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SEAWATER ABSORPTION BY PRECAST PORTLAND CEMENT CONCRETE CONTAINING LIGHTWEIGHT AGGREGATE

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Concrete has been proposed for use as a structural material in column-stabilized floating ocean platforms. The payload performance and stability of such platforms may be affected by changes in structural weight due to seawater absorption.

This paper describes a study of seawater absorption by ASTM type 2 Portland cement with commercially available lightweight aggregate.

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For the three brands of aggregate tested, the percentage by weight of absorbed seawater ranged from 0.1% to 0.5% at 0 psig, 7.5% to 23.3% at 18 psig, and from 1.6% to 3.4% at 155 psig. The high absorption at 18 psig is believed due to incomplete compaction of test specimens during fabrication. Absorption by fully compacted specimens is calculated to range from 0.1% to 0.5% at 0 psig, 2.4% to 6.5% at 18 psig, and 1.6% to 2.1% at 155 psig. The importance of quality control in the fabrication of ocean-going concrete vessels is emphasized.

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INTRODUCTION

Background

This investigation was sponsored by the Advanced Ocean Engineering Laboratory of Scripps Institution of Oceanography (SIO), La Jolla, California 92037.

The design of a stable floating platform was begun by SIO in January 1969. Four buoyant concrete legs, attached to and supporting the steel superstructure, would be horizontal and awash at the oceanic surface while towing the platform to any oceanic region and would swing down into the vertical position to stabilize the platform while at a specific location. During October 1971 an advisory panel on concrete technology met at SIO and discussed the technical problems associated with the four lightweight concrete tubular legs. The author of this report was a member of the panel. In January 1972, SIO solicited the Naval Civil Engineering Laboratory (NCEL) to submit a research proposal on the subject of seawater absorbed by lightweight concrete. Results of the research would indicate the magnitude of weight gain, due to absorption of seawater by the concrete legs, and its subsequent effects on the stability of the floating platform. The investigation was officially authorized at NCEL in July 1972. Design of equipment, procurement of materials, and assembly of the testing apparatus were accomplished during the following three months. Preliminary tests were done in October 1972. Hydrostatic testing began in November 1972 and ended in February 1973.

Each hollow leg would be 350-ft long, 18-ft diameter in the upper 40-ft portion, 28-ft diameter in the lower 310-ft portion, and have a wall thickness of 9 in. throughout its length; a concrete hemisphere, filled with ballast, would constitute the closed bottom. Each leg would consist of a series of 10-ft long precast lightweight concrete rings each of which would be circumferentially prestressed before the series would be longitudinally post-tensioned. Prestressing would be at 600 psi and post-tensioning at 1,200 psi.

The lightweight aggregate would be a commercially available expanded shale, i.e., calcined to incipient fusion. The unit weight or bulk density (in the atmosphere) of the hardened concrete would approximate 110 pcf. The minimum compressive strength would be 5,000 psi at age 28 days. The volume of concrete would total 5,500 cu yd.

In the horizontal position the exposed sections of the legs would be subjected to alternate wetting and drying due respectively to wave action and a combination of solar heat and evaporative effects of wind. In the vertical position the submerged sections would be subjected to hydrostatic pressures ranging from 0 psi at the oceanic surface through 18 psi at the lower ends of the 40-ft portions to 155 psi at the lower ends of the 310-ft portions.

Assumptions

The laboratory experimentation was based on the following assumptions: (1) seawater is incompressible and its density is constant within a hydrostatic pressure range from 0 psi to 160 psi; (2) the bulk modulus or coefficient of compressibility of concrete, i.e., the ratio of hydrostatic stress to corresponding unit change in volume, is constant within a hydrostatic pressure range from 0 psi to 160 psi; (3) the volume of air voids,* entrapped during casting of the concrete test specimens, is constantly 1.5% of the volume of hardened concrete within a hydrostatic pressure range from 0 psi to 160 psi; (4) the temperature of seawater at depths of 350 ft or less may be as low as 29F in polar regions and as high as 103F in certain regions of the Red Sea, and so 66F is a realistic median for the temperature of seawater; (5) the average salinity of 66F seawater is 35 °/₀₀; and (6) the specific gravity of seawater (salinity 35 °/₀₀) at 66F is 1.025 at depths of 350 ft or less.**

Objective

The specific purpose of this investigation was to determine the bulk specific gravity of, and the percentage of seawater absorbed by, three precast lightweight concretes as a consequence of extended submersion in 66F seawater at simulated oceanic depths of 1 ft, 40 ft, and 350 ft (respectively, nearly 0 psi, 18 psi, and 155 psi hydrostatic).

Definitions

Certain words and phrases used in this investigation were defined as shown below.

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*Not entrained air

**Based on References 1 and 2

Absorption. The process by which water is drawn into and tends to fill permeable voids in hardened concrete. Also, the increase in weight of a hardened concrete test cylinder, in the atmosphere, resulting from penetration of water into the permeable voids within the concrete.

Absorbed moisture. Water that has entered a hardened concrete test cylinder by absorption and has physical properties not substantially different from ordinary water at the same temperature and pressure.

Air-dry. Dried in air (73 ± 3F at 50% RH) under natural convection within a laboratory room to simulate the moist condition of hardened concrete that has been stored outdoors near the Pacific Ocean in Southern California.

Bulk density. The weight, in the atmosphere, of a unit volume of hardened concrete including permeable and impermeable voids, at a stated temperature. (The form of expression is "bulk density, pounds per cubic foot at xF" where x is the number of degrees Fahrenheit temperature of the concrete.)*

Bulk specific gravity. The ratio of the weight, in the atmosphere, of a hardened concrete test cylinder, including permeable and impermeable voids, at a stated temperature to the weight, in atmosphere of equal density, of an equal volume of water (freshwater, deionized water, or seawater) at a stated temperature. (The form of expression is "bulk specific gravity xF/yF" where x is the number of degrees Fahrenheit temperature of the concrete and y is the number of degrees Fahrenheit temperature of the water.)*

Burette reader. An optical lens fitted within a metallic barrel which is held against a clear glass tube by means of a spring clamp; the lens, which is focused by drawing the eyepiece in or out, magnifies the liquid meniscus within the tube and also the gradations on the steel rule behind the tube.

Deionized water. Freshwater from which substantially all cations and anions have been removed. Used, in this investigation, as a substitute for gas-free distilled water.

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*The expressive form is an adaptation of that appearing in Reference 3.

Density. Mass per unit volume.

Oven-dry. Dried in 108 ± 2C (226.4 ± 3.6F) air under forced convection within an oven until the weight, in the atmosphere of the hardened concrete test cylinder, cooled in a desiccator until the concrete temperature is equal to that of the atmosphere, decreases to a substantially constant value. (If the difference between two consecutive weighings 24 hr apart exceeds 0.1% of the smaller weight, the specimen is returned to the oven for 24 hr of additional drying; the procedure is repeated until the difference between two consecutive weighings is less than 0.1% of the smaller weight.)

Saturated. The condition of the hardened concrete test cylinder when its permeable voids are infused with water.

Soaked. The condition of the surface-dry hardened concrete test cylinder when its weight, in the atmosphere, has increased to a substantially constant value as the result of either exposure to fog or submersion in water. (In the case of submersion, if the difference between 24 hr apart exceeds 0.1% of the greater weight, the specimen is resubmersed for an additional 24 hr period; the procedure is repeated until the difference between two consecutive weighings is less than 0.1% of the larger weight.)*

Specific gravity. The ratio of the density of a substance in question to the density of water used as a standard.

Standard fog. An atmosphere, maintained at 73.4 ± 3F (23 ± 1.7C) and not less than 98% RH, for the purpose of curing and storing concrete test cylinders. Ambience is achieved by the atomization of temperature-controlled freshwater so that free moisture is continuously maintained on all surfaces of the exposed cylinders.

Surface-dry. The absence of visible water on the exposed surface of the hardened concrete test cylinder.

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*Based on Reference 4 which specifies a limit of 0.5%, relative to the difference between two consecutive weighings 24 hr apart, rather than 0.1%.

Abbreviations

Descriptions of various physical conditions peculiar to, and obtained in, this investigation were abbreviated as shown below.

AD	=	Air-dry.
OD	=	Oven-dry.
RH	=	Relative humidity.
SSD	=	Soaked, as the result of continuous exposure of the hardening concrete test cylinder to 73.4 ± 3F (23 ± 1.7C) freshwater fog while curing for 56 days, and surface-dry.
S'SD	=	Soaked, as the result of recurrent submersion of the previously OD concrete test cylinder in 66 ± 1F (18.9 ± 0.6C) seawater so that the head atop the vertical cylinder is not greater than 8 in. (0.30 psi hydrostatic), and surface-dry.
S_oSD	=	Saturated, as the result of prolonged submersion in 66 ± 1F (18.9 ± 0.6C) seawater at 0 psi hydrostatic (head not greater than 8 in.), and surface-dry. (The S'SD test cylinder is vertically submerged in seawater within an uncovered tub.)
S_{18}SD	=	Saturated, as the result of prolonged submersion in 66 ± 1F (18.9 ± 0.6C) seawater at 18 psi hydrostatic, and surface-dry. (The S'SD test cylinder is vertically submerged in seawater within the open pressure vessel (PC); the seawater surface is under 18 psi helium while the PV is closed.)
S_{155}SD	=	Same as S_{18}SD except that hydrostatic and helium pressures are 155 psi.

Symbols

Terms used in the various calculations were defined as shown below.

V_c = total volume of three S'SD cylinders, cu ft or cu in.

V_f = total volume of seawater added to reservoir, cu in.

V_s = cumulative volume of absorbed seawater, cu in.

V'_s = theoretic V_s, cu in.

V''_s = graphically estimated ultimate volume of absorbed seawater minus V_f, cu in.

