

UNCLASSIFIED

AD 428478

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

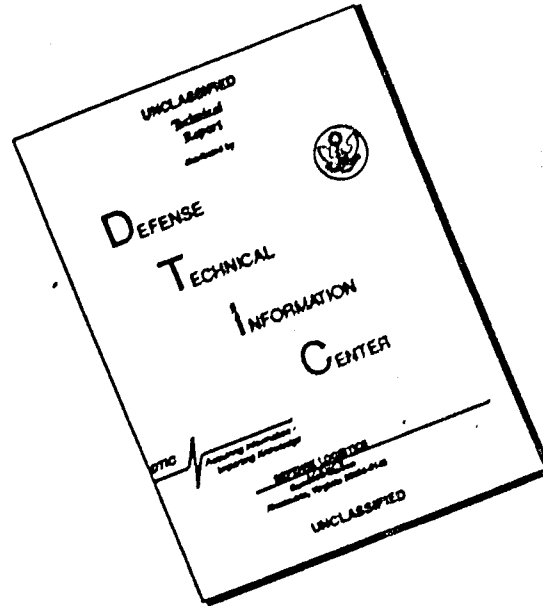
CAMERON STATION, ALEXANDRIA, VIRGINIA



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

# DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

UNITED STATES  
DEPARTMENT OF THE INTERIOR  
BUREAU OF RECLAMATION

LENGTH CHANGE OF CONCRETE CONTAINING GLEN CANYON  
DAM AGGREGATE AND VARIOUS CEMENTS, POZZOLANS  
AND/OR A LIGNIN-TYPE RETARDING AGENT

CONCRETE AND STRUCTURAL BRANCH

Laboratory Report No. C-1068

DIVISION OF RESEARCH



OFFICE OF CHIEF ENGINEER  
DENVER, COLORADO

November 11, 1963

428478

CATALOGED BY DDC  
AS AD No.

428478

FEB 4 1964  
TSD 5

The information contained in this report may not be used in any publication, advertising, or other promotion in such a manner as to constitute an endorsement by the Government or the Bureau of Reclamation, either explicit or implicit of any material, product, device, or process that may be referred to in the report.

CONTENTS

	<u>Page</u>
Introduction . . . . .	1
Conclusions . . . . .	1
Test Apparatus and Procedures . . . . .	2
Materials . . . . .	2
Apparatus . . . . .	3
Procedures . . . . .	3
Discussion . . . . .	3
Acknowledgment . . . . .	5

	<u>Table</u>
Pozzolans Used in Laboratory Concrete Mixes . . . . .	1
Drying-shrinkage Length Change, Compressive Strength, and Elastic Properties of Preliminary Concrete Mixes Containing Pozzolans . . . . .	2
Length Change, Compressive Strength, and Elastic Properties of Preliminary Concrete Mixes Containing Pozzolans . . . . .	3
Autogenous and Drying-shrinkage Length Change, Compressive Strength, and Elastic Properties of Mass Concrete . . . . .	4
Length Change, Compressive Strength, and Elastic Properties of Mass Concrete Containing a Retarding Agent . . . . .	5

	<u>Figure</u>
Expansion of Fog-cured Concrete Containing Pozzolans . . . . .	1
Drying Shrinkage of Concrete Containing Pozzolans . . . . .	2
Drying Shrinkage of Mass Concrete Containing Various Types of Pozzolans . . . . .	3
Drying Shrinkage of Mass Concrete Containing Various Types of Pozzolans . . . . .	4
Drying Shrinkage of Mass Concrete Containing Various Types of Pozzolans . . . . .	5
Drying Shrinkage of Mass Concrete Containing a Retarding Agent . . . . .	6
Drying Shrinkage of Mass Concrete Containing a Retarding Agent Cured under Different Conditions . . . . .	7
Length Change of Mass Concrete Cured under Different Conditions . . . . .	8
Steel Molds Used in the Fabrication of 4- by 4- by 30-inch Concrete Test Specimens . . . . .	9
Vibrating Table Used to Consolidate Fresh Concrete in the Preparation of Test Specimens . . . . .	10
Horizontal Comparator for Measuring Length Change of 4- by 4- by 30-inch Concrete Specimens . . . . .	11

CONTENTS--Continued

	<u>Figure</u>
Electronic Equipment for Determining Young's Dynamic Modulus of Elasticity . . . . .	12
Frame and Loading Head Used in Flexure and Modulus of Rupture Tests . . . . .	13

UNITED STATES  
DEPARTMENT OF THE INTERIOR  
BUREAU OF RECLAMATION

Office of Chief Engineer	Laboratory Report No. C-1068
Division of Research	Compiled by: J. R. Graham
Concrete and Structural Branch	Checked by: E. M. Harboe
Denver, Colorado	G. G. Hoagland
November 11, 1963	Reviewed by: J. E. Backstrom
	Submitted by: E. C. Higginson

Subject: Length change of concrete containing Glen Canyon Dam aggregate and various cements, pozzolans and/or a lignin-type retarding agent.

#### INTRODUCTION

Glen Canyon Dam, located on the Colorado River in northern Arizona, is a gravity-arch dam containing 5 million cubic yards of concrete. As in nearly all recently constructed Bureau of Reclamation massive concrete dams, the concrete in the dam proper contains a pozzolanic material as a replacement for a portion of the cement. The two principal reasons for using pozzolan are (1) economy, and (2) the reduction of heat generation during hydration accruing to its use. Further economies and advantages in the form of reduced cementitious material content, and the attendant reduction in heat generation, usually accompany the use of water-reducing, set-retarding agents.

A preliminary pozzolan investigation, reported in Concrete Laboratory Report No. C-882, evaluated, for compliance with requirements of Specifications No. DS-5053, pozzolans from 74 sources. Selected pozzolans from these sources that met all specifications requirements together with 12 additional pozzolans from different sources, Table 1, were subjected to tests in concrete. Preliminary laboratory concrete investigation, partially reported in Concrete Laboratory Report No. C-526A, was undertaken to evaluate the individual and/or combined effects of various pozzolans and a single lignin base retarding agent on selected properties, such as compressive strength, elastic properties, and length change, including autogenous and drying shrinkage and expansion due to prolonged moist curing of Glen Canyon Dam concrete. Reported herein are the results of this investigation.

#### CONCLUSIONS

From results of tests reported herein, the following conclusions appear to be justified:

1. The use of any of the pozzolans tested; namely, fly ash, clay, shale, pumice, volcanic ash, and blast furnace slag (1) increased, except for fly ash, the water requirement, (2) slightly increased

autogeneous shrinkage, (3) significantly increased drying shrinkage, and (4) decreased the compressive strength (modified cubes) and elastic properties as compared to similar values obtained from control concretes, Tables 2-4, Figures 2-5.

2. Addition of calcium lignosulfonate retarding agent to concrete mixes reduced the water requirement about 10 percent while maintaining the same workability, and generally resulted in somewhat increased drying shrinkage, Table 5, Figures 6, 7, and 8.

3. Expansion of continuously fog-cured concrete containing pozzolan in the amount of 30 percent by weight of cementitious material exceeds the average expansion of control concrete containing no pozzolan by 33 to 120 percent, Figure 1.

#### TEST MATERIALS, APPARATUS, AND PROCEDURES

##### Materials

Aggregate for the laboratory concrete mixes was obtained from the Wahweap deposit which is located about 7 miles northwest of Glen Canyon Dam. The pit run material was shipped to the Denver laboratories, after which it was washed and screened through the laboratory aggregate-processing plant. After drying, the sand was separated into six sizes, Sieves No. 8, 16, 30, 50, 100, and pan, through jigger screens. Lightweight material was removed from the No. 8 size sand and coarse aggregate by the heavy media separation process. Physical properties were then obtained for use in concrete mix design, prior to storing for subsequent use in concrete mixes.

Concrete mixes contained five different Type II, low-alkali cements as follows: Laboratory Samples No.; M-2400, an equal blend of cements obtained from 10 different sources; M-3196, from California; M-3100, an equal blend of cements obtained from 10 different sources; M-3329, from California; and M-3688, from Arizona. Concrete mixes contained 22 different laboratory samples of pozzolans consisting of the following types: clay, shale, pumice, fly ash, and volcanic ash. Pozzolan samples were obtained from various locations throughout the middle and far west states, except for a few which were obtained from the same source, but ground to different finenesses, or calcined under different conditions.

Calcium lignosulfonate water-reducing, set-retarding agent, in the amount of 0.37 percent by weight of cementitious material, was used in seven of the concrete mixes, namely Nos. 99, 103, 112, 116, 123, 134, and 161.

Neutralized vinsol resin (NVX) was the air entraining agent used.

#### Apparatus

Equipment used in the fabrication of the 4- by 4- by 30-inch test specimens consisted of steel molds, Figure 9, and a vibrating table on which the molds were placed for consolidation of the fresh concrete, Figure 10. Length change of the specimens was measured on a horizontal comparator, Figure 11. Data for determining Young's dynamic modulus of elasticity were obtained from an electronic system consisting of an audio oscillator, a driver and pickup, and an amplifier-oscilloscope indicator, Figure 12. Flexural modulus of elasticity and modulus of rupture data were obtained by use of a loading frame and dial gages, shown in the 120,000-pound Universal testing machine, Figure 13.

