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EVALUATION OF CONCRETE BY ULTRASONIC TESTING, F. E. WARREN AUXILIARY SITES, SQUADRON III

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Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

July 1963

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PREFACE

The soniscope investigation of concrete in the F. E. Warren Auxiliary Sites, Squadron III, was verbally authorized by Mr. J. O. Ackerman, Chief, Engineering Division, U. S. Army Engineer District, Omaha, on 17 August 1960, and confirmed by teletype dated 19 August 1960. The group conducting the soniscope testing consisted of Mr. O. Keifer, Jr., Engineering Division, Omaha District, and Messrs. J. H. Sanderson and Dale Glass, Concrete Division, U. S. Army Engineer Waterways Experiment Station (WES). This party was accompanied by Mr. Ralph Newman, Cheyenne Area, who acted as guide and provided general assistance to the group.

The original report of the investigation, F. E. Warren Auxiliary Sites, Squadron III, Report of Evaluation of Concrete by Ultrasonic Testing, dated August 1960, was prepared by Mr. Keifer under the direction of, and with general guidance from, Mr. L. S. Bray, Chief, Materials and Airfield Pavement Design Section, F & M Branch, Engineering Division, Omaha District. This paper, prepared by Mr. H. T. Thornton, Jr., under the supervision of Messrs. T. B. Kennedy, Bryant Mather, and E. E. McCoy, Jr., all of the Concrete Division, WES, is based on the original report, and a considerable amount of the information contained herein was extracted from it verbatim.

Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE, were Directors of the WES during this investigation and the preparation and publication of this report. Mr. J. B. Tiffany was Technical Director.

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SUMMARY

Preliminary investigations of the concrete construction in various areas of the F. E. Warren Auxiliary Sites, Squadron III, established the fact that some of the structures contained low-strength concrete. On 15 August 1960, a meeting was convened at Air Force Ballistic Missile Division to discuss the problem, identify the scope, and determine the course to be taken for the design of corrective action.

To facilitate further investigation, the Waterways Experiment Station was requested to furnish one of its soniscopes to make velocity tests on concrete at the various sites. On 19, 20, and 21 August 1960, velocity tests were made on the structures where low strength was suspected. During this same time, velocity tests were also made on 6- by 12-in. cast cylinders and on cores taken from the questionable areas. After velocity measurements were obtained on these cylinders and cores, they were subjected to compressive strength tests.

The information on pulse velocity and compressive strength obtained from the test cylinders and cores was used to establish correlation between pulse velocity and compressive strength of the concrete being investigated; this correlation and the pulse velocities obtained from the concrete in question were used to assign compressive strength values to the in-place concrete.

It was concluded that (a) a number of the areas tested had concrete of less than adequate quality, (b) some of the suspected areas contained very uniform concrete of acceptable quality, and (c) ultrasonic testing provides a rapid, economical, and satisfactory means of surveying the quality of the concrete in structures of this and similar types.

EVALUATION OF CONCRETE BY ULTRASONIC TESTING

F. E. WARREN AUXILIARY SITES, SQUADRON III

PART I: INTRODUCTION

The Problem

1. This investigation was initiated to evaluate areas of concrete construction at F. E. Warren Auxiliary Sites, Squadron III, near Cheyenne, Wyoming, where the possible existence of low-strength concrete had been indicated by the results of compressive strength tests of cylinders at 28-day age and other ages of the concrete. Some of the questionable areas had been investigated by cutting 4-in. cores from the concrete and testing the cores for compressive strength. The low-strength concrete problem was discussed at a meeting at Air Force Ballistic Missile Division (AFBMD) on 15 August 1960 and reported in "Memorandum for the Record," dated 16 August 1960, by Mr. G. L. Otterson of the Construction Division, Omaha District.

Purpose and Scope of Study

2. To facilitate further investigation of the concrete structures suspected of containing questionable concrete, the Waterways Experiment Station (WES) was requested to furnish a soniscope and crew to make a rapid survey of the quality of the concrete by ultrasonic tests. The investigations were to be concentrated in the areas containing concrete of questionable quality which had been designated as most critical from a structural standpoint, and those areas for which the representative test cylinders indicated extremely low strength. Using these criteria, the most important areas were determined to be in various parts of the Launch and Service Buildings and Launch Operations Buildings at sites 2 and 3, and to a lesser extent in these buildings at sites 7 and 9. The soniscope investigation was confined to these four sites and to the test specimens available in the central laboratory at Cheyenne, Wyoming.

3. Soniscope readings were taken at the four sites on 19, 20, and 21 August 1960. On 19 August areas at site 2 were tested; on 20 August

areas at site 3 were tested; and on 21 August areas at sites 7 and 9 were tested. At each site, areas suspected of containing low-strength concrete were investigated, and in addition, areas of known strength were tested for correlation purposes. Also, during the test period concrete cylinders cast from mixtures used in structures at all the auxiliary sites except site 7, and which were scheduled for compression tests in the central laboratory, were tested with the soniscope. In addition, 4-in.-diameter cores from questionable areas of the in-place concrete were subjected to ultrasonic tests.

PART II: TEST EQUIPMENT AND PROCEDURES

Equipment

4. The soniscope equipment used was similar to that described in Corps of Engineers test method CRD-C 51-57.[2*] The soniscope is an instrument that transmits pulses of ultrasonic waves through a material and electronically measures the time of travel from the transmitter to a receiver while each is held against the surface of the material a known distance apart. Knowing the time of travel and the path length, the velocity of the ultrasonic pulses can be computed. This velocity provides an index of the condition or quality of the concrete. In this investigation the pulse velocities were correlated with the known strengths of test cylinders made in the laboratory, and with the strengths of cores from concrete in place in various portions of the structures, in order to provide a basis for evaluating areas of concrete of unknown quality by means of measured pulse velocities.

Procedures

5. Soniscope readings were taken on the 6- by 12-in. test cylinders and on the cores by transmitting ultrasonic pulses through the cylinders or cores from end to end. Soniscope readings were taken on concrete in place either by transmitting pulses through the concrete from a point on one surface to a point on the opposite surface, or by transmitting pulses through the concrete from one point to another point on the same surface of the concrete. The soniscope measured the time of travel of the pulses from one point to the other point, and the lineal distance between the two points was measured with a steel tape. From these two values the pulse velocity was calculated by the following formula:[2]

$$\text{Pulse velocity, fps} = \frac{\text{path length, ft}}{\text{effective time, sec}}$$

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* Raised numbers refer to similarly numbered items in the list of references at the end of this report.

All pulse velocities were computed to the nearest 10 fps.

6. Soniscope readings were normally taken in sets of two to four readings at locations approximately 1 ft apart. In a few instances the pulse velocity at one point was abnormally high as compared with the other readings in the set. In such cases another reading was taken approximately 6 in. away from the original location, and this reading was compared with the others in the set. In every case the pulse velocity from the extra reading compared favorably with the other velocities of the set, and was recorded in place of the original reading, it being assumed that the original reading had been influenced by reinforcing steel.

PART III: RESULTS

Summaries of Test Results

7. Soniscope readings and compressive strength test results on the 6- by 12-in. concrete test cylinders in the central laboratory are recorded in table 1. Averages for each set of soniscope readings on the concrete in place at the four sites are recorded in tables 2-6, together with compressive strength test results for comparable test cylinders and 4-in. cores.

