, 56-in.-dia. Design collapse pressure 29,000psi.

Atmospheric content, including humidity, pressure, rates of flow and equivalent exhaust must be designed for carefully controlled zones. Wet areas will require more dehumidification, and subsequently, more heating. Laboratory areas require higher rates of ventilation. Where ambient, as opposed to standard atmospheric pressure is to be maintained, adequate pumps must be integrated to force air from the surface via a high pressure umbilical or snorkel. Compressed air vessels are also required for manipulating the structure's bouyancy. Ductwork must be of adequate size and without superfluous grills and all mechanical equipment should be acoustically isolated and insulated. Emergency oxygen systems, laboratory gas and hot water should be available from numerous outlets if the structure is large, and all systems monitored and controlled from the same central console. PVC, formica and other formaldehide or vinyl-containing materials are to be avoided due to the toxicity of the outgases.

Acoustics within sea structures deserve thorough design as its effects are very important in the phenomenal experience of space and social interaction. Conventional sound absorptive materials cannot be used if compression under pressure substantially reduces their effectiveness. The use of compressible buffers, suspension springs and heavy insulation on all vibrating machinery and sound absorptive baffles at air distribution vents can insure quiet. Heavy partitions will assist in achieving privacy, including glass plate for the admission of light.

Communication within a sea dwelling structure can be assisted by the inclusion of a telephone system. A bundle of lines tied to the surface would allow two-way televised communication with the outside world. Communications would pass through the central console along with the electrical energy grid.

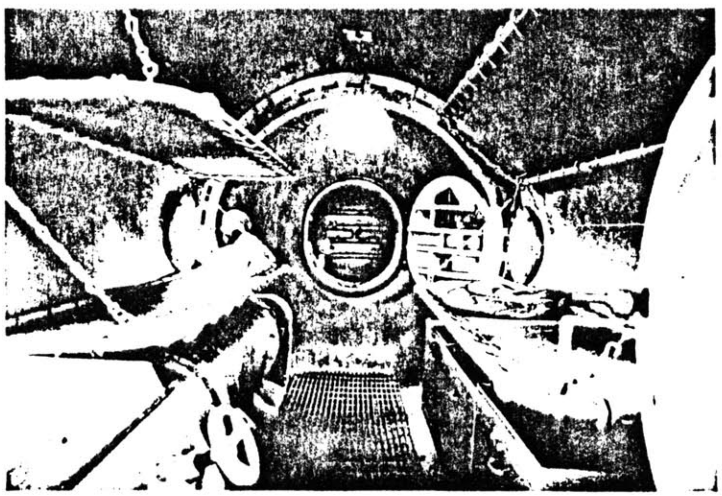
Physiological comfort must be maintained through the functions of the heating, ventilating, and air conditioning system (HVAC). Where saturated divers (with gas saturated in the bloodstream and tissue) wish to be integrated within a sea dwelling community having standard atmospheric pressure, "spacesuits" of tensile fabrics tied by an umbilical to a computerized life support system with outlets in the many work stations would make this possible.

Variable ventilation rates controlled by workers or automatic thermistors and computer would help achieve comfort for individuals depending on age, sex, culture, physical activity, dress and acclimatization. Air temperatures, humidity, air movement and radiation to or from surrounding surfaces play a role and are the mediums of the environmental comfort designer. In warm and hot climates, the water temperature, being cooler than the air will absorb heat as it builds up within the structure. Deeper, cool waters passed through heat exchangers can cool incoming air while condensing moisture from it in the form of pure water.

Inside Starfish House of Conshelf 2.

Breathing oxygen reduces decompression time.

Space is not only a physical phenomena as perception takes into account the psychological aspects of orientation within a space and identification of the self in relation to the space. Orientation can be enhanced through the avoidance of monotony; the creative use of materials to diversify the environment, giving it distinction. Character of the space, the qualities it has chosen from the polarities of the physical states, (hot, cold; wet, dry; light, dark; hard, soft; etc.) can stimulate the inhabitant's perceptual awareness. The dweller can learn to identify with his personal environment and workspace as distinct from all others.



Decompression Chamber, Internal View

A sterile environment offers little stimulus.

(from Nat. Geographic)

Parrot and parrot fish refuse to fraternize through a window. Claude Wesly holds his namesake, whose duty it was to faint if the air grew noxious. Men trusted the bird more than all their warning gauges. Claude returned to the surface unharmed.

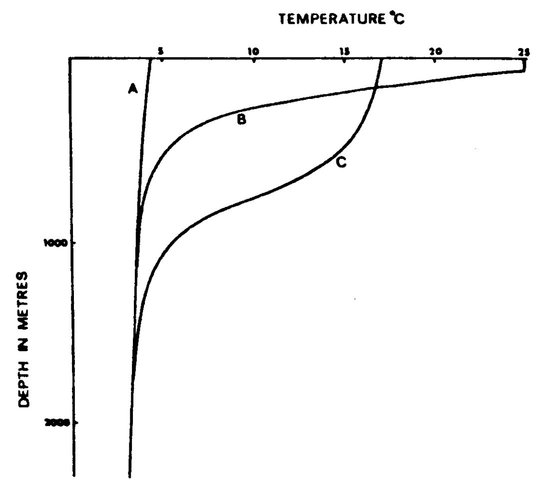
SITE

The location of a sea dwelling has great bearing on the phenomenal experiences of the sea dwellers. Sea dwellings are like bridges in that they connect humanity with the site of gathering the fourfold, earth, sky, mortals and divinities. As Heidegger says:

> "Gathering or assembly, by an ancient word of our language, is called "thing." The bridge is a thing --and indeed, it is such as the gathering of the fourfold . . . "
>
> ". . . it gathers the fourfold in such a way that it allows a site for it. But only something that is itself a location can make space for a site. The location is not already there before the bridge is. Before the bridge stands, there are of course many spots along the stream that can be occupied by something. One of them proves to be a location and does so because of the bridge. Thus, the bridge does not first come to a location to stand on it; rather, a location comes into existence only by virture of the bridge. . . it (the bridge) allows a site for the fourfold. . . "determines" the localities and ways by which a space is provided for.
>
> "Only things that are locations in this manner allow for spaces . . . Raun means a place cleared or freed for settlement and lodging. A space is something that has been made room for, something that is cleared and free; namely within a boundary, Greek peras. A boundary is not that at which something stops, but as the Greeks recognized, the boundary is that from which something begins its presencing. That is why the concept is that of the horismos, that is, the horizon, the boundary."

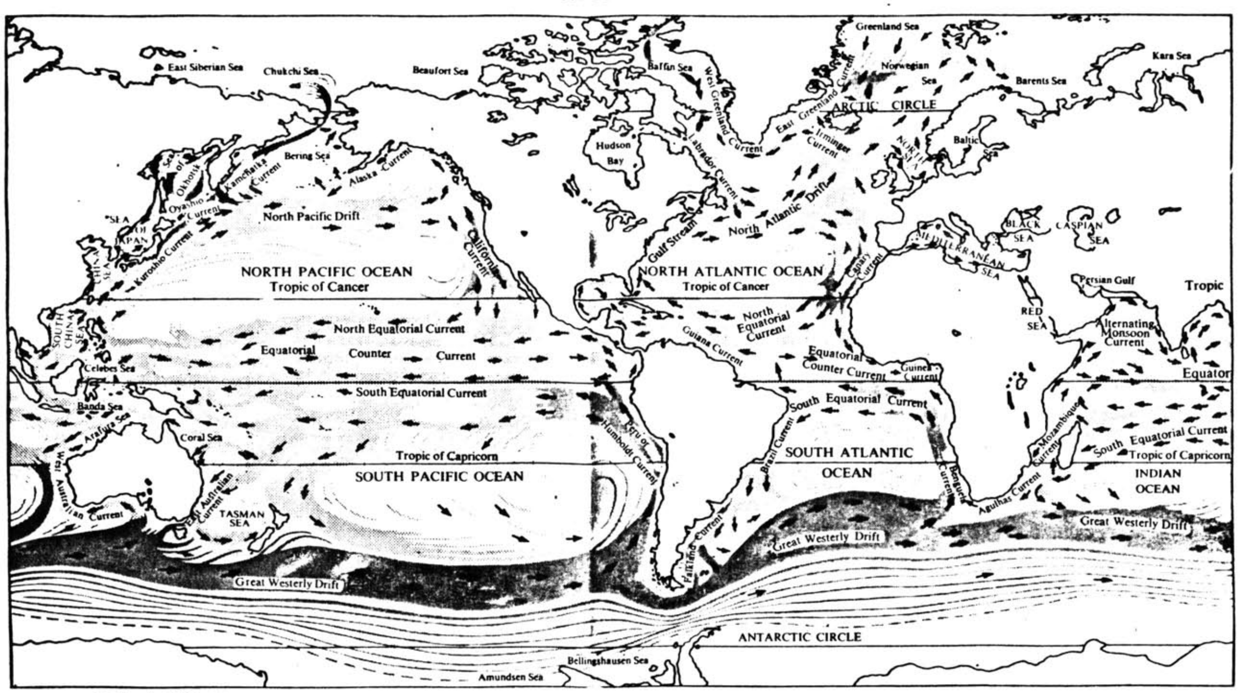
The horizon is the predominent feature of the sea as perceived from above the water. Below the surface, the sea recedes into a deep blue infinity, it is a cosmic environment. In building in the sea, in creating a gathering by which a space comes to be presenced, a site is transformed into a location.

A global view of the world's oceans reveals it is ordered in relation to salinity, temperature and densities. Maps are useful for analyzing or choosing a site in which to locate a sea dwelling. The velocity and regularity of currents as they relate to land masses and water temperature at the surface are predominent considerations. The next considerations might be economic, social, or political in scope; the availability of machines, men and materials to accomplish a building. Considering the political aspects, it is evident that many developing nations are located between the Tropics of Cancer and Capricorn where the water temperatures offer greater comfort than that of the air. Upon the consideration of future energy and economic development needs of these nations combined with the availability of high temperature differentials between the surface and deep water, an energy potential presents itself through the application of a developing industry, ocean thermal energy conversion (OTEC). Also, the potential to cultivate foods in the ocean, as has been done in the orient for cen-

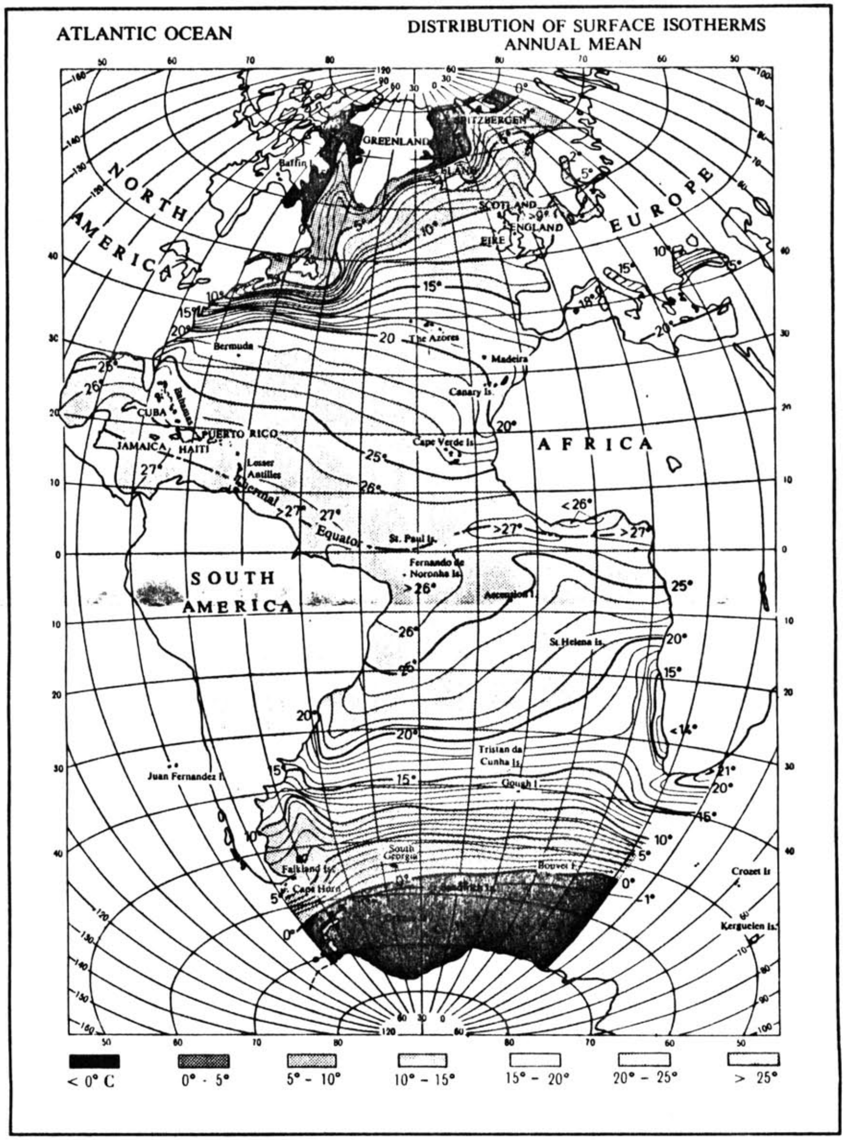


Typical temperature profiles in winter: A, high latitudes; B, near the equator; C, middle latitudes turies, offers the opportuinty to explore the possibility that some part of the world's hunger might be diminished through a greater understanding of the sea's utility which sea dwellings could present. Maps such as the ones shown here are useful in predicting the location of such sites which would best benefit from a sea dwelling technology.

GENERAL CIRCULATION OF THE WORLD OCEAN — JULY



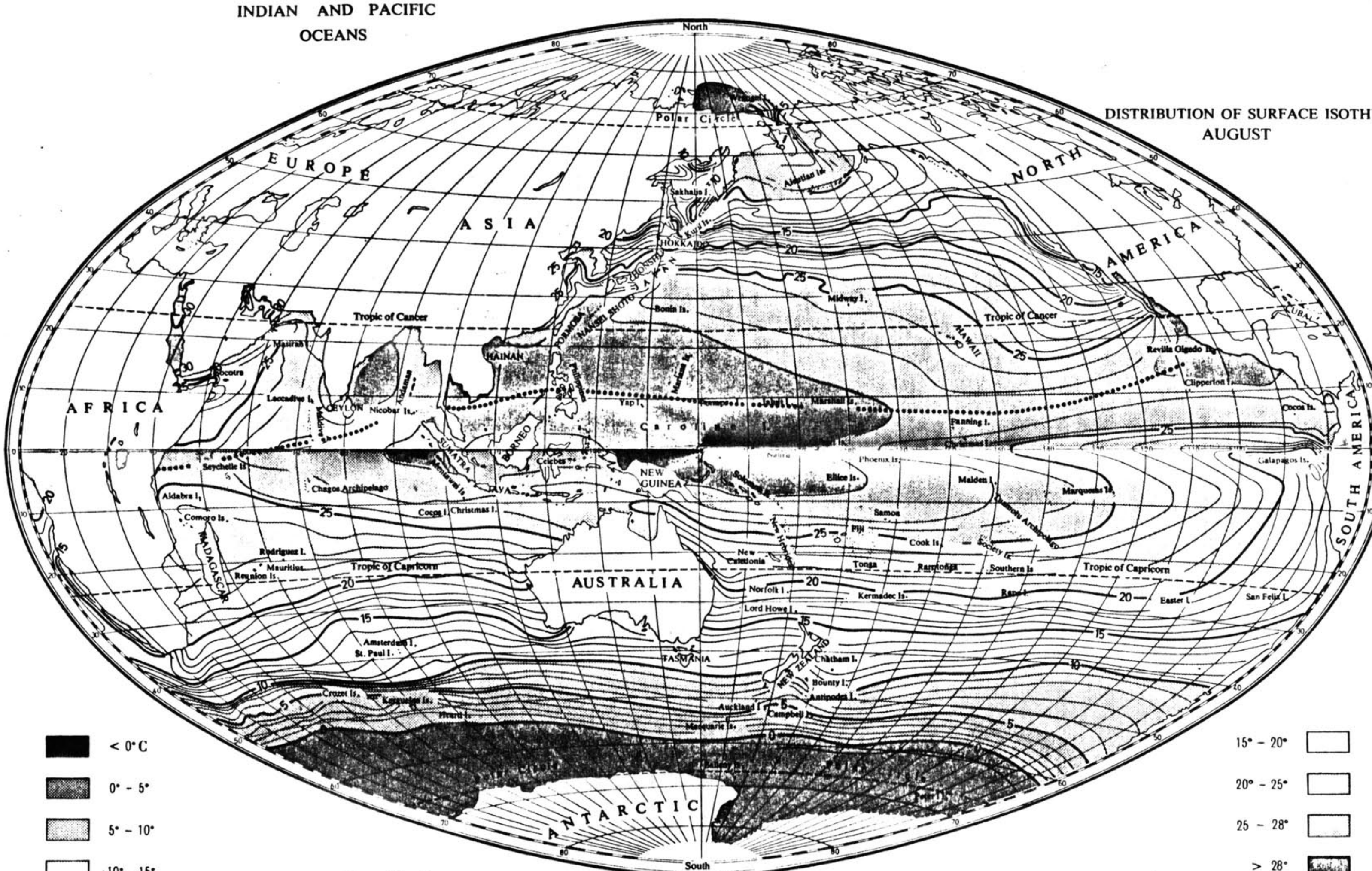
From *Encyclopedia Britannica*



Adapted from G. SCHOTT (1944)

INDIAN AND PACIFIC OCEANS

DISTRIBUTION OF SURFACE ISOTHERMS AUGUST



< 0°C

0° - 5°

5° - 10°

10° - 15°

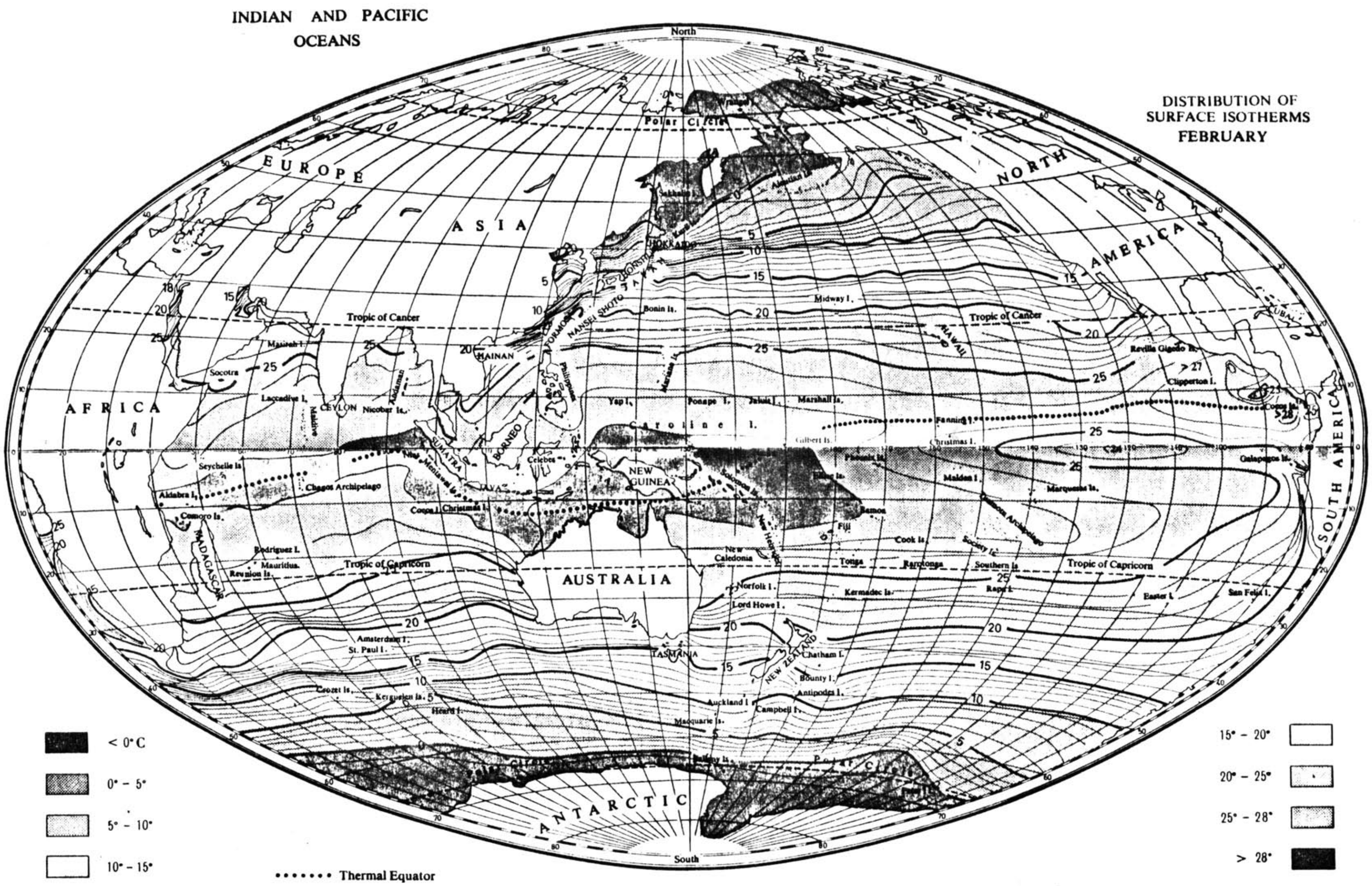
15° - 20°

20° - 25°

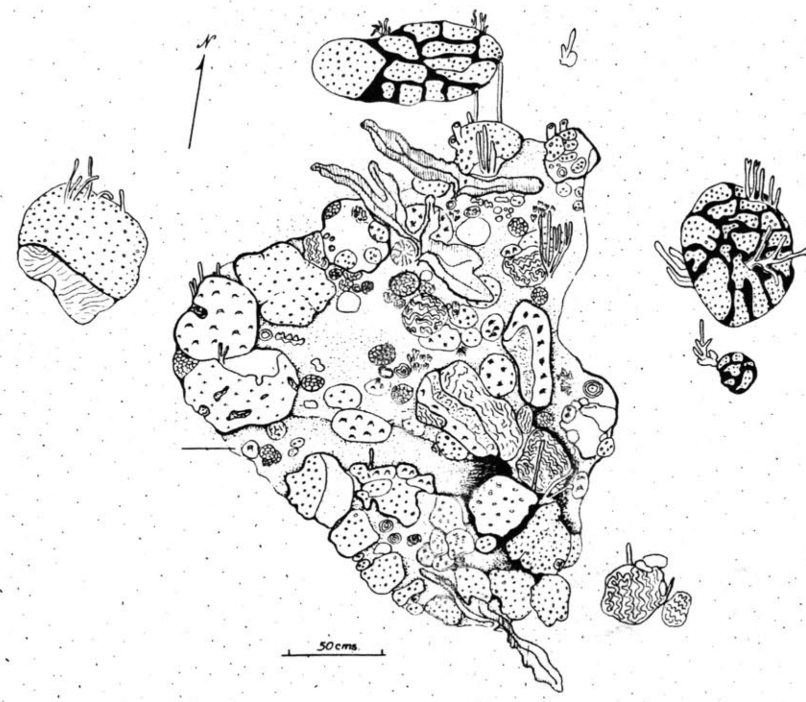
25 - 28°

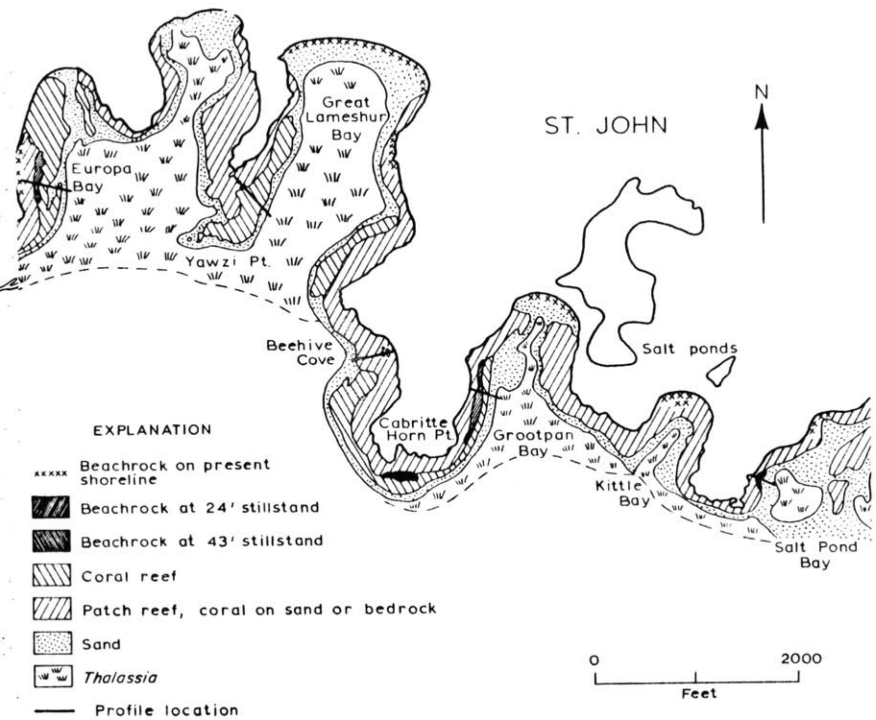
> 28°

••••••• Thermal Equator



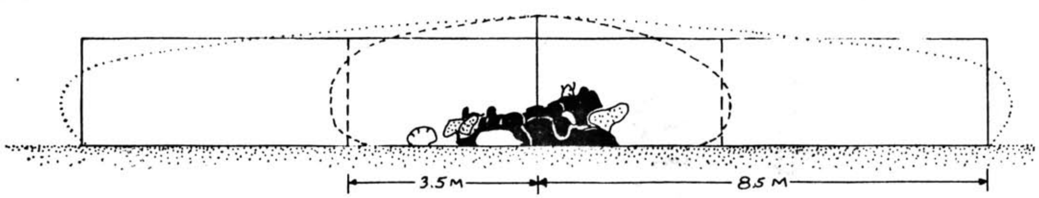
INDIAN AND PACIFIC OCEANS
DISTRIBUTION OF SURFACE ISOTHERMS FEBRUARY
North
South
EUROPE
ASIA
AFRICA
AUSTRALIA
NORTH AMERICA
SOUTH AMERICA
ANTARCTIC
NEW GUINEA
MADAGASCAR
TASMANIA
NEW ZEALAND
CEYLON
SUMATRA
BORNEO
JAVA
HAINAN
HAWAII
Tropic of Cancer
Tropic of Capricorn
Polar Circle
< 0°C
0° - 5°
5° - 10°
10° - 15°
15° - 20°
20° - 25°
25° - 28°
> 28°
Thermal Equator





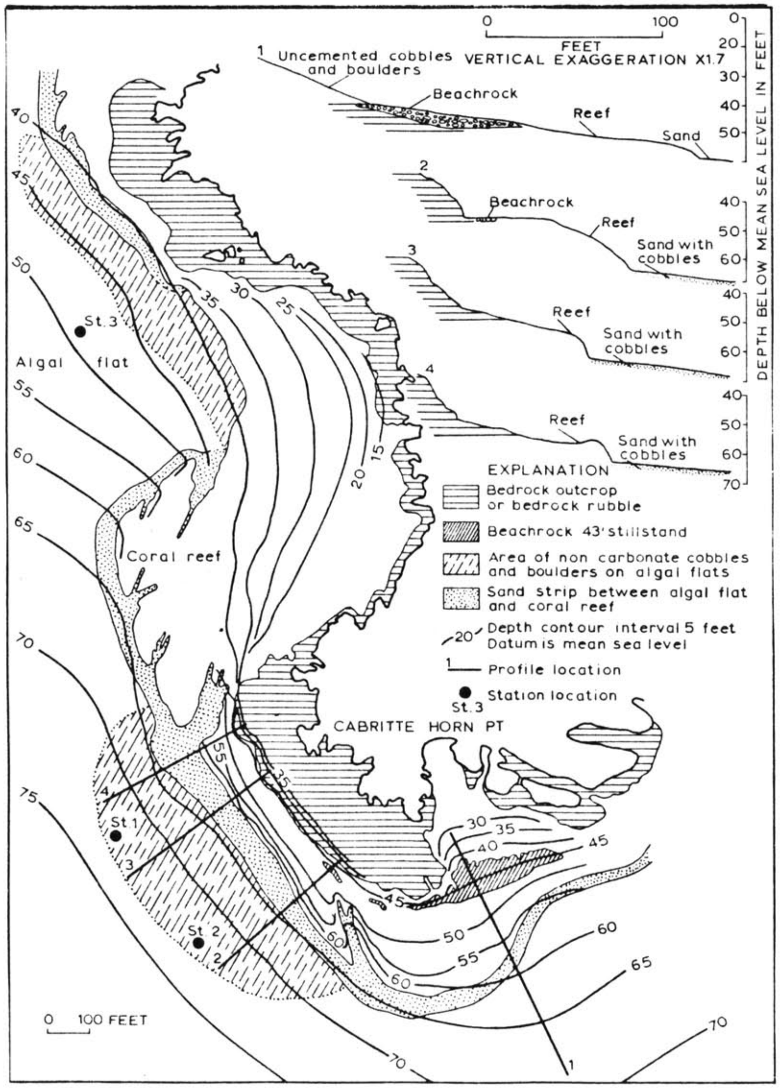
Distribution of bottom type and beachrock from White Point to Ram Head. Contact boundaries interpreted from colored aerial photographs flown at altitudes of 5000 and 10,000 feet

Plan view of Observation Reef, Lameshur Bay, St. John.