#### Procedures

Four- by four- by thirty-inch specimens for the first series (Mixes No. P-1 through P-21) were fabricated from mixes initially designed to contain 1-1/2-inch-maximum-size aggregate; whereas, specimens of the same size for the second series (Mixes No. 31 through 161) were fabricated from a mass concrete mix that was wet-screened to contain 1-1/2-inch-maximum-size aggregate. Drying shrinkage specimens (Nos. 5 and 6) were cured at 100 percent relative humidity and 73.4° F for 14 days and then at 50 percent relative humidity and 73.4° F until 1 year's age. Autogenous cured specimens (Nos. 19 and 20) were hermetically sealed in copper jackets immediately after fabrication and stored at 73.4° F for the duration of tests. Specimens No. 1 and 2 were continuously cured at 100 percent relative humidity and 73.4° F. All specimens were measured for length change and Young's modulus of elasticity periodically.

Each of the specimens, after 1 year of curing under their individual curing conditions, was tested in flexure. Specimens, when tested in the flexure frame, were rotated one-quarter turn from the position in which they were fabricated. Autogenous cured specimens and those with rough surfaces were sulfur capped at the bearing points, Figure 13. Compressive strengths of modified cubes were determined after the flexure tests.

#### DISCUSSION

This investigation included 18 relatively rich preliminary concrete mixes containing 30 percent pozzolan (five types) by weight of cementitious material, Tables 1, 2, and 3. Also included were 21 comparatively lean concrete mixes containing 33 percent

pozzolan (four types) by weight of cementitious material in nine different blends, Table 4. In addition were 13 mixes containing 4 different blends of pumice pozzolan generally in the amount of 33 percent by weight of cementitious material, with 7 of these mixes containing 0.37 percent calcium lignosulfonate-retarding agent by weight of the cementitious material, Table 5. The 13 latter mixes contained 3 different blends of cement. Results of tests performed on the preliminary concrete mixes, Figures 1 and 2, indicated that pozzolans are suitable, with respect to length change, for use in interior mass concrete. The cementitious material in these pozzolan mixes was composed of 30 percent pozzolan (140 to 169 lb/cu yd) and 70 percent cement (315 to 393 lb/cu yd); whereas, the control mixes contained approximately an equivalent weight of cement but no pozzolan, Tables 2 and 3. The second set of mixes, Tables 4 and 5, was prepared with a lower cement content than the "P" series and 33 percent pozzolan to determine the feasibility of using a more economical and workable mix with pozzolans.

From a comparison of the drying shrinkage of specimens fabricated from Mixes No. 111 and 112 with 115 and 116, there are indications of greater drying shrinkage attending the use of a coarser pozzolan.

Results of tests on specimens continuously moist cured (Nos. 1 and 2) indicate that the addition of pozzolans to the mixes will increase the expansion of concrete as compared to the expansion of nonpozzolan concrete similarly cured.

Two sets of sealed bars were fabricated to determine whether or not any free surface moisture remains after 14 days of curing at 73.4° F. The first set (GCD-111, 19, and 20) contained no retarder, while the second set (GCD-112, 19, and 20) contained a calcium lignosulfonate-retarding agent, and both sets of specimens contained pozzolan. There was no free surface moisture apparent on any of the specimens when the copper jackets were removed after 14 days. These bars were then stored at 50 percent relative humidity and 73.4° F to 1 year's age, at which time they had developed a slightly higher shrinkage than companion specimens that had been initially stored for 14 days at 100 percent relative humidity and 73.4° F, Figure 7.

#### ACKNOWLEDGMENT

Significant contributions were made to this investigation and subsequent report by J. C. Librande, L. R. Carpenter, H. S. Fouts, H. F. Avery, E. L. Ore, and the Mix Design Unit. Appreciation is extended to all who contributed their technical assistance and cooperation.

Table 1

POZZOLANS USED IN LABORATORY CONCRETE MIXES  
Length Change Investigation  
Glen Canyon Dam

<u>Pozzolan</u> <u>No.</u>	<u>Type</u>
M-2529 <sup>1/</sup>	Clay
M-2575 <sup>1/</sup>	Clay
M-2537	Shale
M-2540	Pumice
M-2564	Fly ash
M-2626	Shale
M-2833 <sup>3/</sup>	Clay
M-2834 <sup>3/</sup>	Clay
M-2835	Volcanic ash
M-2858	Volcanic ash
M-2883	Pumice
M-2907-C3 <sup>2/</sup>	Shale
M-2907-C4 <sup>3/</sup>	Shale
M-2909-A	Volcanic ash
M-2942	Pumice
M-2942-A	Pumice
M-2942-B	Pumice
M-3439-A	Pumice
M-3439-B	Pumice
M-3470-B	Pumice
M-3587	Pumice
M-3837	Pumice

<sup>1/</sup> Calcined by producer.

<sup>2/</sup> Calcined for 3 hours at 1,600° F.

<sup>3/</sup> Calcined for 4 hours at 1,600° F.

Pozzolans M-2529 through M-2626 were used  
in P-1 through P-21 mix series.

A and B denotes the fineness of the pozzolan,  
A being the coarser of the two.

Table 2

DRYING-SHRINKAGE LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF PRELIMINARY CONCRETE MIXES CONTAINING POZZOLAN  
Length Change Investigation--Glen Canyon Dam

Mix No.	Concrete Mix Data				Air Slump % in.	Bar No. 3/	Length Change Data			Modulus of rupture, psi	Flexural E, million psi	Dynamic E, million psi
	W lb/yd <sup>3</sup>	C+P lb/yd <sup>3</sup>	Water lb/yd <sup>3</sup>	Cement lb/yd <sup>3</sup>			Pozzolan lb/yd <sup>3</sup>	Days of drying 14: 28: 90: 120: 180: 270: 365: cubes, psi	Drying shrinkage Length change in millionths 14: 28: 90: 120: 180: 270: 365: of modified: of rupture, psi			
P-1	0.53	252	474	0	0	3.0	P-1 (5-6)	225:305:462:492:512:520:522:	6,040	760	4.4	4.4:5.0:5.0
P-1R	0.53	251	471	0	0	3.3	P-1R (5-6)	255:332:486:520:550:565:568:	6,060	740	4.2	4.4:4.8:4.9
P-2	0.60	279	326	30	140	3.4	P-2 (5-6)	330:425:578:617:665:693:702:	4,960	575	3.0	3.2:3.7:3.4
P-3	0.60	280	328	30	141	4.7	P-3 (5-6)	330:425:578:617:665:693:702:	4,870	610	3.0	3.2:3.8:3.5
P-4	0.60	283	331	30	143	4.1	M-2537:Shale	370:482:652:682:707:723:730:	5,020	600	3.2	3.3:4.0:3.6
P-5	0.55	261	329	30	142	4.2	M-2540:Pumice	370:482:652:682:707:723:730:	5,070	560	3.2	3.5:4.1:3.6
P-6	0.51	239	327	30	141	4.9	M-2564:Fly ash	255:332:486:520:550:565:568:	5,670	660	4.0	3.9:4.3:4.5
P-7	0.55	260	469	0	0	4.5	Blast furnace slag	370:482:652:682:707:723:730:	5,280	620	3.5	3.7:4.2:4.1
P-8	0.56	265	328	30	141	4.3	M-2626:Shale	330:425:578:617:665:693:702:	5,470	585	3.3	3.6:4.1:3.8
P-9	0.53	250	472	0	0	4.2	P-9 (5-6)	255:332:486:520:550:565:568:	5,630	770	4.0	4.2:4.6:4.7
P-11	0.53	298	393	30	169	4.4	M-2529:Clay	330:425:578:617:665:693:702:	6,000	600	3.0	3.5:3.9:3.6
P-13	0.53	279	368	30	158	4.6	M-2537:Shale	370:482:652:682:707:723:730:	5,150	580	3.2	3.3:3.9:3.7
P-14	0.53	248	469	0	0	4.2	(Control)	255:332:486:520:550:565:568:	5,630	755	4.1	4.4:4.9:4.9
P-16	0.53	257	340	30	146	4.5	M-2540:Pumice	400:516:690:721:756:775:785:	5,060	580	2.9	3.5:4.0:3.6
P-18	0.53	238	315	30	135	4.2	M-2564:Fly ash	255:332:486:520:550:565:568:	5,810	670	3.8	4.2:4.6:4.6
P-19	0.53	249	470	0	0	4.3	(Control)	255:332:486:520:550:565:568:	5,590	670	4.2	4.2:4.6:4.7
P-21	0.53	270	357	30	153	4.8	M-2626:Shale	330:425:578:617:665:693:702:	5,310	615	3.2	3.5:4.0:3.8
P-11R	0.53	293	387	30	166	4.0	P-11R (5-6)	330:425:578:617:665:693:702:	5,820	545	2.8	3.3:3.7:3.6

1/Average of two specimens.

2/Percent by weight of cementitious material.

3/Bars cured 14 days at 100 percent relative humidity and 73.4° F previous to drying at 50 percent relative humidity and 73.4° F.

4/Laboratory Sample No. M-2400, laboratory blend, Type II, low alkali.