Correction for Surface Readings

8. At the start of the investigation an attempt was made to correlate pulse velocity readings taken between points on the same surface of the concrete ("surface readings") with readings taken between points on opposite surfaces of the concrete ("through readings") on an equal basis. However, after the first day's results were computed and studied, it was obvious that there was a variation in the results of the two types of readings. On the last two days of the tests, surface readings and through readings were taken close together wherever possible to provide a comparison. The average for each of the comparable sets of surface and through readings is listed in table 7, and it is apparent that the variation occurred in all cases. The only explanation for this variation is that the surface readings were normally taken with a path length of 6.0 ft, as compared with a path length of 1.5 to 2.5 ft for the through readings. Studies made by personnel of the Concrete Division, WES,[1] indicated that there is a definite decrease in pulse velocity with increase in path length. However, no distinction was made in the study discussed in reference 1 between surface and through readings, and no formula was given for computing the difference to be expected.

9. The data summarized in table 7 are plotted in plate 1 to show the relation of surface readings to through readings (the two aggregate types represented in plate 1 are discussed subsequently and are not relevant here). Plate 1 indicates that a factor of 800 fps should be added to the

surface readings to make them comparable to through readings. This factor has been added to all surface readings listed in tables 2-6.

General Correlation Between Pulse Velocity and Compressive Strength

10. In the evaluation of the data obtained at the F. E. Warren Auxiliary Sites, soniscope readings on concrete of unknown quality were correlated with readings on concrete of known strength without regard to the individual mixture used or the aggregate source. This was done because so many mixtures had been used on the project that it was impractical to get sufficient field data to correlate concrete areas for each mixture. In addition, as may be seen in table 1, most test cylinders available for soniscope testing were from mixtures other than those used in the concrete areas of questionable quality. The concrete tested with the soniscope equipment varied in cement content only from 6-1/2 to 6-3/4 bags per cubic yard except for one mixture which had a cement content of 6 bags per cubic yard. Table 8 lists the mixtures used in the structures and in the test cylinders tested with the soniscope equipment.

11. The fact that so many aggregate sources and combinations of aggregate sources had been used on the project further complicated any comparison of concrete of the same mixture proportions. The aggregates used in all mixtures at all sites were of the same general mineral composition, the main differences being that the aggregates used at sites 1-5 were from dry terrace deposits and those used at sites 6-9 were from river deposits. When the results of the soniscope and compressive strength tests are differentiated on the basis of aggregate source, as shown in plates 1 and 2, it is apparent that the different aggregate sources had an effect on the pulse velocity-compressive strength relation, but did not cause major variations in the comparative results. The method of obtaining and using the correlation will be apparent in the following section.

Discussion of Results

12. Table 1 and plate 2 show the relation between pulse velocities measured in 6- by 12-in. concrete test cylinders and the compressive

strength of the cylinders. The cylinders were tested with the soniscope in the central laboratory 6 to 18 hours before they were tested in the standard compression test. The cylinders were of various ages and from all sites except site 7. All cylinders scheduled to be tested in compression while or immediately after the soniscope test team was at Cheyenne were tested with the soniscope; however, only 26 of the 71 concrete cylinders available for test were from the mixtures that had been used in the areas of questionable concrete (sites 2, 3, and 9). The data on the cores were obtained to assist in establishing the correlation between the pulse velocity and compressive strength data.

13. Table 9 and plate 3 are intended to provide a correlation between pulse velocities in concrete of questionable quality and pulse velocities in concrete of known quality. The value used for the compressive strength of the concrete of known quality is based on the results of the compressive strength tests of 4-in. cores from that concrete. The cores were normally cut in sets of three, and there was often wide variation of strength within the sets, as well as between sets cut from the same placement at different times. However, core tests were used as the basis of comparison, since there was less variation in results of tests of cores than in results of tests of cylinders made from the concrete during placement. The values shown in plate 3 are the averages of each set for each pour in each building tested at each site; table 9 shows these groupings. Plate 3 was then used to obtain the compressive strength value (table 9) assigned to each pour. No attempt was made to compensate for the fact that cores were cut and tested at various ages of the concrete and that soniscope readings were taken at ages different from those represented by the cores. These factors were not considered since they are beyond the degree of accuracy of this investigation.

14. The relation of pulse velocity to core strength shown in plate 3 is similar to the relation of pulse velocity to concrete cylinder strength shown in plate 2. The similarity of the two relations increases the validity of using pulse velocity comparisons to evaluate the quality of concrete of otherwise unknown strength.

PART IV: CONCLUSIONS

15. Estimated compressive strengths of areas of concrete of questionable quality at the F. E. Warren Auxiliary Sites, Squadron III, were derived by a comparison of the ultrasonic pulse velocity readings in the concrete of unknown strength with the pulse velocity readings in concrete of known quality. Concrete of known quality used for this comparison consisted of (a) concrete in placements where core strengths had been established, and (b) test cylinders which were tested with the soniscope equipment immediately before they were tested in the standard compression test. The relation of pulse velocity to compressive strength is shown in plates 2 and 3, and is an identical relation for in-place concrete and for concrete test cylinders.

16. A range of indicated compressive strength values for each value of pulse velocity would conceivably be more realistic than only one individual value. However, an examination of the ultrasonic readings obtained on concrete of known strength indicates that this range would be narrow, and the limits of such a range have not been determined.

17. Also it appears that a family of curves, one for each mixture, would provide a more accurate representation of the relation between compressive strength and pulse velocity. However, due to the large number of mixtures used on this project and the small number of specimens of each, it was not possible to correlate adequately the compressive strength-pulse velocity relation for each mixture, and the correlation used includes all mixtures.

18. The small amount of variation in the pulse velocity readings at various points within each placement indicated uniformity of concrete within each placement. The columns in the Launch Operations Building at site 2 were a critical area and were tested very thoroughly with the soniscope equipment (see table 2). Pulse velocity readings showed that the columns contain very uniform concrete of acceptable strength (table 9).

19. The test results indicate that the different aggregate sources had an effect on the pulse velocity-compressive strength relation, but did not cause major variations in the comparative results.

20. From table 9, the following areas have compressive strengths

indicated by pulse velocity comparison as being less than 4000 psi:

Site	Placement	Compressive Strength Indicated by Pulse Velocity, psi
2	LOB pour 2, floor	3600
	I&S Bldg pour 7, flame pit	Below 3000
	I&S Bldg pour 21, flame tunnel floor	3400
3	LOB pour 8, roof	3700
	I&S Bldg pour 10, flame tunnel	3800
	I&S Bldg pours 12 and 24, flame tunnel:	
	East wall	3600
	West wall	3300
	I&S Bldg pour 17, missile support beam	3800
	I&S Bldg pour 17-A, flame tunnel roof	3800
	I&S Bldg pour 21, flame tunnel floor	3900
	I&S Bldg pour 25, wall	3700
	I&S Bldg pour 34, vestibule wall	3500
	I&S Bldg pour 37, LOX tank housing wall	3500
7	LOB pour 11, vestibule roof	3700
	I&S Bldg pour 25, wall	3700
	I&S Bldg pour 30, wall	3800
9	I&S Bldg pour 24, flame tunnel wall	3800
	I&S Bldg pour 26, wall	3700
	I&S Bldg pour 29, flame tunnel roof	3900
	I&S Bldg pour 30, wall	3700
	I&S Bldg pour 36, mezzanine wall	3600
	I&S Bldg pour 42, ramp retaining wall:	
	East wall	3300
	West wall	3600

Note: LOB is Launch Operations Building; I&S is Launch and Service Building.