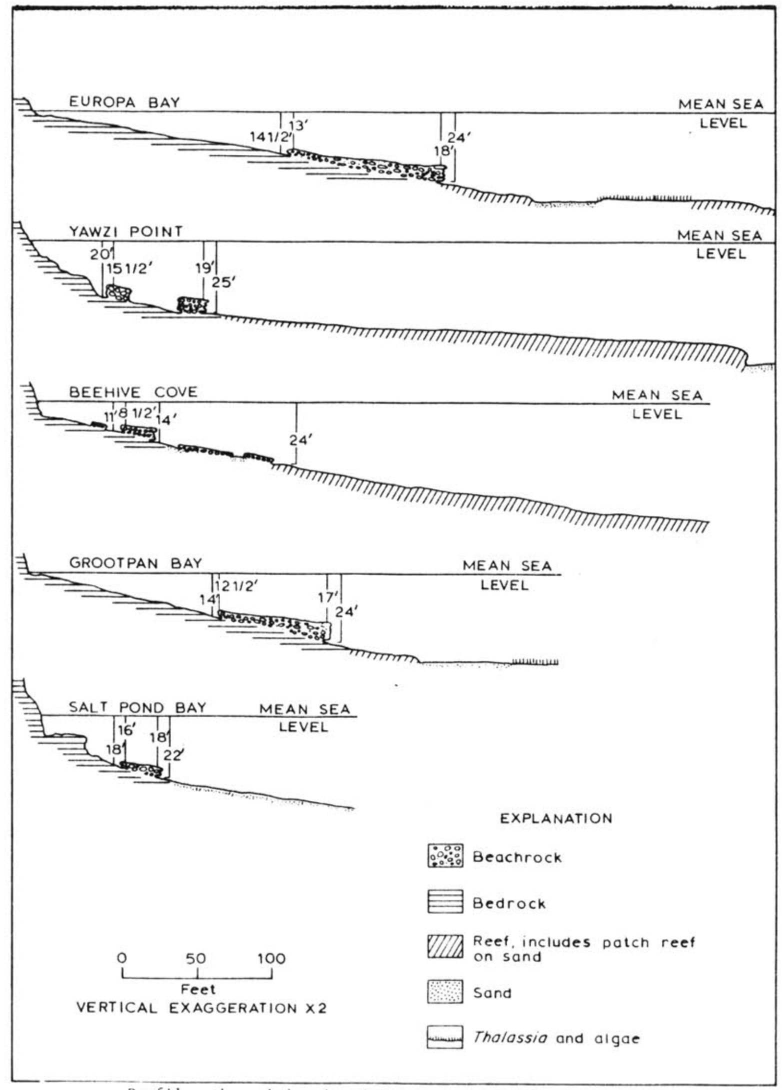


Observation Reef as seen from the west side showing estimated volumes in which 95 percent (dotted Line) and 75 percent (dashed line) of the resident fishes' activities take place.

Example site survey of Tektite 2



Distribution of subsurface features, depth contours, profile locations and beachrock locations off Cabritte Horn Point.



Profiles through beachrock deposits at the 24 foot level. Location of profiles is shown in Figure 1.

Example site analysis of Tektite 2

ENERGY OPTIONS

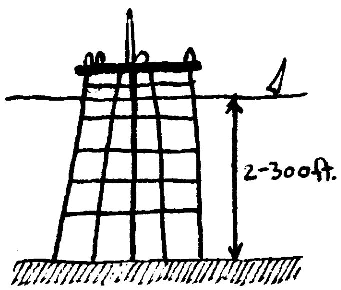
The most pressing economic problem of marine scientists is the escalating cost of marine diesel fuel for powering their research vessels. Fuel was less than 8% of their operating costs at three dollars a barrel in 1973. In 1981 at $28.00 a barrel fuel makes up 27% of the operating costs. It is estimated that in 1982, the largest vessels will expend about $424,000 on fuel. Wind power has thus returned to power not only research vessels but commercial tankers as well.

The production of power from the deep sea's thermal difference may someday form nucleii for the building of sea dwellings. Until then, their form and method of construction could be speculated. Current systems for delivery of electrical energy to users have efficiencies of 33% while a proposed ocean thermal energy conversion (OTEC) - ammonia - fuel cell power alternative would have an efficiency of 50% to 63%. The efficiency will be greater than this if the energy is used at its place of conversion, the sea.

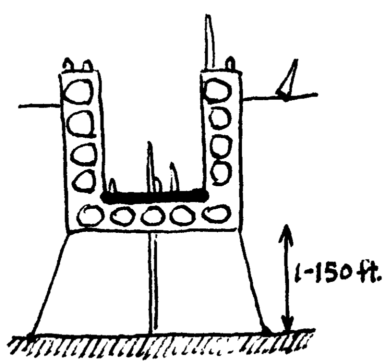
The sea absorbs most of the sun's radiation which reaches our planet through the atmosphere. By the processes of evaporation and condensation and the flow of warm currents to colder regions, the sea regulates the climates. The sea is vertically stratified into isotherms, distinct layers of uniform temperatures which decrease with depth. The upper layers are warm enough to evaporate ammonia under low pressures. The flash evaporation occurs with the release of latent energy with the power to drive turbines and dynamos; mechanical energy which can then be converted into electrical energy. The ammonia travels through a closed loop from the turbine to the condensation heat exchangers which extract the heat in the ammonia with cold water drawn up by pump through pipes from the sea's depths. The condensed ammonia then passes through the evaporator heat exchanger to resume the cycle. Heat exchangers keep the water and ammonia mediums separated by high surface areas of high thermal conductivity materials. Ocean Thermal Energy Conversion is a primary alternative for powering large ocean bases in the tropics. The major technical difficulty is the biofouling which occurs in the heat exchangers.

A bi-product of this process is the upwelling of cold nutrient rich waters to the surface. Being denser than surface waters, they will fall seeking their own levels. In the process, daitoms and other marine algae which form the base of the marine food chain will thrive in the cold waters. This will trigger the flourishing of sea life which will learn to seek the source of the nourishing waters.

One of the many problems confronting the designers of these future systems is the design of support platforms for the pumps, condensers, evaporators, heat exchangers, turbines, the cold water pipe, support personnel, dwellings and other machinery. This research of sea structures will prove useful in the solution of the problem of support. The potential scope of uses of sea structures will find broad interest among backers. The oil industry is among the major users of the sea, and the mention of national defense leaves no option but to support research along these lines. A successful pilot project in Hawaii recently completed a trial of this technology which was begun nearly 100 years ago in Cuba by George Claude.

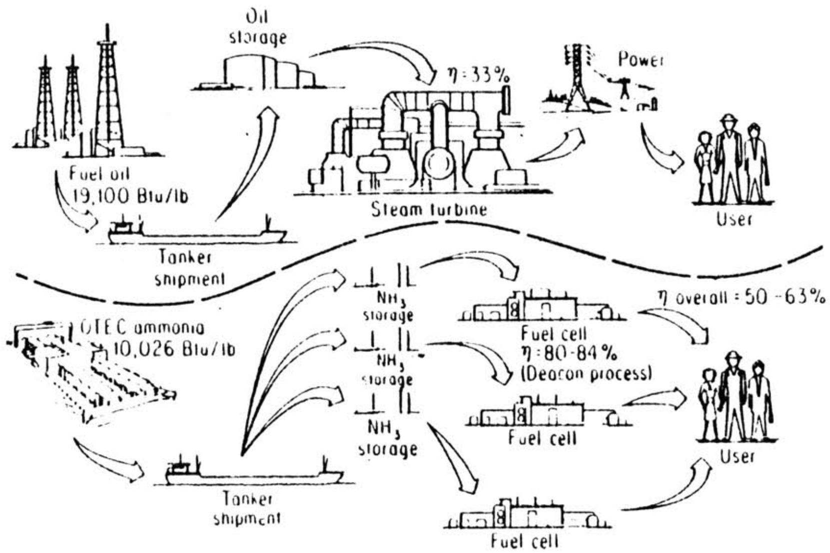


In the oil industry, there is the problem of height of the drilling rig from the oil well. This dimension can be reduced by simply depressing the platform below sea level. The hollow walls of such a structure can serve as storage containers for the oil until it is picked up by tankers.



Existing technologies could perform in deeper waters by placing existing drilling platforms directly on the sea bed. This can be accomplished by employing the diving bell or caisson concepts. Further studies could lead to a wide variety of structural solutions.

Another energy converting method is that of bio-methane, a technology of anaerobic decomposition of a high yield cultivated sea-weed to produce a combustible gas is undergoing a test off the coast of California. An upwelling system draws nutrient rich deep water to fertilize the gregarious culture. This system could be appended to an OTEC system's filtered exhaust. A rich fertilizer would be a bi-product of this system.



OTEC-ammonia-fuel cell power alternatives for the 1990s.

ETHICS IN PROGRAMMING

The term 'ethics' derives from the greek 'ethos', character, and concerns conformity to accepted professional standards of conduct. As a discipline it deals with what is good and bad and with moral duty and obligation. 'Graphein', greek for to write, and pro-meaning before, originates the word program which is to write before.

Whether knowingly or obliviously, human beings in the so-called civilized world are being subjected or subject themselves to environmentally induced illnesses. It is possible cancers, leukemia, radiation poisoning and toxic syndromes may not have been programmed by the shapers of our environment. The upwelling of toxic chemicals in our water suplies, the acid rains, the depletion of ozone and the poisoning of women and children by doctors, and chemical companies with harmful synthetic drugs; the condoned exploitation of infants with ill prescribed nurturless or harmful formulas by the processors of foods continues because of the professional ethic of concentration and concern with other program priorities, tunnel vision.

Within the program for society are variables which can be manipulated to a limited degree. It is infrequent that the program as a whole is open to question.

"With the onset of the technological age, we are witness to environmental destruction of unprecedented scope and magnitude. In recognition of the fact that the present trends cannot long continue without great danger to the life-support system itself, the development of a sophisticated society - environment management system, through which a reasonable balance may be achieved and maintained in perpetuity, is needed".[1]

It appears evident ethical concerns have diminished among professional practitioners as any law student will tell you. There are many theories for the improvement of the environment but few are implemented and none are totally successful. The apparent futility has taken the form of apathy and the mention of environmentalism is shrouded in professional circles. The terms, ethics and environment are diminishing in meaning and value for the majority of the schooled world. There is an increasing attitude that the humanities are not profitable. The concern is shifted to other programs.

The industrial environment is man's nemesis in that it destroys life, the things which man must preserve. Technology in itself is not an evil; how society is using some technology is. Industry is positive in its own right; what is at fault is the inversion of the meaning of industry. Industry has been transformed from the noble application of human capability for

[1] Duxbury, A. C. The Earth and its Oceans. (Addison-Wesley, 1971.)

multiplying the power to build and cultivate into a blind and unconcious mechanical process devoid of recognition of its own adversity to nature.

For instance, highways help us overcome distance, yet they are definitely hostile to living things on the whole in that they divide and make an eye sore of the natural environment. They support vehicles which emit lethal fumes which are daily taking the lives of the infirm and diminishing the quality of life of everyone. The air we breath and the water we drink are being polluted by the products and by-products of our technology.

Submarines also denote hostility. They are fewer in number than automobiles but more direct in their objectives. They are vehicles, not habitats. They shelter man from hostility less than they serve in the creation of hostility. Industrialized society, in the careless use of its technology, has forgotten that it is a part of the environment which it is destroying.

> "We only recognize the fact that man is an integral part of the environment, and that it can only lead to human alienation and environmental disruption if he forgets that. To belong to a place means to have an existential foothold, in a concrete everyday sense. Man is in front of his most basic problem: to cross the threshold and regain the lost place".[1]

1 Norberg-Schulz, C. Genius Loci: Towards a Phenomenology of Architecture. (Rizzoli International Publications, Inc., 1980.)

Humanity seeks to rediscover the natural place; freedom not only from oppressing nations, but from the environment which has produced such nations as well. The solution while freeing us from a socio-economic entrapment, holds us to the surface of a polluted environment. A three dimensional isolation is called for: submersion . The fictional Utopus in founding his nation, Utopia, severed it from the mainland to create an island refuge where humanist culture could flourish. In this age, severance from the mainland is not enough.

The search for the natural place is not a desire to return to the womb, nor a refusal to face reality. It is simply the search for the way of dwelling: the realization of possibility of dwelling as possibility.

Denial of this search is a submission to society's offerings which is as easy as credit, payment plans and cleanup bills for toxic chemical and nuclear wastes. It is the sublimation of humanity's sensibility beneath an auto-mechanical destruction.

Over and over again I have said that there is no way out of the present impasse. If we were wide awake we would be instantly struck by the horrors which surround us . . . We would drop our tools, quit our jobs, deny our obligations, pay no taxes, observe no laws, and so on. Could the man or woman who is thoroughly awakened possibly do the crazy things which are now expected of him or her every moment of the day?

—Henry Miller, in
The World of Sex
(1,000 copies printed
by J.N.H., for
"friends of Henry Miller,"
1941)

Humanity must mature into the civilized organism of the earth's preserver; free from propaganda, erroneous ideology, the spectors of hunger and greed. We can passively retract allowing business to go on as usual or we can withdraw to search and prepare new programs by which to grasp technology and industry for application to new uses which concentrate upon raising awareness of the plight. This awareness is the capital of an evolving culture.

> "On all sides we hear talk about the housing shortage, and with good reason. Nor is there just talk; there is action too. We try to fill the need by providing houses, by promoting the building of houses, planning the whole architectural enterprise. However hard and bitter, however hampering and threatening the lack of houses remains, the real plight of dwelling does not lie merely in a lack of houses. The real plight of dwelling is indeed older than the world wars with their destruction, older also than the increase of the earth's population and the condition of the industrial workers. The real dwelling plight lies in this, that mortals ever search anew for the nature of dwelling, that they must ever learn to dwell. What if man's homelessness consisted in this, that man still does not even think of the real plight of dwelling as the plight? Yet as soon as man gives thought to his homelessness, it is a misery no longer. Rightly considered and kept well in mind, it is the sole summons that calls mortals into their dwelling.
>
> "But how else can mortals answer this summons than by trying on their part, on their own, to bring dwelling to the fullness of its nature? This they accomplish when they build out of dwelling, and think for the sake of dwelling".[1]

[1] Heidegger, M. Poetry, Language, Thought. (Harper and Row, 1971.)

If to build is truly to dwell, what kinds of building should we undertake? We are well aware of the types of building programs which are being implemented. The truly creative builders and craftsmen are subjugated to pure economically motivated investment-construction enterprises which are concerned predominantly with the high rents which will be garnered. In the interests of national defense or public health and safety, the taxpayer's money which should be put to the benefit of the whole is squandered through the political construction connection in the erection of obsolete edifices of thin flashy veneer and antiquated programs. They incorporate heavy unmanagable environmental control systems which add further to the overtaxed environment, sealing the occupants away from the natural atmosphere and ignoring the research which has taught us how to build, to minimize energy consumption and maximize comfort and individual control.

New programs must be developed, but what shall form our criteria for such developments? I would propose pro-generation of life to be the bottom line motivating the construction of buildings as this is in the nature of the meaning of 'to build'. Buildings and environments must be thought of as ecological systems of which humans are only a part (not dominant over nature, but sympathetic with it). Environmental impact assessments should begin to bear consequences as to whether or not constructions take place. There is so much repair and rebuilding necessary throughout the world. Such a concept will yield abundant work which can only benefit rather than hinder humanity. Through Aquatecture, the ocean provides an excellent site for the implementation of the programatic priority of life's pro-generation.

STRUCTURAL DESIGN DEVELOPMENT

FUNDAMENTALS

FUNDAMENTALS

Once a structure submerges in the sea, how can it be made to ascend again? What effect does pressure have upon human beings? How is a structure stabilized and anchored? How can submerged occupants breath? These questions must be answered in the design of sea structures. They depict the basic problems of dwelling underwater and are concerned with structural theory, the properties of water and human anatomy.

BOUYANCY

Cold deep sea water tends to be denser than surface water but generally sea water weighs approximately 64 pounds per cubic foot at most. Objects(including air containers) which weigh less will displace only their own weight of water and remain floating. Such objects have positive bouyancy. Objects weighing more than water will displace their volume of water and sink; they have negative bouyancy.

A submersible structure has a chamber into which a valve will allow water to enter to cause decent. If only enough water is admitted so the submersible and it's contents of water weigh 64 pounds per cubic foot, the submersible will have neutral bouyancy, remaining evenly suspended at any depth. Displacing the water from the chamber with pressurized air, from a container or by pump, will lighten the structure causing it to rise to the surface. This principle is evident in the fish's air sac which is compressed by tissue or expanded to displace more or less water allowing the fish to rise and fall in the sea. The bouyancy compensators used by divers are based on this principle.

PRESSURE

A diver must breath air which has the same pressure as the water in which the diver is immersed. Pressurized air forces an excess of gases into the diver's bloodstream and tissue. This is fine if the gas is not toxic in the quantities which build up. In fact, carbon dioxide, nitrogen and oxygen, components of air, are toxic in sufficient quantities and moreso under pressure. Another problem is when the diver ascends, he must do so slowly enough so that the pressure which has forced the gas into his tissue is not relieved so fast as to allow the gasses to expand in the tissue forming bubbles and a decompression sickness called gas or air embolism. The gasses must be given time to be drawn by the blood to the lungs and emitted in expiration. Because of the buildup of nitrogen, air cannot be breathed at great depths(beyond 50 feet) for extended periods of time. To do so would cause nitrogen narcosis.

It is ideal for submerged sea dwellers to have the option to breath air at less than 50 feet of sea water pressure. Beyond this depth, helium or hydrogen need to be added to the breathing medium to reduce the percentage of nitrogen. Submerged dwelling is possible at one atmosphere of pressure if the pressure of the water is resisted by compression in the structure of the dwelling. One atmosphere of pressure is the pressure of air at sea level due to the pull of gravity on the column of air above it. It is equivalent to 33 feet of seawater. Thus at 33 feet of seawater, there are two atmospheres of pressure. At that pressure, a diver would breath twice the volume of air as a surface dweller would.

A sea dweller who needs to make long dives can use a decompression chamber; an area within or beneath the structure in which the diver may decompress, slowly returning to one atmosphere of pressure. Otherwise, structures can be designed to support the dweller under ambient pressure as in Link's SPID(see Ontogenetic Framework) Such structures are open to the water at the bottom. The air contained within the structure is of the same pressure as the water which forms the submerged sea interface. This pressure is greater than the water pressure above the structure. Thus tension is applied to the container. An inverted jug or diving bell displays this principle.

Inflatable structures are ideally suited for containing the dweller's atmosphere at the ambient pressure, but unless the cost of expensive breathing mixtures is incured, such structures have dwelling potential at less than 50 foot depths and the compressed air must be replenished from the surface by pump or cylinder. There are also methods for replenishing the depleted oxygen through the reverse osmosis of the electrodialysis process by which oxygen and hydrogen are released from water at the cathode and anode terminals of an electric charge which is passed through the water.

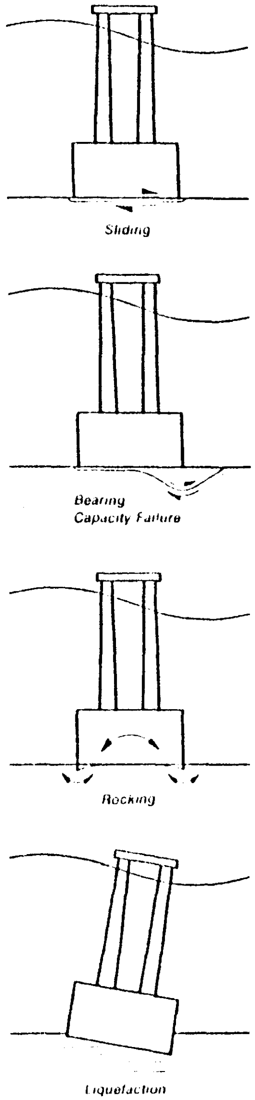
The hydrogen can be stored for energy production or other processes.

Compressible structures can receive oxygen directly from the surface. A wine bottle which floats partially submerged with it's neck out of the water displays this concept. A snorkel can also serve submerged sea dwellers air at the sea level pressure or one atmosphere. Structure 'E', designed in the last chapter is of this type. Entry into the sea is by way of pressure locks or decompression chambers preferably, located in the sides or bottom of the structure.

STABILITY AND ANCHORAGE

A submersible structure has both a center of gravity, the central resultant point of the structure's mass, and a center of bouyancy, the central resultant point of the structure's uplift; the uplift being the weight of the water displaced by the structure. A stable submersible will have a center of gravity below the center of bouyancy. Stability due to the resistance to rolling which is caused by sea motion is directly proportional to the increasing distance between the center of gravity and the center of bouyancy.

The submerged structure requires anchorage to achieve vertical and horizontal stability. Horizontal forces resulting from internal waves and sea currents can be calculated for various shapes upon which the forces act. Such forces are called drag, of which there are two types, friction drag



Possible soil failures

and pressure drag. Friction drag is minimized with smooth surface finishes. Pressure drag can be calculated from

$$F = 1/2 \rho C_D A V^2$$

where F = pressure drag, lb.

ρ = mass density of sea water (2 for sea water, 2.1 at 0°C)

C_D = experimentally determined drag coefficient

A = area of the shape projected onto a plane perpendicular to the direction of current flow in $ft.^2$

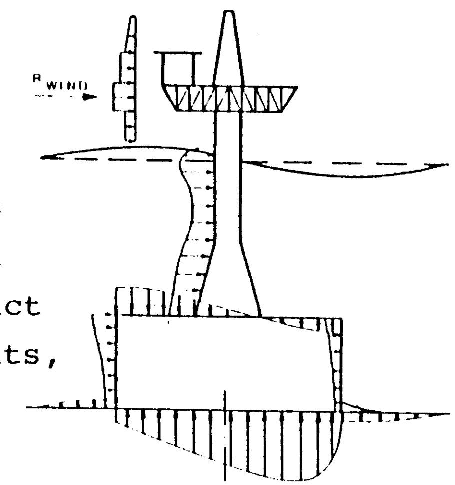
V = the current speed, ft./sec.

Body shape: Description	Body shape: Sketch	Reynolds number R_n	Dimension ratio L/D	Drag coefficient C_D
Circular flat-plate normal to stream		$>10^3$	...	1.12
Rectangular plate normal to stream		$>10^3$	$\frac{b}{h} = 1$ 5 10 ∞	1.16 1.20 1.50 1.90
Circular cylinder – axis parallel to stream		$>10^3$	$\frac{L}{D} = 0$ 1 2 4 7	1.12 0.91 0.85 0.87 0.99
Circular cylinder – axis perpendicular to stream		10^5	$\frac{L}{D} = 1$ 2 5 10 20 40 ∞	0.63 0.68 0.74 0.82 0.90 0.98 1.20
		$>5 \times 10^5$	$\frac{L}{D} = 5$ ∞	0.35 0.34

Body shape: Description	Body shape: Sketch	Reynolds number R_n	Dimension ratio L/D	Drag coefficient C_D
Sphere of diameter D		10^5 3×10^5	...	0.50 0.20
Hemisphere concave to stream		$>10^3$	...	1.33
Hemisphere convex to stream		$>10^3$	...	0.34
Ellipsoid major axis perpendicular to flow		$<5 \times 10^5$ $>5 \times 10^5$	$\frac{L}{D} = 0.75$	0.60 0.21
Ellipsoid major axis parallel to flow		$>2 \times 10^5$	$\frac{L}{D} = 1.8$	0.07
Model airship hull		$>2 \times 10^5$	...	0.05
Solid cone		...	...	0.34
Solid cone		...	...	0.51

Usually, unrealistically high current profiles are used. Drag coefficients have been tabulated for various body shapes.

Surface vicinity currents are greater than deep currents in most cases, due to wind action. Therefore, in the design of structure 'E', material upon which currents would apply pressure was minimized in the form of the access cylinder which has a drag coefficient of 0.63. The ellipsoidal shell, with a drag coefficient of 0.07 is subjected to reduced currents, but over a larger area. Such structures might exhibit a uniform pressure drag profile minimizing the occasion of moments due to enhanced horizontal pressure differentials upon the structure resulting from the various current flows. Another consideration is the fact that most often, currents do not travel parallel with depth but in fact spiral in direction. The occurrence of vertical rip currents, the flow in opposite or perpendicular directions, is also common.



Distribution of environmental loads.

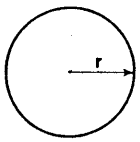
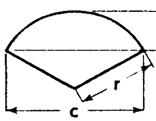
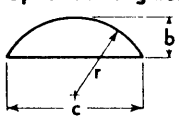
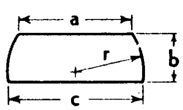
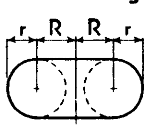
To resist these vertical forces as well as vertical motion due to surface and internal waves, anchorage must be provided to stably secure a structure at its site. The alternative is to allow the structure to drift with the current which is within reason, of course. Propellers can be added and the structure streamlined for motion as well.

In stable concrete shell dwellings, it is best to distribute the anchorage points about the perimeter of the structure so the anchorage cable applies a current resisting force tangentially to the center line of the shell. Highly flexible lightweight mooring cables are attached to the structure anchor points well imbedded and reinforced for tension. The cables connect to heavy chains which lead to anchorages imbedded in the sea floor or to driven piles. Often, weights are attached to the chain to buffer the vertical impacts which might result from rigid anchorage. The anchorage cables must be of sufficient cross-sectional area to resist the calculated horizontal and vertical forces. The sag of the cable and anchor chain catenaries should be great enough to allow the structure to surface when its ballast tanks are emptied. The anchorage assembly should be treated against bio-fouling and over-designed for the penetration of corrosion.

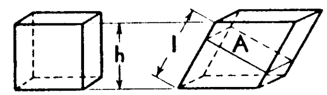
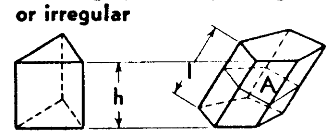
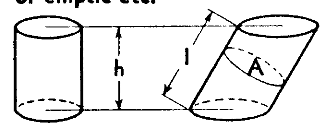
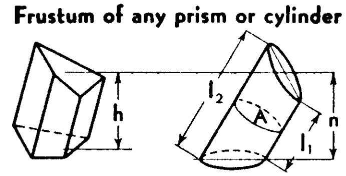
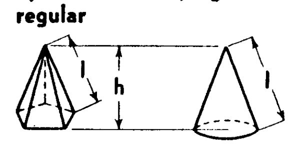
VOLUMES

Considering volumes is important to architects, engineers and all who build structures. The calculation of displacement is the first step in designing submersible structures. To do this we use geometry as geometry is used to generate the forms. Another method is to build a scale model and submerge it in water within a graduated container or allowing the displaced water to run off into a measuring vessel. The geometric method is ancient. It begins by classifying a structure as to its constituent volumes. Each distinct volume has a height and a diameter or height, breadth and width. From a graphic or spacial representation of the structure, its vital measurements are taken and the calculation methods applied to each distinct volumetric shape to yield the displacement which is the sum of the structure's volumes.

FINDING SURFACES AND VOLUMES OF SOLIDS (Cont.)
(S = lateral or convex surface; V = volume)

SHAPE	FORMULAS
Sphere 	$S = 4\pi r^2 = \pi d^2 = 3.14159265\,d^2$. $V = \frac{4}{3}\pi r^3 = \frac{1}{6}\pi d^3 = 0.52359878\,d^3$.
Spherical Sector 	$S = \frac{1}{2}\pi r\,(4b + c)$. $V = \frac{2}{3}\pi r^2 b$.
Spherical Segment 	$S = 2\pi r b = \frac{1}{4}\pi(4b^2 + c^2)$. $V = \frac{1}{3}\pi b^2(3r - b) = \frac{1}{24}\pi b\,(3c^2 + 4b^2)$.
Spherical Zone 	$S = 2\pi r b$. $V = \frac{1}{24}\pi b\,(3a^2 + 3c^2 + 4b^2)$.
Circular Ring 	$S = 4\pi^2 Rr$. $V = 2\pi^2 Rr^2$.