W_c = total weight (in atmosphere) of three S'SD cylinders, lb

W_f = total weight of seawater added to reservoir, lb

W_s = cumulative weight of absorbed seawater, lb

W'_s = theoretic W_s, lb

W''_s = weight of V''_s, lb

t = time, hr

Δ = increment or quantitative difference

Conversion Factors

The equivalences used in this investigation are shown below for the convenience of the reader. The values for seawater were based on a temperature of 66 ± 1F (18 ± 0.6C), an assumed salinity of 35°/oo, and an assumed specific gravity of 1.025.

1.00 cu in.	=	16.39 ml
1.00 cu in.	=	0.004329 gal*
1.00 cu ft	=	1728 cu in.
1.00 cu ft	=	7.480 gal*
1.00 gal*	=	231.0 cu in.
1.00 gal*	=	0.1337 cu ft
1.00 ml	=	0.06102 cu in.

1.00 cu in. seawater	=	0.03698 lb**
1.00 cu ft seawater	=	63.90 lb**
1.00 gal* seawater	=	8.543 lb**
1.00 lb**seawater	=	27.04 cu in.
1.00 ft head seawater	=	0.444 psi

*U.S. liquid gallons
**Avoirdupois

CONCRETE

Constituents

Three brands of commercially produced expanded shale were used as coarse aggregate in fabricating three groups of concrete test cylinders. All three aggregates were processed in Pacific coastal areas. The brands and their sources were: (1) SATURNALITE from Vancouver, British Columbia, (2) KILITE from Oakland, California, and (3) ROCKLITE from Los Angeles, California. The unit weights, in a dry and loose condition, were: 42 pcf for SATURNALITE, 42 pcf for ROCKLITE, and 41 pcf for KILITE.

The fine aggregate used in all three concretes was washed sand derived from the San Gabriel River at Irvindale, California. The unit weight of the sand was 98 pcf in a dry and loose condition.

A modified portland cement, ASTM Type 2, was used in all three concretes. The brand was Victor which is produced by Southwestern Portland Cement Co., Los Angeles.

Plastiment, produced by Sika Chemical Corp., Lyndhurst, New Jersey, was used in all three concretes. It is a water-reducing agent and also a set-retardant.

MBVR, produced by Master Builders, Cleveland, Ohio, was used in two of the concretes. It is a vinsol resin type of air-entraining agent.

All mixing water was freshwater from the Metropolitan Water District distribution system.

Mix Design

Trial mixtures were designed and evaluated under the direction of Robert C. Kuhn, Civil Engineer, of the Smith-Emery Co., Los Angeles. This independent commercial testing laboratory had been engaged by SIO to determine optimum mix proportions of the three concretes and to cast the test specimens used later in the absorption tests at NCEL. The requirements were: (1) a minimum compressive strength of 6,250 psi at age 28 days, (2) a minimum tensile strength (splitting strength in compression) of 500 psi at age 28 days, and (3) composition and consistency typical of that used currently in conventional construction.

Results of the trial mixtures disclosed that KILITE concrete failed to attain the first requirement and that none of the three concretes met the second requirement. Increasing the cement content of KILITE concrete beyond 12.5 bags per cu yd was deemed impractical and contrary to good practice as stipulated in the third requirement. The second requirement was similarly reconsidered as too strict and thus also impractical.

The mix proportions finally used in conjunction with casting the test specimens were those shown in Table 1. The average strengths and bulk densities of the three concretes at age 28 days were determined in the Smith-Emery Co. laboratory and are shown in Table 2; the average values were determined by testing specimens companionate to those used in the absorption tests.

Test Specimens

Each specimen, including those used to determine the average values listed in Table 2, was a right circular cylinder nominally 6 in. diameter by 12 in. high. All were cast 18 August 1972 and cured in standard fog for 28 days at the laboratory of the Smith-Emery Co. Three groups of nine cylinders, representing the three concretes, were removed from standard fog at age 31 days (18 September 1972); each was wrapped with damp burlap and then wrapped with pliable sheets of Saran to preclude moisture loss by evaporation. The 27 cylinders were transported to NCEL the same day in an air-conditioned vehicle, unwrapped, and replaced in standard fog at NCEL to continue curing to age 56 days (13 October 1972).

The identifying numbers marked on the specimens, while at Smith-Emery Co., were the following: 16333 to 16341 inclusively for SATURNALITE, 16345 to 16353 inclusively for ROCKLITE, and 16357 to 16365 inclusively for KILITE.

At age 33 days, a 1-in. thick by 6-in. diameter portion was sawed off the top of each of the 27 test cylinders; these sawed disks were discarded. The surface textures of the tops, as received, were extremely rough in comparison with the molded bottoms and exhibited numerous voids. Sawing obviated any possible difficulties relative to surface drying the tops of the soaked or saturated specimens.

SEAWATER

Seawater was obtained from the Pacific Ocean at a depth of 10 ft and 1,000 ft offshore from NCEL. The outboard end of the pipeline was equipped with a strainer and the inboard end was connected to four 1,000-gal storage tanks in which any visable foreign substances settled to the bottom as sediment. Clear seawater was pumped from one of the large storage tanks through a 5-micron filter to a 500-gal portable tank from which seawater was withdrawn by pumping through a 5-micron filter as needed. After completing all tests of one concrete, the portable tank was emptied and cleaned. Prior to subsequent tests of another concrete, the portable tank was again filled and seawater withdrawn as described above. Thus, all seawater used in testing any group of nine cylinders was new seawater that had been filtered twice. This procedure was considered necessary to (1) ensure a satisfactorily clear meniscus in each glass tube of the water-level gages connected to the pressure vessels and (2) preclude plugging of the capillaries and pores, within the hardened concrete of the test cylinders, by minute intrinsic matter that could be present in unfiltered seawater.

TEST APPARATUS

Hydrostatic Pressure Facilities

These facilities consisted basically of two steel pressure vessels (PV's), each of which was connected to a container of compressed helium and also to a specially designed reservoir equipped with a water-level gage. Helium was used because it was the least water-soluble of the inert gases. Figure 1 is a schematic of the assembly used with each pressure vessel.

The 18 psi hydrostatic PV had an internal diameter of 23 in., an internal height of 37 in., and a flat interior bottom. When closed, the flat lid was secured by eight clamps each of which were screw-tightened to a torque of 50 ft-lb. The lid was equipped with a bleeder valve, pressure relief valve, and hydrostatic pressure indicator.

The 155 psi hydrostatic PV had an internal diameter of 18 3/8 in., an internal height of 42 in., and a flat interior bottom. When closed, the flat lid was secured by 24 bolts each of which was nut-tightened to a torque of 150 lb. The lid was equipped similarly.

Each water-level gage consisted of a 46-in. high chrome-plated steel rule, graduated in 0.01-in. divisions, behind a thick-walled (48-in. high pyrex glass tube which had an interior diameter 0.19 in. and which was equipped with a sliding burette reader. Stainless steel inlet and outlet valves, and drain cock for adjusting the water-level, were integral parts of the gage. The inlet and outlet valves of the water-level gage were connected to the stainless steel reservoir, internal diameter 2.00 in. and internal height 60.00 in. The reservoir, which was equipped with a stainless steel valve for incoming filtered seawater, was rigidly mounted on the wall of the temperature-controlled room and also supported by leveling legs. A water-level decrease of 0.01 in. represented a volume of 0.03 cu in. of absorbed seawater.

Each container of compressed helium was equipped with pressure regulators.

Each PV was equipped with a specially designed stainless steel basket which accommodated three test cylinders in the vertical position while submerged in the seawater of the PV. Each loaded basket was lowered onto the bottom of its PV by means of a chain hoist which also served for extracting the cylinders at the conclusion of a PV test.

Bulk Specific Gravity Determination

All specific gravity test data were obtained by using the principle of Archimedes. Each cylinder, either soaked or saturated in 66 ± 1F seawater, was surface-dried with a damp cotton towel, which had been wrung free of all drippable seawater, preparatory to weighing. Upon removal from the tub or PV, each cylinder was placed on a rack and allowed to drain for 1/2 minute, rolled four times on a seawater-damp towel, and wiped with another seawater-damp towel until all visible seawater was removed from the concrete. Immediately thereafter the surface-dry weight in the atmosphere was determined. Then the cylinder, in a specially designed stainless steel frame, was immersed by suspension in a jar of 66 ± 1F seawater and weighed. The cylinder then was removed, and the jar, seawater, and immersed frame weighed. The various weight data provided the basis for calculating the volume and bulk specific gravity of each cylinder.

TESTING PROCEDURE

Each group of nine cylinders was tested in seven phases as described below.

Phase 1. At age 56 days each cured cylinder was removed from standard fog, its SSD weight determined in an atmosphere of 74 ± 1F at 50 ± 5% RH, and its volume and bulk specific gravity determined by suspension in 73 ± 1F deionized water.

Phase 2. Immediately after Phase 1 the nine cylinders were stored in an atmosphere of 73 ± 1F at 50 ± 2% RH to simulate the environment in coastal regions of Southern California where the 10-ft long precast concrete rings probably would be stored prior to assembly into 350-ft long tubular legs and subsequent submersion in the ocean. Each cylinder was weighed periodically until Phase 3 began.

Phase 3. The nine cylinders were oven-dried to constant weight to ensure uniform physical conditions when first submersed in seawater.

Phase 4. The nine OD cylinders were segregated into three sets so that the OD weights of those in any set were equal or nearly so. Each set was soaked in 66 ± 1F seawater; this procedure was considered basic for any valid comparisons, among the three sets of cylinders within a group and also among the three groups, relative to rates and total amounts of seawater absorbed by the sets while subjected to the three hydrostatic pressures. Subsequently the S'SD weight of each cylinder was determined in an atmosphere of 66 ± 1F at 75 ± 10% RH, and its volume and bulk specific gravity determined by suspension in 66 ± 1F seawater.

Phase 5. Immediately after Phase 4 the first set of three S'SD cylinders, having the lowest average OD weight, was emplaced in a tub of 66 ± 1F seawater for prolonged submersion at 0 psi hydrostatic. Each of the two remaining sets of S'SD cylinders was submersed in the 66 ± 1F seawater of a nearly full PV, the second set (which had the intermediate average OD weight) into the PV that later was pressurized to 18 psi hydrostatic, and the third set (which had the high average OD weight) into the PV that later was pressurized to 155 psi hydrostatic.

