A Study of the Influence of Oil Saturation on the 64-Meter Antenna Hydrostatic Bearing Grout

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Deterioration of the grout supporting the hydrostatic bearing runners in the DSN 64-m antennas has been a continuing maintenance problem. This paper describes an investigation, carried out at the University of California at Berkeley, into the effect of oil saturation on the grout. It is concluded that oil saturation as such did not significantly affect the strength of the concrete in either static or cyclic loading. The possibility is raised that the presence of oil as the concrete is placed may inhibit the development of the full strength of the material.

I. Introduction

Deterioration of the grout under the hydrostatic bearing runner of the 64-m antennas has caused a continuing maintenance problem to assure adequate flatness of the runner. Oil leaking from the reservoir formed by the runner and the side walls has been considered the prime factor in this deterioration. Two mechanisms of failure have been considered: decreased compressive stress of the grout material due to oil saturation, and erosion of the grout by hydraulic action under cyclic loading. Tests of these two mechanisms have been carried out by JPL at a local laboratory and by Professors M. Polivka and P. K. Mehta of the University of California at Berkeley under contract from JPL. Neither failure mode could be demonstrated in laboratory tests. However, a third failure mode was proposed wherein the presence of oil on the under surface of the runner sole plates at the time the grout is placed chemically inhibits setting up the cement in the grout after placement. This mechanism has not yet been tested.

II. Description of the Hydrostatic Bearing

The hydrostatic bearing consists of three pads, supporting the corners of the alidade, running on a steel runner 22 m (72 feet) in diameter (Fig. 1). Oil forced through recesses in the pads forms a thin pressurized film between the pad and the runner providing a very stiff and low friction bearing. Walls are mounted on the inner and outer edges of the runner to form a reservoir into which the oil is discharged and from which it is drawn for recirculation through the pumping system. The runner is made up of 11 segments fastened together with moment- and shear-carrying joints to form a continuous ring. While all of the joints are carefully sealed, oil leakage may occur at the runner joints and between the reservoir walls and the runner edges. The runner sits on sole plates which in turn are supported on a dry-packed grout. The grout is placed after the runner has been leveled, with the sole plates brought up hard against the bottom of the runner. The sole plates are keyed into the grout, while the runner can move across them if required by thermal expansion and contraction.

III. Grout Material

The "dry-pack" grout is composed of a mixture of 1 part Type II portland cement to 1.5 parts (by weight) washed concrete sand. Sufficient water is added and mixed in so that the material upon placement and packing under the sole plate will hold together and retain its dimensions and density. The water-cement ratio (by weight) is approximately 0.23 for the materials used at Goldstone. The grout material characteristically has a compressive strength of 6.9-8.3 MPa (10,000-12,000 psi).

The dry-pack grout mixture is definitely dry – so dry that even engineers experienced in concrete construction may consider it unfit for use. Actually, usual plastic concrete mixes contain almost twice as much water as is required for the full hydration of the cement, the extra water being necessary to make the concrete workable and placeable.

IV. Tests on Oil Saturated Grout Material

A. Test Description

The first series of tests were made for compressive strength and modulus of elasticity of dry-pack mortars and concretes, with and without oil-saturation. Also determined were the drying shrinkage characteristics of the untreated (no oil) mortars and concretes. In the first phase (Phase I) of this test program, the aggregates used were laboratory selected materials, and in Phase II the aggregates were of the same type and from the same sources as those used for the dry-pack mortar currently being employed in the grout replacement program of the antenna at DSS 14. In addition to Type II portland cement, a mixture using ChemComp cement was also included in Phase II of the test program in order to evaluate its potential in reducing the shrinkage and oil absorption characteristics of the dry-pack mortars and concretes. The mix proportions of 1:1.5 (cement:aggregate) used for the mortars and concretes of this investigation are the same as those used for the actual antenna grout at DSS 14. The aggregate in the mortar mixes was only washed concrete sand, whereas for the concrete the aggregate was about a 50:50 blend of washed concrete sand and 3/8-inch pea gravel.

