Assessment of Concrete Compressive Strength by Ultrasonic Non-Destructive Test

AbdulMuttalib I. Said [1, a *] and Baqer Abdul Hussein Ali [1,b]

[1]Department of Civil Engineering, University of Baghdad, Baghdad, Iraq.

[a]Dr.AbdulMuttalib.I.Said@coeng.uobaghdad.edu.iq, [b]baqer1968@gmail.com

Abstract. This paper has carried out an experimental program to establish a relatively accurate relation between the ultrasonic pulse velocity (UPV) and the concrete compressive strength. The program involved testing concrete cubes of (100) mm and prisms of (100×100×300) cast with specified test variables. The samples are tested by using ultrasonic test equipment with two methods, direct ultrasonic pulse (DUPV) and surface (indirect) ultrasonic pulse (SUPV) for each sample. The obtained results were used as input data in the statistical program (SPSS) to predict the best equation representing the relation between the compressive strength and the ultrasonic pulse velocity. In this research 383 specimens were tested, and an exponential equation is proposed for this purpose. The statistical program has been used to prove which type of UPV is more suitable, the (SUPV) test or the (DUPV) test, to represent the relation between the ultrasonic pulse velocity and the concrete compressive strength. In this paper, the effect of salt content on the connection between the ultrasonic pulse velocity and the concrete compressive strength has also been studied.

Keywords: Assessment; evaluation; concrete structures; compressive strength; non-destructive test; ultrasonic pulse velocity method.

Introduction

The (UPV) method estimates the compressive strength of concrete by measuring the (UPV) from the pulse passing the time between the transmitter and receiver at certain distances in a concrete structure. The ultrasonic pulse velocity can evaluate concrete quality factors such as the compressive strength by obtaining a correlation between the (UPV) and the compressive strength. This study aims to correlate the compressive strength of the tested cubes and the results of the non-destructive tests (UPV) for the prism cast from the same concrete mix by using statistical methods.

Several studies have been made to develop the relationship between the ultrasonic pulse velocity and the compressive strength;

- Jones R. Equation in (1962) [1]. $C = 2.8\ e^{0.53D}$ (1)
- Elvery and Ibrahim Equation in (1976) [2]. $C = 0.0012\, e^{2.27\,D} \ldots \pm 6.4$ (2)
- Raouf, Z and Ali Z.M. Equation in (1983) [3]. $C = 2.016\, e^{0.61\,D}$ (3)
- Popovics et al. Equation in (1990) [4]. $C = 0.0028\, e^{0.0021\,D}$ (4)
- Nash't et al. equation in (2005) [5]. $C = 1.19\, e^{0.715\,D}$ (5)
- Jassim, A.K et al. equation in (2013) [6, 7] $C = 0.173\ e^{1.157\,D}$, $C = 0.46\, e^{1.16\,S}$ (6)

Where C: compressive strength in MPa and D: direct ultrasonic velocity in km/sec

Experimental Results

The study covers 383 test results on 172 prisms and nearly 900 concrete cubes of 100 mm [8]. These cubes were a product from the mixtures designed for this research using ordinary Portland cement compatible with the Iraqi standard (No.5) and sulfate resisting Portland cement with different curing conditions. The mixing properties and the experimental results are shown in Table 1. For this

research, different graded and maximum size coarse aggregate are prepared to satisfy the grading requirements. The coarse aggregate grading and characteristics are given in Table 2.

Discussion of Experimental Work Results

The ultrasonic pulse velocity (UPV) had been measured in two ways, the first one was (SUPV) and the second was (DUPV) in order to find the best relation which can be correlated to the compressive strength. A comparison had been made to find the best form of the (UPV) type: surface ultrasonic pulse velocity (SUPV) or direct ultrasonic pulse velocity (DUPV) to represent the relation between UPV and the compressive strength. To investigate the SUPV and DUPV, data have been drawn with the compressive strength for all the samples subjected to normal curing. Two exponential curves were found, as shown in Figures 1 and 2. The correlation factor and R^2 were found for the two curves, as shown in Table 3.