Phase 6. Immediately after Phase 5 the two PV's were closed. Each PV was filled with additional 66 ± 1F seawater, the water-level gage adjusted, the PV pressurized with helium to the required hydrostatic pressure, and the initial water-level determined. Pressurization was accomplished within one minute after obtaining the adjusted water-level in the gage. Subsequent water-levels were observed at 15-minute intervals during the first hour, 30-minute intervals during the second hour, hourly during the following 6 hr, and at 24-hr intervals thereafter for several days until a 24-hr differential weight of absorbed seawater reached a value of 0.1%* of the total weight of seawater absorbed at the beginning of the 24-hr interval. The observed changes in water-level provided the basis for subsequently calculating absorption percent (by volume) which was converted by further calculation into absorption percent (by weight).

Phase 7. Immediately after completing Phase 6 the PV's were depressurized, opened, and the six cylinders submersed vertically in two tubs of 66 ± 1F seawater so that the head atop each cylinder was less than 8 in. The S_0SD weight of each cylinder from the first set, the S_{18}SD weight of each cylinder from the second set, and the S_{155}SD weight of each cylinder from the third set was determined in air atmosphere of 66 ± 1F at 75 ± 10% RH. The volume and bulk specific gravity of each cylinder was determined by suspension in 66 ± 1F seawater.

EXPERIMENTAL DATA

Results

Daily percent absorption, by volume of seawater only and excluding the volume of S'SD concrete comprising the test cylinders, was calculated as follows:

$$\text{daily \% absorption} = \left[\frac{\Delta V_s}{\text{previous day's } V_s}\right]\left[\frac{24}{\Delta t}\right] 100$$

*In the case of SATURNALITE at 155 psi and 18 psi hydrostatic and also ROCKLITE at 155 psi hydrostatic. For ROCKLITE at 18 psi hydrostatic, and also for KILITE at both pressures, the limit was 0.5% (consistent with Reference 4).

where

ΔV_s = incremental volume of absorbed seawater, cu in.
V_s = cumulative volume of absorbed seawater, cu in.
Δt = incremental time, hr

These daily rates are listed in Tables 3, 4, and 5 for the three concretes under 18 psi hydrostatic, and in Tables 6, 7, and 8 for the three concretes under 155 psi hydrostatic.

The cumulative amounts of seawater absorbed by the three concretes under 0 psi hydrostatic were based on measured weights of three cylinders per concrete while in OD, S'SD, and S_oSD condition. These absorption values were expressed as percent of OD weight (Tables 9, 10, and 11) and also as percent of S'SD weight (Tables 12, 13, and 14), calculated as follows:

absorption = (S_oSD wt - OD wt) / (OD wt)

and

absorption = (S_oSD wt - S'SD wt) / (S'SD wt)

The average bulk specific gravity of each of the three concretes is listed in Table 15. The results of all absorption tests of the three concretes are summarized in Table 16.

Discussion

There is no standard criterion for determining when concrete under hydrostatic pressures greater than 0 psi is practically saturated. The term "practically saturated" implies absorption of seawater to a degree where any subsequent slight increase during 24 consecutive hours is considered insignificant; the term "fully saturated" is avoided because attaining absolute saturation is considered interminable. The use of the term "absorption" in Reference 4, which is a method for determining amount of water absorbed under atmospheric pressure (i.e., 0 psi hydrostatic), connotes that saturation is achieved when the gain in weight of the soaking concrete during a 24-hr period is less than 0.5% of the weight at the end of the period.

The graphs in Figures 2, 3, and 4 illustrate the cumulative increases in volumes of seawater absorbed during the passage of time. Semilogarithmic graphs are useful for predicting trends. Log graphs of cumulative seawater absorbed versus time reveal curves rather than straight lines and so extrapolation linearly is impossible.

The curves in Figures 2, 3, and 4 cannot be extrapolated accurately to estimate the number of days required for saturation to be practically achieved. Using the available test data, one can only estimate a rough ultimate value.

Except for SATURNALITE and ROCKLITE cylinders under 155 psi hydrostatic, the cylinders in the PV's apparently were not fully compacted when cast. This condition became evident in those cases where extra seawater had to be added to the reservoirs in order to obtain satisfactory initial water-level values in the gages. If these additional volumes of seawater are discounted SATURNALITE and ROCKLITE under 18 psi hydrostatic, and for KILITE under 18 psi and 155 psi hydrostatic, the percent seawater absorbed (by weight of the S'SD concrete) by each concrete (refer to Item E in Table 16) would be changed to indicate the following:

concrete	psi hydrostatic	% of W_c
SATURNALITE	0	0.5
	18	3.5
	155	1.6
ROCKLITE	0	0.4
	18	6.5
	155	2.1
KILITE	0	0.1
	18	2.4
	155	2.0

The revised percentages for 18 psi hydrostatic are not lower than the revised percentages for 155 psi hydrostatic. This paradox is believed to be related to degree of compaction of the freshly mixed concretes after being cast into the cylindrical molds.

Referring to Figures 5, 6, and 7, one sees that the curves for a specific hydrostatic pressure are very similar, indicating that all three concretes demonstrate roughly the same rates of change (under a certain hydrostatic pressure) in cumulative volume of seawater absorbed. However, when comparing the total volumes of seawater absorbed by the three concretes, one should note the differences in age when hydrostatic testing began and ended, when oven-drying ended, and when air-drying ended; these age values are listed in the upper portion of Table 15. Compared with SATURNALITE, KILITE was 1 1/2 times as old, had been air-dried nearly five times as long, and had been over-dried nearly as long when initially subjected to the hydrostatic pressures.

The tabulation in the text above indicates the lesser amounts of seawater absorbed by KILITE. The principal cause is the relatively short period under hydrostatic pressure, i.e., 5 days for KILITE, 21 days for ROCKLITE, and 34 days for SATURNA-LITE. Aside from the period of exposure to hydrostatic pressure and the comparatively advanced age of KILITE concrete when first pressurized in the PV, another cause may be the microstructure of the hardened KILITE concrete when first pressurized. The porosity of the concrete is related to cement content, aggregate/cement ratio, water/cement ratio, quantity of entrained air, and degree of compaction; it is also affected by the degree of cement hydration during fog-curing and air-drying. A system of capillaries and pores, more or less interconnected, remains within the cement gel microstructure after the hardened concrete has been oven-dried. The shrinkage that occurs while the concrete dries is not completely reversed as the concrete is resaturated with seawater. KILITE concrete apparently had an opportunity to develop a more closely structured gel system while awaiting hydrostatic testing.

Since the hydrostatic tests of KILITE concrete were of 5-day duration, valid comparison of the three concretes must necessarily be limited to their performances during the first 5 days of submersion. In four of the six PV tests the cylinder sets required various amounts of additional seawater, funneled into the reservoirs, before the PV was pressurized at either 18 psi or 155 psi hydrostatic; one explanation for this would be the presence of various volumes of internal voids, (e.g., entrapped air, microscopic bubbles of entrained air, and the unavoidable system of pores interconnected by capillaries), in one or more cylinders of a set, as the result of less than full compaction when cast. The observed total volume of absorbed seawater, 5 days after the set was pressurized to the desired hydrostatic pressure, minus the volume of funneled seawater was the theoretical amount of seawater absorbed (i.e., the amount absorbed had the set of three cylinders been fully compacted). Using the volumetric and gravimetric data in Tables 3 through 8, and 16, the theoretical amount of absorbed seawater in each concrete at the end of 5 days (under a specified hydrostatic pressure in the PV) was calculated as a percentage of the weight of soaked concrete (surface-dry immediately before submersion), as may be seen in Table 17.

Each of the three concretes exhibited more absorption under 18 psi than under 155 psi hydrostatic. Hypothetically, the triaxial strains within hardened concrete under 18 psi hydrostatic are considerably less than are those corresponding to

155 psi hydrostatic; as a consequence, the entrained air bubbles and the system of pores and capillaries undergo greater compression as the hydrostatic pressure increases, and so less space may be accessible to the seawater seeking entry into the concrete.

Comparing the percentages of theoretical absorption at the end of a 5-day submersal period (Table 17), SATURNALITE was less absorptive than either ROCKLITE or KILITE under 18 psi and 155 psi hydrostatic. SATURNALITE was 111 days old, i.e., 63 days younger than KILITE and 39 days younger than ROCKLITE, when first subjected to these hydrostatic pressures.

Examination of the test data in Table 15 discloses that the largest changes in bulk specific gravity occurred in ROCKLITE and KILITE concretes and the smallest change occurred in SATURNALITE concrete, as the result of extended submersion under 0 psi, 18 psi, and 155 psi hydrostatic. The magnitude of the largest change was 0.03, an insignificant value from the practical viewpoint. Stated briefly, submersion under any hydrostatic pressure not greater than 155 psi for 5 days, 21 days, or 34 days evidently has very little or no effect on the bulk specific gravity of any of the three concretes.

CONCLUSIONS

The discrepancies between amounts of seawater actually absorbed and the amount absorbed had the specimens been fully compacted ("theoretical" absorption) shows that careful control of manufacturing processes for concrete vessels is vitally important. This is especially true for column-stabilized platforms, where the payload is generally a small fraction of the structural weight. In this case, a relatively small percentage of seawater absorbed could drastically affect the vessel's payload capability.

Analysis of the test data leads to the conclusions set forth below, provided that the mix designs are identical to those of the concretes used in this investigation and provided that the concretes are fully compacted when cast, moist-cured in 73F freshwater fog for 8 weeks, stored in a drying atmosphere for 5 weeks, soaked in 66F seawater for 3 weeks, and surface-dry immediately before submersion.