The dry-pack mortar and concrete specimens were cast in steel molds, being compacted in layers by the use of a pneumatic sand tamper. The oil used for saturation of the mortars and concretes was ARCO-DURO 700 hydrostatic bearing oil, which is the same type of oil used in the bearings of the antennas. More detailed information on the materials used, preparation of specimens, and test procedures is given in Appendix A.

B. Test Results

Results obtained in the two phases of the test program are summarized in Tables 1 and 2. These results show that oil saturation of the dry-pack mortars and concretes has no significant influence on their compressive strength or compressive modulus of elasticity. Averaging all of the test results obtained on both the dry-pack mortars and concretes, oil saturation reduced their average compressive strength from 8.0 to 7.66 MPa (11,160 to 11,110 psi) and the modulus of elasticity from 4.23 to 4.20. These very small differences in the average values seem to indicate that oil saturation has no effect (8.0 to 7.66 MPa) on strength or modulus of elasticity, and that any differences observed for a given group of dry-pack mortar or concrete specimens are probably due to experiment variations during preparation of specimens, oil saturation and testing. Results also show that the use of ChemComp cement instead of the Type II cement (Table 2) did not have any significant influence on compressive strength or modulus of elasticity of the dry-pack mortar or concrete.

The average oil absorption of the mortars and concretes was about 3.5 percent (oven-dry basis), which is about the same as that determined in earlier tests made by the Smith-Emery Company, as shown in their report dated December 15, 1975. As is to be expected, the oil absorptions are slightly lower for the concretes than for the corresponding mortars. The same is true for the drying shrinkage. The use of the ChemComp cement, although reducing the net drying shrinkage, did not reduce the oil absorption of the dry-pack materials.

C. Conclusions

Based on the results of the first series of tests, it may be concluded that oil saturation of short duration, as used in this test program, has no significant effect on the compressive strength or modulus of elasticity of the dry-pack mortars or concretes. The materials and mix proportions currently being employed for the runner grout at the Goldstone Antenna produce a dry-pack material of high strength and low shrinkage characteristics.

V. Tests of Cyclic Loading of Oil Saturated Grout

A. Test Description

The second and final series of tests were carried out to determine the influence of oil saturation of laboratory prepared mortar samples subjected to cyclic and long-term static loading (creep tests). Also determined was the influence of degree of oil saturation of field samples on compressive strength.

B. Tests on Laboratory Prepared Mortars

In this investigation laboratory prepared dry-pack mortars were evaluated under cyclic and long-term static load conditions (creep), with and without oil saturation. The sand and the Type II cement used in the preparation of the laboratory mortars were of the same type and from the same sources as those being employed in the grout replacement program of the Goldstone Antenna. Also, the mix proportions of 1:1.5 (cement/sand) and the water-cement ratio of 0.22 used for the mortars are similar to those used in the field.

As in the tests on oil saturated grout material, the dry-pack mortar specimens were cast in steel molds and compacted in 3.8 cm (1-1/2-in.) layers using a pneumatic sand tamper. The oil used for saturation was ARCO-DURO hydrostatic bearing oil, which is the same type of oil used in the bearings of the antennas. More detailed information on the materials, mix proportions, mixing and casting procedures and oil-saturation of the specimens is given in Appendix A.

C. Effect of Cyclic Loading

The influence of cyclic loading on oil saturated mortar was determined by applying a cyclic compressive load on the top surface of a mortar specimen, which simulates the interface between the mortar and the steel plate at the Goldstone Antenna. The specimen used was 5.24 cm (6 in.) in diameter and 5.08 cm (2 in.) thick and was immersed in an oil bath during the cyclic loading to ensure that a film of oil is present between the top surface of the mortar and the steel plate transmitting the cyclic load, as is the case in field application. The specimen was subjected to a total of 21,000 cycles in compression, of which the first 13,500 were from 34 KPa to 724 KPa (50 to 1050 psi).