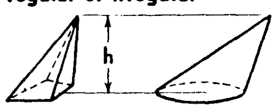
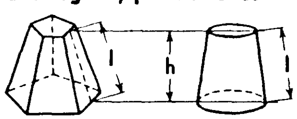
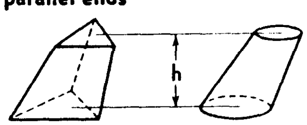
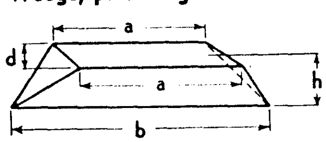
FINDING SURFACES AND VOLUMES OF SOLIDS
(S = lateral or convex surface; V = volume)

SHAPE	FORMULAS
Parallelepiped 	**S** = perimeter, **P**, perp. to sides x lat. length **l** : **P l**. **V** = area of base, **B**, x perpendicular height, **h** : **B h**. **V** = area of section, **A**, perp. to sides, x lat. length **l** : **A l**.
Prism right, or oblique, regular or irregular 	**S** = perimeter, **P**, perp. to sides x lat. length **l** : **P l**. **V** = area of base, **B**, x perpendicular height, **h** : **B h**. **V** = area of section, **A**, perp. to sides, x lat. length **l** : **A l**.
Cylinder, right or oblique, circular or elliptic etc. 	**S** = perimeter of base, **P**, x perp. height, **h**:**Ph**. S_1=perimeter, P_1, perp., x lat. length, **l** : P_1 **l**. **V** = area of base, **B**, x perp. height, **h**:**Bh**. **V**= area of section, **A**, perp. to sides x lat. length **l**: **Al**.
Frustum of any prism or cylinder 	**V** = area of base, **B**, x perpendicular distance **h**, from base to centre of gravity of opposite face: **B h**. For cylinder, ½ **A** $(l_1 + l_2)$
Pyramid or Cone, right and regular 	**S** = perimeter of base, **P**, x ½ slant height **l** : ½ **P l**. **V** = area of base, **B**, x ⅓ perpendicular ht., **h** : ⅓ **Bh**.

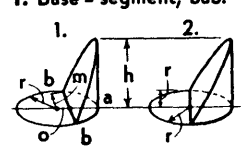
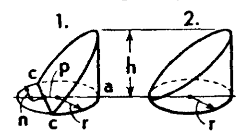
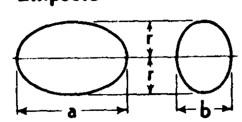
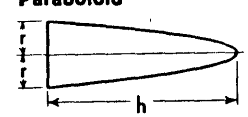
Until the memory of understanding is convinced, available charts are useful to the novice and practitioner. The method will be displayed in the discussion of basic sea structures.

It is necessary to segment large structures, such as submersible 'E', into horizontally parallel segments. Calculus is most helpful in finding the volumes and surface areas of each segment, but for close approximations, volumes of revo-

FINDING SURFACES AND VOLUMES OF SOLIDS (Cont.)
(S = lateral or convex surface; V = volume)

SHAPE	FORMULAS
Pyramid or Cone, right or oblique, regular or irregular 	**V** = area of base, **B**, × $\frac{1}{3}$ perp. height, **h** : $\frac{1}{3}$ **Bh**. **V** = $\frac{1}{3}$ vol. of prism or cylinder of same base & perp. height. **V** = $\frac{1}{2}$ vol. of hemisphere of same base and perp. height.
Frustum of pyramid or cone, right and regular, parallel ends 	**S** = (sum of perimeter of base, **P**, and top, **p**) × $\frac{1}{2}$ slant height **l** : $\frac{1}{2}l\,(P+p)$. **V** = (sum of areas of base, **B**, and top, **b**, + sq. root of their products) × $\frac{1}{3}$ perp. height, **h** : $\frac{1}{3}h\,(B+b+\sqrt{Bb})$.
Frustum of any pyramid or cone, parallel ends 	**V** = (sum of areas of base, **B**, and top, **b**, + sq. root of their products) × $\frac{1}{3}$ perpendicular height, **h** : $\frac{1}{3}h\,(B+b+\sqrt{Bb})$.
Wedge, parallelogram face 	**V** = $\frac{1}{6}$ (sum of three edges, **a b a**, × perpendicular height, **h**, × perpendicular width, **d**) : $\frac{1}{6}\,d\,h\,(2a+b)$

FINDING SURFACES AND VOLUMES OF SOLIDS (Cont.)
(S = lateral or convex surface; V = volume)

SHAPE	FORMULAS	
Ungula of right, regular cylinder **1. Base = segment, bab. 2. Base = half circle** 	1. **S** = $(2rm - o \times \text{arc, } bab)\,\frac{h}{r-o}$. **V** = $(\frac{2}{3}m^3 - o \times \text{area, } bab)\,\frac{h}{r-o}$.	2. **S** = $2rh$. **V** = $\frac{2}{3}r^2h$.
1. Base = segment, cac. 2. Base = circle 	1. **S** = $(2rn + p \times \text{arc, } cac)\,\frac{h}{r+p}$. **V** = $(\frac{2}{3}n^3 + p \times \text{area, } cac)\,\frac{h}{r+p}$.	2. **S** = πrh. **V** = $\frac{1}{2}r^2\pi h$.
Ellipsoid 	**V** = $\frac{1}{3}\pi rab$.	
Paraboloid 	**V** = $\frac{1}{2}\pi r^2h$. Ratio of corresponding volume of a Cone, Paraboloid, Sphere & Cylinder of equal height: $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, 1.	

lutions can be assumed to be composed of segments of cones called cone frustrums. I have used this method in the design of submersible 'E'.

DENSITY

Resolution of the volume of water displaced by a structure is followed by consideration of the density of the material of which the structure is composed. The density of the building material is essential in designing the uplift and weight of the structure which must be equal to achieve equilibrium, a state of neutral bouyancy. Otherwise, the structure will float on the surface or worse yet, sink to the depths. What is important is the ratio of the density of the structural material to the density of water. For instance, the density of dense concrete is 160 pounds per cubic foot, while that of water is 64 pounds per cubic foot. The ratio is 2.5 since concrete is 2.5 times more dense than water.

$$d_c = 2.5\, d_w$$

VERTICAL EQUILIBRIUM

A one foot cube block of concrete will not float; it is negatively bouyant; it weighs 2.5 times more than the water it displaces. It could be made to float if it displaced more than 2.5 times the water it displaced as a solid block. To do this, it must contain air which has negligible weight in such quantity. If the one foot cube block of concrete which weighs 160 pounds is formed into a hollow cube with sides of 1.357..... feet, it would be neutrally bouyant, displacing its own weight in water, able to suspend at any sea depth without rising or sinking.

$$\sqrt[3]{2.5} = 1.357....$$

Such a state of suspension in water is desirable for sea dwellings dependent on links with the surface for existence. It is the state of equilibrium between the uplift, the weight of the structure and the required anchorage to resist the current forces and excess uplift in positively bouyant structure. Where uplift, $\uparrow$U, equals volume displaced times the density of water, W equals the weight of the structure and FA equals the vertical component of the force in the anchorage:

$$W + FA = V \times d_w$$
$$W + FA = U\uparrow$$

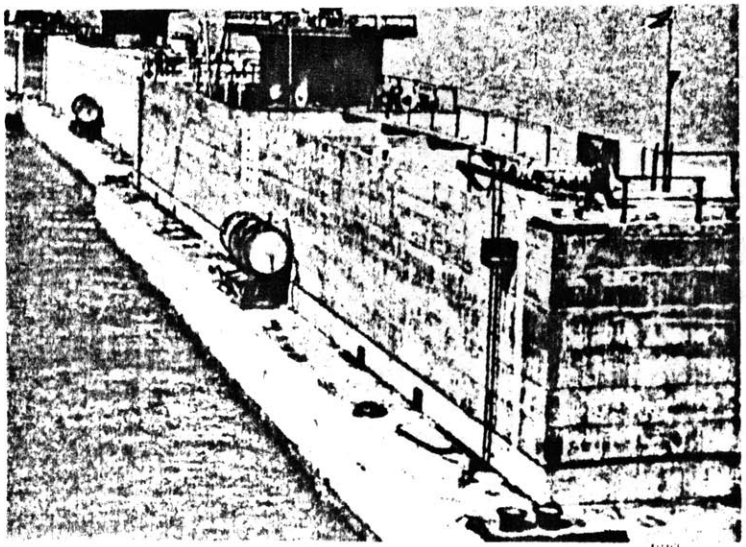
This represents the state of equilibrium of vertical forces.

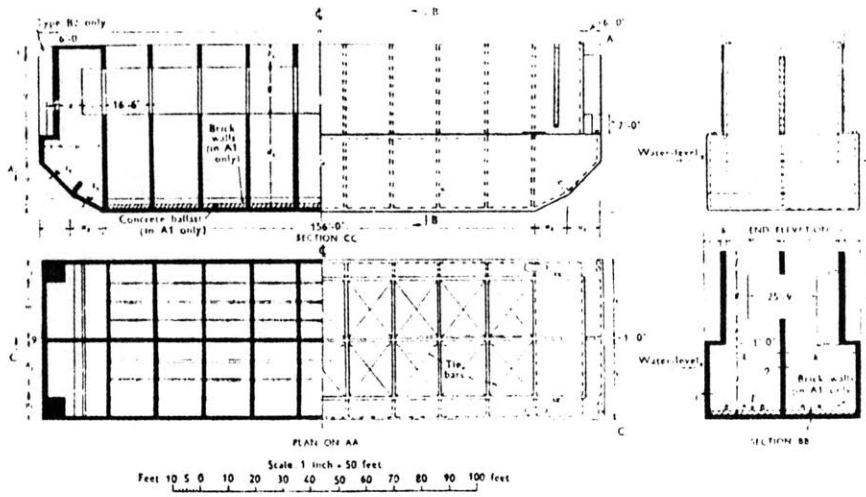
Early sea dwellings should be designed for benign waters having minimal current forces. Neutrally bouyant structures designed for such conditions will require a minimum of anchorage, thus the equation of vertical equilibrium is simply:

$$U \uparrow = W \downarrow$$

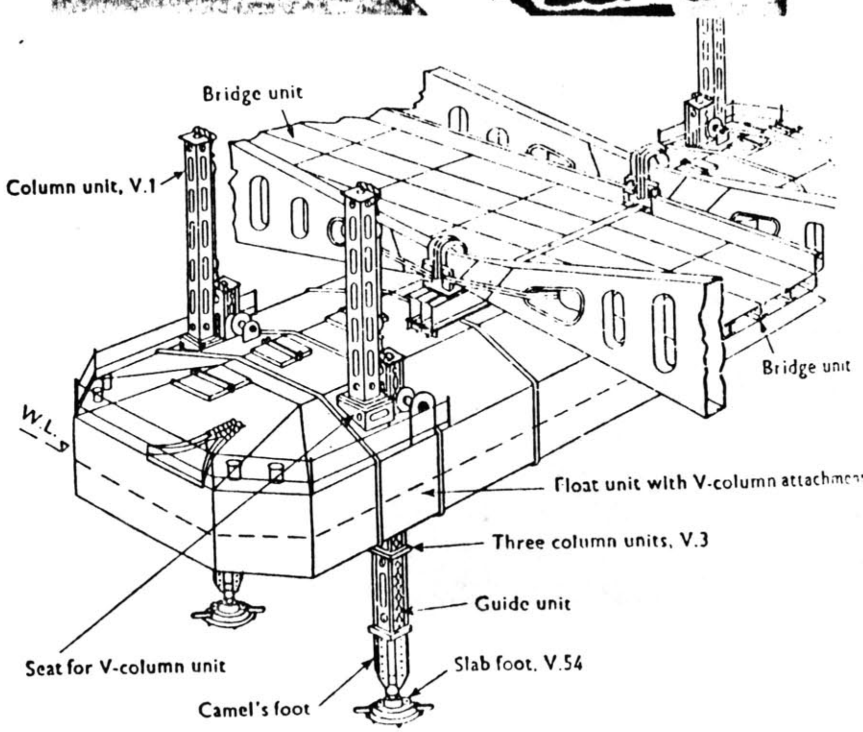
A more reasonable expression may account for the design of a ballast container which would allow the structure to be positively bouyant when empty, and negatively bouyant when full. Where B equals ballast,

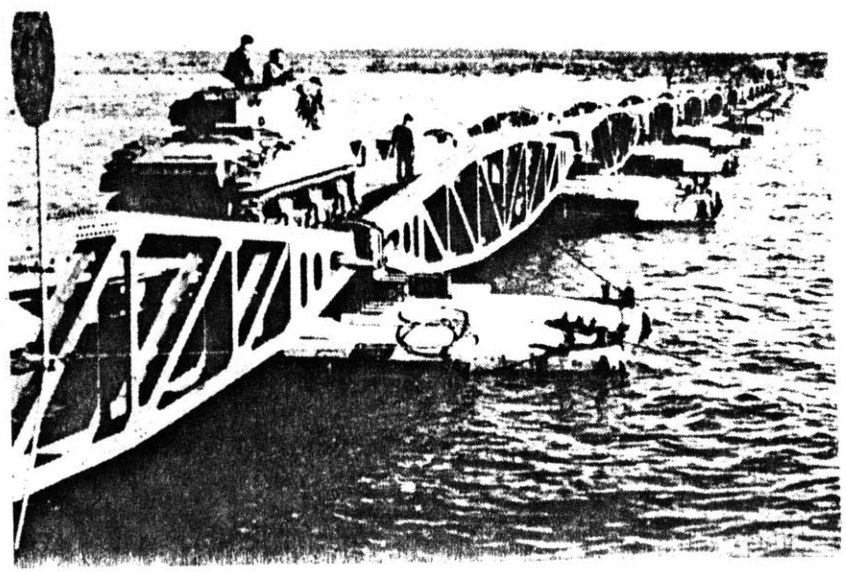
$$U \uparrow = W \downarrow + B \downarrow$$





Mulberry Harbor



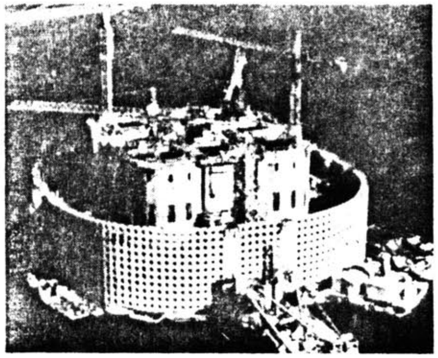


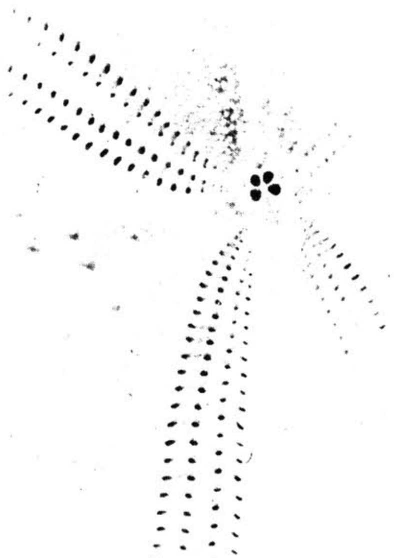
A special study prepared in 1979, for the Electric Power Research Institute of Palo Alto, California by the Massachusetts Institute of Technology Department of Ocean Engineering entitled "Ocean Thermal Energy Conversion: A State-of-the Art Study" states:

"Concrete construction has been suggested as a cost saving measure. There is some limited experience with large concrete structures in the ocean but there appears to be insufficient data to justify the selection of concrete."

In fact, reinforced concrete has had a long history of use in ocean structures. Most prominent are the North Sea platforms, Condeep, Ekofisk and Seatank. Barge type structures, cofferdams, bridge pontoons, sea walls and foundations are other structures which have employed available data for design and construction with concrete. The floating reinforced concrete sea wall of Mulberry Harbor helped land the allies on European soil during World War II. The pontoon bridge supports used in Washington State also employed this technology. Floating drydocks, cargo vessels, car ferries and pleasure craft have all been built of concrete. Not only as a cost cutting measure though, as reinforced concrete has other positive attributes.

Ekofisk





Although the demand for it increases yearly, concrete remains a relatively cheap commodity as the raw materials are abundant in many countries and especially available at the coasts. The lime of concrete comes from calcareous materials, oyster shells, compressed skeletal remains of microscopic sea creatures called chalk, marl and limestone which is simply compressed calcium carbonate. The sea corals also fashion their dwellings of this material. The silica and alumina are derived from argillaceous (clayey) substances: sands, clays, shale, slate, or selected blast-furnace slag. The small quantity of iron in concrete must come from iron ore but the sand and gravel which complete a mix are abundant the world over. Therefore the availability of concrete is a factor in its selection.

A material for the building of sea structures must have the necessary physical requirements to resist the full impact of the ocean. Reinforced concrete has proven its superiority to resist severe earthquake shocks.

Steel is placed where it will best receive the tension of the structure and the concrete distributed where it will best react to compression. The compression due to the pressure of the sea is readily resisted by the concrete, a substance which desires nothing more than to be compressed. Reinforced concrete adapts readily to any shape; it has moldability. The monolithic character of concrete has the greatest amount of strength and rigidity with the maximum amount of elasticity. The great stresses to which sea structures are exposed require a material such as concrete. There is no more liability of failure in concrete than for any other structural material which is properly designed and constructed.

By far, concrete's best asset in sea structures is its long life compared with either steel or wood. If proportioned correctly of the proper materials, mixed and applied properly, it is absolutely impervious to sea water action. It is resistant to corrosion and sea boring animal life.

The small quantities of steel reinforcing bars required can be milled locally minimizing dependence on the large steel fabricators. The availability of materials means construction can proceed rapidly without waiting for shipments.

The first cost of wood structures is lower in some areas than reinforced concrete, but insurance rates are higher and repair and maintenance most expensive in the long run. In most areas, repetition of the building process of reinforced concrete structures diminishes the cost of construction as the reuse of forms and increased efficiency of labor allow. Reinforced concrete is maintenance free. It will not rot; it actually increases in strength with age.

Reinforced concrete compares favorably against steel in initial and life cycle costs as well. Subjected to varying and alternating loads of waves and machinery, concrete deadens vibrations better than other materials. The rivets which join a steel ship are subject to working under alternating loads. Often the cross-sectional areas of the rivets in a ship resist all forces, a very inefficient use of material compared with reinforced concrete which distributes loads throughout its mass.

An important factor in comparing materials for construction is the labor required. Reinforced concrete construction employs a higher percentage of common laborers within the work crews than the other material technologies.

Thus, the selection of concrete for the construction of sea structures is based upon its proven reliability, availability, diversity of uses, adaptability and moldability to any shape, high strength, rigidity and elasticity, resistance to corrosion and boring marine life, its efficient use with steel to resist compression and tension, its distribution and dissipation of forces and vibrations, its use of common labor, its rapidity and ease of construction and its special qualities for submersible structures. Concrete has often been used as an inexpensive ballast for expensive metal constructions as displayed in the last Sea Lab structure. For less cost, the dense concrete could have formed the structure itself. Reinforced concrete is also fireproof, has low thermal conductivity and is stable under thermal stresses as concrete and the steel reinforcing have the identical coefficients of expansion. A bonus is that relatively simple shipyards required for construction of reinforced concrete sea structures are now vacant and available in many parts of the world.

Corrosive sea water can attack concrete in a number of ways. It has long been known that free lime in cement combines with magnesium sulfate of the sea water forming calcium sulfate which, being larger in size than concrete, has a bursting effect on it. Puzzolane and other cements which are free from a surplus of lime and also contain a surplus of silicic acid, which is able to bind free lime, show high resistance to seawater-induced corrosion. The addition of such cements or substances containing silicic acid is protection against the undesirable effects of sea water upon concrete. The hydration of calcium silicate, another means of removal of free lime in the cement, is also prevented by silicic acid's presence.

The sulfates dissolved in water also act on the tricalcium aluminate of cement.

Of the Portland cements, Type I and Type III serve well in the design of fresh water craft, the latter where high early strengths are desired. Type II, modified Portland cement with its low percentage of tricalcium aluminate (5% $3CaOAl_2O_3$) is resistant to the action of sulfates thus suitable for use in sea structures. It is also especially useful when placed in hot weather because its rise in temperature when it hardens is minimized. The Type V sulfate-resistant cement is also specially suited for sea structures. Where temperature rise resulting from heat generated during hydration of very massive structures is a critical factor, the low heat Type IV might be considered or experimented with for inclusion.

Ciment Fondu (melted cement) is produced by melting bauxite (aluminum ore) and a calcareous material (limestone or chalk). A ratio of Alumina (Al_2O_3) to Calcium Oxide CaO is not less than 0.85 and not more than 1.3 without changing the characteristics. It was specially developed to resist attack by sea water and injurious ground waters by eliminating free lime. This aluminous cement also retains binding power to 2500°F. Its initial set is slower than Portland cement, from two to four hours with a final set 30 minutes later, but in 24 hours it achieves the 28-day strength of similar concrete composed with Portland cement. Thus it can be put to use quickly and repair failures in some cases. It is very useful in cold climates as once it begins to set it generates considerable heat.

It might be mentioned that earlier experiments in the United States revealed the addition of five percent fine clay to a concrete mix of 1:3:6 to help it resist corrosion. It is unclear why unless it could be the presence of silicic acid in the clay. Concrete proportions are designated as cement:sand:aggregate.

Sharp, clean, well-graded medium to course sands should be used. High percentages of fine sand must be avoided as they will reduce the strength of the mix. One hundred percent should pass through a Number 8 sieve (8 squares to the inch) and 10 to 15 percent should pass through a Number 100 sieve. Generally, finer sands require more cement. The size of aggregate depends on the structure's scale but should be of irregular shape and clean.

The minimum of water should be used to achieve a workable consistency of the cement and sand mix. This has been found to be equal to about 35 percent of the cement weight, depending on sand grade and cement content of the mix. Test panels are recommended for testing new mixes. Excess water can cause shrinkage and porosity.

Good quality concrete will resist permeability pressures of $14x10^6 N/m^2$. It is doubtful whether lightweight concretes are practical in bouyant sea structures since density helps resist the penetration of sea water. Additives which lighten concrete should be avoided. Calcium chloride or additives containing chloride should be avoided also. This is a special concern at the air-sea interface as chloride ions build up from wetting and drying.

Heavy concrete foundations have used 1:2:4 of clean broken and wet 2-inch stone. Concrete mixed of 1:1:2 with 1/4-inch stone have been used in the design of sea barges.

Cement:sand ratios of 1:1 1/2 or 1:2 have also been recommended. What is clear is that the concrete should be of rich mix (high in good quality cement). The cement should have little free lime gypsum and alumina. The addition of puzzolane or silicic acid will help bind any free lime. Course sand should be used. The concrete should be dense. Place concrete soon after mechanically mixing. A surface treatment such as smoothing with carborundum stone will help seal the surface from the permeation of water. The concrete should be kept continuously moist for at least seven days and preferably until it has reached its 28-day strength. Paint is not required but may help maintain a pleasant appearance of the structure. In such a case, it should be applied after the 28th day.

REINFORCED CONCRETE VESSEL CONSTRUCTION TECHNIQUES

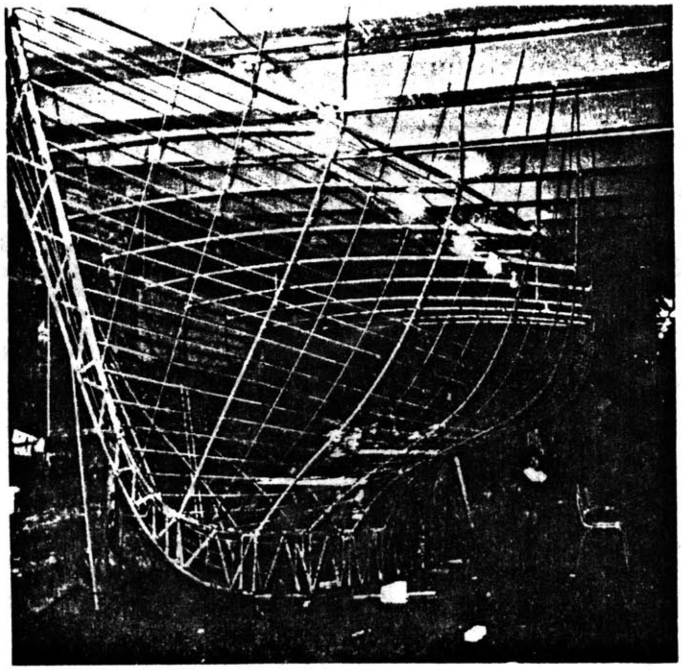
There are many methods by which concrete has been employed in sea structures. The origin of the concept may be found with the early Egyptian Nile boat builders who, using the traditional wattle and daub technique, plastered natural clay of cement over a framework of reed reinforcements.

The concept of the coffer-dam has unknown origins. It is a method by which sea beds and river bottoms are exposed to inspection and clearing before the placement of sub-aquaeous foundations. It allows the bottom to be cleared of water and resists the surrounding hydraulic pressure. Wood cribs or concentric walls of wood forms supported by piles and filled with clay, gravel or concrete to various levels have been early forms of coffer-dams. Recent coffer-dams have employed sheet piles, similarly arranged about the foundation base. The coffer-dam has evolved into the reinforced concrete pneumatic caisson which can be floated and towed to the site of construction, inverted or filled with water ballast to sink around the site or jointed with other elements to form a perimeter around the submerged foundation base. Pumped free of water, the bottom is exposed as with the earlier coffer-dams. Some caissons are used as formwork for the placement of the sub-aquaeous foundations of concrete. They can also be refloated and used again if properly designed.

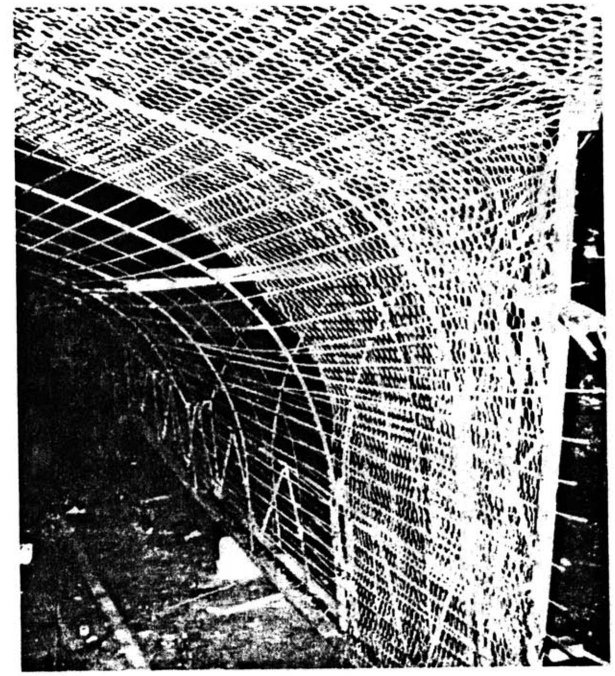
Slip casting of concrete employs movable forms which slide away from the concrete as it sets, providing form walls for the continuous placement of fresh concrete. This method was used in the construction of Ecofisk. Large units have been slip cast and joined into assemblies on land, then towed afloat to the installation site. Welding of metal connectors or the bonding by epoxy cements may be employed to achieve impermeable joints.

The use of flying forms by which large assemblies of the form work can be lifted and rejoined for the placement of fresh concrete also shows promise for use in the construction of large structures composed of repetative units. Another technique for the prefabrication of repetitive units employs forms of steel, plastic, fiberglass or ferro-cement in which reinforced concrete can be cast.

The realization that reinforced concrete can withstand large strains in the vicinity of the reinforcement and that the magnitude of the strains depends upon the distribution and subdivision of the reinforcement throughout the mass of concrete led Pier Luigi Nervi to develop ferro-cement in the 1940's. It maximizes the proportion and subdivision of the reinforcement by using miltiple layers of screen wire with ½ to 1 inch openings. The wire screen is attached by wire ties to the framework of ½ to 1 inch diameter pipe or tubing or concrete reinforcing bars. The purpose of the frame is to maintain the shape of a vessel's hull within very small tolerances. Vertical frames spaced every two to 3 feet or as required are shaped into the proper curvatures over full size templates. Longitudinal stringers of ¼ inch rods are spaced three to four inches on center and tied to the frames. The frame and stringers are built over a rigid keel which is braced and supported at many points. Provisions are made to support a workman inside the hull frame as wire mesh is applied inside and out of the framework. From inside, the cement mortar is applied in a thin coat to a shell thickness of from ½ inch to 3/4 inch for hulls of 25 to 45 feet depending on the number of layers of bars and mesh. Above 45 feet hulls, 7/8 of an inch or more would be required. The hull, its interior and super structure can be made monolithicly with the employment of reinforcing bar joints. To assure bonding of fresh cement to cement which has set, adhesive cement pastes or epoxy cements should be buttered onto the jointing areas which may be exposed to the sea action such as at the keel, the hull, and in the placing of bulkheads. Fittings can be anchored in the reinforcement before cement placement or drilled and groated into the pre-cast surfaces. Plastic sheets or frequently moistened burlap which has been tied to the hull will help keep it moist until complete hardening; seven days may be sufficient, but 28 is preferable.