1. Deducting the amount of seawater that may be absorbed by the concrete during its quick descent to either the 40-ft or 350-ft depth, the seawater absorbed by SATURNALITE concrete is:

a. about one-half the amount absorbed by either ROCKLITE or KILITE at the end of a 5-day submersal period, whether at the 40-ft or 350-ft depth;

b. 0.2% within 1 ft of the oceanic surface, 1.2% at the 40-ft depth, and 0.8% at the 350-ft depth, at the end of a 5-day submersal period; and

c. 0.5% within 1 ft of the oceanic surface, 3.4% at the 40-ft depth, and 1.6% at the 350-ft depth.

2. The effects of extended submersion, at depths ranging from within 1 ft of the oceanic surface to 350 ft, on the bulk specific gravity values of SATURNALITE, ROCKLITE, and KILITE concrete are insignificant.

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The Materials Science Division is one of four divisions in the Civil Engineering Department which is headed by Dr. J. G. Hammer. All technical investigations are under the cognizance of Mr. W. F. Burkart, Technical Director. All operations of the Naval Civil Engineering Laboratory are under the command of Captain E. M. Saunders, Civil Engineer Corps, USN.

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Table 1. Final Mix Design of Lightweight Concretes

Concrete brand	SATURNALITE	ROCKLITE	KILITE
Cement content, bags per cu yd	11.5	11.5	12.5
Water content, gal per cu yd	44.0	44.0	46.0
Plastiment, fl oz per cu yd	23.0	23.0	23.0
MBVR, fl oz per cu yd	11.5	0.0	17.5
Entrained air, % by volume	6.0	6.0	6.0
Slump, in. (maximum)	3.	3.	3.
Aggregate/cement ratio , by wt	1.43	1.40	1.20
Water/cement ratio, by wt	0.34	0.34	0.32
Max size aggregate, in.	3/8	1/2	3/8

Table 2. Strength and Bulk Density of Lightweight Concretes at Age 28 Days

Concrete Brand	*Compressive Strength, psi	*Tensile Strength, psi	**SSD Bulk Density, pcf at 73F
SATURNALITE	6,650	480	111.5
ROCKLITE	6,260	440	111.6
KILITE	6,010	440	109.3

*Each entry is average strength of 3 SSD test cylinders.
**Each entry is average bulk density, determined by suspension in 73F freshwater, of 6 SSD test cylinders subsequently tested for strength.

Table 3. Daily Absorption, Percent of Volume of Seawater, by SATURNALITE Concrete Under 18 psi Hydrostatic.

Date	ΔV_s (cu in.)	Preceding V_s (cu in.)	Δt (hr)	Seawater absorbed (by vol) per 24 hr (cu in./cu in.)	(%)	Cumulative Submersion (days)
7 Dec 72	2.99	308.30[a]	8.35	0.0279	2.8	0
8	1.82	311.29	17.00	0.0082	0.8	1
9	4.09	313.11	16.00	0.0196	2.0	2
10	3.87	317.20	24.00	0.0122	1.2	3
11	4.29	321.07	30.90	0.0104	1.0	4
12	2.04	325.36	23.95	0.0063	0.6	5
13	1.82	327.40	23.80	0.0056	0.6	6
14	3.14	329.22	24.00	0.0096	1.0	7
15	1.95	332.36	24.00	0.0059	0.6	8
18	4.83	334.31	72.00	0.0048	0.5	11
19	1.44	339.14	24.00	0.0042	0.4	12
20	1.47	340.58	24.00	0.0043	0.4	13
21	1.41	342.05	24.00	0.0041	0.4	14
22	1.31	343.46	24.00	0.0038	0.4	15
26	4.54	344.77	96.00	0.0033	0.3	19
27	1.12	349.31	24.00	0.0032	0.3	20
28	1.02	350.43	29.67	0.0024	0.2	21
29 Dec 72	0.26	351.45	18.33	0.0010	0.1	22
1 Jan 73	2.91	351.71	78.00	0.0025	0.2	25
2	0.64	354.62	18.00	0.0024	0.2	26
3	0.83	355.26	24.00	0.0023	0.2	27
4	0.80	356.09	24.33	0.0022	0.2	28
5	0.90	356.89	23.00	0.0026	0.3	29
8	3.23	357.79	72.67	0.0030	0.3	32
9	0.67	361.02	24.00	0.0019	0.2	33
10	0.61	361.69	17.00	0.0024	0.2	34

a/ Added to reservoir before 18 psi hydrostatic was applied

Table 4. Daily Absorption, Percent of Volume of Seawater, by ROCKLITE Concrete Under 18 psi Hydrostatic.

Date	ΔV_s (cu in.)	Preceding V_s (cu in.)	Δt (hr)	Seawater absorbed (by vol) per 24 hr (cu in./cu in.)	(%)	Cumulative Submersion (days)
15 Jan 73	0.45	207.44[a]	2.50	0.0208	2.1	0
16	12.74	207.89	24.00	0.0613	6.1	1
17	9.20	220.63	24.00	0.0417	4.2	2
18	9.28	229.83	24.00	0.0404	4.0	3
19	3.20	239.11	24.00	0.0134	1.3	4
20	8.44	242.31	24.17	0.0346	3.5	5
21	6.08	250.75	22.83	0.0255	2.6	6
22	4.77	256.83	24.00	0.0186	1.9	7
23	4.93	261.60	24.00	0.0188	1.9	8
24	4.86	266.53	24.00	0.0182	1.8	9
26	7.10	271.39	48.00	0.0131	1.3	11
29	10.66	278.49	72.33	0.0127	1.3	14
30	3.04	289.15	23.67	0.0107	1.1	15
31 Jan 73	2.88	292.19	24.00	0.0099	1.0	16
1 Feb 73	2.82	295.07	24.00	0.0096	1.0	17
2	2.85	297.89	24.00	0.0096	1.0	18
5 Feb 73	7.39	300.74	65.00	0.0091	0.9	21

a/ Added to reservoir before 18 psi hydrostatic was applied.

Table 5. Daily Absorption, Percent of Volume of Seawater, by KILITE Concrete Under 18 psi Hydrostatic

Date	ΔV_s (cu in.)	Preceding V_s (cu in.)	Δt (hr)	Seawater absorbed (by vol) per 24 hr (cu in./cu in.)	(%)	Cumulative Submersion (days)
8 Feb 73	-0.21	78.71[a]	2.76	-0.0226	-2.3	0
9	12.93	78.50	24.00	0.1647	16.5	1
10	7.65	91.43	24.00	0.0837	8.4	2
11	5.63	99.08	24.00	0.0568	5.7	3
12	7.48	104.71	24.00	0.0714	7.1	4
13 Feb 73	3.46	112.19	16.00	0.0463	4.6	5

a/ Added to reservoir before 18 psi hydrostatic was applied.

Table 6. Daily Absorption, Percent of Volume of Seawater, by SATURNALITE Concrete Under 155 psi Hydrostatic

Date	ΔV_s (cu in.)	Preceding V_s (cu in.)	Δt (hr)	Seawater absorbed (by vol) per 24 hr (cu in./cu in.)	Seawater absorbed (by vol) per 24 hr (%)	Cumulative Submersion (days)
7 Dec 72	4.72	0.00	8.61	--	--	0
8	2.18	4.72	16.50	0.6718	67.2	1
9	1.37	6.90	16.00	0.2978	29.8	2
10	1.63	8.27	24.00	0.1971	19.7	3
11	1.60	9.90	31.13	0.1246	12.5	4
12	0.93	11.50	23.75	0.0817	8.2	5
13	0.86	12.43	24.00	0.0692	6.9	6
14	0.83	13.29	24.00	0.0624	6.2	7
15	0.77	14.12	24.00	0.0545	5.4	8
18	2.02	14.89	72.00	0.0452	4.5	11
19	0.54	16.91	24.00	0.0319	3.2	12
20	0.54	17.45	24.00	0.0309	3.1	13
21	0.51	17.99	24.00	0.0283	2.8	14
22	0.45	18.50	24.00	0.0243	2.4	15
26	1.63	18.95	96.00	0.0215	2.2	19
27	0.38	20.58	24.00	0.0185	1.8	20
28	0.38	20.96	29.50	0.0147	1.5	21
29 Dec 72	0.19	21.34	18.50	0.0116	1.2	22
1 Jan 73	0.86	21.53	78.00	0.0123	1.2	25
2	0.32	22.39	17.87	0.0192	1.9	26
3	0.26	22.71	23.92	0.0115	1.2	27
4	0.22	22.97	24.33	0.0094	0.9	28
5	0.26	23.19	23.00	0.0117	1.2	29
8	0.93	23.45	72.88	0.0131	1.3	32
9	0.13	24.38	24.00	0.0053	0.5	33
10 Jan 73	0.10	24.51	17.00	0.0058	0.6	34

Table 7. Daily Absorption, Percent of Volume of Seawater, by ROCKLITE Concrete Under 155 psi Hydrostatic

Date	ΔV_s (cu in.)	Preceding V_s (cu in.)	Δt (hr)	Seawater absorbed (by vol) per 24 hr (cu in./cu in.)	(%)	Cumulative Submersion (days)
15 Jan 73	4.19	0.00	1.33	--	--	0
16	9.60	4.19	23.92	2.2988	229.9	1
17	3.43	13.79	24.00	0.2487	24.9	2
18	2.37	17.22	24.00	0.1376	13.8	3
19	1.73	19.59	24.00	0.0883	8.8	4
20	1.47	21.32	24.05	0.0688	6.9	5
21	1.28	22.79	22.95	0.0587	5.9	6
22	1.09	24.07	24.00	0.0453	4.5	7
23	1.09	25.16	24.00	0.0433	4.3	8
24	0.93	26.25	24.00	0.0354	3.5	9
26	1.47	27.18	48.00	0.0270	2.7	11
29	2.05	28.65	72.33	0.0237	2.4	14
30	0.54	30.70	23.67	0.0178	1.8	15
31 Jan 73	0.51	31.24	24.00	0 0163	1.6	16
1 Feb 73	0.61	31.75	24.00	0.0192	1.9*	17
2	0.38	32.36	24.00	0.0117	1.2**	18
5 Feb 73	1.31	32.74	65.00	0.0148	1.5	21

*156 psi hydrostatic
**154 psi hydrostatic

Table 8. Daily Absorption, Percent of Volume of Seawater, by KILITE Concrete Under 155 psi Hydrostatic

Date	ΔV_s (cu in.)	Preceding V_s (cu in.)	Δt (hr)	Seawater absorbed (by vol) per 24 hr (cu in./cu in.)	(%)	Cumulative Submersion (days)
8 Feb 73	6.59	22.33[a]	2.65	2.6726	267.3	0
9	12.38	28.92	24.00	0.4281	42.8	1
10	4.61	41.30	24.00	0.1116	11.2	2
11	3.14	45.91	24.00	0.0684	6.8	3
12	2.50	49.05	24.00	0.0510	5.1	4
13 Feb 73	1.41	51.55	16.00	0.0410	4.1	5

a/ Added to reservoir before 155 psi hydrostatic was applied.