The cyclic load test was performed in a MTS cyclic testing machine. Each cycle, which lasted 60 s, had the load maintained for 27.5 s, a rest period of 27.5 s, with the loading and unloading being done in 2.5 s. Every few hundred cycles a stress-strain curve was obtained on an X-Y recorder and any change in the modulus of elasticity was determined by scaling the X-Y stress-strain plots. The results obtained (Fig. 2) indicate that there was no deterioration of the mortar during the cyclic loading, as judged from the fact that the modulus of elasticity remained practically constant throughout the tests. The 21,000 cycles used represent almost 10 years of load application in the field, assuming that the antenna rotates on the average of six times per day.

D. Long-Term Static Load Tests

Both the oil saturated and untreated (no oil) control specimens were tested for creep characteristics by subjecting them to a sustained compressive stress of 2.8 MPa (4000 psi) (about 40 percent of ultimate strength) for a period of 7 months (210 days). The results obtained on the 7.62 by 15.24 cm (3 by 6 in.) cylindrical specimens are shown in Fig. 3. The data show that oil saturation of the dry-pack mortar has no significant influence on the elastic or creep deformation.

E. Strength of Samples Taken from the Goldstone Antenna

Although all of the results obtained on laboratory prepared samples have indicated that oil-saturation has no significant effect on compressive strength, a visual inspection of the samples removed from the Goldstone antenna clearly indicated some deterioration of the oil soaked mortar, especially near the top of the 7.6 cm (3 in.) thick layer where it is in contact with the steel plate of the hydrostatic bearing runner. Many of these surfaces were relatively soft and had a sandy appearance. This damage to the top layer of the mortar may have been caused by the oil permeating the top layer of the dry-pack mortar at an early age, or by improper tamping when placed.

To evaluate the influence of oil-saturation on the degree of damage to the mortar, compressive strength was determined on a number of samples taken from the Goldstone antenna which had varying degrees of oil saturation. These samples, all representing the top layer of the mortar, were cut into small prismatic specimens having an area of about 0.27 cm^2 (1.7 sq. in.) and a height of about 4.4 cm (1-3/4 in.). The results obtained are summarized in Table 3, and a plot of the compressive strength against degree of saturation is given in Fig. 4. The degree of saturation was determined only by visual inspection by determining the proportion of the sample containing oil. As shown by the data in Fig. 4 the degree of oil saturation has a significant influence on the strength of the mortar. For mortar containing no oil, the strength is about 6.3 – 8.3 MPa (10,000 – 12,000 psi), whereas for the fully oil saturated samples the compressive strength is in the range of only 4.1 – 5.5 MPa (6000 – 8000 psi).

F. Conclusions

Based on the results obtained, it appears that oil saturation of the laboratory prepared specimens does not fully represent the oil-saturated samples obtained from the Goldstone antenna. As was shown in the first series of tests, oil saturation of laboratory prepared specimens had no significant effect on compressive strength or modulus of elasticity. Also, as shown in this report, oil saturation does not affect the properties of mortars when subjected to cyclic or long-term loads. However, a limited number of compressive strength tests made on samples of the top layer of mortar taken from the Goldstone antenna show a significant loss of strength with increasing degree of oil saturation. This deterioration of the quality of the grout may have been caused by the oil getting into the top layer of the grout at an early age, either during the dry-pack operation or prior to the mortar being sufficiently cured.

Table 1. Properties of dry-pack mortars and concretes containing U.C. laboratory aggregates

Mojave Type II cement; sand, F.M. 2.90; 1/2-in. max. size coarse aggregate
Mix proportion: mortar 1:1.5 (cement:sand), concrete 1:0.8:0.7 (cement:sand:coarse aggregate)

	Non-oil-soaked specimens								Oil-soaked specimens[c]		
Mix	W/C	Compressive[a] strength (28 days)	E[a], psi (28 days)	Drying shrinkage, %[b], days					Compressive[a] strength (28 days)	E, (28 days)	Oil absorption, % by weight
Mortar	0.21	69.6 MPa (10,100 psi)	4.0×10^6	0.012	0.022	0.031	0.038	0.051	77.9 MPa (11,300 psi)	27 GPa (3.9×10^6 psi)	3.2
Gravel concrete	0.22	76.5 MPa (11,100 psi)	4.4×10^6	0.007	0.013	0.017	0.022	0.032	75.1 MPa (10,900 psi)	30 GPa (4.3×10^6 psi)	2.5
Crushed limestone concrete	0.23	80 MPa (11,600)	4.0×10^6	0.005	0.009	0.014	0.019	0.030	77.2 MPa (11,200 psi)	30 GPa (4.3×10^6 psi)	2.8

[a]Average of three 76 × 150 mm (3 by 6-in.) cylinders sealed in plastic to age of test (28 days).