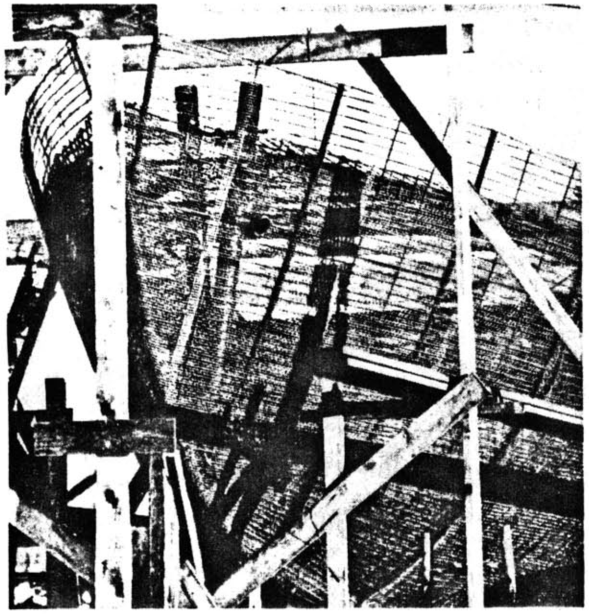
One half inch reinforcing bar frames are anchored to overhead beams.



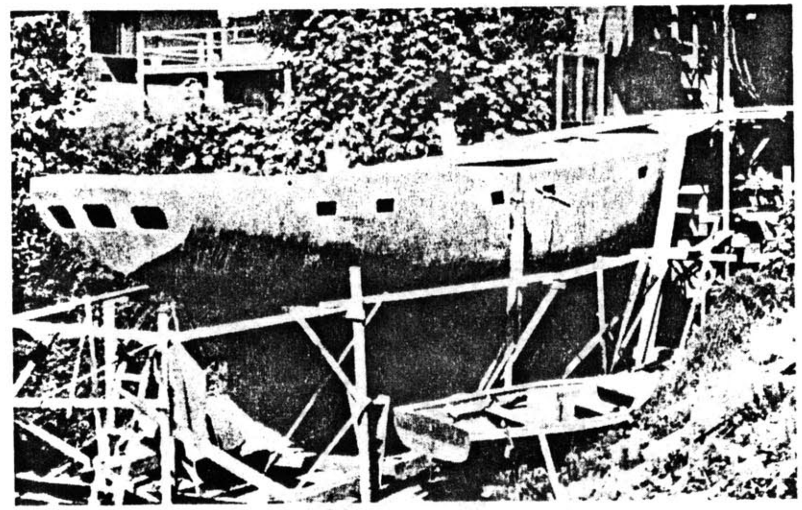
Detail of wire reinforcement.

Projecting ends of wires should be cut off or pushed under the mortared surface which is trowelled smooth on the outside of the hull by the first workman as it is applied from the interior by the second.

Great care must be taken to maintain the proper curvatures as deviations will greatly diminish the strength of the hull. Upon hardening, it is abraded with a carborundum stone. This is a labor intensive process, but maintains an initial cost



Framework with mesh ready to be mortared.



Fifty-three foot ferro cement hull.

of one half to three quarters of the cost of the more conventional types of wood, fiberglass and steel hulls. Compared with these other methods, a 50 foot vessel will be lightest if composed of ferro-cement which weighs 165 pounds per cubic foot due to the inclusion of fifteen percent reinforcement by weight. The mortar, for sea structures can be 66 pounds of Type II cement to 100 pounds sharp clean sand as specified earlier. The water cement should be 0.35 at most. Bending strength, shear strength and Young's Modulus increase constantly with the number of layers of mesh employed. Leaks resulting from the local damage of fine cracks due to collisions or running aground of such vessels are easily controlled and readily repaired. If painting is anticipated, curing compounds should be avoided if incompatible with the paint.

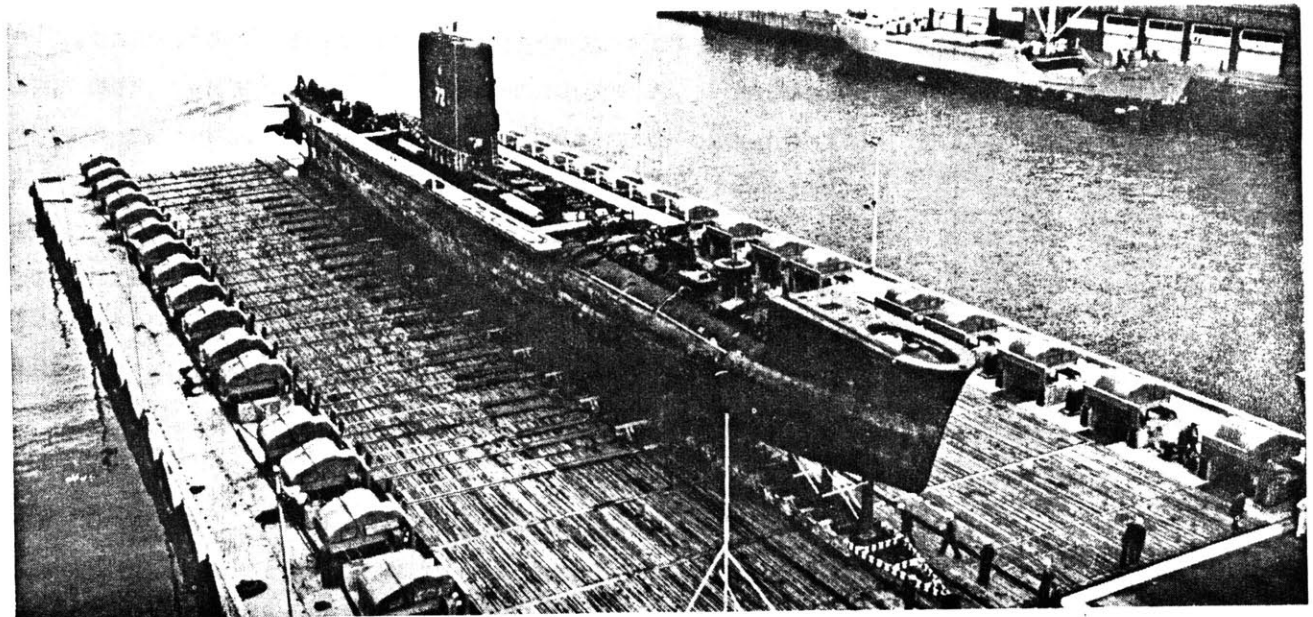
The careful process of shaping and assembling the steel pipe and bar framework can be eliminated if a selected hull will be mass produced. The alternative process is to build one prototype hull, coat it with a bond breaker, build formwork around it into which concrete can be placed and vibrated into the shape of a negative mold of the hull bottom. The inclusion in the mold of a piping system with nozzles spaced two to three feet apart over the surface of the hull to conduct water under low pressure levels can assist in raising the prototype mold. The prototype can be re-used to make more negative molds or positive molds in a similar manner. Upon curing, the bond breaker is applied to the interior of the negative mold. The frameless layers of wire mesh can be tied together against the mold. The mortar cement can be shotcreted or plastered onto the mesh reinforcement beginning at the bottom and working upwards. Upon hardening, the smooth faced hull is floated from the mold bythe water from the nozzels and the process repeated.

Positive molds of the hull's interior can be inverted and a similar process employed for construction. Freeing the mold can be accomplished by rolling the hull over and floating the mold free. Combining an inverted positive mold with stackable units of an exterior negative mold will allow the ferrocement to be placed with greater precision between the two mold faces.

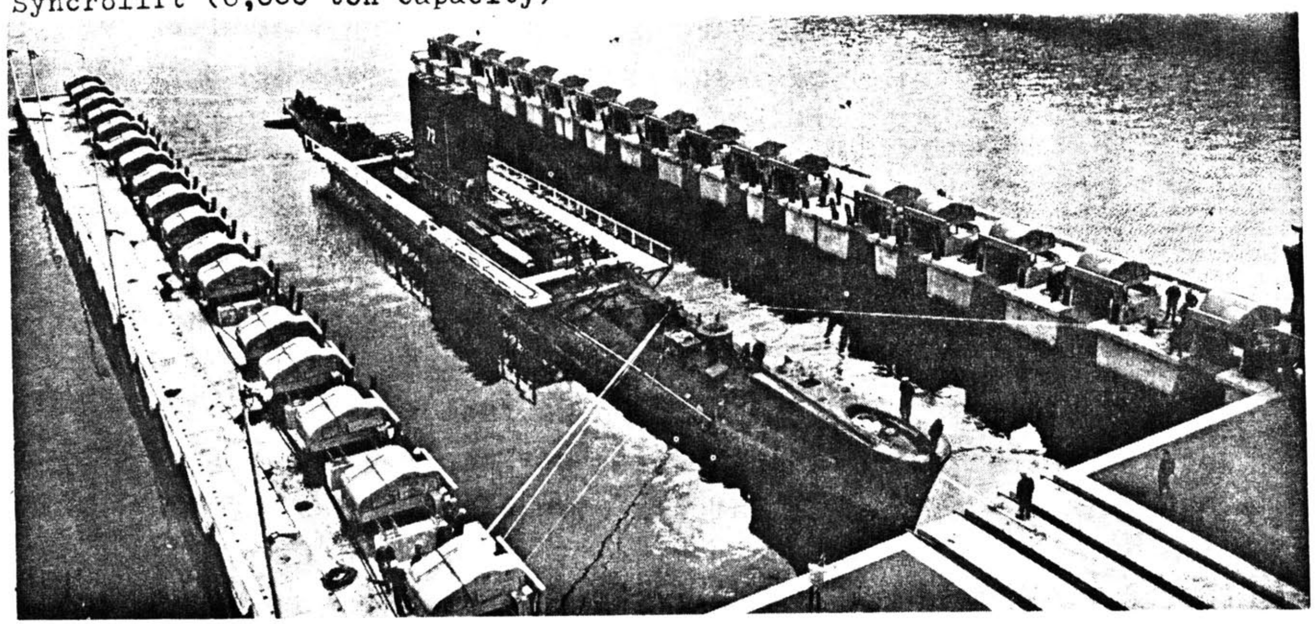
In large structures such as thick shell submersible or semi-submersible reinforced concrete structures, single monolithic molds may not be practical. For such cases, molds composed of workable units which are stackable can be used as forms for the placement of concrete. They are fitted with a water nozzel insert on the exposed face and a water outlet to the separating face. A flexible hose conducting water will free the mold units independently. Pulleys and counter weight or ramps and fork lifts can stack or remove the molds.

An alternative is for the molds to be cast as assemblies to be integrated with the reinforced concrete shell by metal anchorages. Designed in parallel stackable horizontal rings, a single prototype pattern of workable size will be required to cast a negative mold for the production of the entire horizontal ring for each parallel. This method of construction is proposed for building structure 'E'.

The construction of sea dwelling structures can be accomplished in many ways. First is to build the structure on land, in a drydock or upon a hydraulic lift platform which



Syncrolift (6,000 ton capacity)



employs the bouyancy compensation principle for accent and decent. A second method is to cast the shell mold units on land and tow them to the sub-aqueous construction site as separate units upon a barge or as assemblies floated by bouyant balloons or hollow pantoon cylinders. Submergence can be controlled so only the part being constructed is just above water level. The pontoons and floating work platforms used in this method must be rigorously moored and bouyancy carefully controlled.

Floating work platforms or caissons can be used where a worksite on land is unavailable and when bargeloads of unmixed concrete can be delivered at the lowest cost. Construction can take place on the dry seabed inside the perimeter of the caisson. After construction, the caisson enclosed area can be flooded, submerging the structure for testing and the caisson floated, dismantled and removed. It is possible to design the caissons to form part of a re-usable shell mold also.

Where divers can be employed, the structure can be designed to be built underwater and pumped free of water after completion. In such cases, thin shells with steel exposed at the interior surface would initiate the natural concretization of calcium carbonate in the form of coral.

Given sufficient time to grow, this would form a fantastic natural polychromatic shell of great thickness. When the shell thickness approaches that required for neutral bouyancy, it would be pumped free of water arresting the growth. Coral can be readily cut and could thus be sculpted and smoothed in bulging areas or where the sea dwellers need to avoid the sharp face of the coral.

The growth of calcareous accretions upon metal mesh frameworks can be accomplished by charging the framework with an electrical current. The use of floating wind turbines in areas of reliable high winds close to sources of wire mesh can bring about the growing of sea dwelling at very low life cycle cost.

GROWING SEA STRUCTURES: AN ALTERNATIVE

Water is an ampholyte; it behaves as an acid if it contains carbon dioxide which combines to form carbonic acid; and it behaves as a base when the carbon dioxide escapes as a gas precipitating materials it had dissolved while in the acid state. Our veins, filled with oxygen enriched blood, carry mineral and protein nutrients to our cells which through a process of spontaneous combustion transforms into carbon dioxide precipitating waste products carried by our arteries to be expelled from the lungs or siphoned off with liquid or solid wastes.

Cell wall (CW) of coral forming exoskeleton.

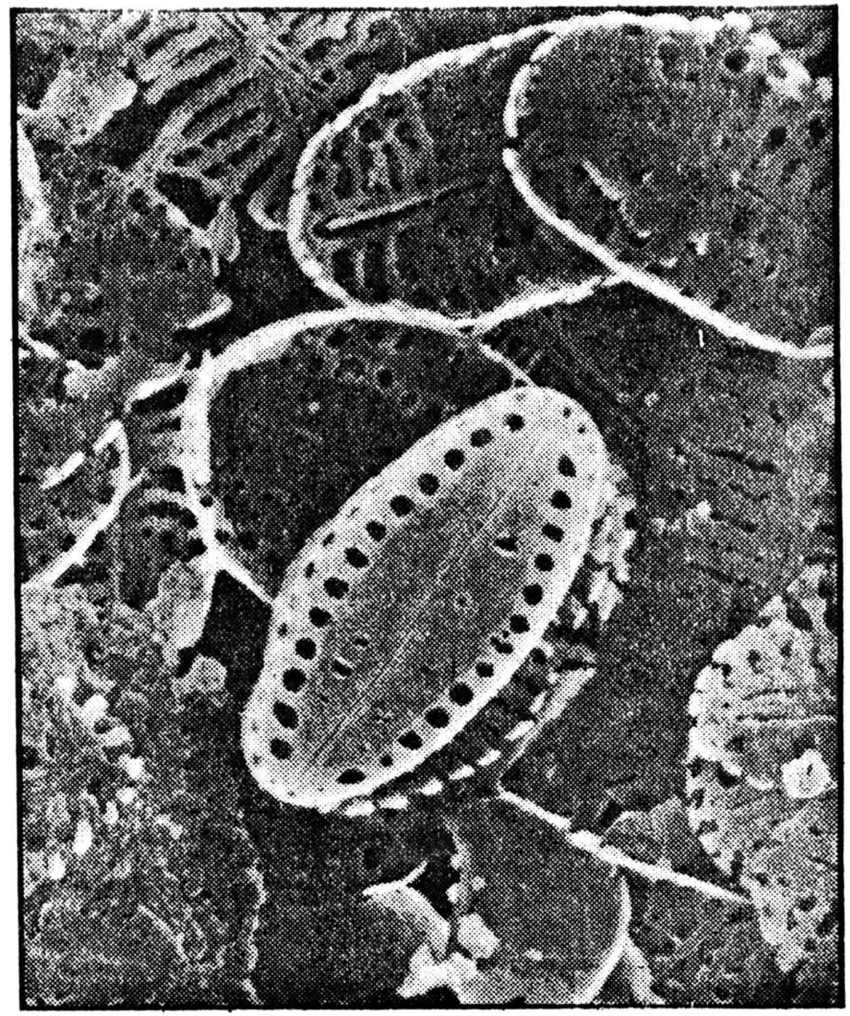
The mineralization of mollusk shells occurs with the deposition of negatively charged residues precipitated from sea water alternating with layers of positively charged calcium ions (Ca++). It is believed electrical potentials attract the minerals for shell formation upon a template formed by the negatively charged aspartic acid in the organism's soluble protein.

The secretion by coral of a supersaturated solution of calcium carbonate forms the calcite crystals of coral structures.

Symbiosis occurs between diatoms (one celled plants), and foraminifer, (one celled animals). They feed off their mutual waste products of carbon dioxide and oxygen. Similarly, the fixation of carbon dioxide by the photosynthesis of dinoflagellate algae called zooxanthellae helps remove carbonic acid (H2CO3) from the vicinity of calcifying organisms, thus enhancing carbonate formation in the following reaction:

$$Ca^{++} + 2HCO_3 = Ca\ CO_3 + CO_2 + H_2O$$

The supersaturation of calcium carbonate ($CaCO_3$) occurs with the removal of Carbon Dioxide (CO_2) by the plant organisms. Phosphates, inhibitors of calcification, are also removed by plant life further enhancing the crystalization of calcium carbonate.



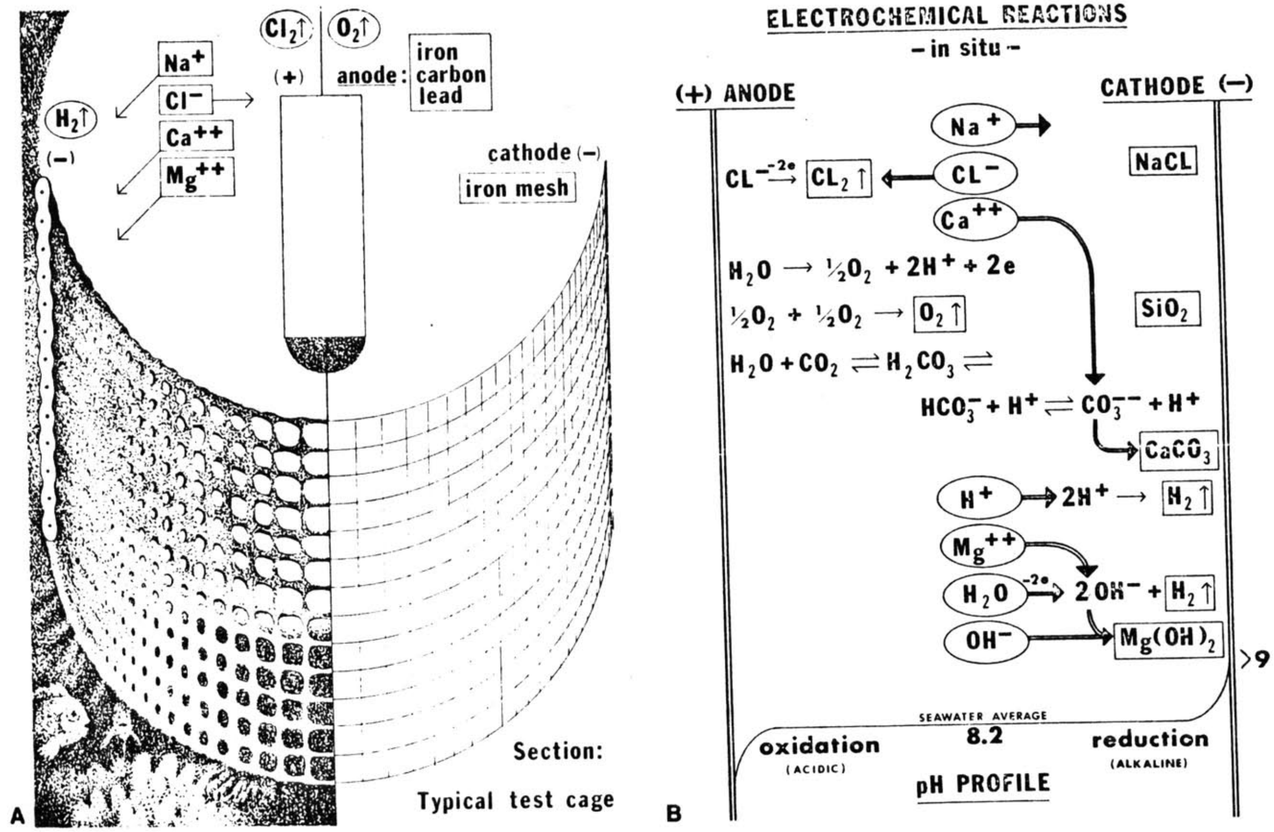
Diatoms and Protozoa in symbiotic relationship

Inorganic and organic conglomerate accretions of sand, clay corrosion products, shell, coral and other forms of calcium carbonate which crystalize on metal objects can withstand compression forces in excess of 2000 pounds per square inch (p.s.i.).

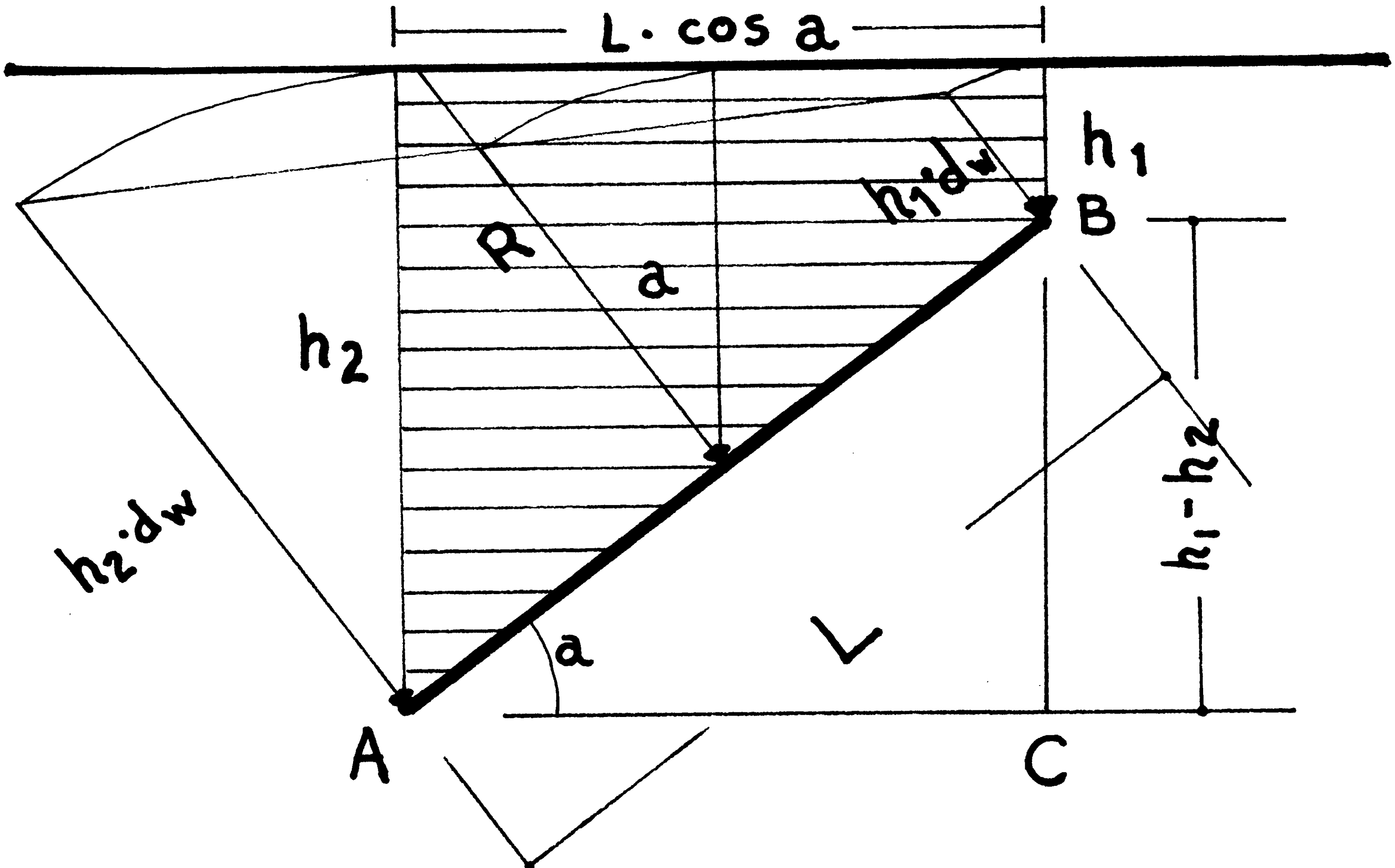
Electrolysis of sea water causes the attraction of ions and the production of heat at the electrode surfaces. The PH rises with the temperature causing thermal decomposition, the removal of carbonic acid (H_2CO_3) from the sea water and the escape of carbon dioxide (CO_2). The resulting shift towards the carbonate side of the hydrogen carbonate - carbonate equilibrium ($H\ CO_3{}^{--}/CO_3{}^{--}$) induces the precipitation of ionic calcium carbonate crystals on the cathode ($CaCO_3$). Further alkalinization of the sea water ($PH > 9$) inhibits the structural development of the crystals because of the precipitation of brucite [Mg(OH)2] which returns seawater to the acidic state. Phosphates, hydroxides and sodium carbonate are inhibitors of crystal growth.

The major crystal of this process, by percentage, has been experimentally proven to be brucite in its foliate form (harder than gypsum and talc) when precipitated slowly, or in its massive material form (which has a soapy appearance) when rapid precipitation occurs. Sixty to 200 D.C. watts

Schematic of the electrolitic process.



per hour are sufficient to induce growth on wire mesh. Future ocean based energy production facilities and the location of mining, refining and processing facilities in the open sea will increase the potential for sea-born structures to be grown in and of the sea.



$$\cos a = \frac{AC}{AB}$$

SEA STRUCTURE DESIGN

Once the fundamental principles of designing structures underwater are understood it becomes necessary to calculate the loads which any particular structure must resist. The predominant load is the pressure differential between the interior and exterior of a submerged craft. Structures which are at ambient sea pressure will usually have the internal pressure exerting an outward tensile force on the container. Membranes are best suited for such vessels and the design method is almost identical as for compressive structures. Structures which have internal pressures lower than ambient sea pressure will have a hydrostatic pressure exerting an inward compressive force.

Let us assume we have a flat inclined plane called element 'L', one unit wide and L units long submerged from h_1 to h_2 units deep under water. Always remember that water applies pressure on objects or containers perpendicularly to the surface of contact and with a magnitude in direct proportion to the water depth at which the pressure is applied. The pressure at any point of contact is the density of water times the depth.

Returning to our inclined plane, the resultant of the weight of the water upon it (R) is equivalent to the total load acting perpendicular to element 'L'. Graphically, we can see how R is equal to the average depth times the density of water (d) times the area, L.

$$R = \left(\frac{h_1 + h_2}{2}\right) d \cdot L$$

The vertical component (V) of the total perpendicular pressure upon 'L' is the resultant times the cosine of angle a:

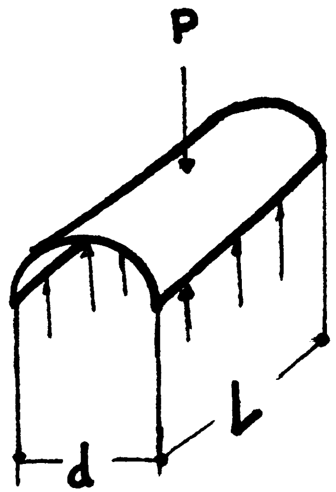
$$V = R \cdot \cos a$$

$$= \frac{h_1 + h_2}{2} d \cdot L \cdot \cos a$$

$$= \frac{h_1 + h_2}{2} L \cdot \cos a \cdot d$$

Aside from discerning the weight of water upon a surface, it is important to be able to design for bouyancy. While working with materials denser than water, this is accomplished by the inclusion of a light gas, such as air, within the structure. This means the design of hollow, watertight containers. Submarines are such structures. They are designed of steel to resist water pressure and dynamic forces while supporting a crew. An examination of submarines reveals they are usually composed of an internal and external skin connected by ribs, the interstice forming ballast containers, the regulation of which allows ascent and descent.