21. The concrete placements listed in paragraph 20 as having compressive strengths lower than 4000 psi, as indicated by ultrasonic tests, have been further evaluated by considering the results of tests on cores cut from a number of the placements. These average core strengths are also listed in table 9. Considering both ultrasonic test results and results of tests on cores, where available, the following are the placements which are definitely indicated as having concrete of strength excessively lower than 4000 psi (3500 psi or lower):

Site	Placement
2	I&S Bldg pour 21, flame tunnel floor
3	LOB pour 8, roof I&S Bldg pours 12 and 24, flame tunnel, west wall
9	I&S Bldg pour 42, ramp, east retaining wall

22. It appears to be a further conclusion of this investigation that ultrasonic testing is a rapid, economical, and satisfactory means of making a survey of the quality of the concrete in structures of this and similar types.

REFERENCES

1. Mather, Bryant, McCoy, E. E., Jr., Roshore, E. C., and Sanderson, J. H., "Use of the soniscope by Concrete Division, U. S. Army Engineer Waterways Experiment Station." Effects of Concrete Characteristics on the Pulse Velocity--A Symposium, Highway Research Board Bulletin 206 (1959), pp 42-45.

2. U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, with quarterly supplements. Vicksburg, Miss., August 1949.

3. __________, Field Soniscope Tests of Concrete; 1953 Tests, by E. C. Roshore. Technical Memorandum No. 6-383, Report 1, Vicksburg, Miss., April 1954.

Table 1

Results of Ultrasonic and Compressive Strength Tests on 6- by 12-in. Test Cylinders from Sites 1-6, 8, and 9

Site No.	Concrete Placement	Cylinder No.	Cylinder Age days		Pulse Velocity fps	Compressive Strength psi
			Mix C-5558B-Revised			
1	L&S* Bldg pours 12, 24	1-145	28		13,490	4984
		1-146			14,110	4370
		1-147			13,910	4081
				Avg	13,840	4478
	Equipment space, flame tunnel	1-161	28		14,850	4478
		1-162			14,850	4587
				Avg	14,850	4532
			Mix C-4226B			
8	L&S Bldg pour 7	8-223	28		13,720	4478
		8-224			13,830	4695
		8-225			13,560	4478
				Avg	13,700	4550
	West curb of ramp	8-272	7		12,920	3973
		8-273			13,090	4117
				Avg	13,000	4045
			Mix C-4236B-Revised			
9	L&S Bldg pours 29, 42	9-179	28		13,680	3395
		9-180			12,860	2998
				Avg	13,270	3197
			Mix C-6782			
4	L&S Bldg pour 26	4-244	28		14,230	3937
		4-245			14,190	4045
		4-246			14,270	4009
				Avg	14,230	3997
	L&S Bldg pour 30	4-250	28		14,690	3864
		4-251			14,440	3828
		4-252			14,230	3937
				Avg	14,450	3876
3	L&S Bldg pour 26	3-216	28		14,010	4045
		3-219			13,820	4442
				Avg	13,920	4243

(Continued)

* Launch and Service Building.

Table 1 (Continued)

Site No.	Concrete Placement	Cylinder No.	Cylinder Age days		Pulse Velocity fps	Compressive Strength psi
			Mix C-6782 (Continued)			
3	I&S Bldg roof	3-254	7		14,420	3467
		3-255			14,210	3286
		3-256			14,010	3178
		3-244			14,630	3937
		3-245			14,210	3250
		3-247			14,210	3431
		3-248			13,820	3576
				Avg	14,220	3446
			Mix C-6781			
1	I&S Bldg pour 15	1-154			14,310	5381
		1-155			14,230	4912
		1-156			14,920	5381
				Avg	14,490	5224
2	I&S Bldg pour 18	2-229	28		13,950	4226
		2-230			14,470	4551
		2-231			13,910	4406
				Avg	14,110	4394
		2-235	28		14,140	3864
		2-236			14,780	4370
		2-237			15,240	4551
				Avg	14,720	4262
	I&S Bldg walls	2-277	7		13,950	3467
		2-278			14,000	3684
		2-279			14,570	3612
				Avg	14,170	3588
	I&S Bldg pour 25	2-241			14,440	Not determined
		2-242			14,030	
		2-243			14,030	
				Avg	14,170	
			Mix C-6784			
4	I&S Bldg pour 35	4-282	14		14,420	4081
		4-283			14,850	4081
				Avg	14,640	4081
	I&S Bldg pours 32, 38	4-301	7		13,450	3467
		4-302			14,010	3431
		4-303			13,450	3395
				Avg	13,640	3431

(Continued)

Table 1 (Concluded)

Site No.	Concrete Placement	Cylinder No.	Cylinder Age days		Pulse Velocity fps	Compressive Strength psi
			Mix C-6784 (Continued)			
5	I&S Bldg pour 26A	5-238	28		13,990	4587
		5-239			14,110	4370
		5-240			14,110	4406
				Avg	14,070	4454
	I&S Bldg pour 23	5-244	28		14,470	4731
		5-245			14,440	4406
		5-246			14,610	4515
				Avg	14,510	4551
	I&S Bldg pour 27	5-295	7		14,270	3973
		5-296			14,030	4153
				Avg	14,150	4063
		5-302	7		14,030	4370
		5-303			13,990	4623
		5-304			13,950	4840
				Avg	13,990	4611
			Mix C-6783			
6	I&S Bldg pour 39	6-260	28		13,530	4515
		6-261			13,790	4262
		6-262			13,830	4551
				Avg	13,720	4443
	I&S Bldg pours 33, 41	6-266	28		13,450	4442
		6-267			13,450	4153
		6-268			14,010	4515
				Avg	13,640	4370
	I&S Bldg pour 32	6-328	7		13,100	3576
		6-329			12,960	3720
				Avg	13,030	3648
			Mix C-4733B-Revised			
5	I&S Bldg pour 42	5-308	7		13,980	3864
		5-309			14,110	3612
				Avg	14,050	3738
		5-315	7		13,990	4045
		5-316			13,910	4153
		5-317			14,480	4153
				Avg	14,130	4117

Table 2

Results of Ultrasonic Tests on In-Place Concrete and Compressive Strength Tests on Test Cylinders and Cores, Site 2

Concrete Placement	Soniscope Tests: Conc Age days	Soniscope Tests: Test Location	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores: No.	4-in. Cores: Compressive Strength psi
Mix C-6034						
LOB pour 7 columns	72	B-2	14,410	3250	No cores	
		B-3	14,290	3503		
		C-2	14,410	3576		
		C-3	14,440	Avg 3443[a]		
		D-2	14,290			
		D-3	14,130			
		E-2	14,180			
		E-3	14,550			
			Avg 14,340			
LOB pour 9 vestibule walls	56	West wall	13,250*	3359	No cores	
		Interior wall	14,420	3648		
			Avg 13,840	Avg 3503[a]		
				3431[b]		
LOB pour 8 roof	60	Near core 55	13,920	3460	55	4690
		Near core 56	13,820	3220	56	3320
			Avg 13,870	3400	57	4730
				3575		Avg 4247[c]
				3460		
				Avg 3423[a]		
				3509[b]		
L&S Bldg pour 24 flame tunnel walls	57	East wall	13,510	3612	No cores	
				3684		
				Avg 3648[a]		
				3287[b]		
	45	West wall	13,530	3395	No cores	
				3395		
				Avg 3395[a]		
				3142[b]		
L&S Bldg pour 7 flame pit	88	Floor	11,265*	3431	62	3710
		West wall	11,170*	3395	63	3380
		Near cores 62, 63	10,890*	2467	64	4620
		Near core 64	11,090*	3214		Avg 3903[d]
			Avg 11,100**	3214		
				3359		
				Avg 3180[a]		
				3142[b]		

(Continued)

Note: LOB is Launch Operations Building; L&S is Launch and Service Building.