[b]Average of three 3 by 76 × 254 mm (3 by 10-in.) prisms sealed in plastic for 14 days and then exposed to drying at 50 percent relative humidity.

[c]Same size specimens as non-oil-soaked. Specimens sealed for 7 days, then oven-dried and vacuum saturated with ARCO-DURO 700 hydrostatic bearing oil; 1 day vacuum, 5-days oil at 690 kPa (100 psi).

Table 2. Properties of dry-pack mortars and concretes containing Conrock Co. aggregates (San Bernardino)

Washed concrete sand; F.M. 2.82, 3/8-in. max. size gravel
Mix proportions: mortar 1:1.5 (cement:sand), concrete 1:0.75:0.75 (cement:sand:coarse aggregate)

Mix	W/C	Compressive[a] strength (28 days)	E × 10^6,[a] psi (28 days)	1	3	7	14	28	56	Compressive strength (28 days)	E (28 days)	Oil absorption, % by weight
Mojave Type II	Mortar 0.20	84.1 MPa (12,200 psi)	4.6	0.007	0.011	0.018	0.024	0.031	0.040	82.0 MPa (11,900 psi)	30 GPa (4.4 × 10^6 psi)	3.8
Portland cement	Concrete 0.19	72.4 MPa (10,500 psi)	4.3	0.004	0.009	0.015	0.021	0.028	0.036	76.5 MPa (11,100 psi)	28 GPa (4.1 × 10^6 psi)	3.4
Chem-Comp cement	Mortar 0.20	85.5 MPa (12,400 psi)	4.4[c] 4.4[d]	+0.011 0.006	+0.011 0.011	+0.007 0.019	+0.002 0.028	0.018 0.032	0.027 0.041	78.6 MPa (11,400 psi)	30 GPa 4.3 × 10^6 psi)	4.6
	Concrete 0.19	70.3 MPa (10,200 psi)	3.9[c] 3.9[d]	+0.004 0.004	0.000 0.009	0.006 0.016	0.014 0.025	0.024 0.030	0.033 0.040	68.9 MPa (10,000 psi)	28 GPa (4.1 × 10^6 psi)	4.4

[a]Average of three 76 × 150 mm (3 by 6-in.) cylinders sealed in plastic to age of test (28 days).

[b]Average of three 76 × 254 mm (3 by 10-in.) prisms; average of three 76 × 254 r wall (3 × 10 in.) prisms; sealed in plastic for 14 days and then exposed to drying at 50 percent relative humidity.

[c]Shrinkage values include early age expansion (+ values are expansion).

[d]Values are for drying shrinkage only, not including early age expansion.

[e]Same size specimens as non-oil-soaked. Specimens sealed for 7 days in plastic.

Table 3. Influence of degree of oil saturation on compressive strength of mortar[a] removed from Goldstone antenna

Mortar sample	Specimen No.	Degree of saturation, %	Compressive strength, MPa (psi)
A	1	0	72.4 (10,500)
	2	0	82.0 (11,900)
	3	100	44.1 (6400)
	4	100	54.5 (7900)
B	1	5	105.5 (15,300)
	2	30	78.6 (11,400)
C	1	3	66.2 (9600)
	2	15	64.8 (9400)
D	1	0	90.3 (13,100)
	2	5	88.9 (12,900)
E	1	100	53.1 (7700)
	2	100	51.7 (7500)
	3	100	51.0 (7400)
	4	100	46.2 (6700)
F	1	100	40.7 (5900)
	2	100	34.5 (5000)
G	1	3	72.41 (10,500)
	2	10	71.0 (10,300)
	3	30	68.9 (10,000)
	4	100	44.1 (6400)
	5	100	44.8 (6500)
	6	100	49.6 (6200)
H	1	5	49.0 (7100)
	2	95	36.5 (5300)
I	1	0	76.5 (11,100)
	2	50	63.4 (9200)
J	1	0	62.1 (9000)
	2	30	60.0 (8700)
	3	40	50.3 (7300)
	4	55	54.5 (7900)

[a]Specimens cut from mortar samples. Average area of sample 1100 mm^2 (1.7 $in.^2$) and a height of 34 mm (1-3/4 in.).