Table 3

LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF PRELIMINARY CONCRETE MIXES CONTAINING POZZOLAN  
Length Change Investigation--Glen Canyon Dam

Concrete Mix Data				Length Change Data <sup>1/</sup>										Compressive:			Dynamic E	
Mix No.	W/C <sup>2/</sup>	Water: lb/yd <sup>3</sup>	Cement: lb/yd <sup>3</sup>	Pozzolan No.	Type	Air: %	Slump: in.	Bar No.	Length change in millionths	Days of curing	Modulus of rupture, psi	Flexural E, million, psi	Flexural E, million, psi	Age				
									7 : 14 : 28 : 90 : 120 : 180 : 270 : 365	Days of curing	psi	million, psi	million, psi	7 : 28 : 365				
P-9	0.53	250	472	0	(Control)	4.2	3.4	P-9 (1-2)	+3 : +8 : +24 : +30 : +37 : +45 : +52	6,470	4.7	4.1	5.0	5.9				
P-11	0.53	298	393	169	M-2529:Clay	4.4	2.8	P-11 (1-2)	+30 : +49 : +84 : +93 : +109 : +117 : +122	6,830	4.3	4.1	4.6	5.4				
P-11R	0.53	293	387	166	M-2529:Clay	4.0	3.0	P-11R (1-2)	+53 : +75 : +111 : +122 : +135 : +151 : +163	6,820	4.2	3.3	4.4	5.2				
P-13	0.53	279	363	158	M-2537:Shale	4.6	2.7	P-13 (1-2)	+17 : +30 : +61 : +68 : +81 : +90 : +98	6,430	4.6	4.1	4.8	5.5				
P-14	0.53	248	469	0	(Control)	4.9	3.2	P-14 (1-2)	+15 : +27 : +53 : +62 : +69 : +79 : +84	7,000	4.8	4.3	5.1	6.1				
P-16	0.53	257	340	146	M-2540:Pumice	4.5	2.8	P-16 (1-2)	+30 : +49 : +92 : +103 : +118 : +133 : +142	7,210	4.7	3.6	4.9	5.9				
P-18	0.53	238	315	135	M-2564:Fly ash	4.2	3.2	P-18 (1-2)	+17 : +30 : +63 : +72 : +87 : +100 : +110	7,480	5.1	4.2	5.0	6.3				
P-19	0.53	249	470	0	(Control)	4.3	3.3	P-19 (1-2)	+12 : +23 : +52 : +61 : +73 : +83 : +89	6,430	5.0	4.0	4.9	6.0				
P-21	0.53	270	357	153	M-2626:Shale	4.8	2.8	P-21 (1-2)	+30 : +49 : +84 : +93 : +109 : +123 : +132	5,420	4.5	3.5	4.3	5.5				
P-9	0.53	250	472	0	(Control)	4.2	3.4	P-9 (19-20)	0 : -7 : -18 : -30 : -29 : -26 : -14	None	4.6	4.0	4.8	5.4				
P-11	0.53	298	393	169	M-2529:Clay	4.4	2.8	P-11 (19-20)	0 : -16 : -40 : -95 : -120 : -135 : -138	None	4.1	3.3	4.4	4.8				
P-13	0.53	279	368	158	M-2537:Shale	4.6	2.7	P-13 (19-20)	+2 : -8 : -29 : -80 : -94 : -115 : -129	None	4.1	3.3	4.4	4.9				
P-14	0.53	248	468	0	(Control)	4.9	3.2	P-14 (19-20)	+4 : -4 : -10 : -10 : -10 : -10 : -10	None	4.7	4.1	4.8	5.5				
P-16	0.53	257	340	146	M-2540:Pumice	4.5	2.8	P-16 (19-20)	+4 : -3 : -16 : -62 : -80 : -106 : -124	None	4.6	3.5	4.6	5.7				
P-18	0.53	238	315	135	M-2564:Fly ash	4.2	3.2	P-18 (19-20)	-7 : -13 : -19 : -36 : -40 : -44 : -44	None	5.2	3.9	4.7	5.6				
P-19	0.53	249	470	0	(Control)	4.3	3.3	P-19 (19-20)	-3 : -7 : -10 : -5 : -2 : +2 : +5	None	4.7	4.1	4.8	5.5				
P-21	0.53	270	357	153	M-2626:Shale	4.8	2.8	P-21 (19-20)	-14 : -16 : -20 : -38 : -46 : -60 : -77	None	4.4	3.4	4.4	4.9				
P-11R	0.53	293	387	166	M-2529:Clay	---	--	P-11R (19-20)	0 : -11 : -32 : -81 : -92 : -107 : -124	None	4.3	3.1	4.1	4.6				

1 Average of two specimens.

2 Bars No. 1 and 2 were cured continuously at 100 percent relative humidity and 73.4° F. Bars No. 19 and 20 were sealed in copper jackets, and stored at 73.4° F.

Table 4  
 AUTOGENOUS AND DRYING-SHRINKAGE LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF MASS CONCRETE  
 Length Change Investigation  
 Glen Canyon Dam

Mix No.	Water (CF)	Cement (lb/yd)	Pozzolans (lb/yd)	Air (slump)	Type	Concrete mix data		Drying length change data <sup>1/</sup>		Autogenous length change data <sup>2/</sup>		Compressive strength of modified cubes, psi	Modulus of rupture, million psi	Dynamic E, million psi	Age								
						Bar No.	Length change in millinths	Bar No.	Length change in millinths	Bar No.	Length change in millinths												
1	0.54	157	0	5.4	2.5	CCD-31	104:175:250:349:370:395:405:407	5.140	635	4.84	5.2:5.4:5.3:CCD-31	3-8-12	-20	-22	-27	-29	None	630	6.1	4.8:5.8:6.0			
2	0.56	161	95	5.0	2.0	CCD-32	110:204:272:394:422:450:460:465	4.240	505	3.88	4.6:4.8:4.7:CCD-32	2-5-8	7	4	-4	-21	-36	None	565	4.9	3.6:5.2:5.3		
3	0.58	165	95	5.2	2.0	CCD-33	110:204:272:394:422:459:475:482	3.920	470	3.87	4.7:4.6:4.4:CCD-33	2-5-8	6	2	-5	-21	-36	None	470	4.9	3.7:5.3:5.4		
4	0.59	162	93	6.0	2.5	CCD-34	1125:222:332:470:500:540:562:568	2.960	420	3.35	3.9:3.8:3.6:CCD-34	3-8-14	-25	-28	-34	-39	-43	None	490	5.3	3.9:5.7:5.9		
5	0.59	153	284	5.2	1.9	CCD-37	104:160:230:337:357:376:390:400	4.860	650	5.27	5.6:5.8:5.8:CCD-37	7-18-19	-10	-10	-15	-21	-25	None	615	5.7	5.4:6.0:6.2		
6	0.57	161	188	4.8	2.2	CCD-38	130:187:270:364:386:412:437:443	3.990	480	3.96	4.6:4.5:4.3:CCD-38	4-9-14	-22	-27	-41	-52	-57	None	545	5.4	4.3:5.8:6.0		
7	0.56	157	283	4.6	2.2	CCD-41	104:160:230:337:357:376:390:400	4.740	605	4.92	4.9:5.6:5.5:CCD-41	3-7-13	13	11	8	6	5	None	575	5.4	4.9:5.9:6.1		
8	0.56	158	188	4.9	2.2	CCD-42	100:180:265:430:455:465:500:507	3.190	470	3.96	4.5:4.5:4.4:CCD-42	21-14-18	8	0	-12	-21	-32	None	615	5.6	4.0:5.8:6.0		
9	0.55	151	280	4.4	2.1	CCD-43	105:166:244:381:405:420:428:435	4.960	620	5.26	5.3:5.6:5.5:CCD-43	6-10-11	4	2	1	4	5	None	675	5.6	5.0:6.0:6.1		
10	0.55	157	191	3.4	2.7	CCD-46	135:212:292:420:442:468:480:482	5.080	540	4.37	5.0:5.0:4.9:CCD-46	8-23	-35	-44	-47	-50	-52	-54	None	595	5.5	4.8:6.1:6.2	
11	0.54	151	281	4.5	2.0	CCD-49	105:166:244:381:405:420:428:435	4.800	645	5.08	5.3:5.6:5.7:CCD-49	20-18-12	2	5	8	9	9	None	620	5.7	4.8:5.8:6.0		
12	0.61	178	188	4.5	4.3	CCD-50	107:171:270:498:545:592:627:639	3.090	355	2.60	3.6:3.3:3.2:CCD-50	23-31-33	12	0	-13	-24	-32	None	430	4.2	3.3:5.0:5.2		
13	0.51	152	282	4.5	1.6	CCD-57	100:162:254:415:430:448:465:470	4.940	625	4.58	--	--	--	--	--	--	--	None	540	5.1	4.9:5.6:5.8		
14	0.55	156	190	3.3	1.5	CCD-58	1130:195:275:440:465:490:505:507	4.810	585	4.24	5.0:5.0:5.0:CCD-58	10-13	-25	-27	-31	-33	-33	None	535	5.4	4.8:5.8:6.1		
15	0.56	156	287	5.0	1.9	CCD-61	100:162:254:415:430:448:465:470	4.990	630	4.62	5.3:5.4:5.3:CCD-61	4-10-16	-27	-38	-52	-63	-71	None	585	5.4	4.9:5.9:5.9		
16	0.59	170	191	4.7	2.0	CCD-62	132:217:317:482:510:535:553:560	3.520	415	3.28	4.7:4.6:3.8:CCD-62	0	0	1	-23	-38	-52	-63	-71	None	530	4.8	3.3:5.5:5.6
17	0.64	152	276	4.3	2.1	CCD-69	75:120:185:325:350:368:380:385	3.880	530	4.70	5.0:5.3:5.2:CCD-69	7-10	11	8	-10	-11	-12	-12	None	495	5.0	4.5:5.7:5.8	
18	0.68	162	191	4.4	2.0	CCD-70	110:183:262:419:442:470:485:490	3.560	500	3.80	4.2:4.6:4.4:CCD-70	7-10	11	8	-10	-11	-12	-12	None	550	5.2	3.7:5.5:5.4	
19	0.67	160	190	4.2	1.9	CCD-71	110:175:260:425:452:475:487:493	3.000	490	3.76	4.3:4.5:4.3:CCD-71	7-10	11	8	-11	-11	-12	-12	None	600	5.6	4.0:5.8:5.9	
20	0.67	157	188	5.0	2.0	CCD-72	100:155:250:417:440:465:482:485	3.370	445	4.14	4.5:4.7:4.5:CCD-72	6-11	8	-19	-20	-21	-24	-25	None	470	5.0	4.2:5.4:5.6	
21	0.48	132	1865	4.1	1.6	CCD-161	135:221:307:424:457:475:496:503				4.7:4.7:4.4:CCD-161	5-6	7	-21	-27	-40	-53	-46	7,430	805	6.5	4.8:5.9:6.3	