Table 9. Cumulative Absorption, Percent of OD Weight, by SATURNALITE Concrete Under 0 psi Hydrostatic

Date	Age (days)	Absorption (% of OD* weight) Cylinders 16358	16360	16363	avg	Cumulative Soaking (days)
18 Nov 72	92	2.6	2.9	2.5	2.7	1
19	93	2.8	3.4	2.8	3.0	2
20	94	3.1	3.6	3.1	3.3	3
21	95	3.3	4.0	3.2	3.5	4
22	96	3.4	4.2	3.3	3.6	5
23	97	3.4	4.2	3.3	3.6	6
24	98	3.5	4.4	3.4	3.8	7
25	99	3.6	4.5	3.6	3.9	8
26	100	3.7	4.6	3.6	4.0	9
27	101	3.7	4.6	3.6	4.0	10
28 Nov 72	102	3.7	4.6	3.6	4.0	11
1 Dec 72	105	3.8	5.1	3.9	4.3	14
6	110	4.3	5.5	4.3	4.7	19
7	111	4.2	5.4	4.2	4.6	20
18	122	4.4	5.8	4.3	4.8	31
22 Dec 72	126	4.4	5.8	4.3	4.8	35
10 Jan 73	145	4.6	6.3	4.5	5.1	54

*Age when OD = 91 days = 17 Nov 72.

Table 10. Cumulative Absorption, Percent of OD Weight, by ROCKLITE Concrete Under 0 psi Hydrostatic

Date	Age (days)	Absorption (% of OD* weight) Cylinders 16349	16351	16352	avg	Cumulative Soaking (days)
29 Dec 72	133	1.2	1.3	1.3	1.3	1
30	134	2.5	2.5	2.5	2.5	2
31 Dec 72	135	4.0	3.8	3.7	3.8	3
**1 Jan 73	136	5.0	5.1	5.0	5.0	4
2	137	5.1	5.2	5.1	5.1	5
3	138	5.2	5.3	5.3	5.3	6
4	139	5.4	5.4	5.4	5.4	7
**5	140	5.5	5.6	5.5	5.5	8
6	141	5.6	5.6	5.6	5.6	9
7	142	5.6	5.7	5.7	5.7	10
8	143	5.7	5.8	5.8	5.8	11
**9	144	5.8	5.8	5.9	5.8	12
**10	145	5.8	5.8	5.9	5.8	13
**11	146	5.9	5.9	6.0	5.9	14
12	147	5.9	5.9	6.0	5.9	15
13	148	5.9	5.9	6.0	5.9	16
14	149	5.9	5.9	6.0	5.9	17
**15 Jan 73	150	5.9	5.9	6.0	5.9	18
** 5 Feb 73	171	6.3	6.3	6.5	6.4	39

*Age when OD = 132 days = 28 Dec 72.

**Dates of actual weighings; entries for other dates based on extrapolated and interpolated values.

Table 11. Cumulative Absorption, Percent of OD Weight, by KILITE Concrete Under 0 psi Hydrostatic

Date	Age (days)	Absorption (% of OD* weight) Cylinders 16339	16340	16341	avg	Cumulative Soaking (days)
31 Jan 73	166	4.9	4.9	4.8	4.9	2
1 Feb 73	167	5.3	5.2	5.1	5.2	3
2	168	5.5	5.4	5.3	5.4	4
7	173	6.0	5.8	5.8	5.9	9
8	174	6.0	5.8	5.8	5.9	10
13 Feb 73	179	6.2	5.9	5.8	6.0	15

*Age when OD = 164 days = 29 Jan 73.

Table 12. Cumulative Absorption, Percent of S'SD Weight, by SATURNALITE Concrete Under 0 psi Hydrostatic.

Date	age (days)	avg[a] wt (lb)	Cumulative avg gain in wt (lb)	Cumulative avg absorption (by wt) (%)	Cumulative Submersion (days)
7 Dec 72	111[b]	19.14	--	--	0
18	122	19.17	0.03	0.2	11
22 Dec 72	126	19.17	0.03	0.2	15
10 Jan 73	145[c]	19.23	0.09	0.5	34

[a]Average of three cylinders.

[b]Age when S'SD.

[c]Age when S_oSD

Table 13. Cumulative Absorption, Percent of S'SD Weight, by ROCKLITE Concrete Under 0 psi Hydrostatic

Date	age (days)	avg[a] wt (lb)	Cumulative avg gain in wt (lb)	Cumulative avg absorption (by wt) (%)	Cumulative Submersion (days)
15 Jan 73	150[b]	19.29	--	--	0
5 Feb 73	171[c]	19.37	0.08	0.4	21

[a]Average of three cylinders.

[b]Age when S'SD.

[c]Age when S_oSD.

Table 14. Cumulative Absorption, Percent of S'SD Weight, by KILITE Concrete Under 0 psi Hydrostatic

Date	age (days)	avg[a] wt (lb)	Cumulative avg gain in wt (lb)	Cumulative avg absorption (by wt) (%)	Cumulative Submersion (days)
8 Feb 73	174[b]	18.90	--	--	0
13 Feb 73	179[c]	18.91	0.01	0.05	5

[a]Average of three cylinders.

[b]Age when S'SD.

[c]Age when S_oSD.

Table 15. Summary of Bulk Specific Gravity Values of Lightweight Concretes at Various Ages

	Concrete Brand	SATURNALITE	ROCKLITE	KILITE
age when	fog-curing ended, days	56	56	56
	air-drying ended, days	77	112	154
	oven-drying ended, days	91	132	164
	hydrostatic testing began, days	111	150	174
	hydrostatic testing ended, days	145	171	179
Avg bulk spec grav of number of cyls shown	9 SSD at age 28 days, 73F/73F	1.79*	1.79*	1.76*
	9 SSD when fog-curing ended, 73F/73F	1.79**	1.79**	1.75**
	3 SSD when fog-curing ended (a), 66F/66F	1.79**	1.78**	1.75**
	3 SSD when fog-curing ended (b), 66F/66F	1.79**	1.80**	1.75**
	3 SSD when fog-curing ended (c), 66F/66F	1.79**	1.80**	1.76**
	9 S'SD when hydrostatic began, 66F/66F	1.69	1.70	1.68
	3 S'SD when hydrostatic began, (a), 66F/66F	1.70	1.71	1.68
	3 S'SD when hydrostatic began, (b), 66F/66F	1.70	1.72	1.68
	3 S'SD when hydrostatic began, (c), 66F/66F	1.69	1.70	1.66
	3 S_oSD when hydrostatic ended, 66F/66F	1.69	1.73	1.67
	3 S_{18} SD when hydrostatic ended, 66F/66F	1.70	1.75	1.71
	3 S_{155} SD when hydrostatic ended, 66F/66F	1.70	1.71	1.68

*Estimated from known bulk density of concrete and density of freshwater.
**Determined in deionized water.
(a) Tested later in S_oSD condition.
(b) Tested later in S_{18}SD condition.
(c) Tested later in S_{115}SD condition.

NOTE: Unless shown otherwise, 66F seawater was used.

Table 16. Summary of Absorption Tests of Lightweight Concretes Under 0 psi, 18 psi, and 155 psi Hydrostatic for Various Submersal Periods