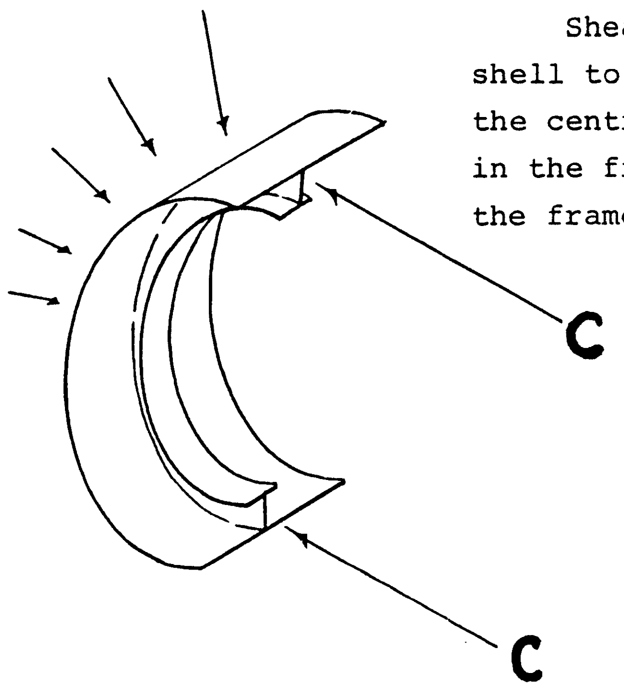
The cylindric tube is the primary element of submarines for two reasons: it is easier to arrange internal equipment and other than a sphere it is the lightest, strongest structure to resist external pressure. There is an elementary relationship which exists between the longitudinal (axial) stress and tangential (circumferential) stress of a cylinder under pressure: the axial stress is half of the circumferential stress.



where t = thickness
P = pressure
L = length
d = diameter
C = circumferential stress
A = axial stress

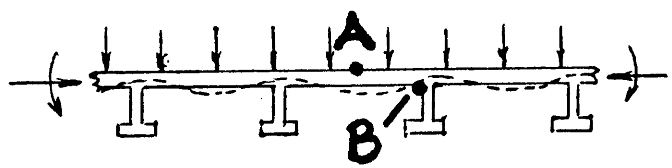
$$C = \frac{Pd}{2t}$$

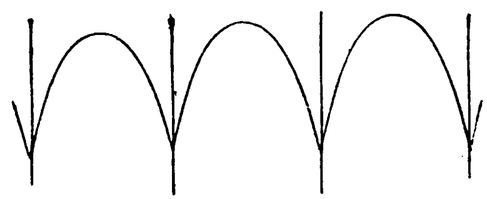
$$A = \frac{Pd}{4t}$$



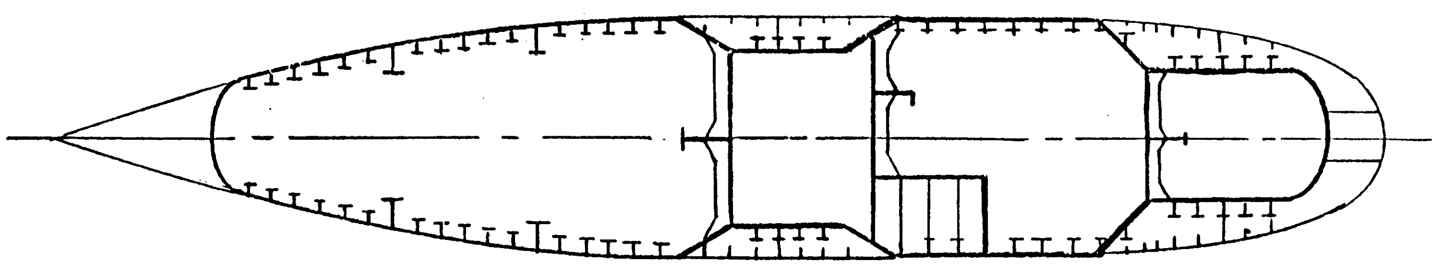
Shear distributes the load from the cylindric steel shell to the frame members with the load resisted by it at the centroid of the frame/shell section. The stress developed in the frame is found by dividing the load by the area of the frame.

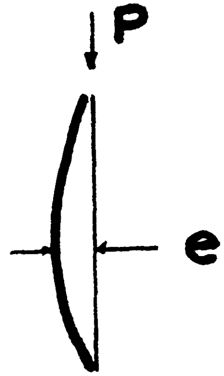
Such a concept of submarine design relies on the shell's behavior as a thin plate which develops bending moments as diagrammed. Maximum stresses appear midbay (A) and at junctures with the frame (B). Longitudinally eccentric loading induces accordian type failure. Thus, the frames must be carefully spaced at no more than 10% of the diameter and a collapse depth safety factor of 1.5 is adopted.



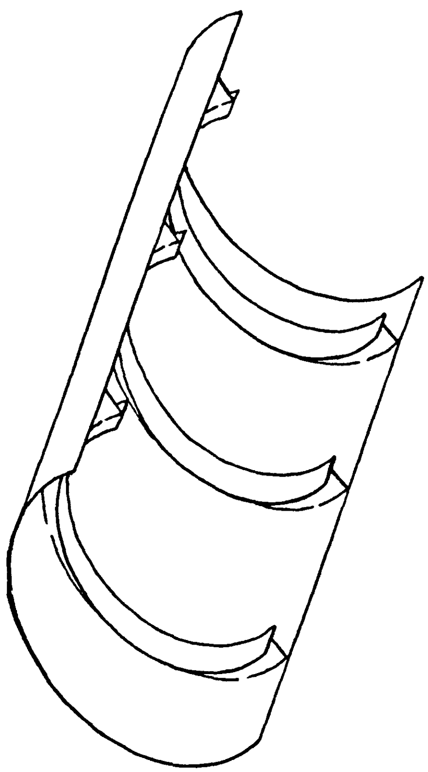


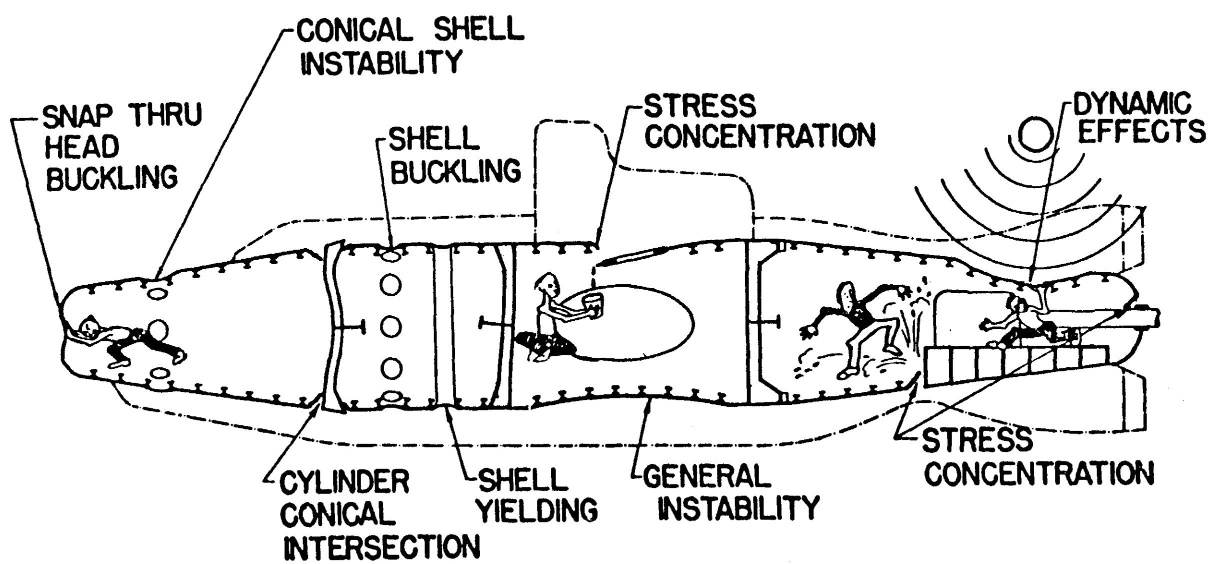
Bending Moment diagram for shell section





It is evident that the frame does more than maintain shell circularity as loads are distributed about the centroid of the frame/shell combination. As a deformed column under load deflects eccentricly with added load, so are deflections of the shell plates about the frame exacerbated. As the frames are spaced closer and closer together, strength is gained. Why not use a true shell structure instead and avoid induced moments due to varying rigidity? Steel shells of the thickness required to resist high pressures are very difficult to weld while maintaining proper curvature, which is essential to strength. Therefore, concrete is recommended.





STEEL SHELL/FRAME

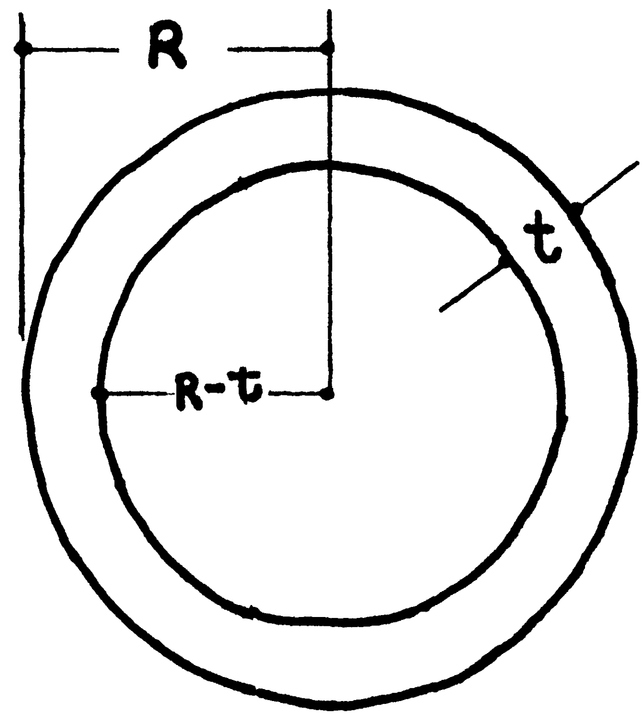
DESIGN OF A CONCRETE TUBE OF NEUTRAL BOUYANCY

(Assume ends sealed) Neutral bouyancy of a structure is where the uplift is equal to the structure's own weight.

$$U = \pi R^2 \cdot dw$$

where $d_{water} = 64 \text{ lbs/ft}^3$
$d_{concrete} = 150 \text{ lbs/ft}^3$

Own weight if thickness is t:



$$W = (\pi R^2 - (R-t)^2 \pi) dc$$
$$= \pi dc [R^2 - R^2 + 2Rt - t^2]$$
$$= \pi dc [2Rt - t^2]$$

First, state the equality:

$$U = W$$

since:

$$\frac{t}{R} = a \qquad \frac{dw}{dc} = b$$

then:

$$t = Ra$$

follow:

$$\pi R^2 dw = \pi dc[2Rt-t^2]$$

$$R^2 dw = dc[2Rt-t^2]$$

$$\frac{R^2 dw}{R^2} = \frac{dc[2R(Ra)-(Ra)^2]}{R^2}$$

$$dw = \frac{dc[2R^2a-R^2a^2]}{R^2}$$

$$\frac{dw}{dc} = \frac{dc[2a-a^2]}{dc}$$

$$\frac{dw}{dc} = [2a-a^2]$$

$$a^2-2a+b = 0$$

$$\text{since } b = \frac{dw}{dc} = \frac{64}{150} = .43$$

$$a_{1,2,n...} = 1 \mp \sqrt{1-b}$$

$$a = 1-\sqrt{1-b}$$

$$= 1-\sqrt{.57}$$

$$= 1-.75$$

$$a = .25$$

thus:

$$T = .25\ R$$

This design shows how any neutrally bouyant 150 lb/ft^3 concrete tube will have a shell thickness of one quarter the external tube radius. Such a thick shell can use thin shell theory to approximate the solution of static relations.

How deep can a neutrally bouyant concrete cylinder descend in the ocean if it is 25 feet in diameter?

The circumferential stress is the determining factor.

$$R = 12.5 \text{ feet}$$
$$t = .25\ R$$
$$= 3.125 \text{ feet}$$

Assume: 3000 ksi concrete, safety factor = 1.5

Allowable compression in concrete = $f_{all}c$ = 2000 ksi

Concrete in tube section can resist:

$$C = 144tf_{all}c = 900{,}000 \text{ kips}$$

Where: $$C = \frac{Pd}{2t}$$

$$C2t = Pd$$

$$P = \frac{C2t}{d}$$

$$P = \frac{900{,}000(2)3.125}{25}$$

$$P = 225{,}000 \text{ kips}$$

$$P = dw \cdot \text{depth}$$

$$D = \frac{P}{dw}$$

$$D = \frac{225{,}000}{.064}$$

$$D = 3{,}515{,}625 \text{ feet}$$

Such a structure could submerge to the deepest parts of the ocean.

BOUYANCY FUNCTION

In order that structures may ascend and submerge at will, a bouyancy system is required. The concept is the same as with the bouyancy compensators used by divers where inflation, by a compressed air source, achieves the displacement of a larger amount of water by the structure thus achieving a positive bouyancy. In the design of the structure 'E', the chambers for containing the expandable and contractable air pocket is located in the skirt or apron which rings its bottommost points. The chambers would be formed of inflatable membranes of ellipsoidal design, displacing 10% of the structure's volume and depressed in the forms prior to the placement of the concrete. The membranes remain imbedded forming a redundant watertight seal.

Assuming we begin with a hypothetical structure of a calculated volume:

DISPLACEMENT

The volume displaced by the complete structure is 250,000 $ft.^3$

UPLIFT

Uplift of the structure is equivalent to the volume displaced times the density of water:

$$= 250{,}000 \times 64 = \text{(in kips)},\ 250{,}000 \times .064$$

$$\text{Total Wd} = 16{,}000 \text{ Kips} \uparrow$$

LOAD

The weight of the structure is 90% of the water displaced: .9 (250,000 x .o64)

$$Wc = 14{,}400 \text{ Kips} \downarrow$$

BOUYANCY

The volume of the air chamber required for regulation of bouyancy is 16,000 - 14,400 = 1,600 Kips

The volume of the chamber times the density of water yields the weight of the water displaced by the chamber which is uplift.

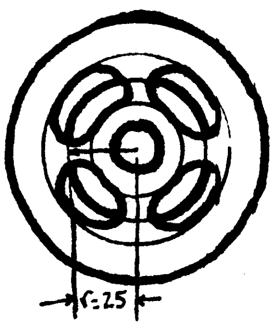
$$W_{chamber} = V_{chamber} \times .064 = 1{,}600 \text{ Kips, therefore,}$$

remembering the ratio of concrete to water density is 2.5:

$$V_{\text{air chamber}} = \frac{1{,}600\ k - \left(\frac{1{,}600k}{2.5}\right)}{.064\ k/ft^3} \qquad d_c : d_w = 2.5$$

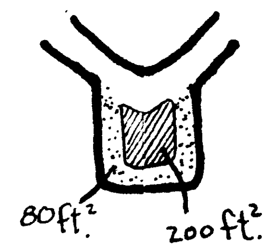
$$= 25{,}000\ k - 10{,}000\ k$$

$$= 15{,}000\ ft^3$$



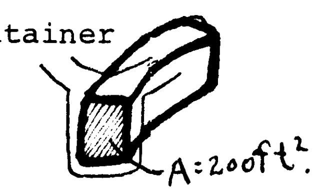
The perimeter of the ballast container along its center line is $2\pi \times 25 = 157$ feet.

Say that the length of the ballast container along its center line is $\frac{25{,}000}{200} = 125$ feet.
Then, the vertical cross sectional area is 200 feet^2.



The vertical cross sectional area of the concrete forming the container is: $\frac{200}{2.5} = 80$ feet^2.

The total vertical cross sectional area of the container plus the air chamber is 280 feet^2.



The ballast chamber form utilizes tensile reinforcement as the empty chambers must resist the outward pressure exerted when the water is emptied by air pressure causing the structure to rise.

In discussion with ocean engineers, it was suggested that either a sphere be employed for the dwelling form, or a tear or blimp shape with a length to diameter ratio of from 5 to 7. The former because of its superior structural capacity and the latter to minimize frictional drag. In analyzing the minimum drag solution I realized hydrostatic forces would flow primarily through the curvature of minimum radius and secondarily perpendicular to the primary curvature. While minimum drag configurations are apt to minimize hydrodynamic forces even in stationary structures in the sea, the merits of a circular structure in terms of access, circulation and internal arrangements led to its selection. An alternative, for reducing drag in a circular, ellipsoidal structure, is to link a number of them together in groups along a line parallel to the current flow by tethering. Tabular links were considered but have not yet been developed for connection. Grouping in clusters of trimarang, quatramarang, quintomarang and hexamarang would offer greater stability and social potential. The blimp shaped structure was rejected because there were few repetitive parts in it as well. The multi-hulls or slenderization were deemed as good as elongation to minimize the impact area per volume.

Spherical structures designed according to the forumla

$$P \times R = T$$

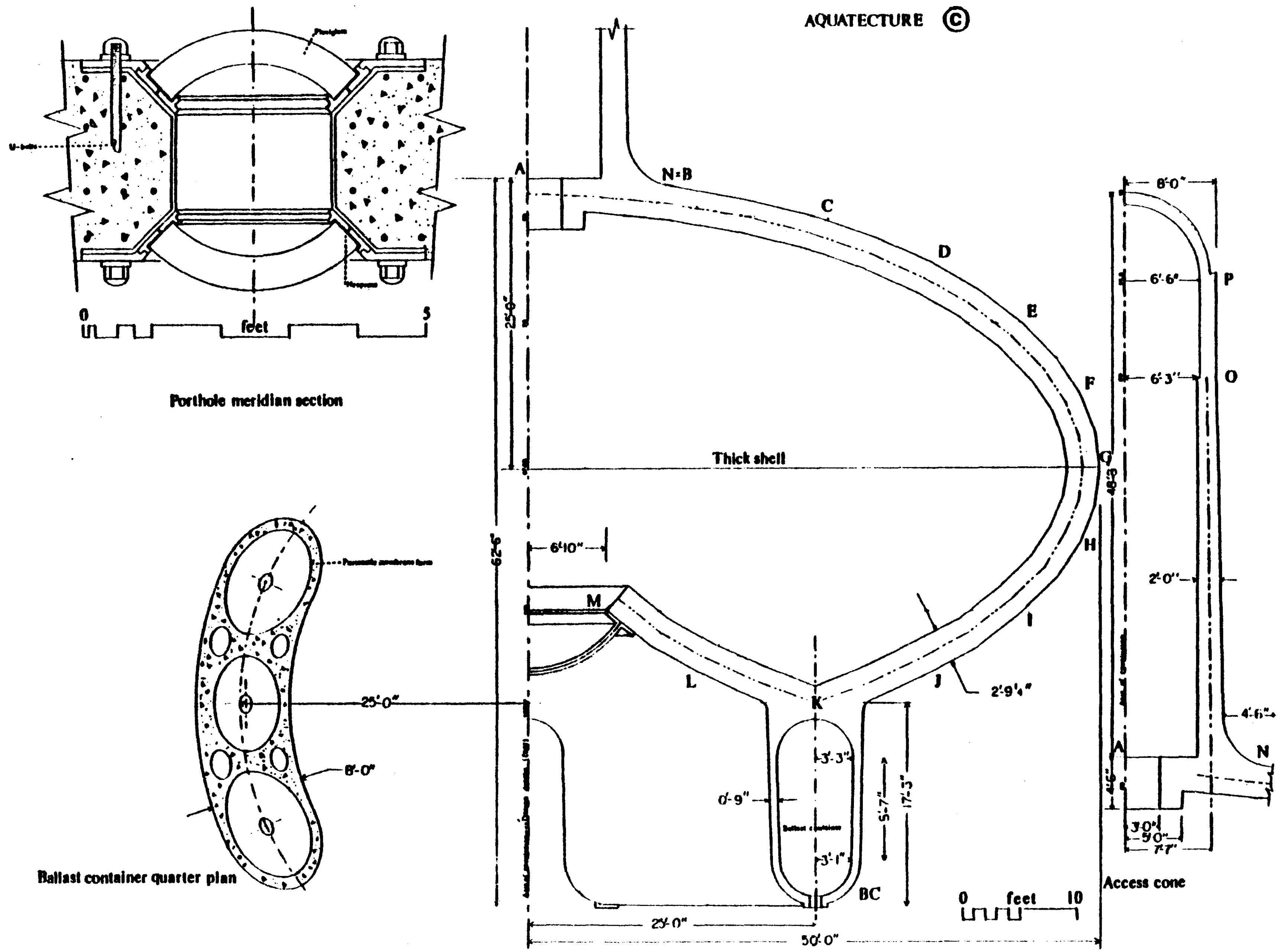
where

P = pressure

R = radius

T = tension or compression

impact greater hydrostatic loads than ellipsoidal forms. In attempting to efficiently use the vertical height of a spherical structure, much of the internal and lower volumes are diminished in the intensity of natural light due to the stacking of floors. It has been found after calculations that a 10% bouyant reinforced concrete submersible, properly designed, is as feasible from a structural viewpoint as a sphere. In fact, in achieving neutral bouyancy and applying temperature reinforcement to the concrete mass, the structure was more than adequate to resist design loads.



STRUCTURE 'E' SCHEMATIC — SECTION OF REVOLUTION — Ricardo Guillermo 5/82

THE DESIGN OF STRUCTURE 'E'

Structure 'E' is the most recent in a series of underwater structures I have designed as manifesting my inquiry and learning process about structure, form and content. It is meant as a universal structure with a multitude of applications. While a pragmatic program may have been applied, I have decided to continue with the design after this thesis' submittal with a cosmological program integrating the arts and techniques of our age.

DISPLACEMENT

Begin by finding the volume enclosed by the submerged structure. This is accomplished by segmenting the structure into geometric types along horizontal ring lines. Label each ring. the sum of the volumes enclosed by the ringed segments is the volume of water displaced by the structure, V, in cubic feet.

$$V = 163{,}745 \text{ ft.}^3$$

UPLIFT

Uplift of a submerged structure is equivalent to the volume of water displaced by it times the density of water. The density of water, dw, is equivalent to 64 pounds per cubic foot (64 lbs./ft.^3) or 0.064 kips per cubic foot in large structures.

$$dw = 0.064 \text{ k/ft.}^3$$

$$Vdw = U\uparrow, \text{ in kips}$$

$$U\uparrow = 10,480 \text{ kips}\uparrow$$

LOAD

The weight of the structure is assigned as a given percentage, x, of the uplift. For bouyant structures, x is less than one

$$L_c\downarrow = xU\uparrow$$

For example, for a structure having 10% buoyancy, $L_c\downarrow = .9Vdw$ which means the structure weighs the same as 90% of the water it displaces.

$$L_c\downarrow = 9.U\uparrow = 9,432 \text{ kips}$$

BOUYANCY

A water ballast container is required for the regulation of bouyancy. The volume of the ballast container, Vb, times the density of water is equivalent to the uplift minus the load and equal to the bouyancy uplift, $B\uparrow$.

$$Vbdw = U\uparrow - Lc\downarrow = B\uparrow$$

$$B\uparrow = 1,048 \text{ kips}\uparrow$$

BALLAST DESIGN

The structure will submerge when the ballast tanks are full of water. When empty, they are air chambers allowing the structure to float with its designed bouyancy. The volume of the air chamber is equivalent to the difference between uplift and load, minus the same difference divided by the ratio between the density of the material composing the ballast container and the density of water, all divided by the density of water and yielding the result in cubic feet.

$$Va = \left[(U\uparrow - Lc\downarrow) - \frac{(U\uparrow - Lc\downarrow)}{(dc \div dw)} \right] \div dc$$

where dc, density of concrete equals 0.16 kips per cubic foot and dw, density of water equals 0.064 kips per cubic foot.

$$dc - dw = 2.5$$

$$Va = \left[(U\uparrow - Lc\downarrow) \div \frac{(U\uparrow - Lc\downarrow)}{2.5} \right] \div .064$$

$$Va = \left[(B\uparrow) - \frac{(B\uparrow)}{2.5} \right] \div .064$$

$$Vc = \frac{(B\uparrow)}{2.5} \div .064 \qquad Vb = \frac{B\uparrow}{.064}$$

$$Vb = Va + Vc$$

where

Vb	=	the total volume of the ballast container
Va	=	the volume of the air/water chamber
Vc	=	the volume of concrete forming the container

$Vb = 16,375 \text{ ft.}^3$

$Va = 9,825 \text{ ft.}^3$

$Vc = 6,550 \text{ ft.}^3$

BALLAST SECTION

In our example, the perimeter of the ballast container where the radius equals 25 feet along its centerline is:

$$P = 2\pi r = 2\pi x\ 25 = 157 \text{ feet}$$

The length of the air/water chamber along its center line times its vertical cross secitonal area, Aa, equals the volume of the chamber. Thus,

$$Va = Aa\ La \qquad La = \frac{Va}{Aa} \qquad Aa = \frac{Va}{La}$$

Say the length of the air/water chamber, La, equals 104.66 ft., then the vertical cross sectional area of the chamber: $Aa = \frac{Va}{La}$

$$\underline{Aa = 94 \text{ ft.}^2}$$

The vertical cross sectional area of the concrete forming the container, Ac, is:

$$Ac = \frac{Aa}{2.5} = \underline{37.6 \text{ ft.}^2}$$

The total vertical cross sectional area of the ballast container, Ab, is

$Ab = Aa + Ac = \underline{131.6\ ft.^2}$

The ballast chamber, when full of water, compensates for the structure's bouyancy allowing it to submerge at will. Forcing the water out of the chambers with compressed air or pumps causes the structure to rise. Thus: $L_{BC} \downarrow = B \uparrow$

$L_{BC} \downarrow = 1{,}048 \text{ kips} \downarrow$

CONCRETE SHELL VOLUME

.9 times the volume of the water displaced by the shell divided by the ratio of water density to concrete density yields the volume of concrete in the shell required to achieve the desired 10% bouyancy

$$Vs = \frac{.9\ Vaim}{2.5}$$

$$Vs = \underline{55{,}433\ ft.^3}$$

CONCRETE SHELL WEIGHT

The weight of the concrete shell is .16 Vs

$Ls = .16\ Vs$

$\underline{Ls = 8869\ kips}$

Or $Ls = .9(.064\ Vaim) = \underline{8869\ kips}$

CONCRETE SHELL THICKNESS

The shell thickness is equivalent to the volume of concrete in the shell divided by the shell's center line surface area. An initial assumption is made for where the center line is. Initially, center line is assumed 2.15 ft. from shell exterior.

$$t = \frac{Vs}{SL} \qquad t = \frac{55433}{20262}$$

Vs = Volume of Shell
SL = Surface at Center Line

initial t = 2.74 ft.

Notice the discrepancy of center line location

Adjust the center line location as required recalculating the surface area about which a new t is distributed:
Try t = 2.5, the center line will be 1.25 ft. from the exterior shell surface. See appendix for tabulation of this re-evaluation.

$$t = \frac{Vs}{SN}$$

Use t = 2.76 ft.

The center line of the shell is located at distant .5t from the shell's exterior surface.

c.L. = .5t = 1.38 ft.

SHELL LOADS

The shell loads of each segment is found by multiplying the volume of concrete in the segment times the density of concrete.

$\underline{Ls = Vsdc}$

The volume of each segment is approximated by multiplying the shell thickness, t, times the segment area as has been tabulated in Appendix I.

$\underline{Vs = St}$

The shell load at any horizontal parallel is the sum of the structural loads above the parallel including the surface access part. The ballast chamber is also included as a downward structural load, the resultant of which acts upon the lowest point of the structure.

The sum of the downward vertical loads equals 10,480 kips.

$\underline{\Sigma V \downarrow - L \downarrow = 10,480 \text{ kips}}$

This downward load must equal the uplift of the structure to achieve equilibrium.

V, equals volume displaced

An, equals anchorage

L, equals the weight of concrete (load)

Since internal loads are negligible in magnitude compared to structural loads and hydrostatic pressure, it is neglected.