* Soniscope readings taken on one surface of concrete corrected to values of equivalent through readings; all other pulse velocity values taken through concrete.

** Averages using corrected surface readings.

a Cylinders tested at 28-day age.

b Cylinders tested at 45-day age.

c Cores cut when concrete was 43 days old.

d Cores cut when concrete was 71 days old.

Table 2 (Concluded)

Concrete Placement	Soniscope Tests: Conc Age days	Soniscope Tests: Test Location	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores No.	4-in. Cores Compressive Strength psi
			Mix C-6034 (Continued)			
I&S Bldg pour 13 missile support beam	52		13,980	3214 3251 Avg 3233[a] 3395[b]	No cores	
			Mix C-6781			
I&S Bldg pour 25 wall	23	West part of north wall	13,720	3972 3792 3756 Avg 3840[e]	No cores	

a Cylinders tested at 28-day age.
b Cylinders tested at 45-day age.
e Cylinders tested at 7-day age.

Table 3

Results of Ultrasonic Tests on In-Place Concrete and Compressive Strength Tests on Test Cylinders and Cores, Sites 2 and 3

Concrete Placement	Soniscope Tests: Conc Age days	Soniscope Tests: Test Location	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores: No.	4-in. Cores: Compressive Strength psi
			Mix C-1702			
Site 2	109	Near core 49	13,620*	3007	49	4420[d]
LOB pour 2		Near core 50	12,510*	3024	50	3[illegible]00[d]
floor		Near core 51	12,790*	3305	51	3090[d]
		Near core 50A	13,200*	Avg 3112[a]	50A	3560[e]
			13,480*		51A	4120[e]
			11,710*	3936	52A	3120[e]
		Near cores 51A, 52A	12,850*	3612		Avg 3552
			Avg 12,880**	4081	(51A is 1.5 ft from 52A)	
				Avg 3876[b]		
Site 3	110		12,970	3287	35	3060
L&S Bldg			12,930	2817	36	2630
pour 21, flame			14,050*	Avg 3052[c]	37	2870
tunnel floor			13,740*	3467[b]		Avg 2853[f]
			Avg 13,420**			
Site 3	123			3070	38	3400
L&S Bldg				2853	39	3810
pour 8, flame				Avg 2961[c]	40	2840
tunnel floor				3214[b]		Avg 3350[g]
					28	3740
		Near core 29	14,210*		29	2850
		Near core 30	13,790*		30	2920
			Avg 14,000**			Avg 3170[h]
						Avg 3246[i]
						Avg 3485[j]
					Overall avg	3313
Site 3	109		13,610*	3756	No cores	
L&S Bldg				3684		
pour 7, flame				3792		
tunnel floor				Avg 3744[c]		

(Continued)

Note: LOB is Launch Operations Building; L&S is Launch and Service Building.

* Soniscope readings taken on one surface of concrete corrected to values of equivalent through readings; all other pulse velocity values taken through concrete.

** Averages using corrected surface readings.

a Cylinders tested at 23-day age.

b Cylinders tested at 45-day age.

c Cylinders tested at 28-day age.

d Cores cut when concrete was 91 days old.

e Cores cut when concrete was 64 days old.

f Cores cut when concrete was 62 days old.

g Cores cut when concrete was 77 days old.

h Cores cut when concrete was 100 days old.

i Average of three cores cut at 45-day age.

j Average of three cores cut at 32-day age.

Table 3 (Continued)

Concrete Placement	Conc Age days	Soniscope Tests: Test Location	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores: No.	4-in. Cores: Compressive Strength psi
			Mix C-4702 (Continued)			
Site 3 I&S Bldg LOX sump	135	South wall	13,740	4623		No cores
				4550		
				4659		
				Avg 4611[c]		
Site 3 I&S Bldg pour 37, LOX storage tank housing	103	South wall	12,680	2998	32	3850
			12,560*	2781	33	3680
			Avg 12,620**	Avg 2890[c]	34	358[illegible]
				3214[b]		Avg 3703[k]
			Mix C-4701B			
Site 3 I&S Bldg pour 17, missile support beam	60		13,290	4220		No cores
				3684		
				3790		
				3431		
				3960		
				3756		
				Avg 3807[c]		
Site 3 I&S Bldg pour 18-A, floor	64		13,590	3611	19	4730
			13,430*	3395	20	3710
			Avg 13,510**	3377	21	4170
				3287		Avg 4203
				3395		
				3142		
				Avg 3368[c]		
Site 3 I&S Bldg pour 25, wall	54		13,110	3647		No cores
				3323		
				3431		
				Avg 3467[c]		
				3323		
				3431		
				3106		
				Avg 3287[b]		

(Continued)

* Soniscope readings taken on one surface of concrete corrected to values of equivalent through readings; all other pulse velocity values taken through concrete.
** Averages using corrected surface readings.
b Cylinders tested at 45-day age.
c Cylinders tested at 28-day age.
k Cores cut when concrete was 57 days old.

Table 3 (Concluded)

Concrete Placement	Conc Age days	Soniscope Tests: Test Location	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores: No.	4-in. Cores: Compressive Strength psi
			Mix C-4701B (Continued)			
Site 3	66		13,820*	3575	16	4450
I&S Bldg pour				3611	17	4450
15, floor				3900	18	3100
				3828		Avg 4000[l]
				3792		
				3756		
				3684		
				Avg 3735[c]		
				3647		
				3685		
				Avg 3666[b]		
Site 2	98		13,490	3467	65	3830
I&S Bldg pour			12,990	3720	66	4890
21, flame			10,830*	3539	67	3930
tunnel floor			Avg 12,440**	3864		Avg 4217[m]
				3720	53	2930
				4117	54	2220
				4153	55	3080
				3792		Avg 2743[n]
				3539	Overall avg	3480
				Avg 3768[c]		

* Soniscope readings taken on one surface of concrete corrected to values of equivaleng through readings; all other pulse velocity values taken through concrete.
** Averages using corrected surface readings.
b Cylinders tested at 45-day age.
c Cylinders tested at 28-day age.
l Cores cut when concrete was 42 days old.
m Cores cut when concrete was 80 days old.
n Cores cut when concrete was 53 days old.