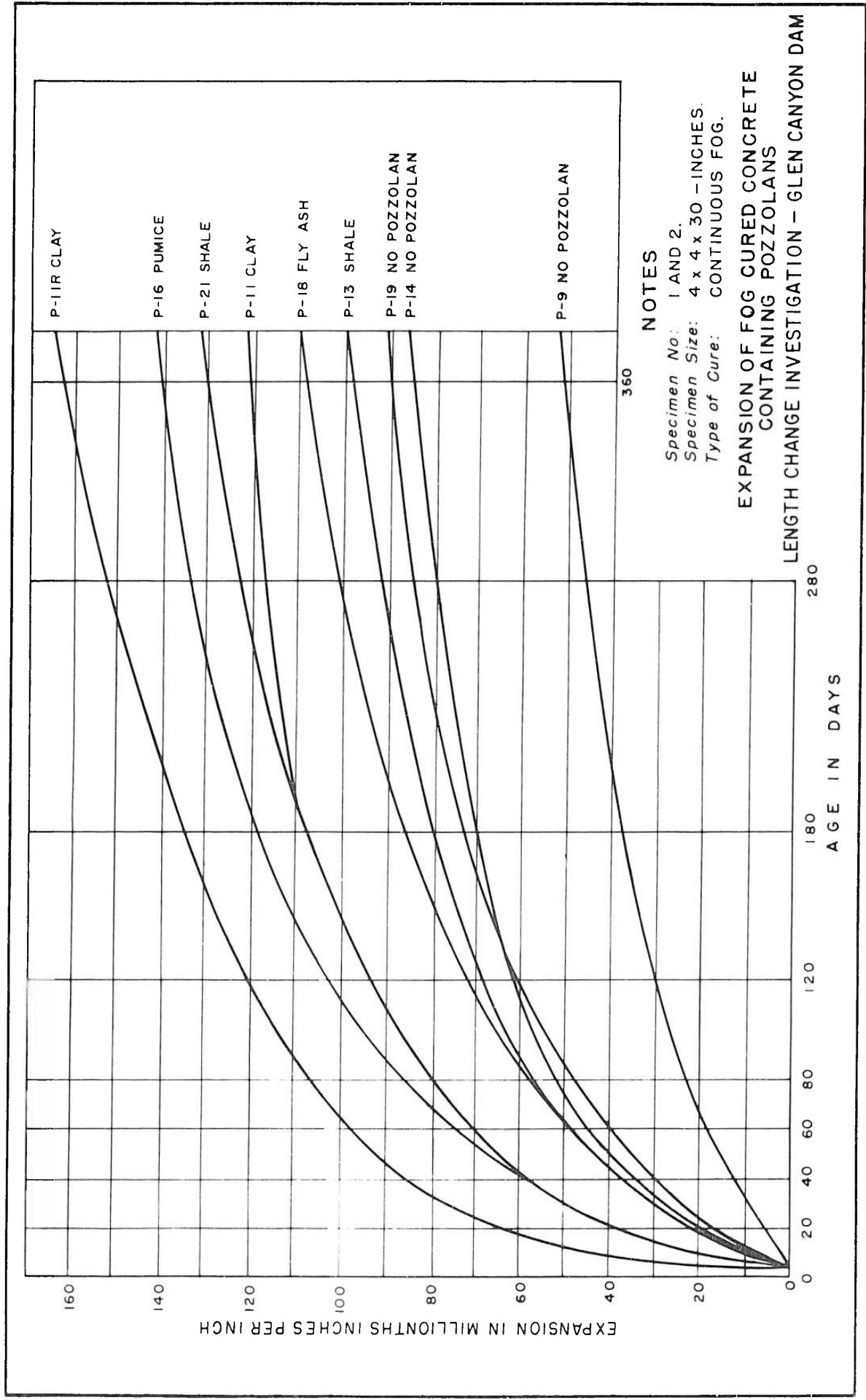
1/Average of two specimens.  
 2/Laboratory blend, No. M-2400.  
 3/Contains 0.37 percent calcium lignosulphonate by weight of cementitious material.  
 4/Laboratory blend, No. M-3688.  
 5/These values indicate shrinkage and are comparable to the negative values shown under Autogenous length change.  
 6/Mixes 1, 16, 17, reported in Tables 5 and 6 of Laboratory Report C-528-A. Mix 161 unreported to date.

Table 5  
LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF MASS CONCRETE CONTAINING A RETARDING AGENT  
Length Change Investigation--Glen Canyon Dam

Concrete Mix Data										Length change data 1/									
Mix No.	Water, lb/yd <sup>3</sup>	Cement, lb/yd <sup>3</sup>	Pozzolan <sup>2/</sup> , lb/yd <sup>3</sup>	Retarding agent, %	Air, %	Slump, in.	Bar No.	Length change in millionths <sup>3/</sup> , days of drying or curing	Compressive strength, psi	Modulus of rupture, psi	Flexural E, million psi	Dynamic E, million psi							
No.	W.P.	C.P.	P.P.	R.P.	A.P.	S.P.		7 : 14 : 28	90 : 120 : 180 : 270 : 365	of cubes	of rupture	Age							
95:0.67:	159	190	M-3100	0	4.9	2.4	GCD-98 (5-6)	120:200:322:514:545:573:594:609	3,590	500	3.5	4.0: 3.9: 3.8							
99:0.62:	146	189	M-3100	0.37	4.9	3.0	GCD-99 (5-6)	175:280:395:574:610:638:660:674	3,430	475	3.2	4.1: 3.9: 3.8							
102:0.56:	159	191	M-3100	0	4.4	2.2	GCD-102 (5-6)	115:172:242:375:396:425:447:450	4,120	515	3.8	4.6: 4.6: 4.3							
107:0.50:	43	190	M-3100	0.37	3.7	2.6	GCD-103 (5-6)	158:228:310:454:484:505:528:535	5,410	580	3.7	4.7: 4.3: 4.4							
111:0.56:	156	187	M-3329	0	3.9	1.9	GCD-111 (5-6)	150:212:298:442:468:500:523:530	5,520	510	3.7	4.6: 4.8: 4.3							
111:0.56:	156	187	M-3329	0	3.9	1.9	GCD-111 (9-20)	180:255:350:458:507:535:555:559	5,320	295	4.1	--: 4.8: 4.2							
112:0.52:	179	177	M-3329	0.37	4.2	1.6	GCD-112 (5-6)	145:210:290:398:422:456:475:485	6,080	485	4.2	5.1: 5.1: 4.5							
115:0.55:	156	188	M-3329	0.37	4.2	1.6	GCD-112 (9-20)	188:254:337:469:495:523:530:530	5,720	480	4.3	--: 4.8: 4.3							
116:0.53:	142	178	M-3329	0.37	5.0	2.0	GCD-116 (5-6)	145:215:295:400:440:470:490:500	5,420	540	4.0	4.8: 4.5: 4.2							
122:0.54:	154	189	M-3329	0	5.2	2.3	GCD-122 (5-6)	150:230:337:450:475:506:528:530	4,760	475	4.1	4.9: 4.6: 4.4							
133:0.54:	137	170	M-3329	0.37	4.9	2.1	GCD-123 (5-6)	150:230:337:450:475:506:528:530	5,190	515	3.7	4.4: 4.3: 4.0							
133:0.54:	157	193	M-3688	0	3.9	1.7	GCD-133 (5-6)	120:187:266:380:407:434:455:459	4,490	530	3.9	4.7: 4.4: 4.1							
174:0.52:	142	181	M-3688	0.37	3.9	2.7	GCD-134 (5-6)	120:187:266:400:426:451:474:476	4,980	530	4.0	4.4: 4.6: 4.5							
161:0.48:	132	186	M-3688	0.37	4.1	1.6	GCD-161 (5-6)	145:216:304:430:453:473:496:503	4,980	572	3.8	4.7: 4.7: 4.4							
161:0.48:	132	186	M-3688	0.37	4.1	1.6	GCD-161 (1-2) 1/2	145:216:304:430:453:473:496:503	7,120	801	5.6	4.7: 6.2: 6.7							

1/Average of two specimens.  
 2/Pumice pozzolan used in all mixes.  
 3/0.37 percent calcium lignosulphonate by weight of cementitious material, then stripped at 14 days' age and stored at 50 percent relative humidity for drying shrinkage.  
 4/These specimens were cured continuously at 100 percent relative humidity and 73.4° F.  
 5/Except where length change is indicated +, all changes in length are (-) resulting from drying shrinkage.  
 6/Mixes 95-161 unreported to date.