$Vdw = L + An$

Since AN equals zero, the sum of vertical forces

$\underline{\Sigma V = 10480-10480 = 0}$

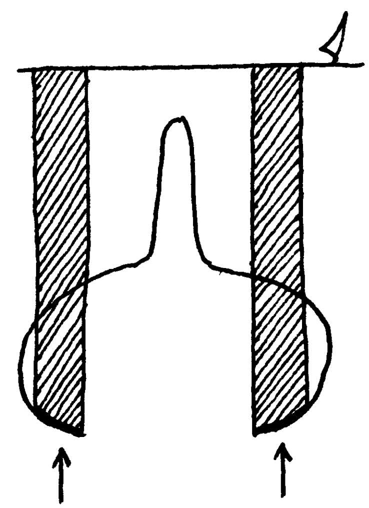
VERTICAL HYDROSTATIC LOADS

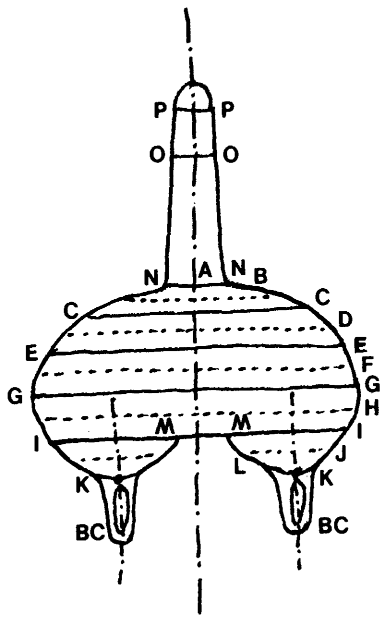
The vertical hydrostatic load acting on an inclined surface is the vertical component of the weight of water acting perpendicular to the surface times the water column above the surface. The volume of water upon a horizontal parallel is equivalent to the area within the perimeter of the parallel times the volume displaced by the structure.

Where Ad equals the volume of the water column upon a parallel, Vd is the volume displaced by the structure and LH is the hydrostatic load:

$$LH = dw\ (Ad - Vd)$$

In finding the hydrostatic load upon a segment bound by horizontal parallels A_1 and C for instance, the volume of water displaced by A_1C plus the water column above A, must be subtracted from the water column above C; the resulting volume times the water density equals the vertical hydrostatic load acting at C resulting from the pressure applied to the segment A_1C. This load plus the vertical hydrostatic loads acting on segments above segment A_1C is the total hydrostatic load acting at point C. Vertical hydrostatic loads also act upward on structures from underneath and are similarly equivalent to the water column above the area of interface. Upward hydrostatic forces are negative loads as they represent forces acting against gravity. The sum of upward hydrostatic forces beneath a horizontal parallel is the total vertical hydrostatic force acting upon it.





Q FORCES

The sum of vertical forces upon a horizontal parallel, Q, is the sum of vertical hydrostatic loads and structural loads acting upon it.

Parallel Segment	Vertical Q Kips
P	238
O	335
NAB	831
CD	7,648
E_F	28,709
G_H	136,890
I_J	44,794
K_L	23,682
M_K	5,119

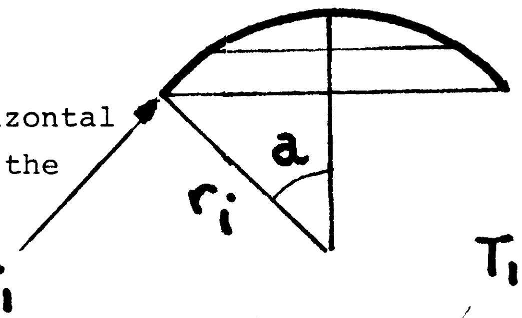
PP	=	Plexiglass Sphere
PO	=	Port
ON	=	Access Cone
G	=	Girdle
K	=	Keel
M	=	Middle Ring
BC	=	Ballast Container (Bouyancy Compensator)

EQUILIBRIUM OF VERTICAL FORCES

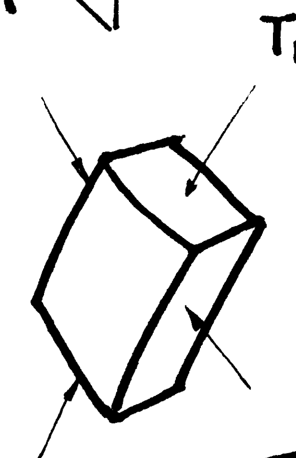
T_1 is the condition of equilibrium in the vertical direction of forces acting on a structure along any horizontal parallel and internal force (meridian).

$$T_1 = \frac{Q}{2\pi r_i \sin a}$$

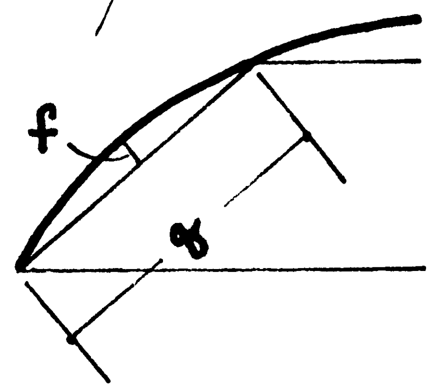
Where Q is the total vertical load above the horizontal parallel. It is composed of LH, and the dead load of the structural weight, Lc.



$$T_1 = \frac{Q}{2\pi r_i; \sin a}$$



UNITS	Q KIPS	Ri ft.	Sin a	T_1 kips
NAB	831	59.6	0.13	17.1
C_D	7,648	48.5	0.89	28.2
E_F	28,708	27.9	0.98	167.1
G_H	136,840	27.9	0.98	-796.9
I_J	44,794	48.5	0.89	165.9
K_L	23,682	48.5	0.89	- 87.4
M_K	5,199		--	--

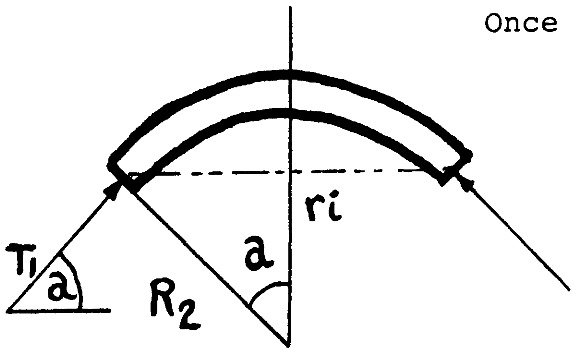


To find the radius, Ri of the meridian at the shell segment's neutral axis, where f equals sag and q equals chord length:

$$Ri = \frac{q^2}{8f}$$

RING FORCES

Ring forces, T_2, act perpendicularly to the meridian forces. Once T_1 is found, we use the formuli:



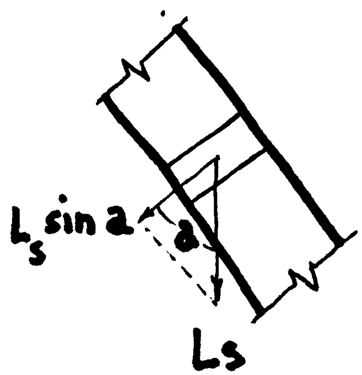
$$p^{\perp} = \frac{T1}{R1} + \frac{T2}{R2}$$

$$T^{i}_{2} = \left(Pi^{\perp} - \frac{T1}{R1}\right) R2$$

$$R_2 = \frac{ri}{\sin a}$$

Where P is pressure per square inch (or ksf = kips per square foot) applied perpendicular to the shell. Hydrostatic pressure always works this way and is simply depth times water density.

$$P^{\perp} = 0.64 \text{ (depth)}$$



The perpendicular component of the shell weight is the weight of the shell (per inch in Ksi or per foot in ksf) times the sine of angle a.

$$L_s{\perp} = L_s \sin a$$

L_s is the weight of the shell per square foot area along the neutral axis. With a shell of uniform thickness, it is the thickness timesthe density of concrete.

$$L_s = t\ d\ c$$

$$L_s = 0.16\ t$$

which is expressed in ksf or changed to ksi by dividing by 144.

L_s = .4416 kfs
L_s = 0.0003 ksi
L_s = 0.3 psi

TABULATION OF MERIDIAN AND RING FORCES

Tension reinforcement is required in half of segments of CE and GI to help resolve the tension forces acting at E_F and G_{FH} (negative values).

TABULATION OF MERIDIAN AND RING FORCES

	T_1 kips	T_2 kips
N=A	17.1	3.9
C_D	28.2	4.2
E_F	167.1	- 0.77
G_{FH}	796.9	-22.5
K_I	165.2	3.4
M_K	87.4	5.6

A safety factor of 3 acknowledges secondary loads such as hydrodynamic and imperfections due to labor or materials.

Using 3500 ksi concrete and the safety factor of 3, the concrete has an allowable compression strength of 1167 ksi.

$f_{all}c$ = 1167 ksi

AREA OF CONCRETE REQUIRED

The area of concrete required (A_c) to resist the vertical force (T_1) at a parallel is the vertical force divided by the allowable strength of concrete.

$$A_c = \frac{T1}{f_{all}c}$$

The required concrete areas for resisting parallel and meridian forces are located in Appendix I. The greatest stress at the girdle (G) requires 0.69 inches square per linear foot to resist the vertical forces. Steel is required to resist the horizontal forces.

AREA OF CONCRETE AVAILABLE

The area of concrete available to resist T_1 and T_2 is equal to one times the thickness (t).

A shell with thickness t is more than adequate to resist all the forces T_1,

Were the concrete in the shell not sufficient to resist the loads (as in T_2 at meridians E and G), steel reinforcement would make up the difference or the shell would merit redesign.

STEEL REINFORCEMENT

Steel which has a modulus of elasticity (E_{ST}) which is 8 times greater than that of concrete (E_c) means the steel is capable of resisting 8 times more load than concrete in order to deform the same amount. Therefore, where

C = compression

A_{ST} = Area of steel

$$C = (A_c + \frac{EST}{E_c} \times AST) \times f_{all}c$$

$$= (A_c = 8A_{ST})f_{all}c$$

By multiplying the steel area by 8, we find the equivalent amount of concrete to resist a force and inversely to find the area of steel to make up for a deficiency in the area of concrete, we can divide the deficiency by 1/8: where

A_c = concrete required area

$$A_v = \frac{(Ac-Av)}{8}$$

TENSION REINFORCEMENT

Ring forces (T_2) which travel along the extreme parallels (E and G) require tensile reinforcement of steel to achieve horizontal reinforcement of steel to achieve horizontal equilibrium. The area of steel required can be found directly by dividing the ring force by the allowable tension in the steel which is the yield strength divided by a safety factor of 3. If using 29,000 ksi steel:

$$f_{all}ST = \frac{29000}{3} = 9667 \text{ kips}$$

$$A_{ST} = \frac{T2}{f_{all}st}$$

In the case of structure 'E', tensile reinforcement can be achieved with temperature reinforcement.

TEMPERATURE REINFORCEMENT

To resist expansions and contradictions in the concrete due to thermal stresses, 2% of the concrete area should be constituted by steel bar reinforcement.

$$A_{ST} = 0.02\ A_c = 2\%\ A_c$$

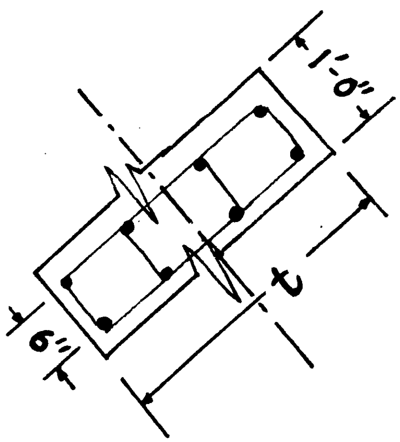
As previously described:

$$C = (A_c + 8\ A_{ST}) f_{all} c$$
$$C = (A_c + 8 \times 0.02\ A_c) f_{all} c$$
$$= A_c (1 + 0.16) f_{all} c$$
$$= A_c (1.16) f_{all} c$$

To find the temperature reinforcement requried

$$A^T_{ST} = 0.02\ A_c$$

$$A^T_{ST} = 8\ \text{in.}^2$$



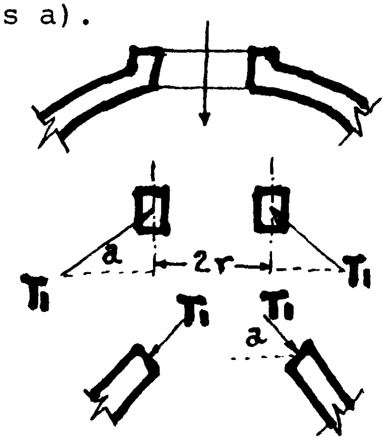
where $A_c = lxt = 2.76\ \text{ft.}^2$
$= 397.44\ \text{in.}^2$

Use 8 number 9 bars with a cross section area of one inch each distributed horizontally throughout the mass of concrete on 6 inch centers as shown:

use 8 ϕ 9 - 6" O.C.

COMPRESSION IN RING

The edges of a shell around an opening must resist the horizontal component of the meridian forces (T_1). The reinforcing ring which articulates such an opening having a radius, r, at its central axis, must resist a compressing force equivalent to T_1 times the cosine of angle (cos a).



Where C_R = compression in ring

$C_R = t_1 \cdot \cos a \cdot r$

C_R = 68 kips

AREA OF CONCRETE IN RING

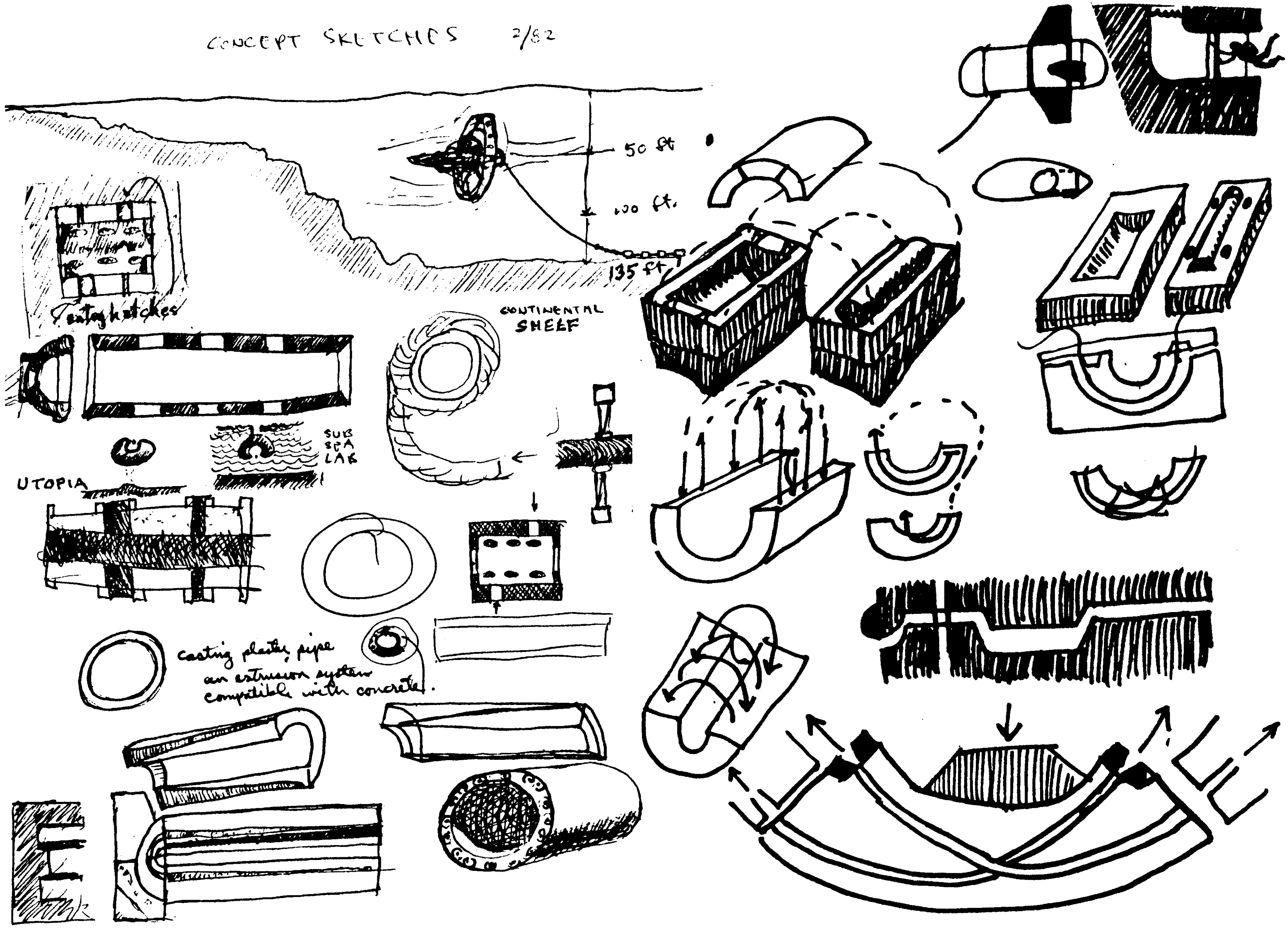
Since $C = A_c(1.16)f_{all}c$

$$A_c = \frac{C}{(1.16)f_{all}c}$$

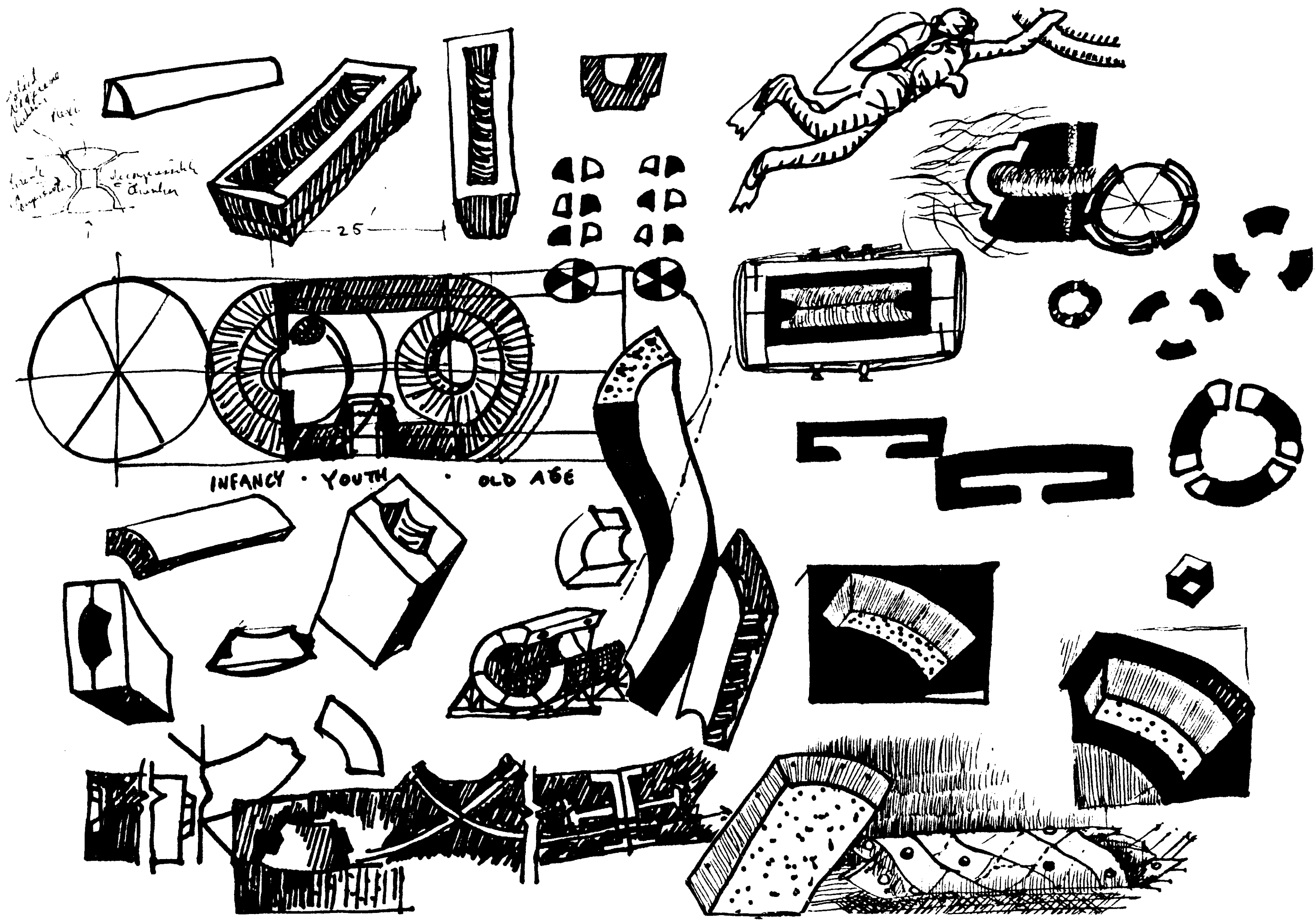
A_c = 0.006 in.^{2}

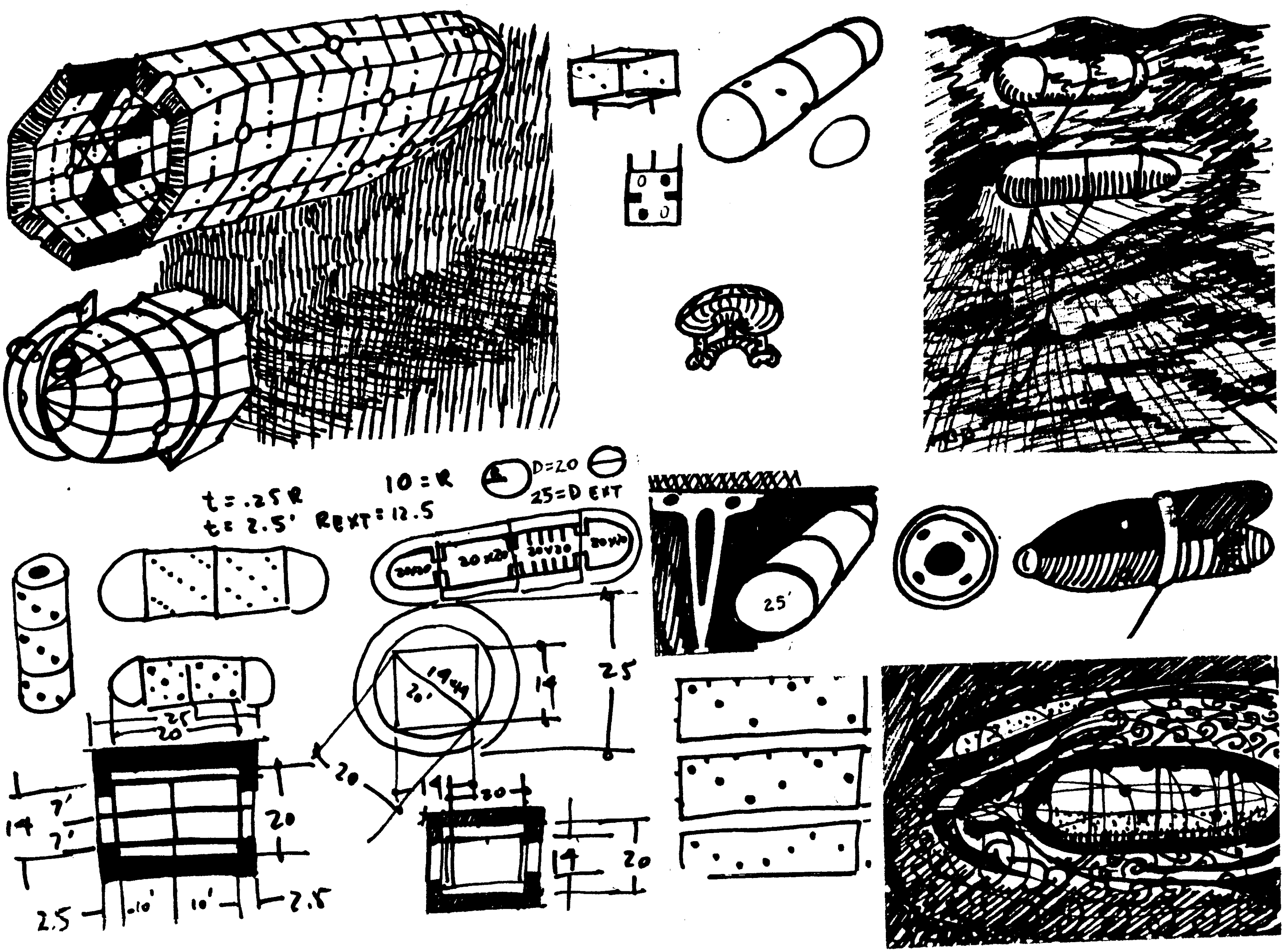
Since the concrete required in the ring is minimal, simply distribute it around the opening of the concrete displaced by it. The forces resulting from the presence of the access cone acting horizontally on the shell (T_1) are equilibrated by the reaction in the shell (T_1).