Table 4

Results of Ultrasonic Tests on In-Place Concrete and Compressive Strength Tests on Test Cylinders and Cores, Site 3

Mix C-4702B-Revised

Concrete Placement	Soniscope Tests: Conc Age days	Soniscope Tests: Test Location	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores: No.	4-in. Cores: Compressive Strength psi
L&S Bldg pours	72	East wall	12,850	3756	34	3700
12, 24, flame			12,460*	3720	35	3660
tunnel walls			13,200*	3395	36	3490
			Avg 12,840**	3900		Avg 3617[c]
				3684		
				3612		
				Avg 3678[a]		
	81	West wall	12,650	2889	37	3000
			11,010*	2889	38	3170
			12,990*	2709	39	3150
			Avg 12,220**	3250		Avg 3107[d]
				2708		
				Avg 2889[a]		
				3040[b]		
L&S Bldg pour 10	85	West wall		3828	25	5000
flame tunnel		Near cores 25, 26	12,950*	3576	26	5010
wall		Near core 27	13,590*	Avg 3702[a]	27	4740
			Avg 13,270**	3720[b]		Avg 4917[e]
L&S Bldg pour 10	77		13,240	2456	41	3840
flame tunnel			—	2456	42	3470
wall, north				2384	43	3320
part missile				2311		Avg 3543[f]
support area				2492		
				2456		
				Avg 2426[a]		

(Continued)

Note: L&S is Launch and Service Building.
* Soniscope readings taken on one surface of concrete corrected to values of equivalent through readings; all other pulse velocity values taken through concrete.
** Averages using corrected surface readings.
a Cylinders tested at 28-day age.
b Cylinders tested at 45-day age.
c Cores cut when concrete was 50 days old.
d Cores cut when concrete was 59 days old.
e Cores cut when concrete was 62 days old.
f Cores cut when concrete was 32 days old.

Table 4 (Concluded)

Concrete Placement	Soniscope Test: Conc Age days	Soniscope Test: Test Location	Soniscope Test: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores No.	4-in. Cores Compressive Strength psi
I&S Bldg pour 34 vestibule wall	71	West wall	12,540	3973 3684 3503 3539 3684 Avg 3677[a] 3901[b]	13 14 15	3700 4660 4600 Avg 4320[g]
I&S Bldg pour 17-A, flame tunnel roof	72		13,180*	3467 3431 3359 3250 3359 3540 Avg 3401[a]	31 32 33	3220 3640 3520 Avg 3460[c]
I&S Bldg pour 20 flame tunnel roof	38		14,085*	4804 4659 4298 Avg 4587[a]		No cores
LOB pour 8 roof†	79	Near core 10 Near core 11 Near equip. hatch	13,150 12,910 12,880 Avg 12,980	343[illegible] 2744 2817 2889 3178 3142 2889 3142 Avg 3029[a] 3250[b]	10 11 12	2980 3070 3470 Avg 3173[h]

Note: LOB is Launch Operations Building.

* Soniscope readings taken on one surface of concrete corrected to values of equivalent through readings; all other pulse velocity values taken through concrete.

† Soniscope readings were made on 6-in. concrete cores cut from LOB pour 8 at 77-day age. These 6-in. cores were cut near (within 2 ft of) the same locations as the 4-in. cores with the same basic number.

6-in. Cores: No.	Pulse Velocity, fps	Compressive Strength, psi
10-1	12,890	3928
11-2	12,560	2542
12-4	12,510	2311
	Avg 12,650	Avg 2927

a Cylinders tested at 28-day age.
b Cylinders tested at 45-day age.
c Cores cut when concrete was 50 days old.
g Cores cut when concrete was 47 days old.
h Cores cut when concrete was 55 days old

Table 5

Results of Ultrasonic Tests on In-Place Concrete and Compressive Strength Tests on Test Cylinders and Cores, Site 7

Mix C-4226B

Concrete Placement	Soniscope Tests: Conc Age Days	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi	4-in. Cores: No.	4-in. Cores: Compressive Strength psi
I&S Bldg	45	13,300	3756	No cores	
pour 30		13,260*	3684		
wall		Avg 13,280**	4081		
			4009		
			4009		
			Avg 3908[a]		
			3792[b]		
I&S Bldg	61	12,690	4030	No cores	
pour 25		13,270*	3828		
wall		Avg 12,980**	4040		
			Avg 3966[a]		
LOB pour 11	79	13,100*	3683	78	3860
vestibule			3250	79	4040
roof			Avg 3467[a]	80	3790
			3760[b]		Avg 3897[c]

Note: LOB is Launch Operations Building; I&S is Launch and Service Building.

* Soniscope readings taken on one surface of concrete corrected to values of equivalent through readings; all other pulse velocity values taken through concrete.

** Averages using corrected surface readings.

a Cylinders tested at 28-day age.

b Cylinders tested at 45-day age.

c Cores cut when concrete was 62 days old.

Table 6

Results of Ultrasonic Tests on In-Place Concrete and Compressive Strength Tests on Test Cylinders, Site 9

Concrete Placement	Soniscope Tests: Conc Age days	Soniscope Tests: Test Location	Soniscope Tests: Pulse Velocity fps	Cylinders Compressive Strength psi
		Mix C-4232B-Revised		
L&S Bldg pour 30, wall	43		12,990	3251
			13,130*	3395
			Avg 13,060**	Avg 3323[a]
L&S Bldg pour 36, mezzanine wall	13		12,790	1806
				1878
				Avg 1842[b]
L&S Bldg pour 26, wall	45		12,985	4984
			13,175*	4840
			13,270	4948
			Avg 13,140**	Avg 4924[c]
		Mix C-4236B-Revised		
L&S Bldg pour 24, flame tunnel walls	53	West side	13,330	3828
			12,960*	3539
		East side	13,520	Avg 3683[c]
			13,120*	3612[d]
			Avg 13,080**	
L&S Bldg pour 29, flame tunnel roof	30	Near top	13,310	3395
			13,500*	2998
			Avg 13,400	Avg 3196[c]
L&S Bldg pour 42, ramp retaining walls	30	East wall	12,390	(same placement as 29)
			13,120*	
			Avg 12,750**	
	19	West wall	12,730	3503
			12,560	3720
			13,200*	3503
			Avg 12,830**	Avg 3575[e]

Note: L&S is Launch and Service Building.
No cores cut at any test sites.

* Soniscope readings taken on one surface of concrete corrected to values of equivalent through readings; all other pulse velocity values taken through concrete.

** Averages using corrected surface readings.

a Cylinders tested at 31-day age.

b Cylinders tested at 3-day age.

c Cylinders tested at 28-day age.

d Cylinders tested at 45-day age.

e Cylinders tested at 8-day age.

Table 7

Relation of Surface Readings to Through Readings

Site and Placement	Surface Readings Pulse Velocity fps	Through Readings Pulse Velocity fps
	Mix C-6034	
Site 2		
LOB pour 9	12,450	14,420
	Mix C-4702	
Site 3		
L&S Bldg pour 21	13,090	12,950
L&S Bldg pour 37	11,760	12,680
	Mix C-4702B-Revised	
Site 3		
L&S Bldg pours 12, 24 (east)	12,030	12,850
L&S Bldg pours 12, 24 (west)	11,200	12,650
	Mix C-4701B	
Site 2		
L&S Bldg pour 21	10,030	13,240
Site 3		
L&S Bldg pour 18-A	12,630	13,590
	Mix C-4226B	
Site 7		
L&S Bldg pour 25	12,470	12,690
L&S Bldg pour 30	12,460	13,300
	Mix C-4232B-Revised	
Site 9		
L&S Bldg pour 26	12,380	13,130
L&S Bldg pour 30	12,330	12,990
	Mix C-4236B-Revised	
Site 9		
L&S Bldg pour 24 (west)	12,160	13,330
L&S Bldg pour 24 (east)	12,320	13,520
L&S Bldg pour 29	12,700	13,310
L&S Bldg pour 42 (east wall)	12,320	12,390
L&S Bldg pour 42 (west wall)	12,400	12,650

Note: LOB is Launch Operations Building; L&S is Launch and Service Building.