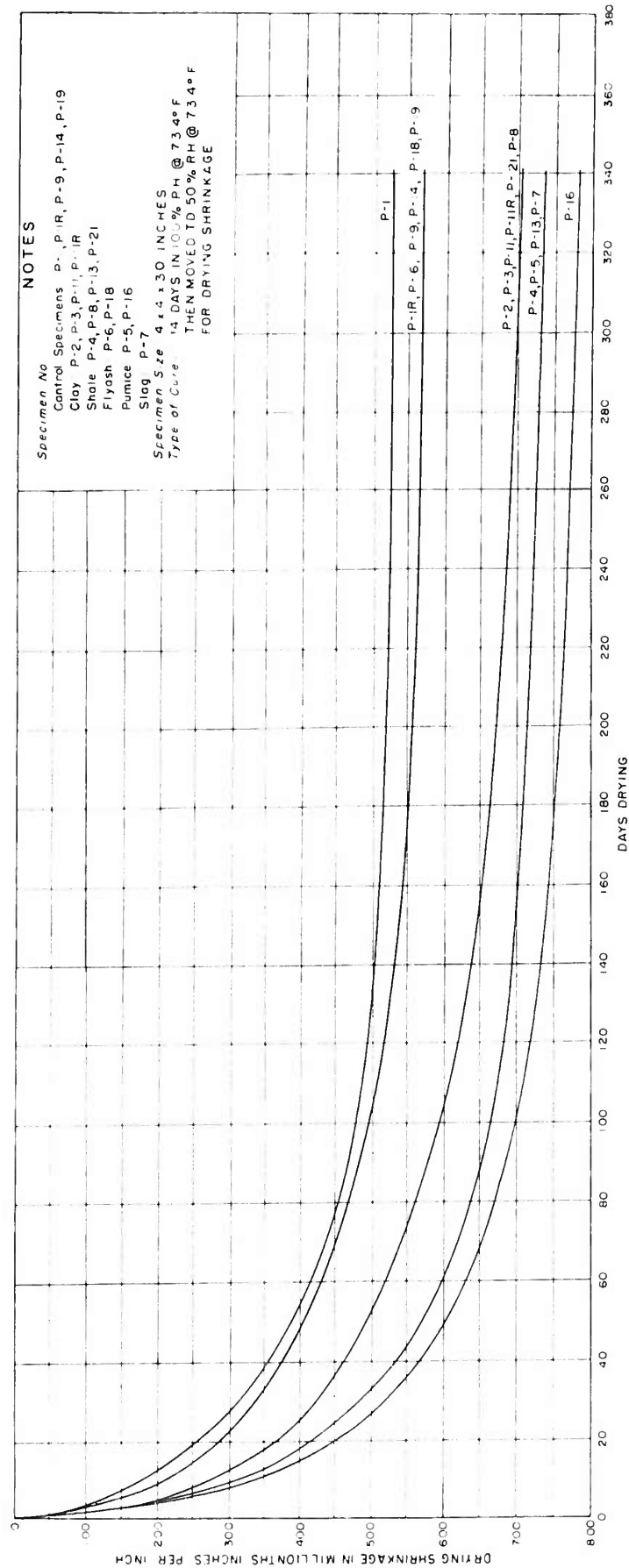
FIGURE 1



NOTES  
Specimen No: 1 AND 2.  
Specimen Size: 4 x 4 x 30 - INCHES.  
Type of Cure: CONTINUOUS FOG.

EXPANSION OF FOG CURED CONCRETE  
CONTAINING POZZOLANS  
LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 2

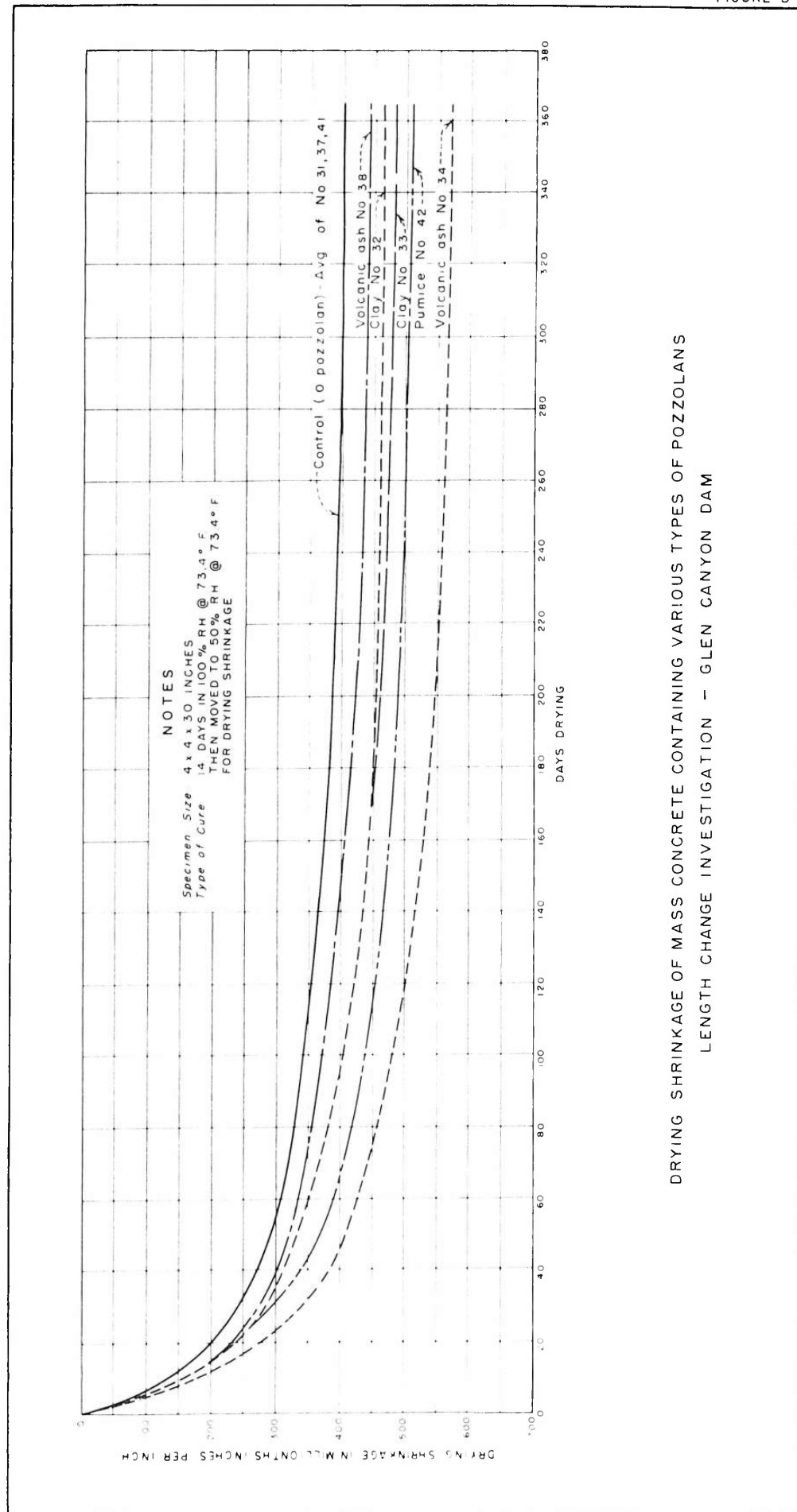


NOTES

Specimen No  
 Control Specimens P-1, P-1R, P-9, P-14, P-19  
 Clay P-2, P-3, P-11, P-1R  
 Shale P-4, P-8, P-13, P-21  
 Flyash P-6, P-18  
 Pumice P-5, P-16  
 Slag P-7  
 Specimen Size 4 x 4 x 30 INCHES  
 Type of Cure 14 DAYS IN 100% RH @ 73.4°F  
 THEN MOVED TO 50% RH @ 73.4°F  
 FOR DRYING SHRINKAGE

DRYING SHRINKAGE OF CONCRETE CONTAINING POZZOLANS  
 LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 3



DRYING SHRINKAGE OF MASS CONCRETE CONTAINING VARIOUS TYPES OF POZZOLANS  
 LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 4