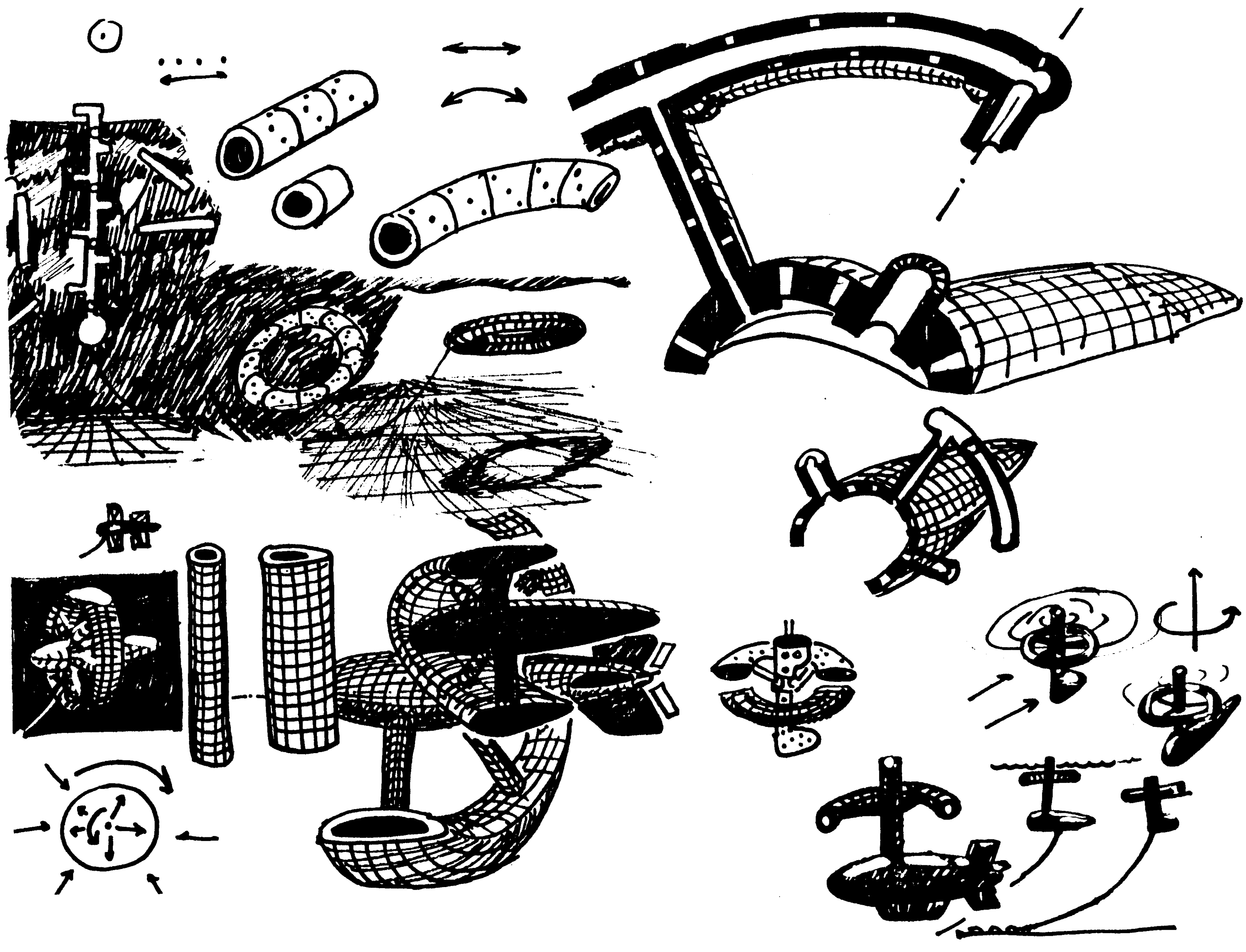
MORPHOLOGY

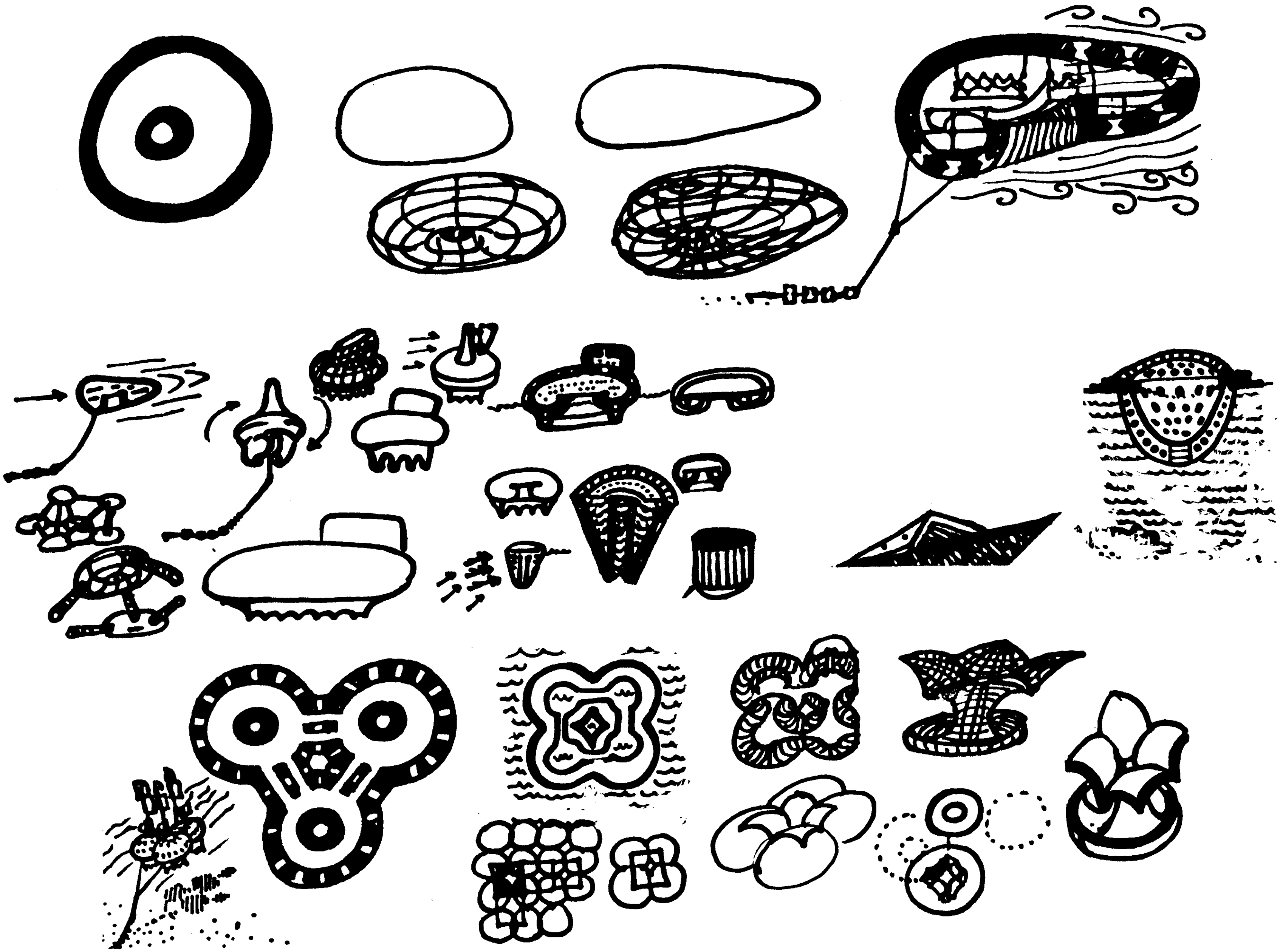


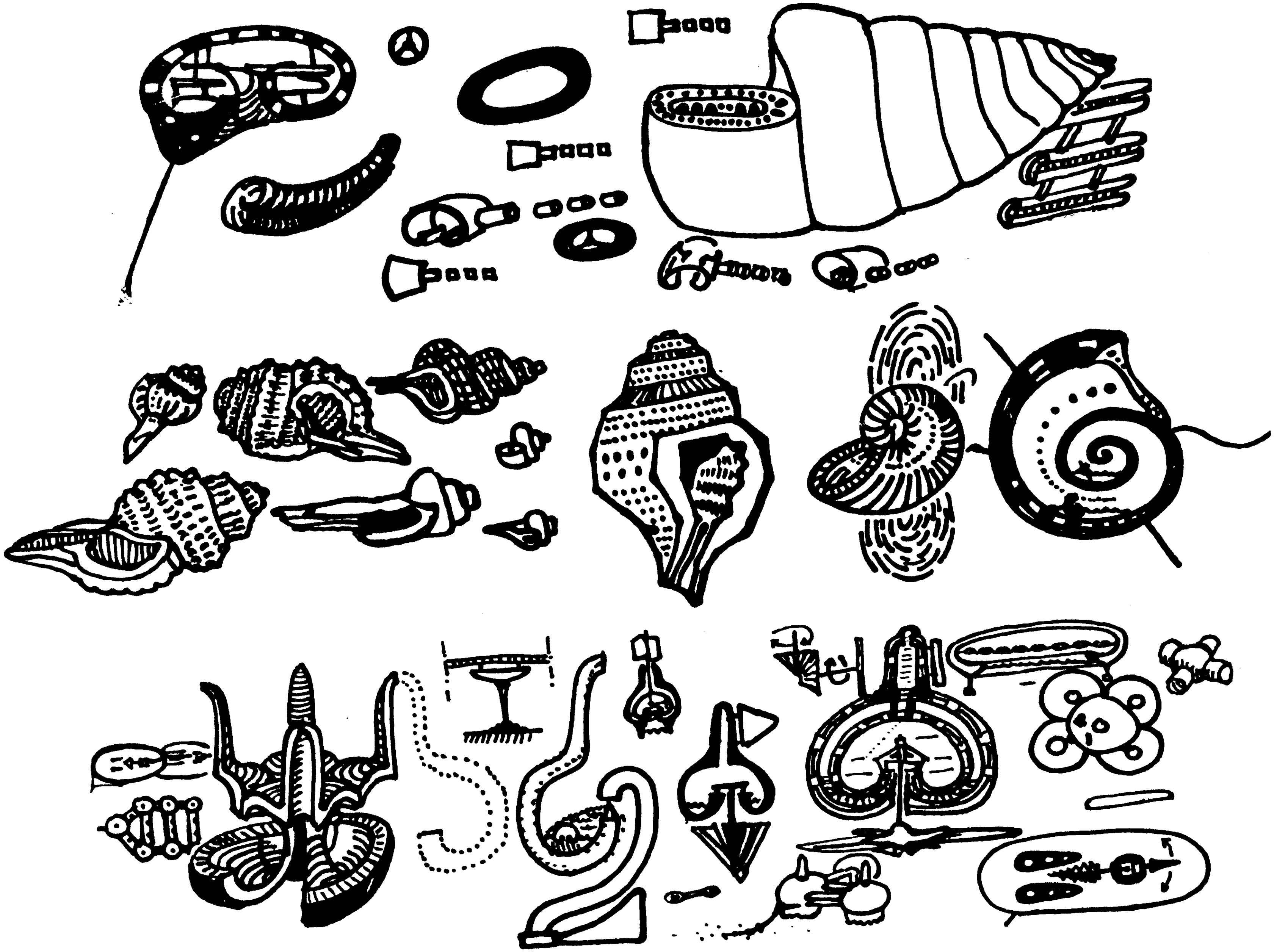
CONCEPT SKETCHES 2/82
50 ft
100 ft.
135 ft
CONTINENTAL SHELF
SUB SEA LAB
UTOPIA
casting plastic pipe
an extrusion system
compatible with concrete.

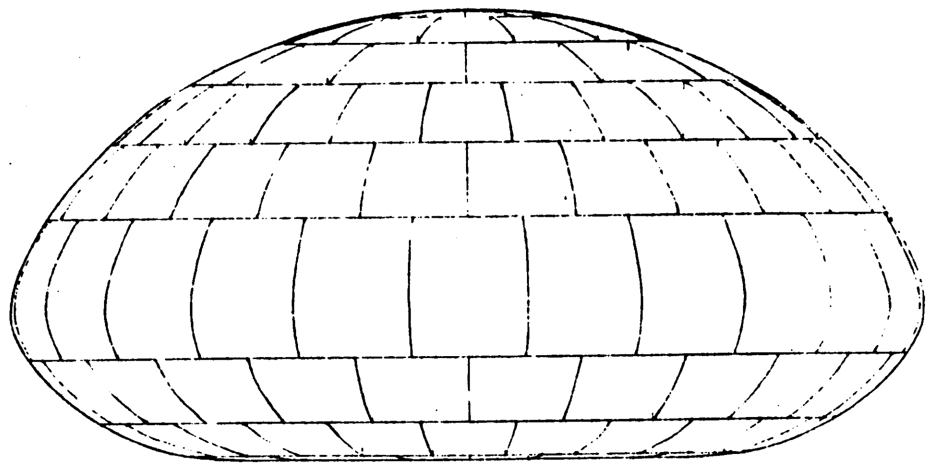

25
INFANCY · YOUTH · OLD AGE

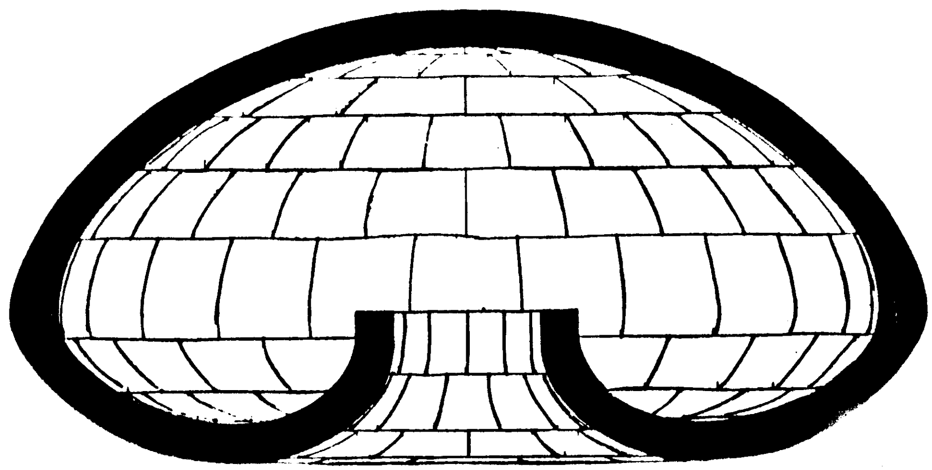

t=.25R
t=2.5' REXT=12.5
10=R
D=20
25=D EXT
20x20
25'
25
20
14
7'
7'
2.5
10'
10'
2.5
20'
19.44
30











This project proposes a structural solution for supporting researchers of ocean related arts and sciences to further advance sea culture and technology.

The project's intent is to further our understanding of environmental and design constraints and potentials of an ecological sea untilization framework.

DESIGN CONCEPT

The dome is the funicular structure for resisting the external environmental forces of the sea as it readily dissipates hydrostatic pressure due to its double curvature. The horizontal attenuation into a circloidal or ovaloidal form responds to the sea's vertically graduated pressures reflected in the structure's increasing curvature relative to depth. Such forms also minimize resistance from internal ocean waves and currents. Vertical appendages articulate the transition which makes interchange possible with the surface and submarine environments.

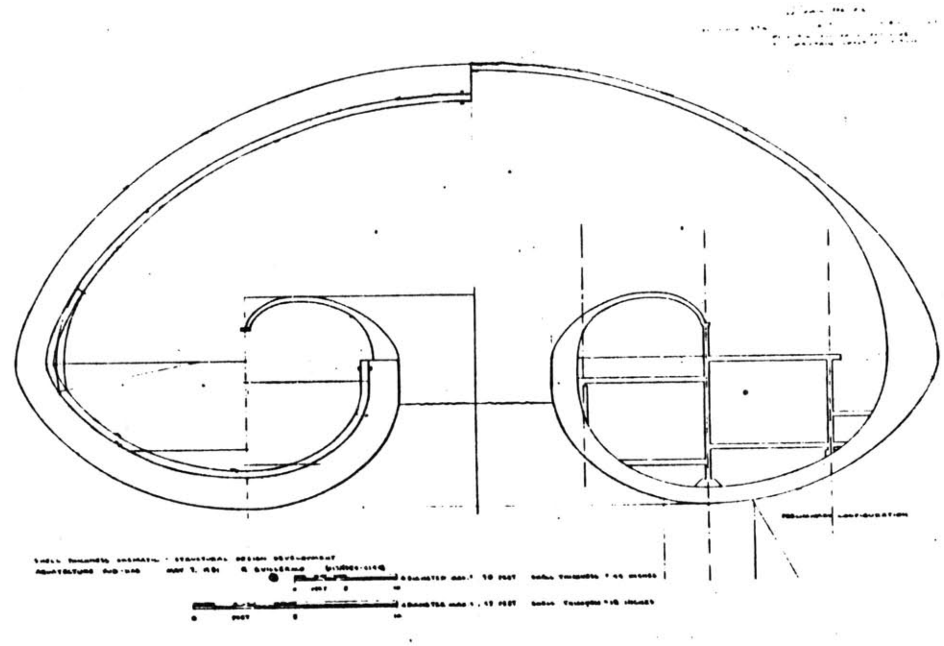
DESIGN DECISIONS

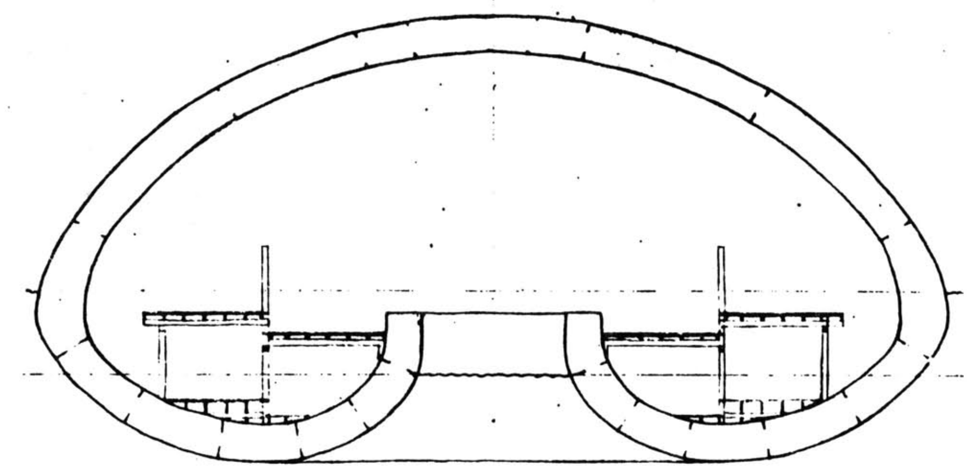
The Balaesbus design began in 1979 with the analysis of an idealized spherical structure having minimal surface and maximum structural resistance. The original concept was of a diving bell with a single access point centered at the bottom. A hypothetical radius of 45 feet appeared to provide ample work and dwelling space for a minimum of twelve inhabitants without the claustrophobic disadvantage of conventional sea habitats.

The structure's vertical axis was reduced for three reasons: first, while the dome provides a perceptually expansive environment, the upper hemisphere enclosed an excessive atmospheric volume; second, a squat ellipsoidal form could provide the required platform area and expansiveness while reducing the surface area resisting horizontal dynamic loads due to currents; third, the ellipsoidal form has affinity with the form of an ascending gas bubble which deforms as it encounters vertical resistance in a liquid medium. As mentioned in the design concept, such a form morphologically corresponds to the environmental forces being exerted upon it. Thus, the vertical axis was reduced.

STRUCTURAL DESIGN DEVELOPMENT

Originally, a tensile membrane was conceived to resist the tension forces acting upward on a structure with solely a bottom entry. Such a lightweight structure would require an inordinate quantity of dead ballast or mooring anchorage weight to compensate for the upward force of the bouyant internal atmosphere.





A self ballasting structural shell with 10% bouyancy thus replaced the membrane roof option. The structure and its contents would weigh 90% of the weight of the water displaced by its submerged volume. With a displacement of 190,000 cubic feet or 12,160,000 pounds of sea water, a 10% bouyancy would equal 1,216,000 pounds as the shell and its contents would weigh 10,944,000 pounds. This would be achieved with a shell thickness of 44 inches. This dimension also corresponds to the maximum pressure differential acting upward at the apex of the dome at the maximum design depth of 99 feet.

A shell of such thickness is comparable to wartime designs of bouyant reinforced concrete structures such as the World War II Mulberry Harbor Project in which an artificial harbor was formed of reinforced concrete vessels and pontoon bridges. In peacetime use as well, box pontoons measuring 350 feet by 60 feet and 14.5 feet deep weighing 8,116,000 pounds serve as supports for two bridges on Lake Washington in Seattle, Washington as well as on the Hood Canal near Seattle on the Olympic Peninsula. Precast of concrete and towed to their site, these pontoons display the feasibility of this technology.

DESIGN DECISIONS CONTINUED

The actual curvature is derived from the overall concept of the circle, symbolic of unity and the cyclical processes of nature. Formally, the project responds to the architectonic challenge of designing within a circular format. Further study has revealed the necessity of transitory amendments to the primary concept form designated as the external support shell.

DESIGN COMPONENTS

The Balaebus Sub-Sea Laboratory is composed of five distinct design components: the shell, the surface access port, the stabilizing apron, the internal support structure and the life support systems.

The shell encloses the habitat environment protecting the indwellers. Hydrostatically designed, it is equipped with decompression chambers for equalizing pneumatic pressure upon entry and exit.

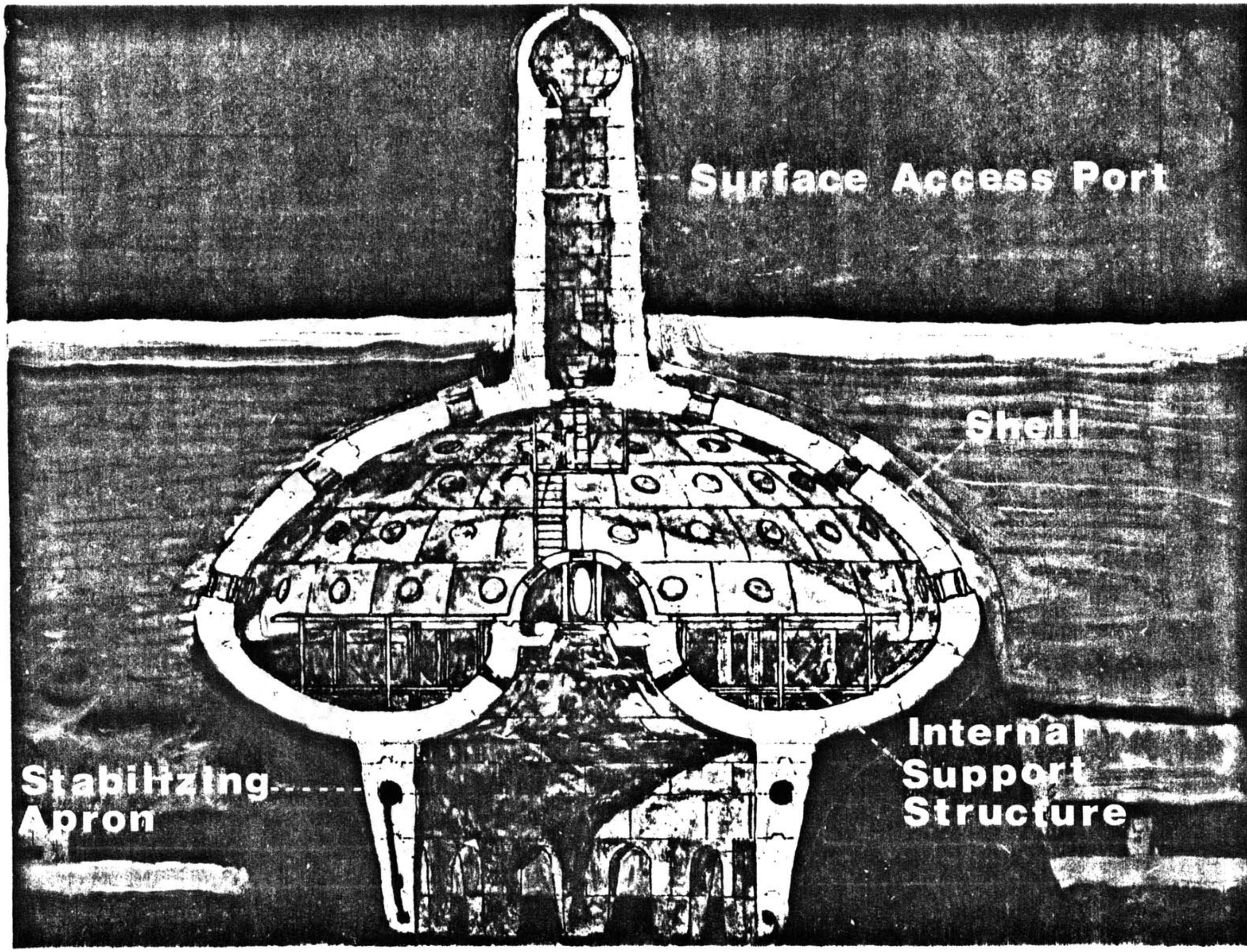
The surface access port serves as snorkel, surface craft mooring, communication tower and entry tower.

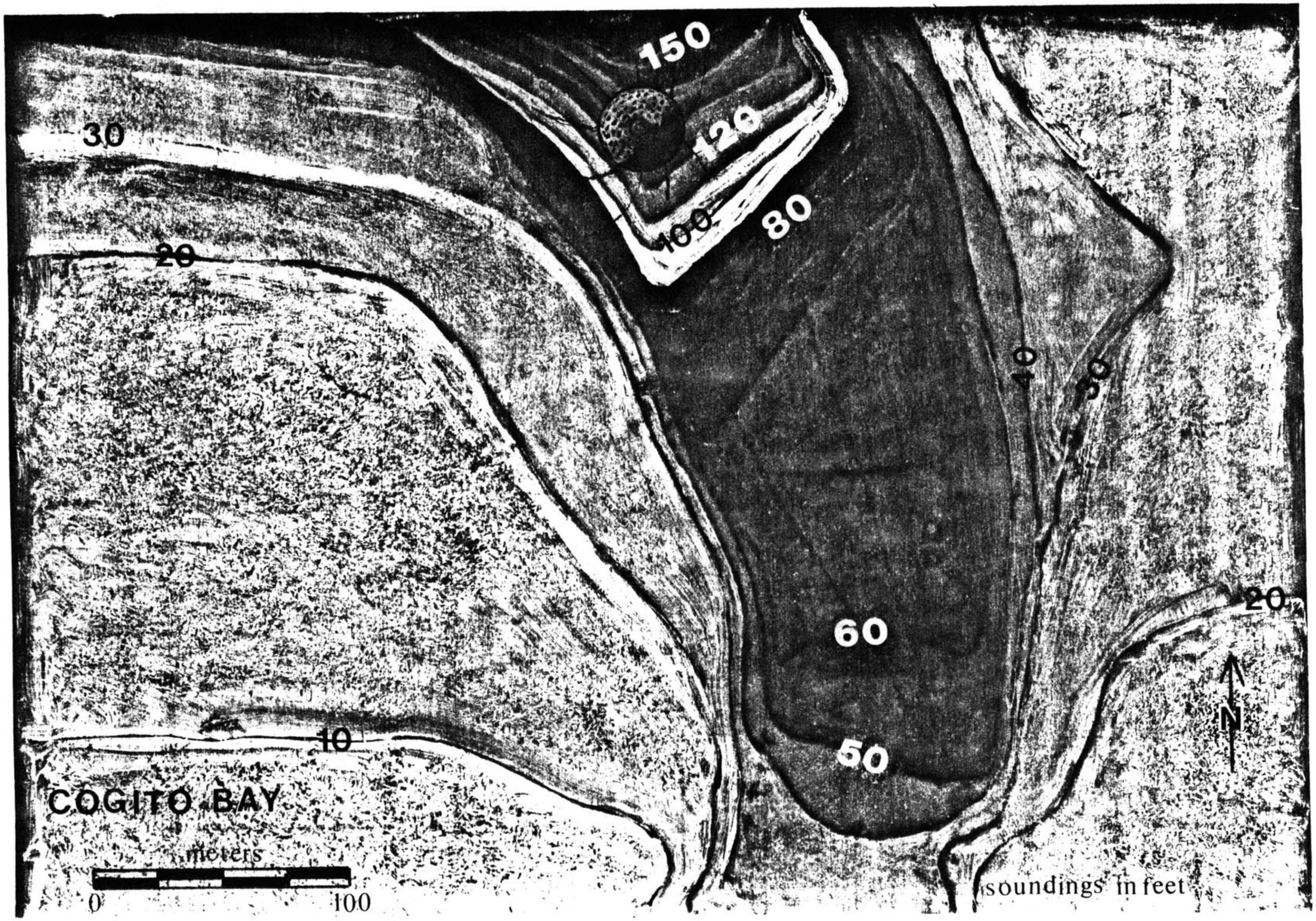
The stabilizing apron serves as ballast, bouyancy compensator, submerged access port, energy unit bearing and, in shallow water, can function as variable bearing footings for level settlement on the sea shelf.

The internal support structure is borne by the shell and in turn bears the habitable platforms of the dwelling. It may be suspended from the dome or bear upon the shell's hull. Laboratory supports, individual and community resources and amenities are included.

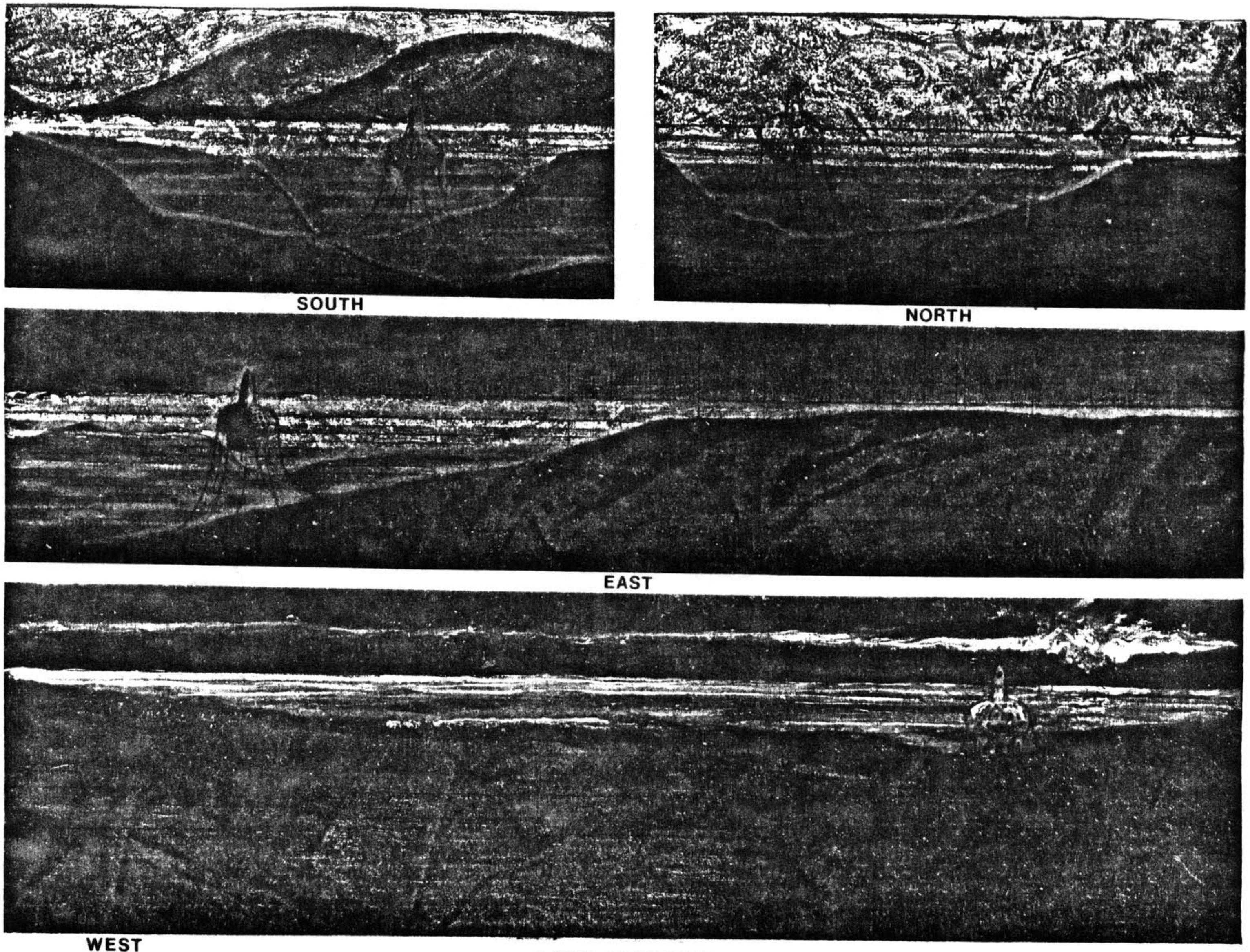
DESIGN COMPONENTS CONTINUED

The life support systems include all pneumatic and hydraulic equipment, energy grid, communications network, computer monitoring and controls for analysis, switching and valving to maintain levels of comfort and promote smooth functioning of all systems within the habitat.