Table 8

Mixtures Used in Areas Tested with the Soniscope

1. SITE 1, C-[illegible]-Revised. Class AAA, PROTEX, 4000 lb

BROWN PIT AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Protex	4.7 oz	
Sand	1020 lb	
Gravel, 3/4 in. max	1000 lb	
Gravel, 1-1/2 in. max	1000 lb	
Water	275 lb (33 gal)	
Water/cement ratio	4.89 gal/bag	

2. SITE 2, C-6781. Class AAA, POZZOLITH 3R, 4000 lb

JOHN W. BROWN PIT AGGREGATES

Cement	611 lb	6-1/2 bags/cu yd
Pozzolith 3R	1.63 lb	
Sand	1100 lb	
Gravel, 3/4 in. max	1020 lb	
Gravel, 1-1/2 in. max	1020 lb	
Water	250 lb (30 gal)	
Water/cement ratio	4.62 gal/bag	

3. SITE 2, C-6034. Class AAA, PROTEX, 4000 lb

JOHN W. BROWN PIT AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Protex	5.4 oz	
Sand	970 lb	
Gravel, 3/4 in. max	930 lb	
Gravel, 1-1/2 in. max	1135 lb	
Water	283 lb (33 gal)	
Water/cement ratio	4.88 gal/bag	

4. SITES 2 AND 3, C-4702. Class AAA, PROTEX, 4000 lb

LARSEN PIT AGGREGATES

Cement	564 lb	6 bags/cu yd
Protex	4.5 oz	
Sand	1110 lb	
Gravel, 3/4 in. max	980 lb	
Gravel, 1-1/2 in. max	980 lb	
Water	275 lb (33 gal)	
Water/cement ratio	5.50 gal/bag	

5. SITE 3, C-6782. Class AAA, AQUAREX 310 or POZZOLITH 3R, 4000 lb

JOHN W. BROWN PIT SAND, LARSEN GRAVEL

Cement	611 lb	6-1/2 bags/cu yd
Aquarex 310	38 oz	
Sand	1110 lb	
Gravel, 3/4 in. max	1010 lb	
Gravel, 1-1/2 in. max	1010 lb	
Water	250 lb (31 gal)	
Water/cement ratio	4.77 gal/bag	

6. SITES 3 AND 4, C-6784. Class AAA, AQUAREX 310, 4000 lb

WASHED LARSEN SAND, LARSEN GRAVEL

Cement	611 lb	6-1/2 bags/cu yd
Aquarex 310	38 oz	
Sand	1110 lb	
Gravel, 3/4 in. max	990 lb	
Gravel, 1-1/2 in. max	990 lb	
Water	271 lb (32.5 gal)	
Water/cement ratio	5.0 gal/bag	

7. SITES 3 AND 4, C-4702B-Revised. Class AAA, PROTEX, 4000 lb

ALL LARSEN PIT AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Protex	5.1 oz	
Sand	1050 lb	
Gravel, 3/4 in. max	980 lb	
Gravel, 1-1/2 in. max	980 lb	
Water	275 lb (33 gal)	
Water/cement ratio	4.89 gal/bag	

8. SITES 2, 3, AND 4, C-4701B. Class AAA, Nonair, 4000 lb

ALL LARSEN PIT AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Sand	1140 lb	
Gravel, 3/4 in. max	980 lb	
Gravel, 1-1/2 in. max	980 lb	
Water	292 lb (35 gal)	
Water/cement ratio	5.19 gal/bag	

9. SITE 5, C-4733B-Revised. Class AAA, Nonair, 4000 lb

McCURRY SAND, LARSEN COARSE AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Sand	1190 lb	
Gravel, 3/4 in. max	990 lb	
Gravel, 1-1/2 in. max	990 lb	
Water	267 lb (32 gal)	
Water/cement ratio	4.74 gal/bag	

10. SITE 5, C-6784. Class AAA, AQUAREX, 4000 lb

McCURRY SAND, LARSEN COARSE AGGREGATES

Cement	611 lb	6-1/2 bags/cu yd
Aquarex 310	38 oz	
Sand	1110 lb	
Gravel, 3/4 in. max	990 lb	
Gravel, 1-1/2 in. max	990 lb	
Water	271 lb (32.5 gal)	
Water/cement ratio	5.0 gal/bag	

11. SITES 6 AND 7, C-6783. Class AAA, POZZOLITH 3R, 4000 lb

COWAN AGGREGATES

Cement	611 lb	6-1/2 bags/cu yd
Pozzolith 3R	1.63 lb	
Sand	1160 lb	
Gravel, 3/4 in. max	980 lb	
Gravel, 1-1/2 in. max	980 lb	
Water	258 lb (31 gal)	
Water/cement ratio	4.77 gal/bag	

12. SITES 6, 7, AND 8, C-4226B. Class AAA, PROTEX, 4000 lb

COWAN AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Protex	4.0 oz	
Sand	1020 lb	
Gravel, 3/4 in. max	1020 lb	
Gravel, 1-1/2 in. max	1020 lb	
Water	258 lb (31 gal)	
Water/cement ratio	4.59 gal/bag	

13. SITES 6, 7, AND 8, C-4226. Class AAA, PROTEX, 4000 lb

COWAN AGGREGATES

Cement	611 lb	6-1/2 bags/cu yd
Protex	2.7 oz	
Sand	1040 lb	
Gravel, 3/4 in. max	1020 lb	
Gravel, 1-1/2 in. max	1020 lb	
Water	256 lb (31 gal)	
Water/cement ratio	4.77 gal/bag	

14. SITE 9, C-4236B-Revised. Class AAA, PROTEX, 4000 lb

WEITZEL AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Protex	5.1 oz	
Sand	1030 lb	
Gravel, 3/4 in. max	980 lb	
Gravel, 1-1/2 in. max	980 lb	
Water	283 lb (34 gal)	
Water/cement ratio	5.04 gal/bag	

15. SITE 9, C-4232B-Revised. Class AAA, Nonair, 4000 lb

WEITZEL AGGREGATES

Cement	635 lb	6-3/4 bags/cu yd
Sand	1120 lb	
Gravel, 3/4 in. max	980 lb	
Gravel, 1-1/2 in. max	980 lb	
Water	300 lb (36 gal)	
Water/cement ratio	5.33 gal/bag	