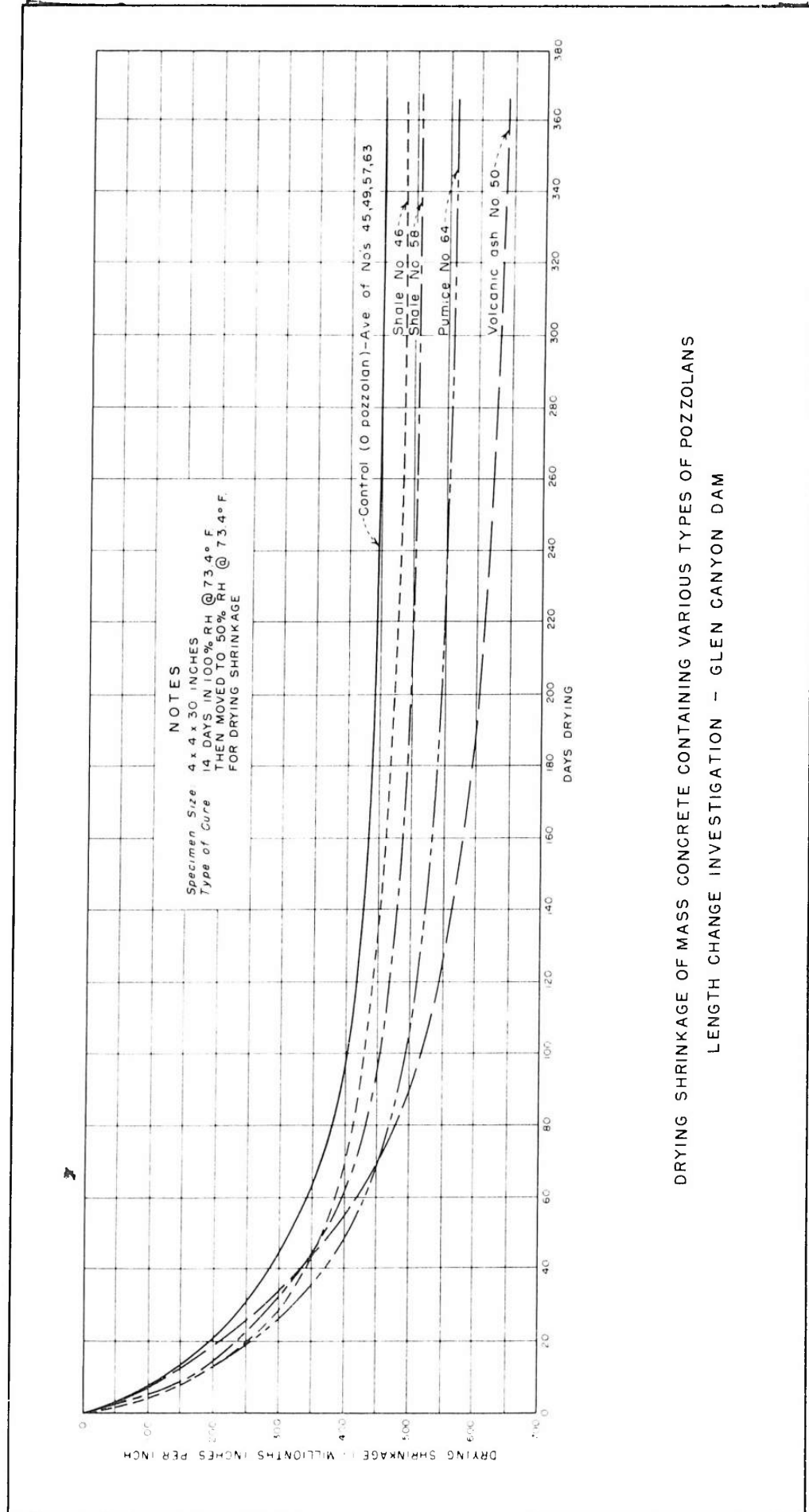
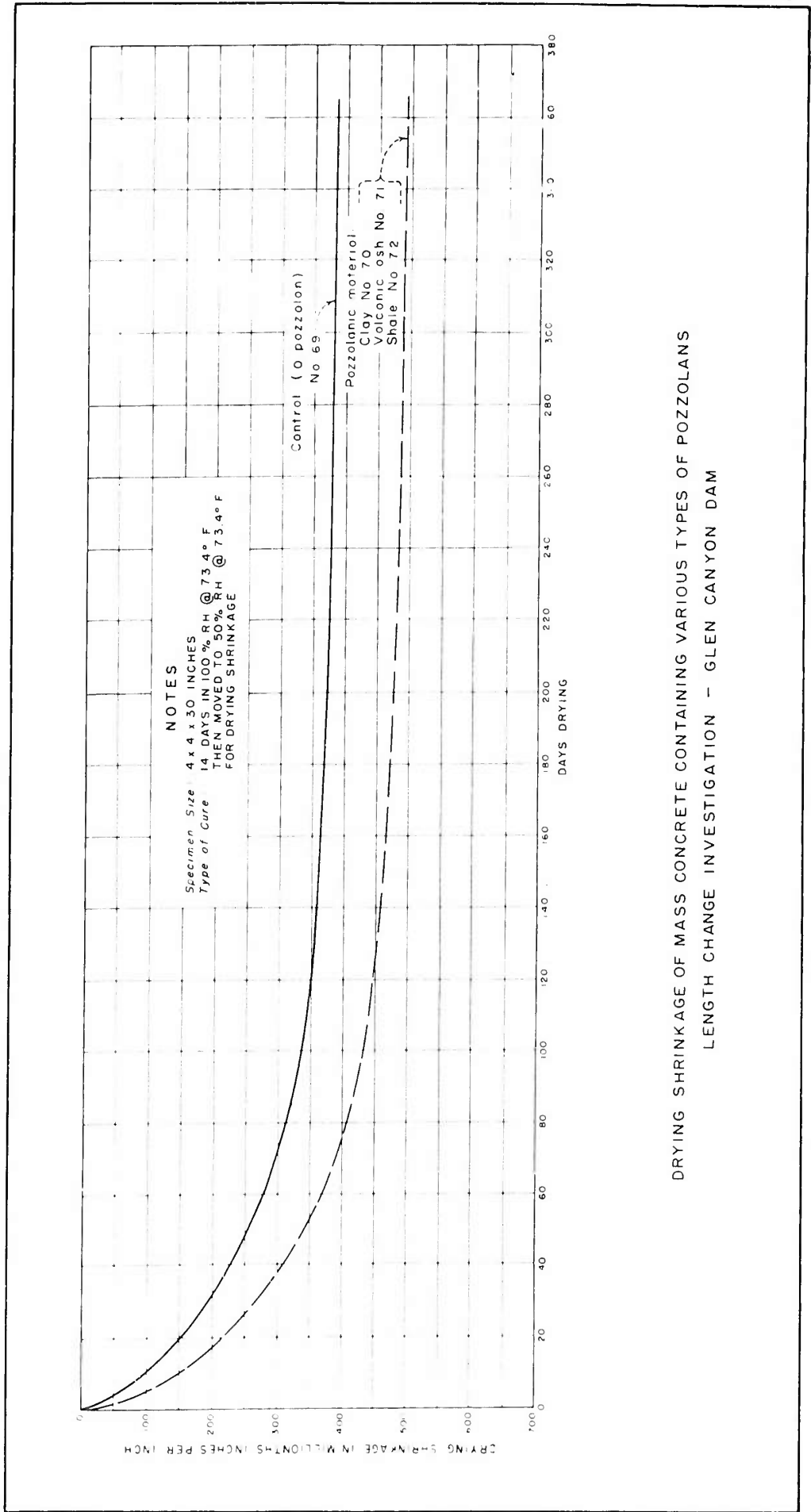
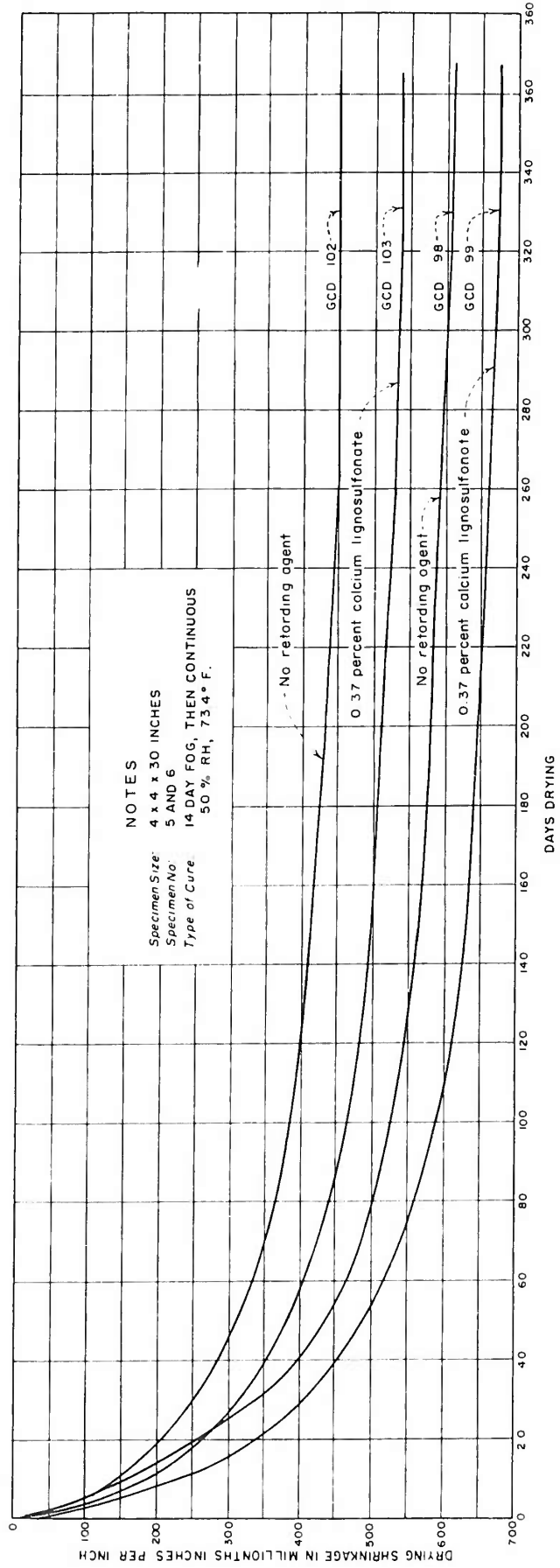


FIGURE 5



DRYING SHRINKAGE OF MASS CONCRETE CONTAINING VARIOUS TYPES OF POZZOLANS  
 LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 6