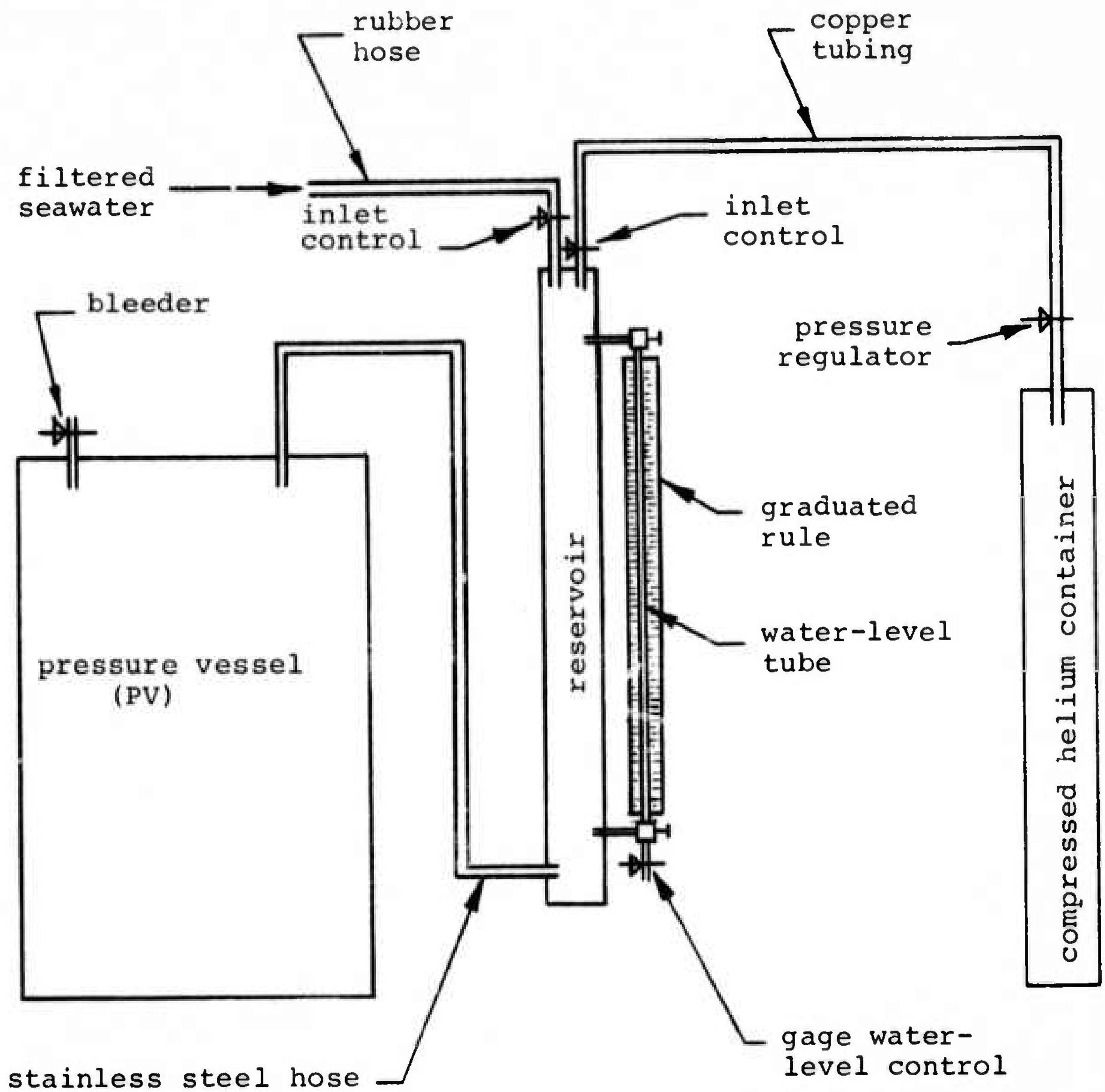
Concrete Brand	SATURNALITE			ROCKLITE			KILITE		
Start of hydrostatic test, date		7 Dec 1972			15 Jan 1973			8 Feb 1973	
End of hydrostatic test, date		10 Jan 1973			5 Feb 1973			13 Feb 1973	
Age at end of test, days		145			171			179	
Submersal period, days		34			21			5	
Hydrostatic pressure, psi	0	18	155	0	18	155	0	18	155
Age OD wt became constant, days	91	91	91	132	132	132	164	164	164
Total OD wt of 3 cylinders, lb	54.85	55.05	55.18	54.62	55.10	55.40	53.54	53.77	54.01
W_c = total wt of 3 S'SD cyls, lb	57.42	57.46	57.48	57.86	58.36	58.73	56.69	57.08	57.20
V_c = total vol of 3 S'SD cyls, cu ft	0.5306	0.5304	0.5311	0.5324	0.5329	0.5328	0.5293	0.5330	0.5342
F = Avg bulk density of 3 S'SD cyls at start of test, pcf at 66F	108.2	108.4	108.3	108.7	109.5	110.2	107.1	107.1	107.0
V_s = total vol seawater absorbed by 3S'SD cyls, cu in.	7.30	362.30	24.61	6.76	308.13	34.05	1.08	115.65	52.96
W_s = total wt seawater absorbed by 3S'SD cyls, lb	0.27	13.40	0.91	0.25	11.40	1.26	0.04	4.28	1.96
66F seawater absorbed*: A = cu in. seawater per cu ft of S'SD concrete	14	683	46	13	578	64	2	217	99
B = lb seawater per cu ft of S'SD concrete	0.5	25.3	1.7	0.5	21.4	2.4	0.1	8.0	3.7
C = lb seawater per lb of S'Sd concrete	0.005	0.233	0.016	0.004	0.195	0.021	0.001	0.075	0.034
D = % of V_c	0.8	39.5	2.7	0.4	33.5	3.7	0.9	12.6	5.7
E = % of W_c	0.5	23.3	1.6	0.4	19.5	2.1	0.1	7.5	3.4

*For 0 psi hydrostatic: V_s is calculated on basis of observed S'SD weights.
$V_s = 27.04W_s$, $A=V_s \div V_c$, $B=W_s \div V_c$, $C=W_s \div W_c$, $D=V_s \div (V_c)(1728)$, $E=W_s \div W_c$.
For 18 psi and 155 psi hydrostatic: $A=V_s \div V_c$, $B=0.03698A$, $C=B \div F$, and D and E as in preceding.

NOTE: Absorption percentages shown in Items D and E include seawater added to reservoirs before pressurization (all three concretes at 18 psi and KILITE at 155 psi hydrostatic).

Table 17. Theoretical Absorption Values for Lightweight Concretes At The End of 5 Days of Submersion Under 18 psi and 155 psi Hydrostatic

Concrete Brand	SATURNALITE		ROCKLITE		KILITE	
Hydrostatic pressure, psi	18	155	18	155	18	155
V_s = actual total vol of seawater absorbed by 3 S'SD cyls, cu in.	327.40	12.43	250.75	22.79	115.65	52.96
V_f = vol of seawater added to reservoir, cu in.	308.30	0	207.44	0	78.71	22.33
V_s' = theoretical total vol of seawater absorbed by 3 S'SD cyls, cu in. = $V_s - V_f$	19.10	12.43	43.31	22.79	36.94	30.63
W_s = actual total wt of seawater absorbed by 3 S'SD cyls, lb = $0.03698V_s$	12.11	0.46	9.27	0.84	4.28	1.96
W_f = wt of seawater added to reservoir, lb = $0.03698V_f$	11.40	0	7.67	0	2.91	0.83
W_s' = theoretical total wt of seawater absorbed by 3 S'SD cyls, lb = $0.03698V_s'$	0.71	0.46	1.60	0.84	1.37	1.13
V_c = actual total vol of 3 S'SD cyls, cu in.	916.53	917.74	920.85	920.68	921.02	923.10
W_c = actual total wt of 3 S'SD cyls, lb	57.46	57.48	58.36	58.73	57.08	57.20
Theoretical absorption:						
% of V_c = $100(V_s') \div (V_c)$	2.1	1.4	4.7	2.5	4.0	3.3
% of W_c = $100(W_s') \div (W_c)$	1.2	0.8	2.7	1.4	2.4	2.0



Note: water-level gage is plumb and vibration-free.

Figure 1. Schematic of Apparatus for 18 psi and 155 psi Hydrostatic.

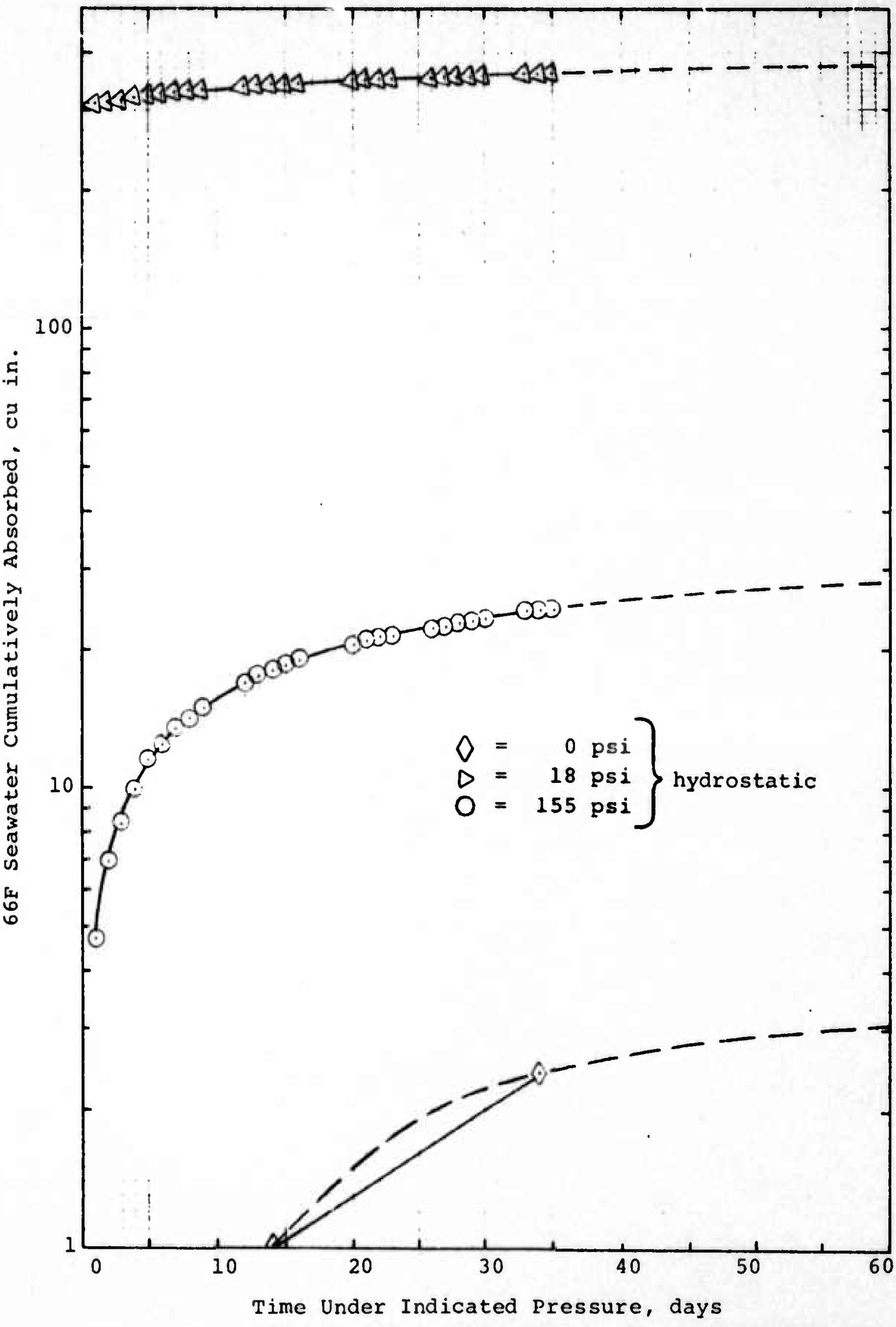


Figure 2. Seawater Absorbed (Volumetric) by SATURNALITE Concrete. Note: Dashed Lines Indicate Probable Variations.