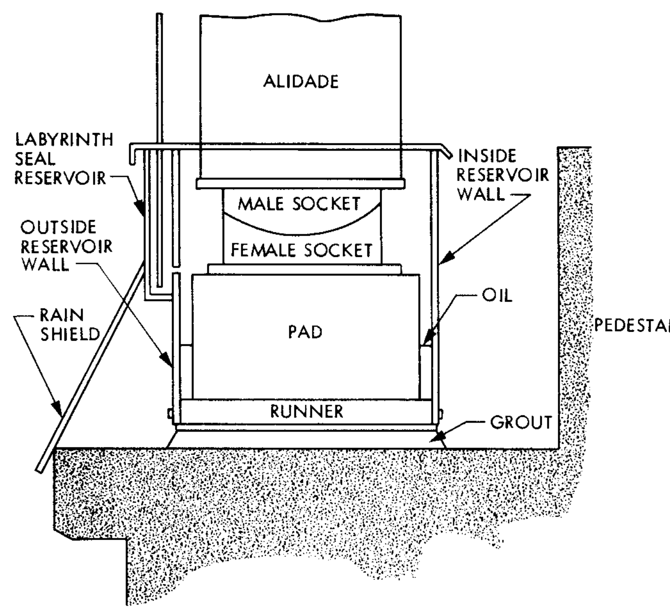

Fig. 1. Cross section of hydrostatic bearing runner and pad

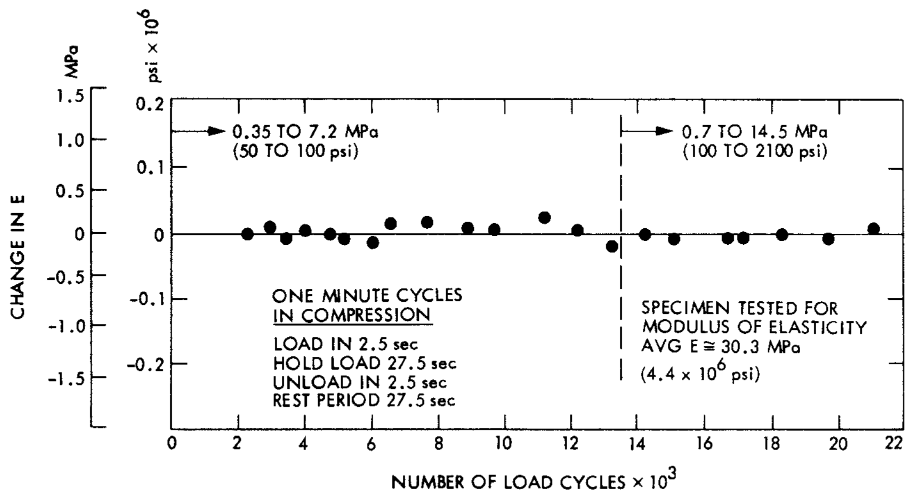

Fig. 2. Effect of cyclic loading of oil-saturated mortar on modulus of elasticity

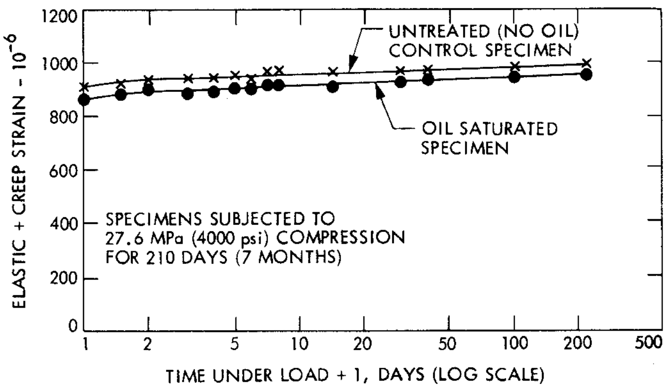

Fig. 3. Effect of long-term static load on creep of oil-saturated and control (no oil) mortars