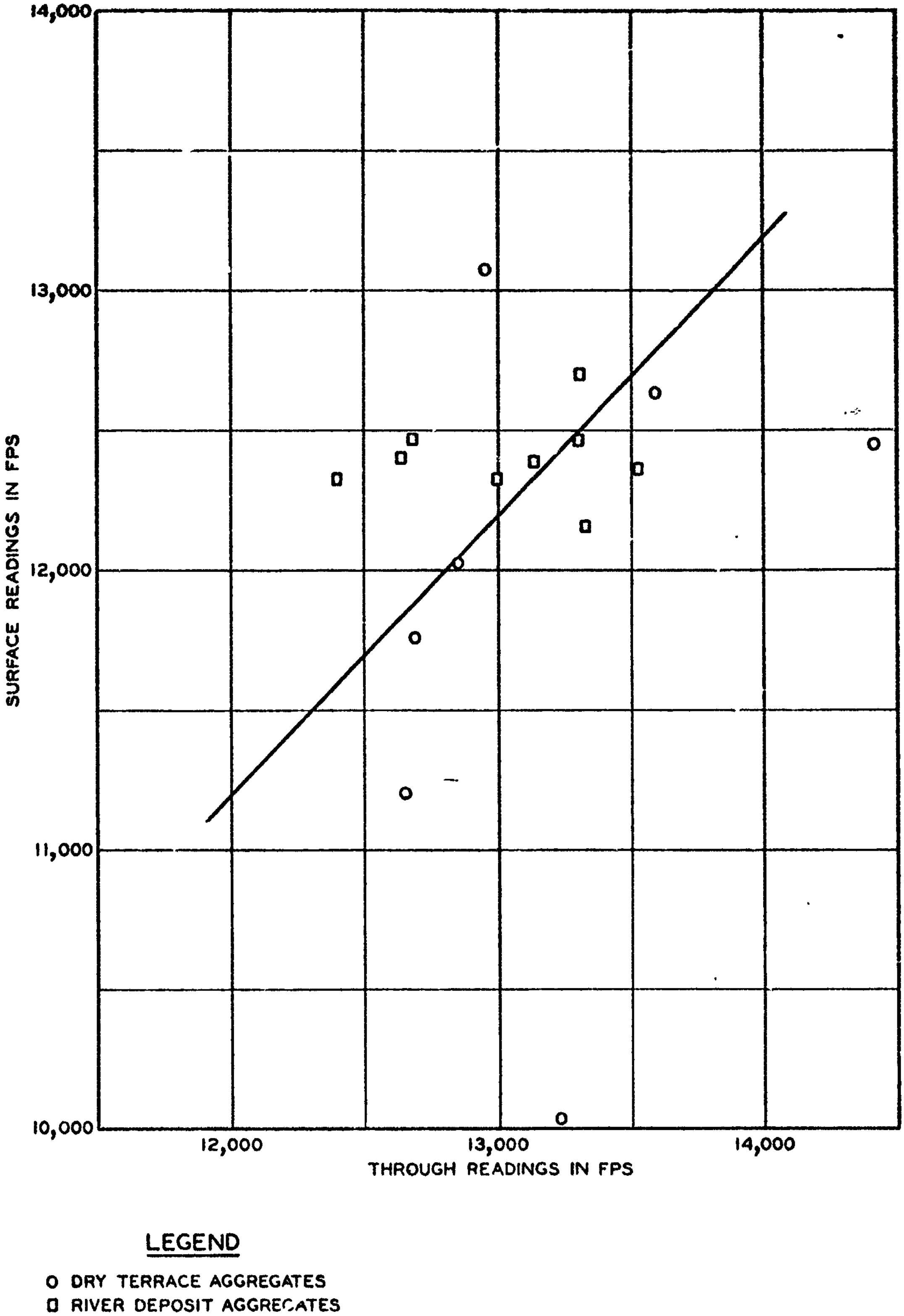
Table 9

Evaluation of Concrete of Questionable Quality

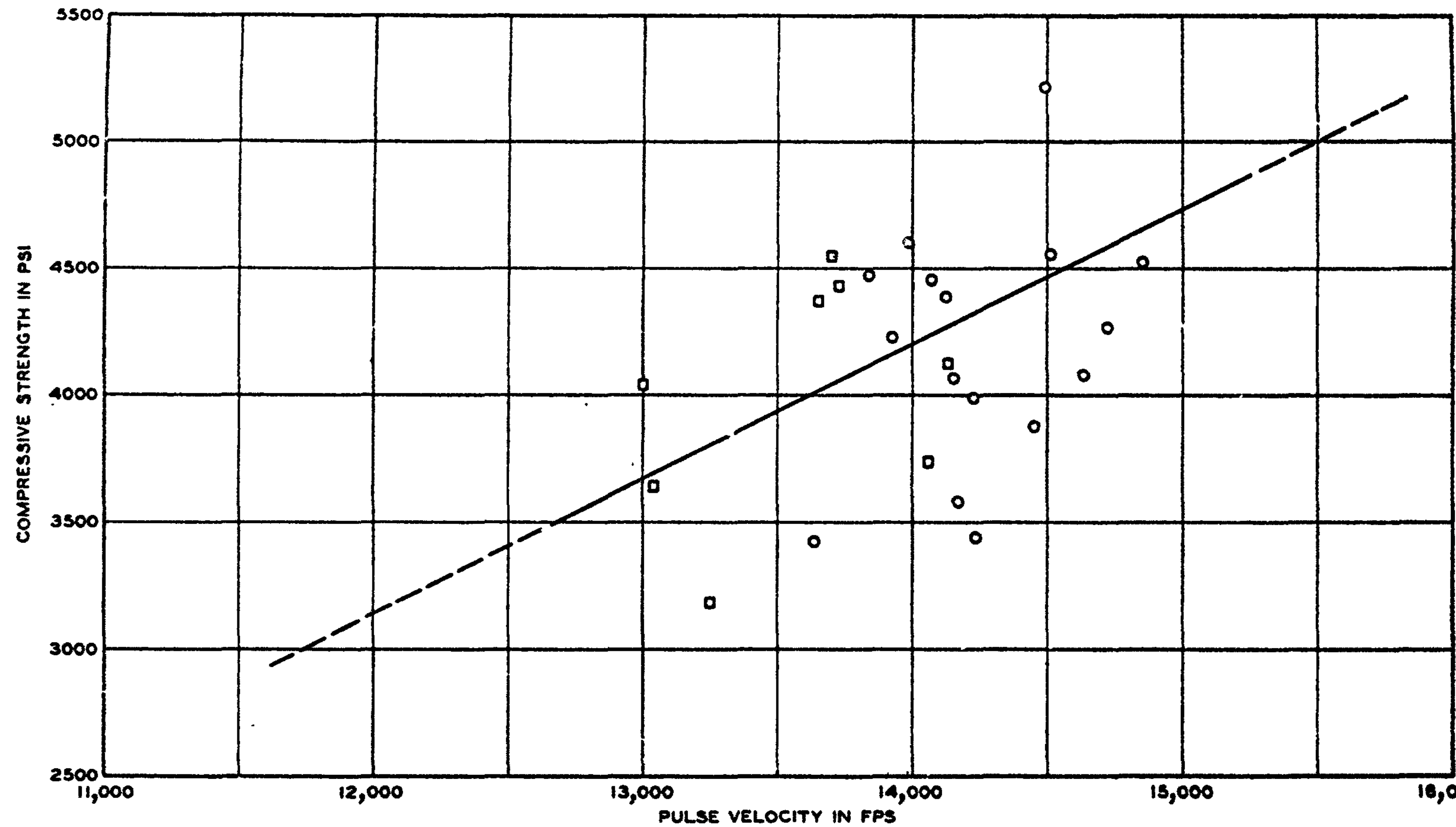
by Comparison of Pulse Velocities

Site and Placement	Average Pulse Velocity fps	Strength Indicated by Pulse Velocity, psi	Average Core Strength psi
Site 2			
LOB pour 2, floor	12,880	3600	3552
LOB pour 7, columns	14,340	4350	
LOB pour 8, roof	13,870	4100	4247
LOB pour 9, vestibule walls	13,840	4100	
L&S Bldg pour 7, flame pit	11,100	Below 3000	3903
L&S Bldg pour 13, missile support beam	13,980	4200	
L&S Bldg pour 21, flame tunnel floor	12,440	3400	3480
L&S Bldg pour 24, flame tunnel (east wall)	13,510	4000	
L&S Bldg pour 24, flame tunnel (west wall)	13,530	4000	
L&S Bldg pour 25, wall	13,720	4000	
Site 3			
LOB pour 8, roof	12,980	3700	3173
L&S Bldg pour 7, flame tunnel floor	13,610	4000	
L&S Bldg pour 8, flame tunnel floor	14,000	4200	3313
L&S Bldg pour 10, flame tunnel (north part)	13,240	3800	3543
L&S Bldg pour 10, flame tunnel (west wall)	13,270	3800	4917
L&S Bldg pours 12, 24, flame tunnel (east wall)	12,840	3600	3617
L&S Bldg pours 12, 24, flame tunnel (west wall)	12,220	3300	3107
L&S Bldg pour 15, floor	13,820	4100	4000
L&S Bldg pour 17, missile support beam	13,290	3800	