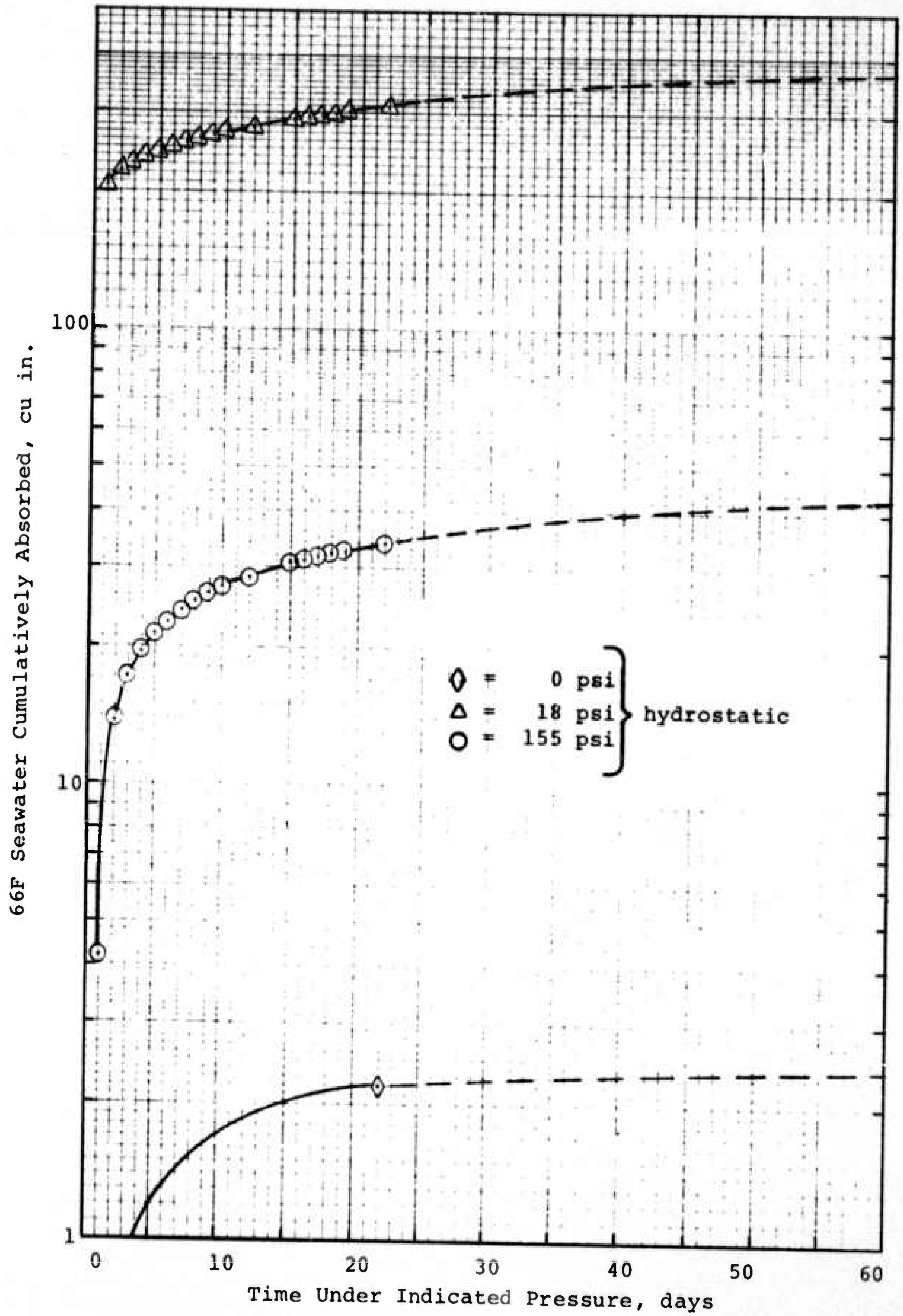


Figure 3. Seawater Absorbed (Volumetric) by ROCKLITE Concrete. Note: Dashed Lines Indicate Probable Variations.

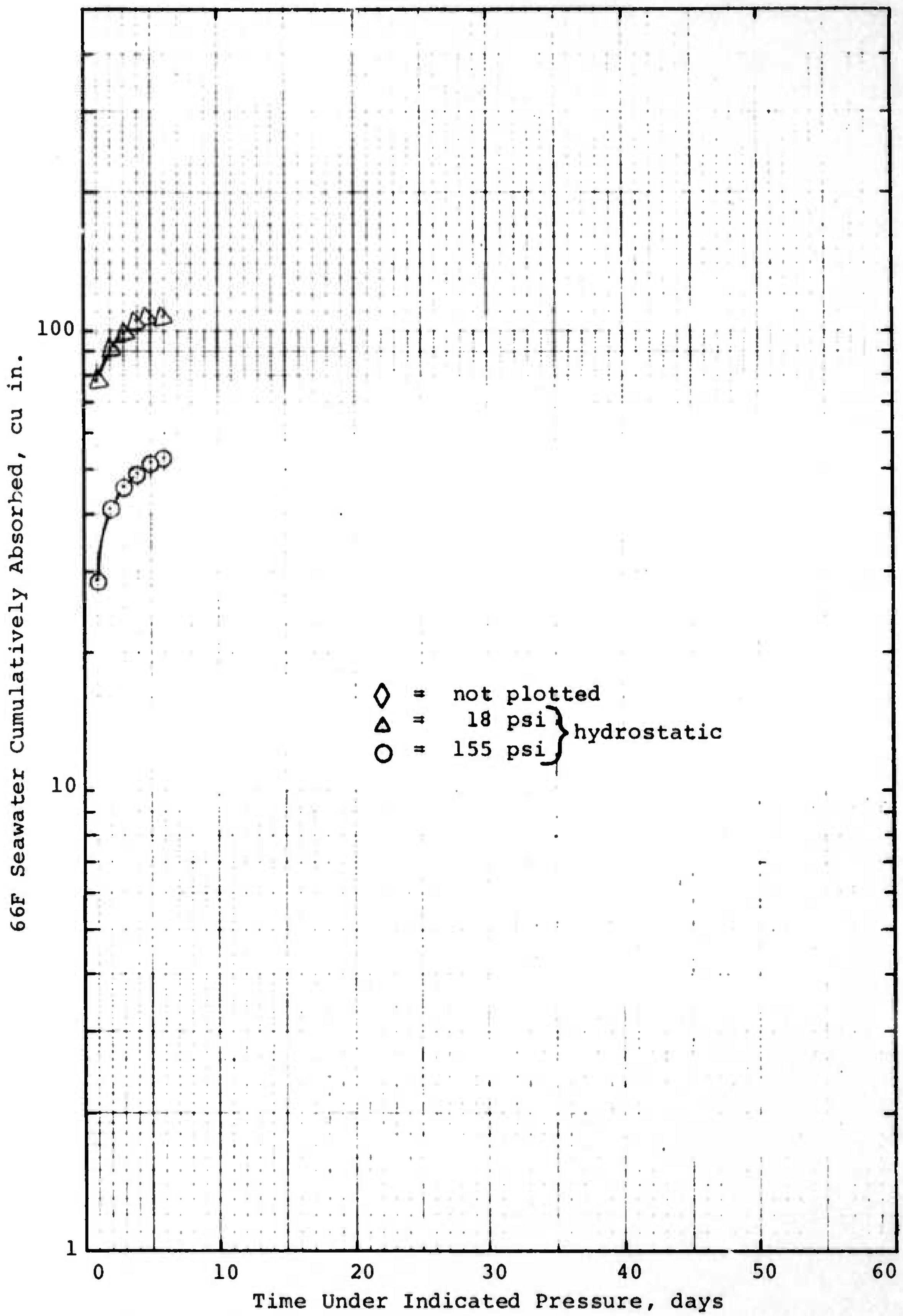


Figure 4. Seawater Absorbed (Volumetric) by KILITE concrete. Note: Cumulative Absorption at 0 psi Hydrostatic Is 0.3 cu in. and Is Not Plotted.