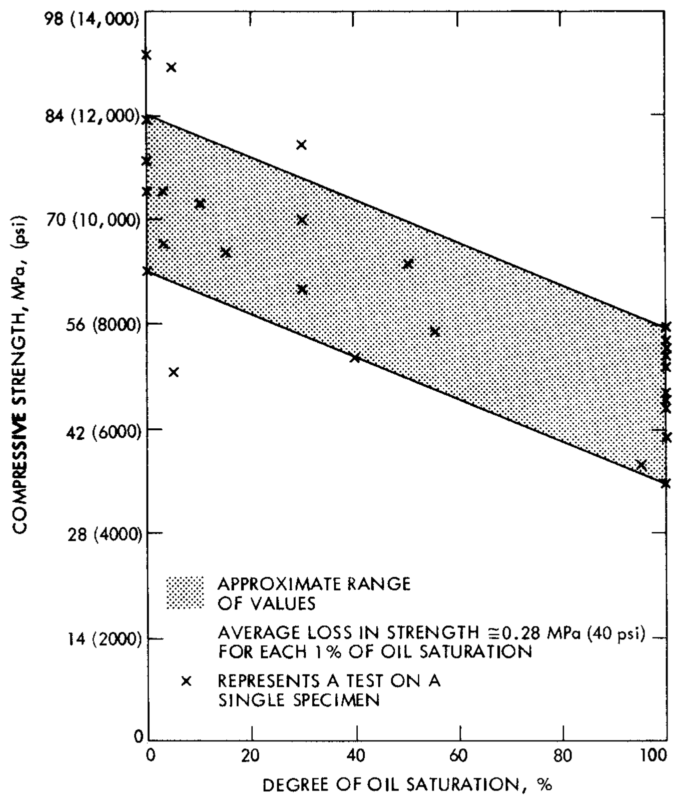

Fig. 4. Influence of oil saturation on compressive strength of mortar removed from the Goldstone antenna

Appendix A

Dry-Pack Mortars and Concretes: Materials and Test Procedures

Given in this Appendix is information on materials, mix proportions, mixing, casting, curing and testing of plain and oil-saturated dry-pack mortars and concretes.

I. Materials and Mix Proportions

The materials and proportions used for the dry-pack mortars and concretes of this test program are summarized in the following tabulations:

Phase I – Mixes Containing Laboratory Aggregates

Mix proportions –

Mortar:	1:1.5 (cement:sand); W/C = 0.21
Concrete:	1:0.8:0.7 (cement:sand:coarse aggregate)
	W/C = 0.22 for gravel mix; 0.23 for limestone mix
Cement –	Type II Portland cement, Mojave brand, California Portland Cement Co.
Sand –	Pleasanton top sand; F.M. 2.90, sp. gravity 2.67, absorption 1.3 percent
Coarse aggregate –	1/2-in. river gravel, Fair Oaks, California; sp. gravity 2.82, absorption 1.1 percent 13 mm crushed limestone, Kaiser sand and gravel Co.; sp. gravity 2.70, absorption 1.1 percent

Phase II – Mixes Containing Conrock Aggregates, San Bernardino, California

Mix proportions –

Mortar:	1:1.5 (cement:sand); W/C = 0.20
Concrete:	1.0.75:0.75 (cement:sand:coarse aggregate) W/C = 0.19
Cements –	Type II Portland Cement, Mojave brand, California Portland Cement Co.; and Chemcomp Cement, Southwestern Cement Co.
Sand –	Conrock Co., washed concrete sand; F.M. 2.87, sp. gravity 2.66, absorption 1.2 percent
Coarse aggregate –	3/8-in. gravel, Conrock Co., San Bernardino, California; sp. gravity 2.66, absorption 1.3 percent
Water –	Chilled with ice chips to 2.7 ± 1.7°C (37 ± 3°F)

The water/cement ratios used were selected to produce mortars or concretes suitable for a dry-pack application as judged during the manufacture of the specimens. A rubbery behavior during dry packing indicated an excessive amount of water and a tendency to crumble an insufficient amount of water.