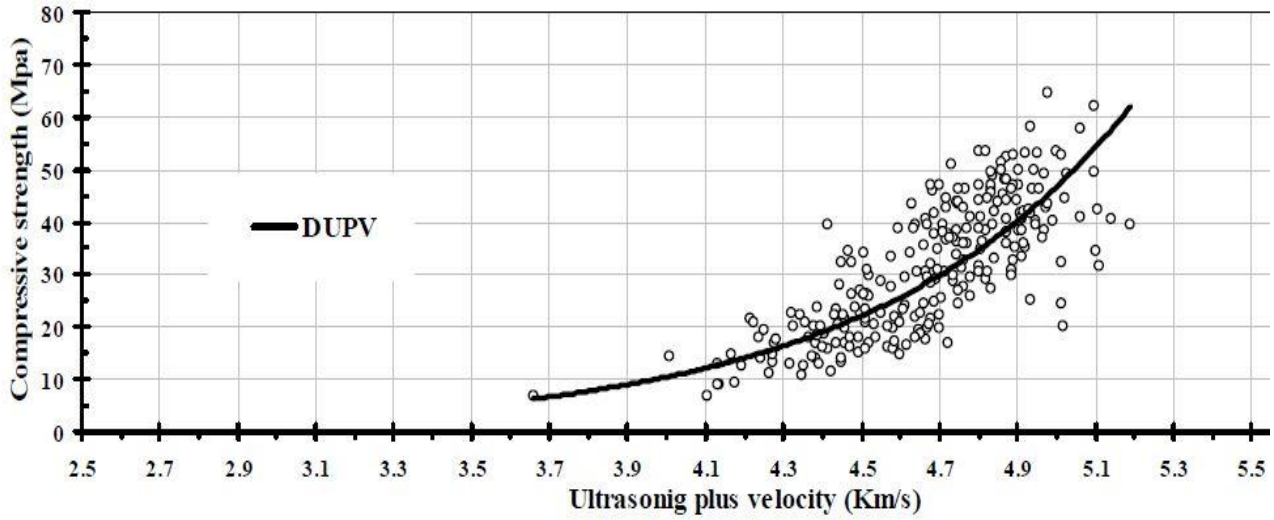

Figure 1. Relation between (DUPV) with the compressive strength for concrete samples subjected to normal curing.

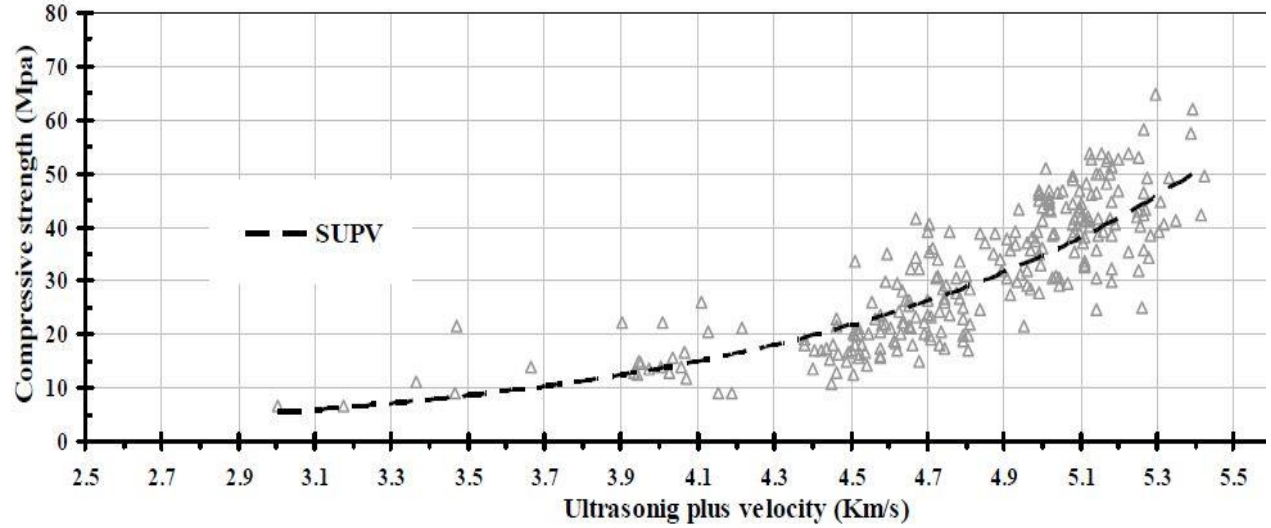

Figure 2. Relation between (SUPV) with the compressive strength for concrete samples subjected to normal curing.