NOTES

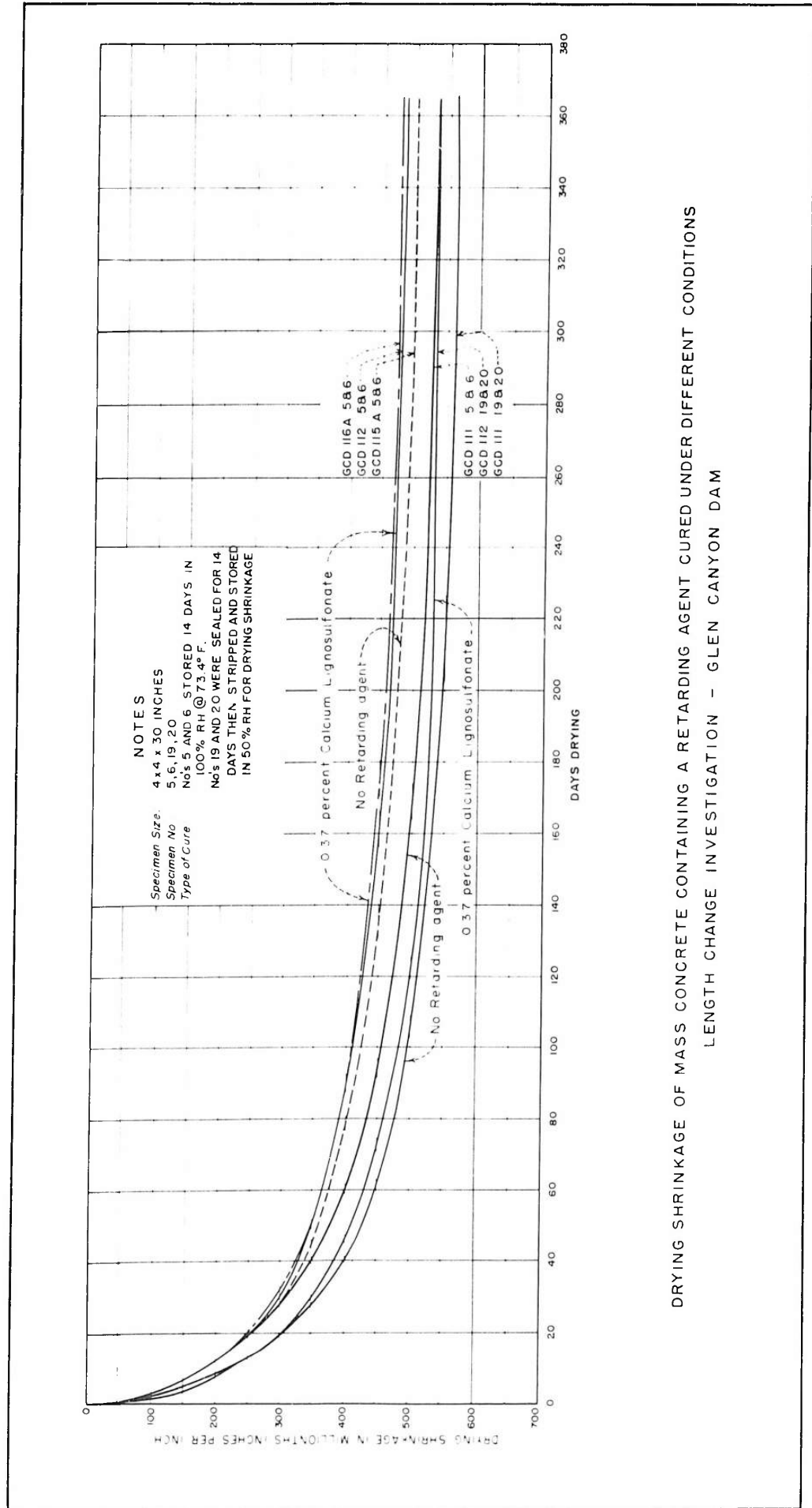
Specimen Size: 4 x 4 x 30 INCHES

Specimen No: 5 AND 6

Type of Cure: 14 DAY FOG, THEN CONTINUOUS

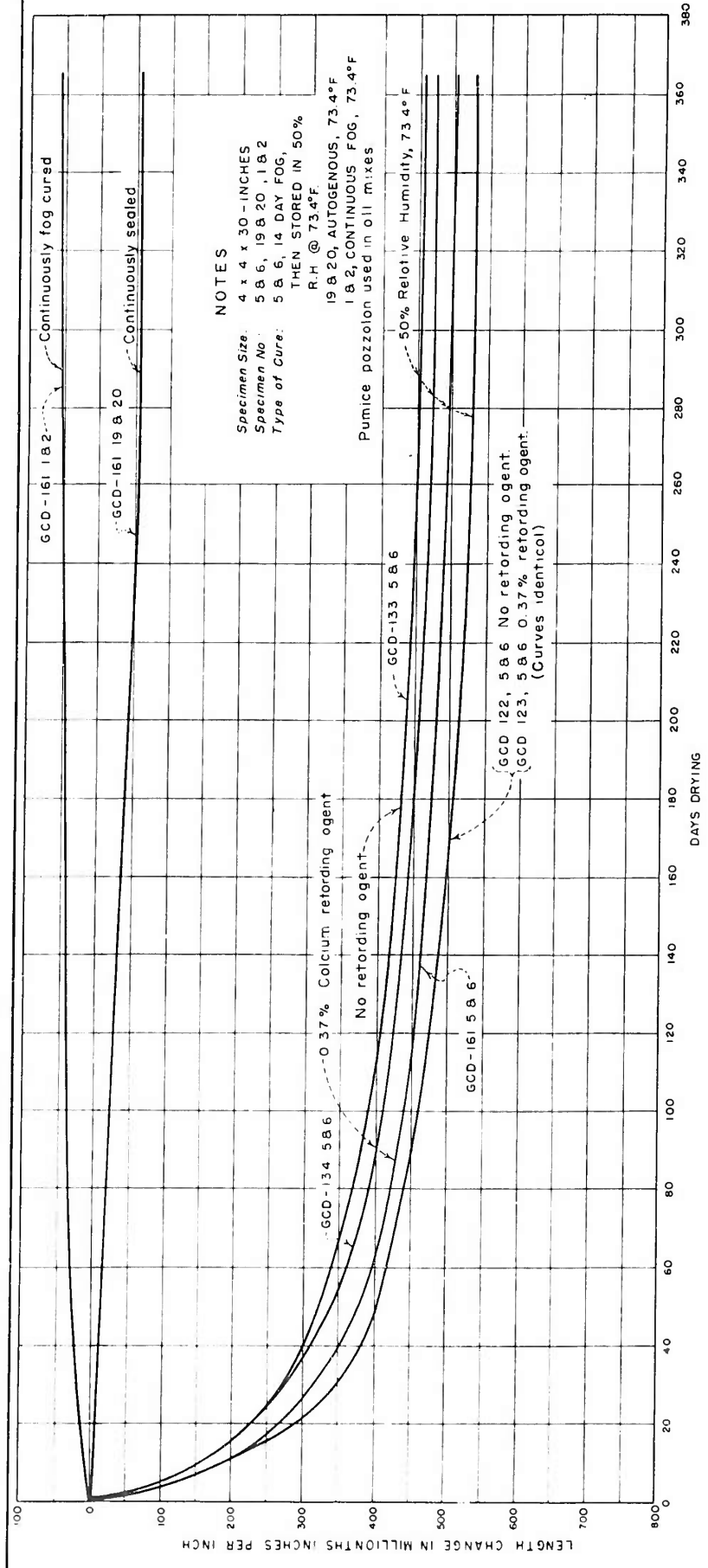
50% RH, 73.4° F.

DRYING SHRINKAGE OF MASS CONCRETE CONTAINING A RETARDING AGENT  
LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM



DRYING SHRINKAGE OF MASS CONCRETE CONTAINING A RETARDING AGENT CURED UNDER DIFFERENT CONDITIONS  
 LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 8



LENGTH CHANGE OF MASS CONCRETE CURED UNDER DIFFERENT CONDITIONS  
LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

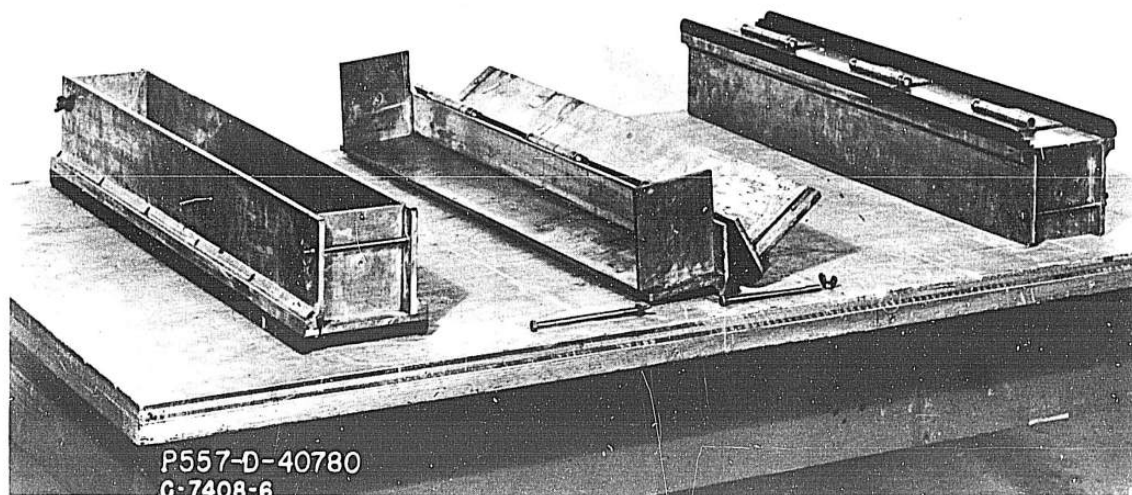


Figure 9 Steel molds used in the fabrication of 4 by 4 by 30 inch concrete test specimens.