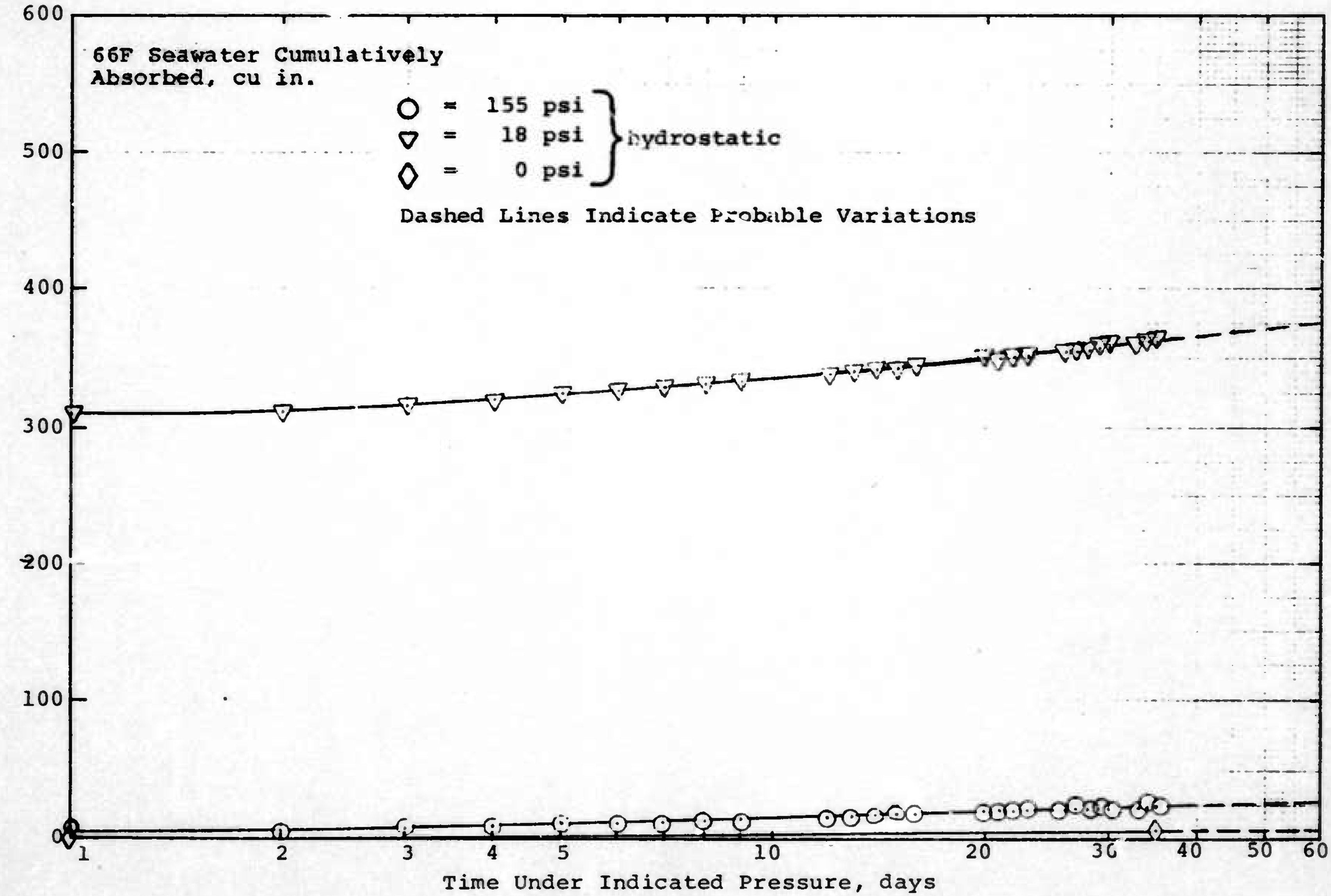


Figure 5. Seawater Absorbed (Volumetric) by SATURNALITE Concrete

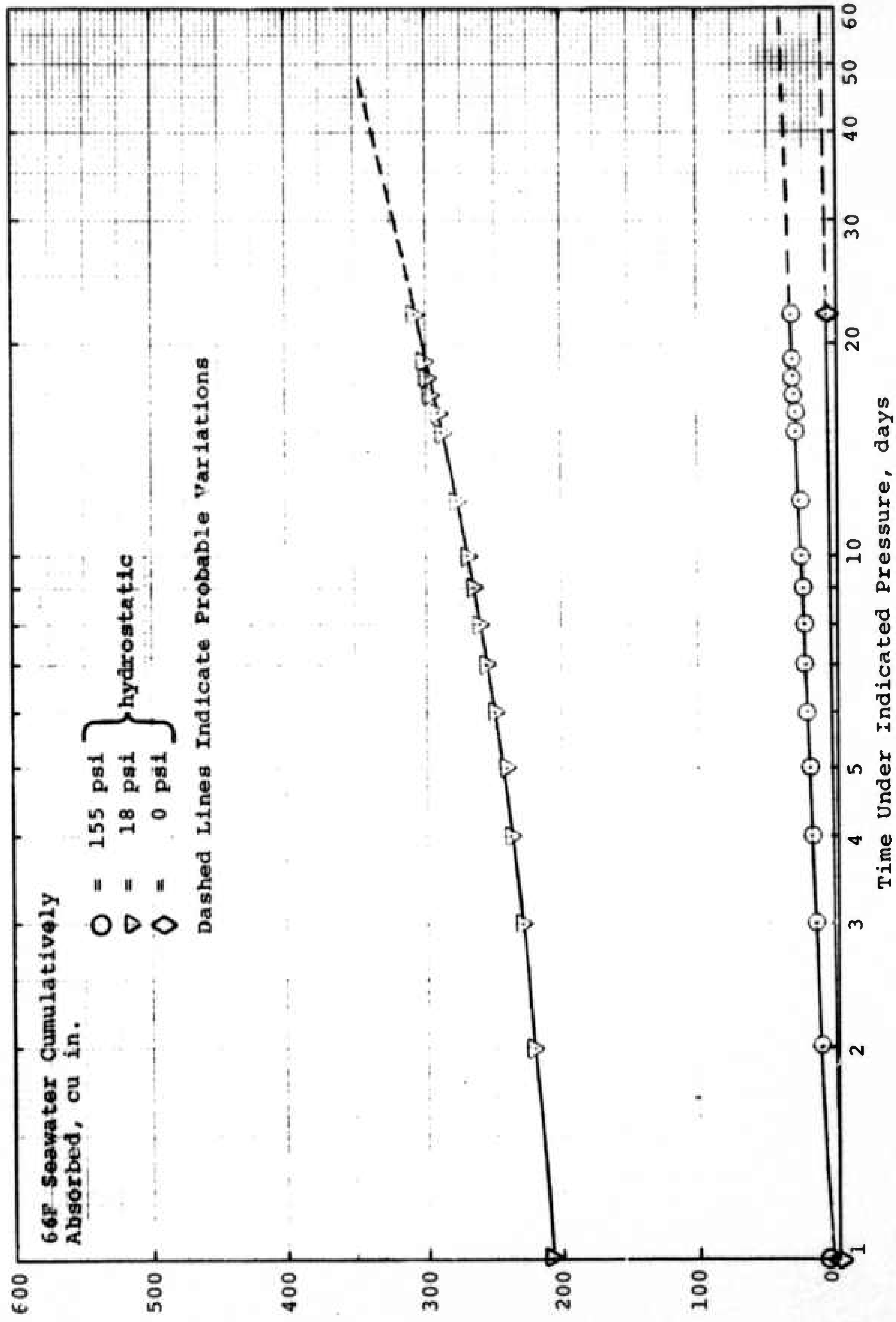


Figure 6. Seawater Absorbed (Volumetric) by ROCKLITE Concrete

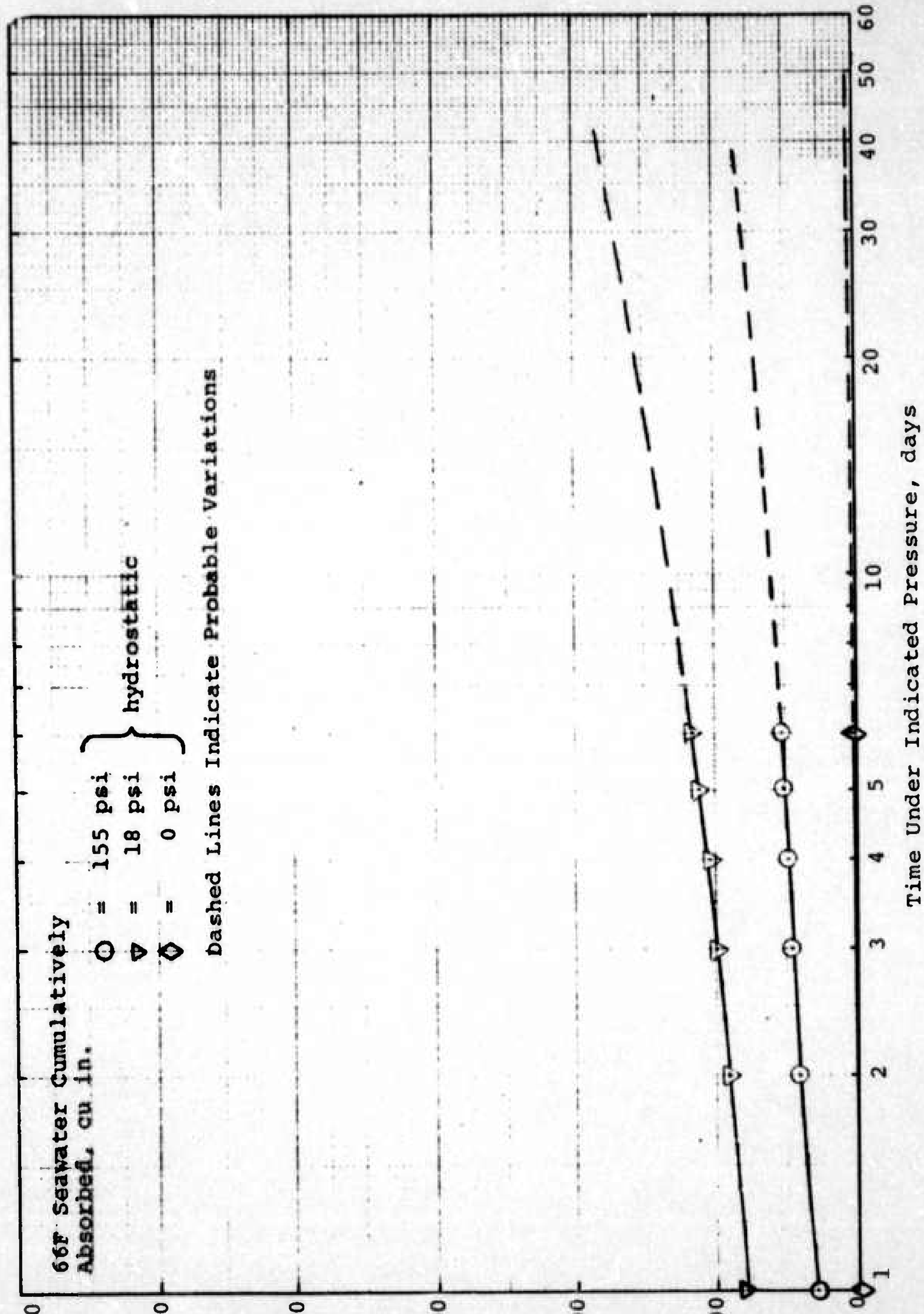


Figure 7. Seawater Absorbed (Volumetric) by KILITE Concrete