II. Mixing and Casting Procedures

The mixing of the Phase I mortars and concretes was done in a pan-type mixer of 14 dm^3 (1/2-cu ft) capacity. Any lumps formed during the mixing operation were broken up by passing the freshly mixed dry-pack materials through a screen having an opening one size greater than the minimum size aggregate. The mixing of the Phase II mortars and concretes was done in a laboratory-size Hobart bowl type mixer (ASTM C 305). The use of this type mixer prevented the formation of lumps.

The casting of the specimen 7.6 × 150 mm (3 by 6 in.) cylinders and 7.6 × 25 mm (3 by 10 in.) prisms was done in 38 mm (1.5 in.) layers, each layer being compacted with a laboratory-size pneumatic sand tamper equipped with a 38 mm (1.5 in.) diameter tamping head. The tamper was operated at an air pressure of 345 kPa (50 psi). The duration of compaction of each 40 mm (1.5 in.) layer was 30 s for the cylinders and 120 s for the prisms. To ensure uniformity of compaction of the test samples, all specimens were cast with an extra 40 mm (1.5 in.) layer on top (using mold extension) which was cut off immediately after completion of casting.

III. Curing, Oil Saturation, and Testing Strength of Specimens

The curing conditions and test schedule for the non-oil-soaked (control) and oil-soaked 76 × 150 mm (3 × 6 in.) specimens used to determine compressive strength and modulus of elasticity are summarized in the following tabulations:

Non-oil-soaked specimens (control)	Total time, days
7 days in mold; sealed with plastic to prevent moisture loss; demolded at age 7-days	0-7
7 days sealed in plastic	7-14
1 day drying in 230°F oven	14-15
6 days storage at 50% relative humidity	15-21
Test at age 21 days for compressive strength and modulus of elasticity	21
Oil soaked specimens	
Same as for non-oil-soaked controls	0-15
Same as for non-oil-soaked controls	0-15
Same as for non-oil-soaked controls	0-15
Vacuum saturation with oil, 6-days	15-21
Test at age 21 days for compressive strength and modulus of elasticity	21

The oil used for saturation of the mortar or concrete specimens was ARCO-DURO 700 hydrostatic oil, which is the same type of oil used for the antenna bearings. The procedure used in vacuum-saturating the dry-pack mortar or concrete specimens with oil consisted of subjecting them first to a vacuum of 710 mm (28 in.) mercury for 24 hours; then while maintaining this vacuum the saturation chamber was filled with oil, and after shutting off the vacuum a pressure was applied to the oil and maintained for 5 days. The oil pressure used for the Phase I specimens was 690 kPa (100 psi) and for the Phase II specimens 896 kPa (130 psi). The amount of oil absorbed by the test samples was determined from the weight of the specimens before and after oil saturation and expressed as a percentage of the oven-dry weight.

The compressive strength tests on all of the 76 X 150 mm (3 by 6 in.) mortar and concrete specimens were performed in accordance with ASTM C 39 method of test, "Compressive Strength of Cylindrical Concrete Specimens." The procedure used for determining the modulus of elasticity was based on ASTM C 469, "Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression." The longitudinal deformations of the test specimens during the compression strength test were measured by two linear variable differential transformers (LVDT's).

IV. Curing and Testing of Drying Shrinkage Specimens

The 76 X 254 mm (3 by 10 in.) drying shrinkage prisms remained in their molds and were sealed in plastic for 7 days; then after demolding they were resealed in plastic to prevent moisture loss and remained sealed for an additional 7 days. At age 14 days the seal was removed and the specimens exposed to air maintained at 50 percent relative humidity. Measurements of drying shrinkage were made using a vertical dial gage comparator after 1, 3, 7, 14, and 28 days exposure to the dry 50 percent relative humidity. The drying shrinkage was expressed as a percentage length change.