Length Change Investigation—Glen Canyon Dam

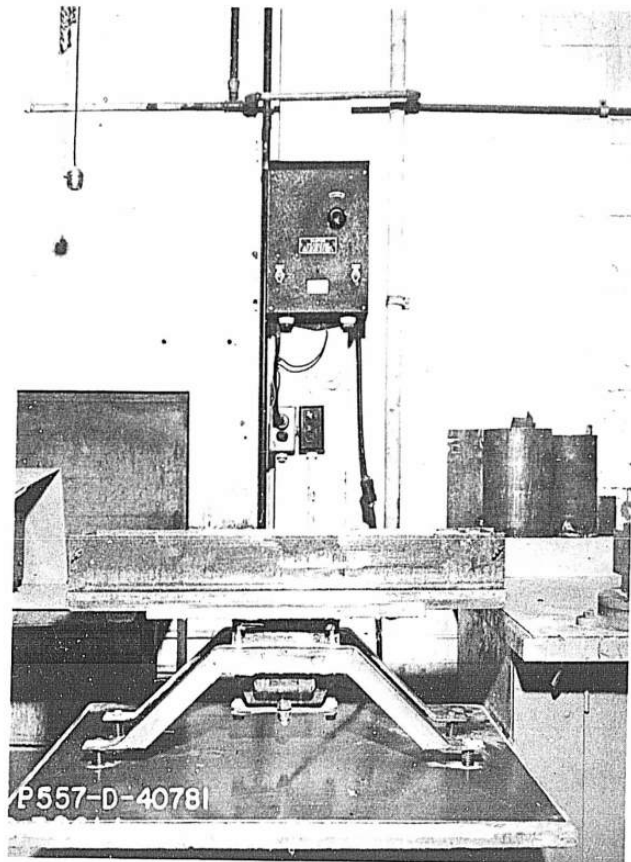


Figure 10 Vibrating table used to consolidate fresh concrete  
in the preparation of test specimens.

Length Change Investigation--Glen Canyon Dam

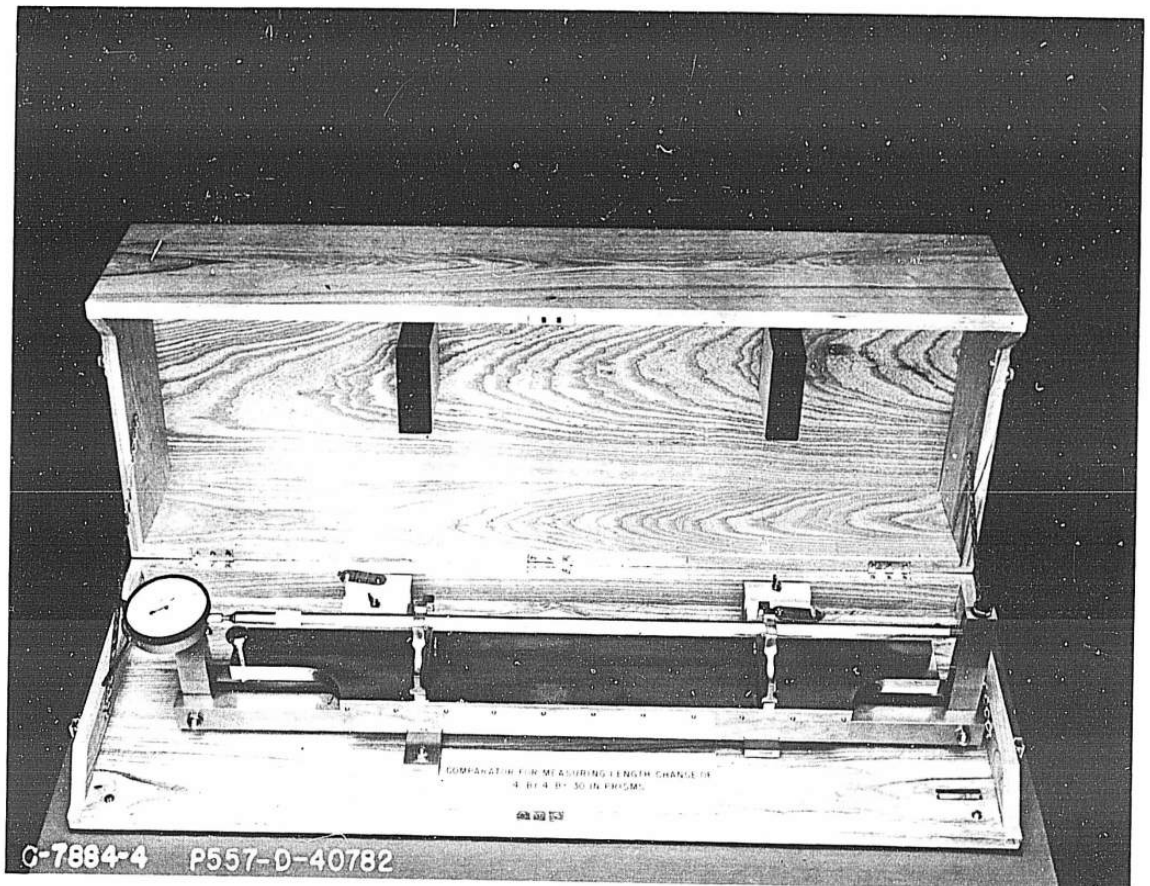


Figure 11 Horizontal Comparator for measuring length change of 4 by 4 by 30 inch concrete specimens.

Length Change Investigation--Glen Canyon Dam

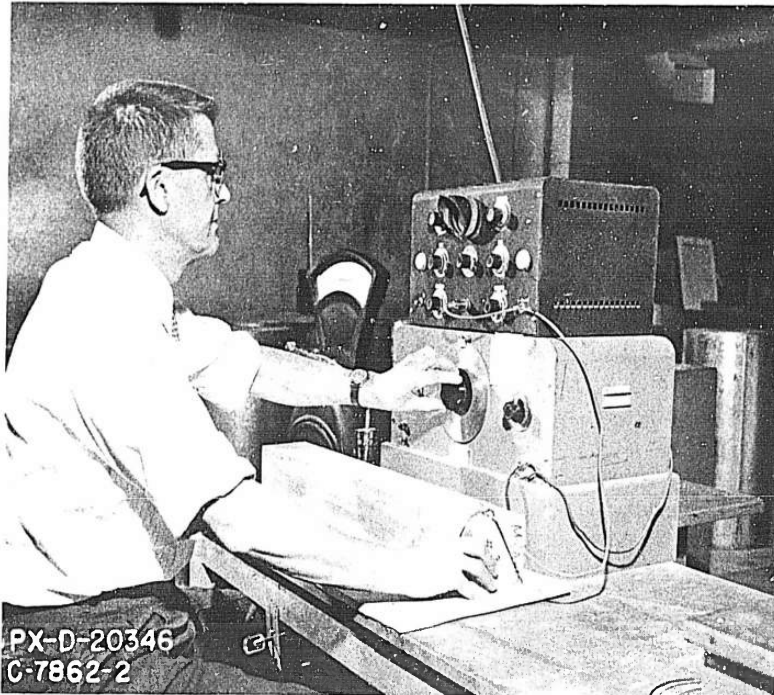


Figure 12 Electronic equipment for determining Young's Dynamic modulus of elasticity.

Length Change Investigation--Glen Canyon Dam

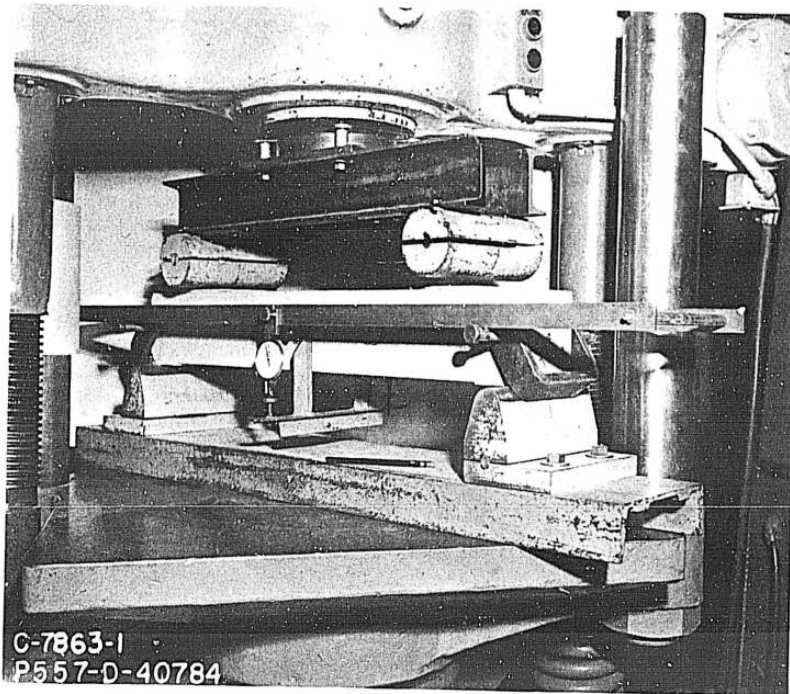


Figure 13 Frame and loading head used in flexure and modulus of rupture tests.

Length Change Investigation--Glen Canyon Dam