L&S Bldg pour 17-A, flame tunnel roof	13,180	3800	3460
L&S Bldg pour 18-A, floor	13,510	4000	4203
L&S Bldg pour 20, flame tunnel roof	14,085	4200	
L&S Bldg pour 21, flame tunnel floor	13,420	3900	2850
L&S Bldg pour 25, wall	13,110	3700	
L&S Bldg pour 34, vestibule wall	12,540	3500	4320
L&S Bldg pour 37, LOX tank housing wall	12,620	3500	3703
L&S Bldg, LOX sump, south wall	13,740	4100	
Site 7			
LOB pour 11, vestibule roof	13,100	3700	3897
L&S Bldg pour 25, wall	12,980	3700	
L&S Bldg pour 30, wall	13,280	3800	
Site 9			
L&S Bldg pour 24, flame tunnel wall	13,080	3800	
L&S Bldg pour 26, wall	13,140	3700	
L&S Bldg pour 29, flame tunnel roof	13,400	3900	
L&S Bldg pour 30, wall	13,060	3700	
L&S Bldg pour 36, mezzanine wall (13-day age)	12,790	3600	
L&S Bldg pour 42, ramp, east retaining wall	12,750	3300	
L&S Bldg pour 42, ramp, west retaining wall	12,830	3600	

Note: LOB is Launch Operations Building; L&S is Launch and Service Building.



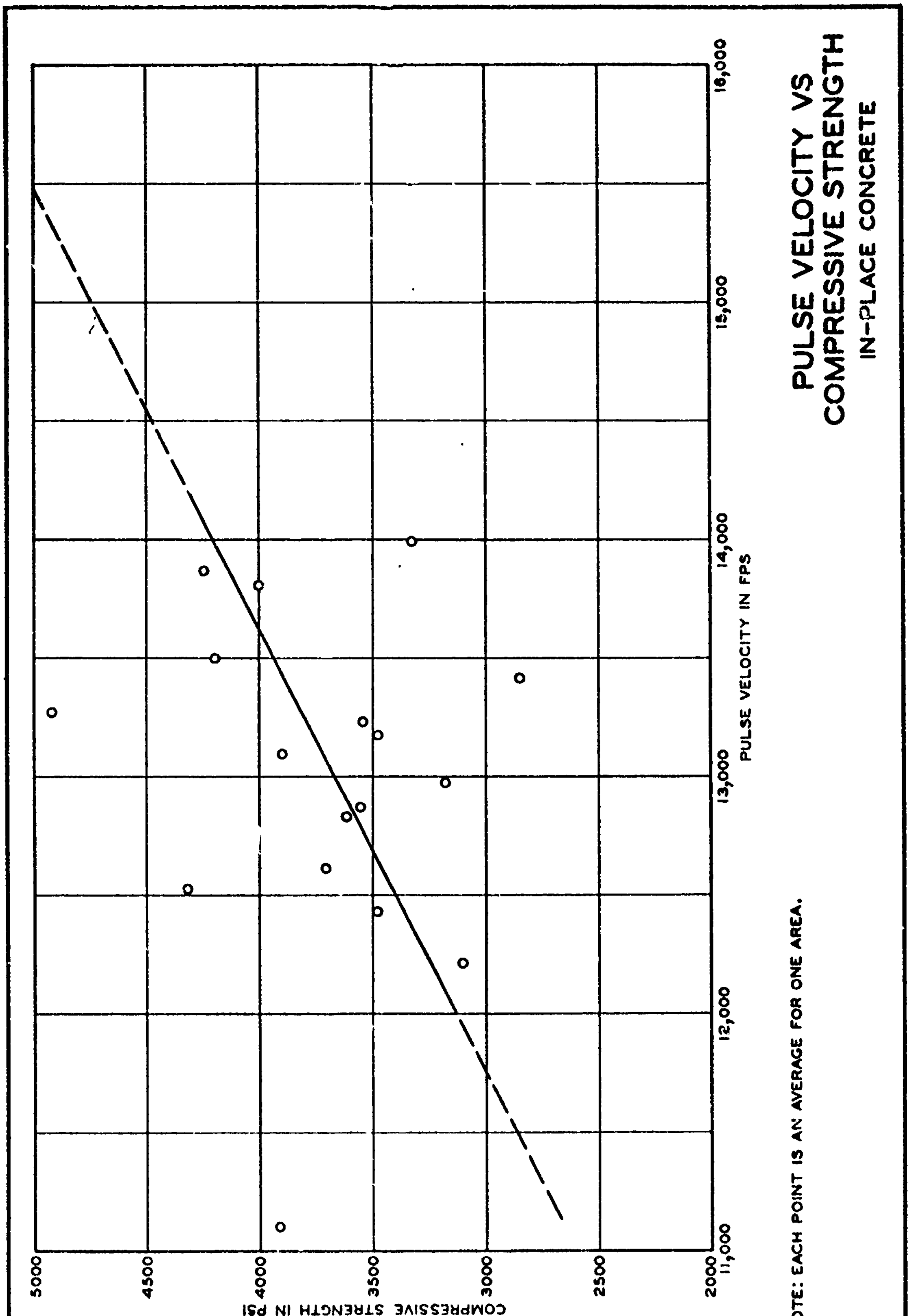
RELATION OF SURFACE READINGS TO THROUGH READINGS



PULSE VELOCITY VS COMPRESSIVE STRENGTH

TEST CYLINDERS FROM ALL LOCATIONS AND ALL SITES (EXCEPT SITE 7)

PLATE 2



PULSE VELOCITY VS COMPRESSIVE STRENGTH
IN-PLACE CONCRETE