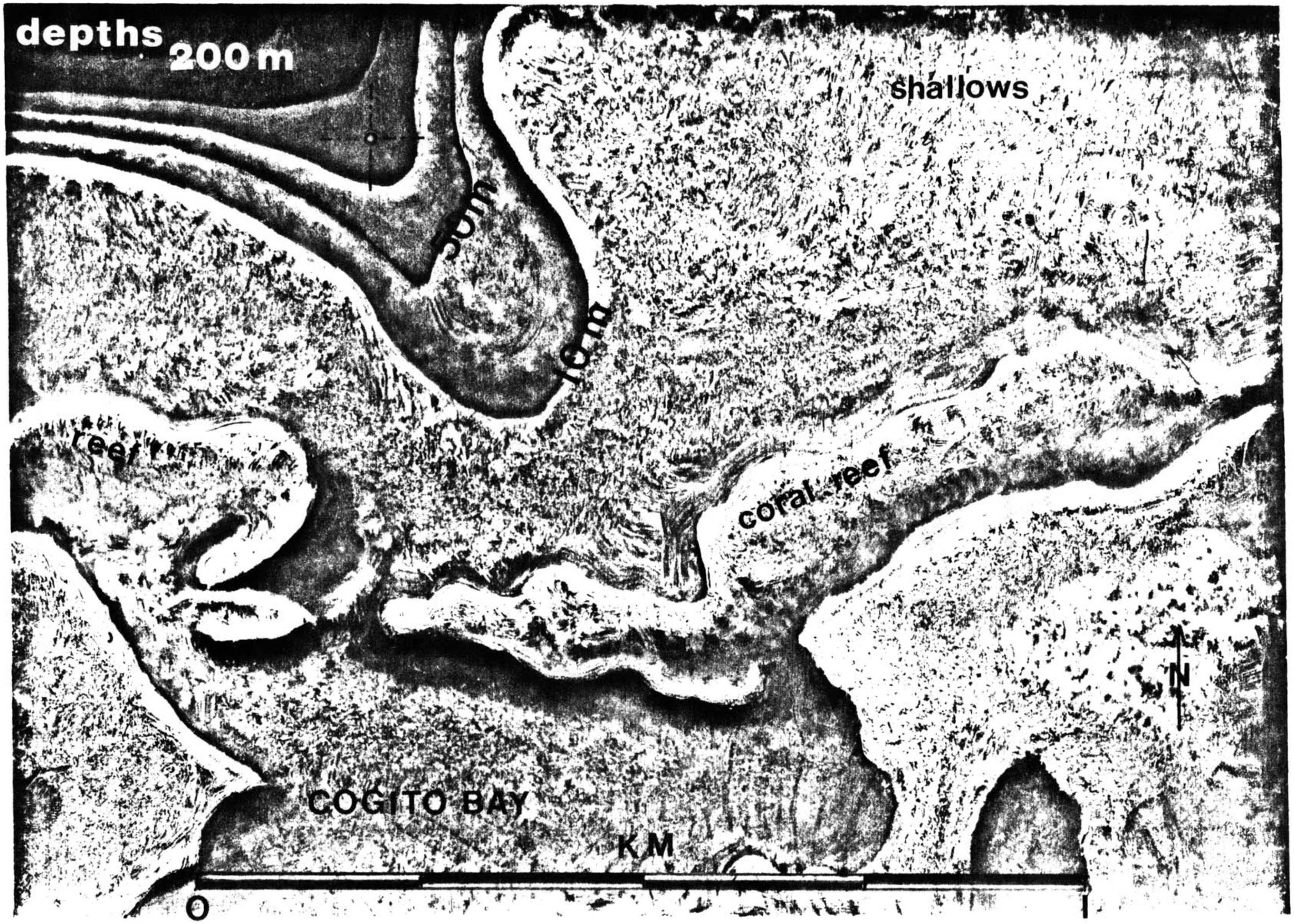

Surface Access Port
Shell
Internal Support Structure
Stabilitzing Apron


150
120
100
80
30
20
40
30
20
60
50
10
COGITO BAY
meters
0
100
soundings in feet
N

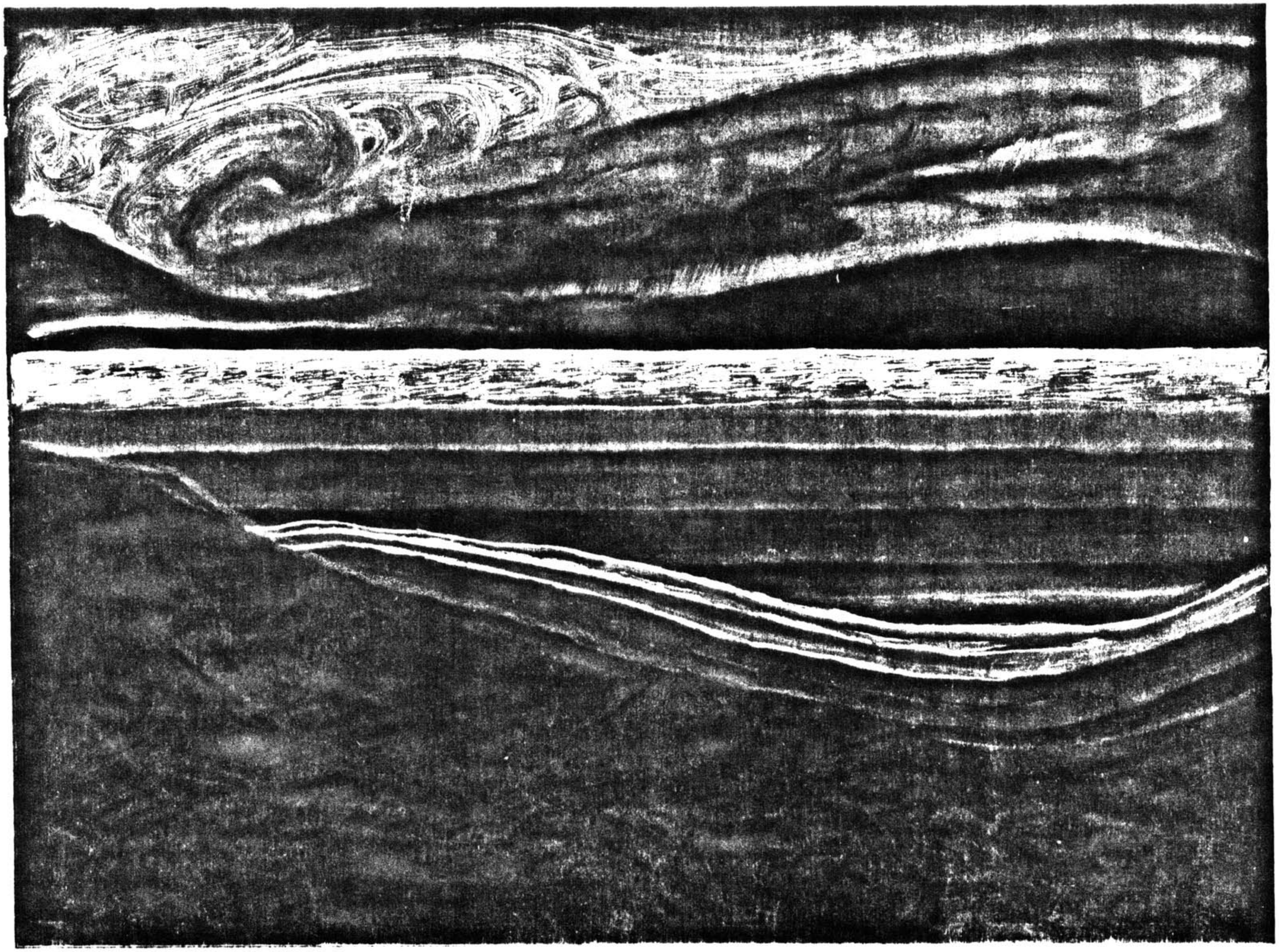
SITE PLAN



SITE SECTIONS


depths
200m
30m
10m
shallows
reef
coral reef
N
COGITO BAY
KM
0
1

SITE PLAN



SITE SECTION

THE DESIGN PROCESS

My intent has been to examine the heuristic design process, the forces underlying it. To meet this end, the process of design itself was engendered and forms both object and subject of this work. The topic I have chosen is in keeping with the nature of the work. The process of design occurs within the drawing out from the inner self, which we might call the psyche's struggle to manifest the etheric bond of nature through the forms of constructions and cultivations. This process occurs only through dwelling.

By examining the notion of habitat, i.e., a housing for a controlled physical environment in which people can live under surrounding inhospitable conditions, such as underwater, it has become possible to separate and objectify the form and meaning of dwelling in order to recreate it and in this activity, come to know the design process through a discrete set of thoughts and actions.

Beneath the physical surface of design are the conceptual underpinnings. The concepts from which designs arise are founded in ideology. Ideology gives substance to design, forms the basis by which it comes about and is concealed or enshrouded within the subsequent design. A hidden meaning lost in the object or evident in the archetype.

Archetypes go beyond revealing the conceptual underpinnings and ideological foundations of design. They reveal the common bond of the etheric realm which binds mankind in our universe. Through natural physical laws, which can manifest themselves through the systems of numbers and mathematics, the etheric forms reveal their patterns through our sensitive sciences and primitive dreams alike. The dreams of flight are common to all cultures. This dream of levitation incites the spiritual realm with the activation of the psychic ascent, the elevation, ostensibly, of consciousness.

All which unfolds before and about us closes behind us and contains us. We are skeins of bundled nerve fiber, electrical energy, tissue, blood and bone, we circulate and inspire.

What we perceive through our presensing, is that which our sensors can gather and is retained through the network of our brains which rejects that which we cannot classify and commit to memory. Our minds act as great sieves which gather.

This analog of the brain as a sieve, is a metaphor for knowledge. I prefer the analog of the fishnet. How the net's edges are bound is unclear, but its pattern is evident in its tissue and it is extendable at its perimeter. Some areas of the nets are unfathomable to some and others have been rent by scientific dispute. Yesterday's conceptual universe is no longer valid. Increased awareness in the technological age negates our former ideologies. Culture is losing ground to automatism.

RECAPITULATION

In this work I have sought to decipher a recurring pattern in design and nature, to typify and isolate a pattern which existed prior to the work and which the work enacts to give form. Ultimately, concepts, ideology and etheric bonds must be brought forth. It is this bringing forth which is at issue here. More than a making, here is a letting something appear. We arrived at the definition of technology in the Greek sense of not the knowing, but the mode of knowing. That is, the way of seeing, not the seeing; the way of making, not the making; the mode of production, not the production. Such a bringing forth of knowledge is a disclosure or bringing out into the unconcealedness of being which is the nature of technology, the meaning of thesis and the method and content of architecture.

PURPOSE

The purpose of this thesis is to educate, and possibly, inspire others to follow the heuristic design method of self-education. Here is a model of the design process, bearing with it some of the fundamental knowledge needed for creating a conceptual network to be cast into the sea of knowledge. I have tried to bind our current knowledge of the pattern of structuring dwellings in sea habitats. With this knowledge it is possible to project further into civilization's potential of cultural development within the limited context of the sea as a dwelling place. This network may form a new horizon for our species' collective evolution on this rare planet.

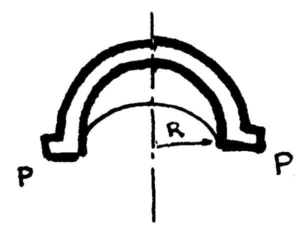
CASE I ANALYSIS

Complete submergence with one atmosphere internal pressure. Design depth is 100 feet seawater measured at points G = M. The upper and lower ports are closed.

DISPLACEMENT: $V = 164{,}205\ \text{ft.}^3$

WATER DISPLACEMENT VOLUMES: ACCESS

SEGMENT

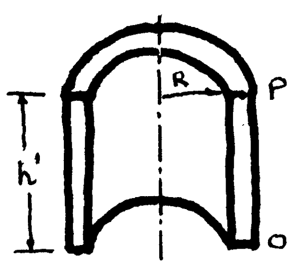


PP PLEXIGLASS HEMISPHERE

$V_{pp} = 2/3\ \pi R^3$ $R = 7.5$ ft.

$V_{pp} = 884\ \text{ft.}^3$

(L_p = 52 kips)



PO CYLINDRIC COLLAR PORT

$V_{po} = h^1 \pi r^2$ $h^1 = 8.33$ $R = 8$ ft.

$V_{po} = 1675\ \text{ft.}^3$

(L_c = 97 kips)

ON SURFACE ACCESS CONE

$V_{on} = 1/3h\ (B + b + \sqrt{Bb})$

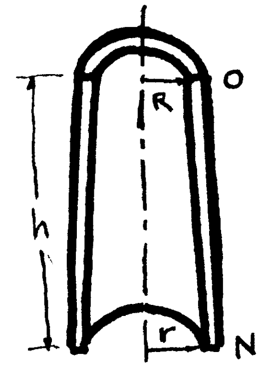
$B = \pi R^2$ = Area of Top

$b = \pi r^2$ = Area of Base

$V_{on} = 7203\ ft.^3$ h = 33 ft. R = 8 ft. r = 8.66 ft.

$B = 201.\ ft^2$ $b = 235\ ft.^2$

(Lc = 414)



ACCESS = $_{PN} = 9762\ ft.^3$

$V_{CA} = 3514$

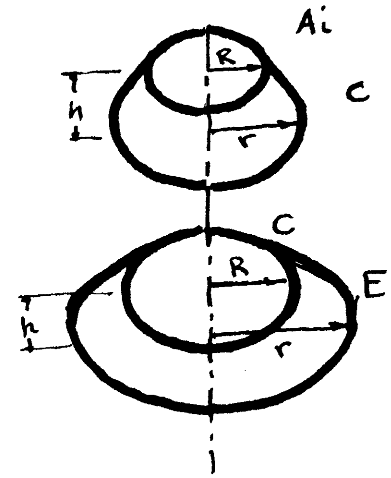
$L_{ACCESS} = 563$

WATER DISPLACEMENT VOLUMES: SHELL

<u>SEGMENT</u>

ASSUMED CONE FRUSTRUMS

$V = 1/3\ h\ (B + b + \sqrt{Bb})$ $B = \pi R^2$ $b = \pi r^2$



AC h = 5 ft. R = 8.66 ft. r = 25 ft.

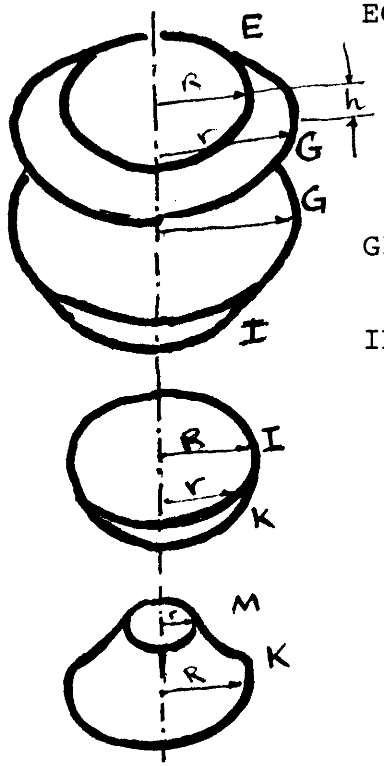
$B = 235\ ft.^2$ $b = 1964\ ft.^2$

$VA_1C = 3745\ ft.^3$

CE h = 9.1 ft. R = 23 ft. r = 43.25 ft.

$B = 1662\ ft.^2$ $b = 5877\ ft.^2$

$V_{CE} = 32348\ ft.^3$



EG

$h = 12.5$ ft. $R = 43.25$ ft. $r = 50$ ft.

$B = 1662$ ft.^{2} $b = 7854$ ft.^{2}

$V_{EG} = 54,704$ ft.^{3}

GI

$V_{GI} = V_{EG} = 54,704$ ft.^{3}

IKM

$h = 9.1$ ft. $R = 43.25$ ft. $r = 25$ ft.

$B = 1662$ ft.^{2} $b = 1964$ ft.^{2}

$V_{IK} = 16,479$ ft.^{3}

$h = 9.1$ ft. $R = 25$ ft. $r = 6.75$ ft.

$B = 1964$ ft.^{2} $b = 143$ ft.^{2}

$V_{KM} = 7,999$ ft.^{3}

$V_{IKM} = [V_{IK} - K_{KM}] = 8480$ ft.^{3}

SHELL

$A_1M = 153,981$ ft.^{3}

$V = V_{PN} = 163,743$ ft.^{3}

SHELL $\sum VA_i M = 153,981 \text{ ft.}^3$

$$V = \sum V_{PN} + \sum VA_i N = 163,743 \text{ ft.}^3$$

UPLIFT: $U\uparrow = V_{dw} = 163,743 \times 0.064 = 10480 \text{ kips}\uparrow$

LOAD: $L_c\downarrow = .9U\uparrow = .9(10480) = 9432 \text{ kips}$

BOUYANCY: $B\uparrow = V_b dw = U\uparrow - L_c\downarrow$

$B\uparrow = 10480-9432$

$B\uparrow = 1048 \text{ kips}\uparrow$

BALLAST

DESIGN: $V_b = \frac{B\uparrow}{dw} = \frac{1048}{.064}$

$V_b = 16375 \text{ ft.}^3$

$$V_a = \frac{(B\uparrow) - \left(\frac{B\uparrow}{2.5}\right)}{.064} = \frac{1048 - \left(\frac{1048}{2.5}\right)}{.064}$$

$$V_a = \frac{1048 - (419.2)}{.064}$$

$V_a = 9825 \text{ ft.}^3$

$$V_c = \left(\frac{B\uparrow}{dw}\right) - dw = \left(\frac{1048}{2.5}\right) - .064$$

$V_c = 6550 \text{ ft.}^3$

$$V_s = \frac{.9VAiM}{2.5}$$

$$V_s = \frac{.9\ (153,981)}{2.5}$$

$$\underline{Vs = 55433\ ft.^3}$$

$$L_s = .16\ V_s$$

$$\underline{Ls = 8869\ kips}.$$

BALLAST

SECTION: If $L_a = 104.66$ ft.

$$A_a = \frac{Va}{La} = \frac{9825}{104.66} = 93.88$$

$$A_a = 94\ ft.$$

SYMBOLS USED

h	=	slant height, ft.
h^1	=	vertical height, ft.
r_1, r_2	=	radius, ft.
p_1, p_2	=	perimeter, ft.
S	=	surface area, $ft.^2$
V	=	volume, Sxt, $ft.^3$
t	=	thickness
L	=	load, kips, 1000 lbs.
lbs.	=	pounds
ft.	=	feet
L_s	=	weight of concrete shell
d_c	=	density of concrete
d_w	=	density of water
VaiM	=	displacement of shell
V_s	=	volume of concrete in shell
b, B	=	cone areas

STRUCTURAL LOADS L FROM

SHELL SURFACE RE-EVALUATION: SN where t = 2.5 ft.

SEG.	h ft.	r_1 ft.	r_2 ft.	P_1 ft.	P_2 ft.	S $ft.^2$	V $ft.^3$	L kips	L kips	
AC	22.75	3	25.5	18.8	160.2	203.6	5619	899	1462	+563 ACCESS LOAD
CE	20.3	25.5	43.5	160.2	273.3	4378	12083	1933	3395	
EG	13.5	43.5	100	273.3	268.3	3656	10091	1615	5010	
GI	13.5	100	43.5	268.3	273.3	3656	10091	1615	6625	
IK	20.3	43.5	25	273.3	157	4368	12056	1929	*	10480
KM	19.5	25	7.5	157	47	1989	5490	878	878	
SN						20083		L=8869		

SHELL THICKNESS

$t = \frac{VS}{SN} = \frac{55463}{20083}$

$t = 2.76$ ft.

SHELL WEIGHT (LOAD)

$L_s = Stdc$

$L_s = 2036 \times 2.75 \times .16 =$

$L_s = 899$ kips

STRUCTURAL LOAD ON KEEL *

$\downarrow L_{PB} = 6625$

$\downarrow L_{KM} = 818$

$\downarrow L_{Ic}{}^2 = 1048$

$\downarrow L_{IK}{}^2 = \underline{1929}$

10480 kips

$\Sigma V = L \downarrow - U \uparrow = 0$

$\Sigma V = 10480-10480$

FINDING Q FORCES

PARALLEL SEGMENT	LH KIPS	L_C KIPS	SEGMENT	PARALLEL SEGMENT	VERTICAL Q KIPS
P	181 ↓	57 ↓	PP	P	238
O	181 ↓	154 ↓	PO	O	335
$N=A_1$	268 ↓	563 ↓	ON	N_{AB}	831
C	6,156 ↓	1,492 ↓	AC	C_D	7,648
E	25,313 ↓	3,395 ↓	CE	E_F	28,708
G	56,784 ↓	5,010 ↓	EG	G_H	136,890
IG	- 75,096 ↑	--	--	--	--
KI	- 38,169 ↑	6,625 ↓	GI	I_J	44,794
MK	- 13,202 ↑	10,480 ↓	IK	K_L	23,682
MM	- 4,241 ↑	878 ↓	KM	M_K	5,119

EQUILIBRIUM OF VERTICAL FORCES

VERTICAL HYDROSTATIC LOADS

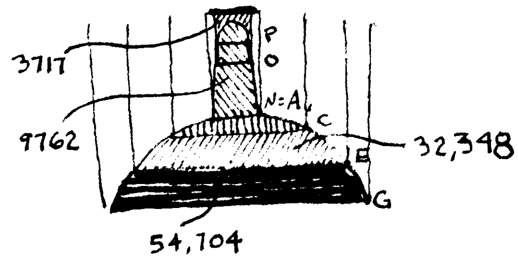
	UNITS	DEPTH FT.	ΣV DISPLACED FT.^{3}	r FT.	A FT.^{2}	WATER COLUMN FT.^{3}	WATER COLUMN MINUS V DISPLACED FT.^{3}	HYDROSTATIC LOAD L_H KIPS	ΣL_H KIPS
P	P	21	884	7.5	177	3,717	2,833	181 ↓	181 ↓ P
A	O	30	2,559	8	201	6,030	--	0	181 ↓ O
R	$N=A_i$	63	13,479	8.66	236	14,843	1,364	87 ↓	268 ↓ $N=A_1$
A	C	66	17,686	23	1,662	109,692	92,006	5,888 ↓	6,156 ↓ C
L	E	75.1	142,040	43.25	5,877	441,363	299,323	19,157 ↓	25,313 ↓ E
L	G	87.66	196,744	50	7,854	688,482	491,738	31,471 ↓	56,784 G
E	IG	100	166,200	50	--	$V_A + V_B$	576,986	36,927 ↑	75,096 ↑ IG
L	KI	109.1	214,076	25	--	$V_A + V_B$	390,103	24,967 ↑	38,169 ↑ KI
S	MK	109.1	7,999	25	1,964	214,272.4	206,273	13,202 ↑	13,202 ↑ MK
	M	100	0						M

LH

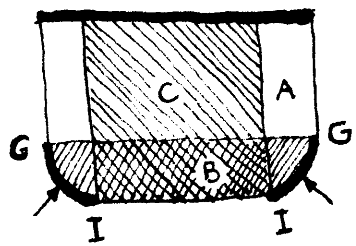
$-$ LH

$-$ 19000 kips ↑

LH = .064 (Water column - V displaced)



EXAMPLE CALCULATIONS OF VERTICAL FORCES



$V_{IG} = V_A + V_B - V_C$

$r_A = 50$ ft.

$A_A = 7854$ ft.^{2}

$V_A = A_A \times 87.66$

$V_A = 688{,}482$ ft.^{3}

$V_B = 54{,}704$ ft.^{3}

$r_C = 43.25$

$A_C = 1662$ ft.^{2}

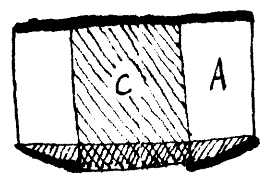
$V_C = A_C \times 100$

$V_C = 166{,}200$ ft.^{3}

$V_{IG} = (V_A + V_B) - V_C$

$V_{IG} = (743{,}186) - 166{,}200$

$V_{IG} = 576{,}986$



$V_{IK} = V_A + V_B - V_C$

$r_A = 43.25$ ft.

$A_A = 5877$ ft.^{2}

$V_A = 5877 \times 100 = 587{,}700$ ft.^{3}

$V_B = V_{IK} = 16{,}479$ ft.^{3}

$r_C = 25$ ft.

$A_C = 1964$ ft.^{2}

$V_C = A_C \times 109 = 214{,}076$ ft.^{2}

$V_{IK} = V_A + V_B - V_C$

$V_{IK} = (604{,}179) - 214{,}076$

$V_{IK} = 390{,}103$ ft.^{3}

FINDING r_1

q= chord length

f= sag

$$r_i = \frac{q^2}{8f}$$

SEGMENT	POINT	q FT.	f FT.	r_{i1} FT.	a DEGREES	SIN a
NA	B	24.9	1.3	59.6	7.6	.13
C	D	19.7	1.0	48.5	63.3	.89
E	F	13.2	.78	27.9	78.3	.98
G	H			27.9	78.3	.98
K	J			48.5	63.3	.89
M	L			48.5	63.3	.89

FINDING R_2

$$R_2 = \frac{ri}{\sin a}$$

	r_1	Sin a	R_2
N=A	59.6	.13	7.8
C	48.5	.89	43.2
E	27.9	.98	27.4
G	27.9	.98	27.4
I	48.5	.89	43.2
K	48.5	.89	43.2

FINDING T_2i

$T_2 = \frac{Pi^{\perp} - T_1}{R_1}$

	$P^{\perp}$ ksf	T_1 kips	R_1 ft.	T_2 kips	
N=A	4.2	17.1	59.6	3.9	
C	4.7	28.2	48.5	4.2	
E	5.23	167.1	27.9	- 0.77	TENSION REIN-
G	6.13	796.9	27.9	- 22.5	FORCED AREA
I	6.8	165.2	48.5	3.4	
K	7.4	87.4	48.5	5.6	

FINDING $LS^{\perp}$, LH, and P

$L_s+ = L_s \sin a$

$L_s = .4416$ ksf.

$L_H = 0.64 \times \text{depth}$

$P^{\perp} = LS^{\perp} + L_H$

	LS ksf	Sin a	Lsf ksf	Depth ft.	LM ksf	PT ksf
N=A	.4416	.13	0.057	63	4.1	4.2
C	.4416	.89	0.393	66	4.3	4.7
E	.4416	.98	0.433	75.1	4.8	5.23
G	.4416	.98	0.433	87.1	5.7	6.13
I	.4416	.89	0.393	100	6.4	6.8
K	.4416	.89	0.393	109.2	7.0	7.4

AREA OF CONCRETE REQUIRED

where T_1 = reaction to vertical forces parallel

A_c = area of concrete required

$f_{all}c$ = allowable compression

$$A_c = \frac{T1}{f_{all}c}$$

ex: T_1 = 17.1 kips

$f_{all}c$ = 1167 ksi

$$A_c = \frac{17.1}{1167} = 0.02$$

	A_{c1} in.^{2}	A_{c2} in.^{2}
N	0.02	0.01
C	0.03	0.01
E	0.15	--
G	0.69	--
K	0.14	0.01
M	0.08	0.01

AREA OF CONCRETE AVAILABLE

$T = 2.75$ ft. $A_V = 1xt = 2.76$ ft.^{2}

TENSION REINFORCEMENT

$$A_{ST} = \frac{T2}{f_{all}st}$$

Use 29,000 ksi steel

where: $f_{all}st$ = allowable stress in steel

3 = safety factor

$$f_{all}st = \frac{29000}{3} = 9667 \text{ kips}$$

$$A_{STE} = \frac{.77}{9667} = \text{nominal}$$

$$A_{STG} = \frac{22.5}{9667} = \text{nominal}$$

Use temperature reinforcement

TEMPERATURE REINFORCEMENT

$$A^{T}_{ST} = 0.02\ A_c$$

$$= 0.02\ (397.44)$$

$$= 7.94 \text{ say } \underline{8 \text{ in.}^2}$$

where

$$A_c = lxt = 2.76 \text{ ft.}^2$$

$$A_c = 397.44 \text{ in.}^2$$

Use 8 ϕ 9 - 6" O.C.

COMPRESSION IN RING

$$C_R = T_1 \cos a \times r$$

where $a = 6.5°$

$$T_1 = 17.1 \text{ kips}$$

$$r = 4 \text{ ft}$$

$$C_R = 17.1 \times 994 \times 4 = 67.96 \approx 68 \text{ kips}$$

AREA OF RING IN CONCRETE

$$A_c = \frac{C}{(1.16) f_{all} c}$$

$$= \frac{68}{1.16(9667)}$$

$$A_c = .006 \text{ in.}^2$$

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