Table 1. Experimental results of cubes and prism (normally curing).

Sample no.	SLUMP (mm)	SLUMP range (mm)	SO_3 % in fine agregate	W/C	Coarse Aggregate	Mix proportions	Age (day)	Comp. str. (Mpa)	Ult. V(km/s) direct	Ult. V(km/s)surface	Density (gm /cm3)
1	90	(60-180)	0.34	0.6	Type 1	1:2.09:2.66	7	7.05	4.26	3.36	2.42
2	90	(60-180)	0.34	0.6	Type 1	1:2.09:2.66	14	13.35	4.58	3.98	2.42
3	90	(60-180)	0.34	0.6	Type 1	1:2.09:2.66	21	23.00	4.54	4.51	2.39
4	90	(60-180)	0.34	0.6	Type 1	1:2.09:2.66	28	27.25	4.60	4.68	2.41
5	90	(60-180)	0.34	0.6	Type 1	1:2.09:2.66	60	30.78	4.65	4.80	2.43
6	90	(60-180)	0.34	0.6	Type 1	1:2.09:2.66	90	30.77	4.69	4.79	2.39
7	90	(60-180)	0.34	0.6	Type 1	1:2.09:2.66	120	31.13	4.70	4.81	2.40
8	68	(60-180)	0.34	0.4	Type 2	1:1.13:1.7	14	31.92	4.68	4.90	2.33
9	68	(60-180)	0.34	0.4	Type 2	1:1.13:1.7	21	43.75	4.74	5.00	2.35
10	68	(60-180)	0.34	0.4	Type 2	1:1.13:1.7	28	43.30	4.75	5.02	2.35
11	68	(60-180)	0.34	0.4	Type 2	1:1.13:1.7	60	48.66	4.84	5.08	2.36
12	68	(60-180)	0.34	0.4	Type 2	1:1.13:1.7	90	46.43	4.83	5.04	2.35
13	56	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	14	18.12	4.34	4.57	2.33
14	56	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	21	20.77	4.18	4.61	2.33
15	56	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	28	23.42	4.44	4.65	2.33
16	56	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	60	28.29	4.50	4.69	2.32
17	56	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	90	27.40	4.53	4.73	2.33
18	10	(0-10)	0.34	0.4	Type 5	1:1.36:3.03	7	37.72	4.72	4.91	2.47
19	10	(0-10)	0.34	0.4	Type 5	1:1.36:3.03	14	48.21	4.87	5.17	2.51
20	10	(0-10)	0.34	0.4	Type 5	1:1.36:3.03	21	46.88	4.90	5.20	2.52
21	10	(0-10)	0.34	0.4	Type 5	1:1.36:3.03	28	58.04	4.93	5.27	2.52
22	10	(0-10)	0.34	0.4	Type 5	1:1.36:3.03	60	64.73	4.98	5.30	2.50
23	10	(0-10)	0.34	0.4	Type 5	1:1.36:3.03	90	49.11	5.03	5.33	2.50
24	27	(10-30)	0.34	0.4	Type 5	1:1.26:2.45	7	39.29	4.42	4.99	2.44
25	27	(10-30)	0.34	0.4	Type 5	1:1.26:2.45	14	44.20	4.80	5.02	2.41
26	27	(10-30)	0.34	0.4	Type 5	1:1.26:2.45	21	46.88	4.83	5.06	2.43
27	27	(10-30)	0.34	0.4	Type 5	1:1.26:2.45	28	48.21	4.87	5.12	2.44
28	27	(10-30)	0.34	0.4	Type 5	1:1.26:2.45	60	46.43	4.94	5.14	2.43
29	27	(10-30)	0.34	0.4	Type 5	1:1.26:2.45	90	50.00	4.94	5.14	2.42
30	27	(10-30)	0.34	0.4	Type 5	1:1.26:2.45	100	34.82		4.60	
31	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	150	43.75	4.85	5.05	2.38
32	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	7	28.06	4.63	4.76	2.36
33	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	14	29.61	4.69	4.88	2.33
34	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	21	31.38	4.76	4.91	2.38
35	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	28	38.45	4.76	4.98	2.39
36	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	60	43.31	4.80	5.01	2.38
37	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	90	40.22	4.82	5.03	2.37
38	73	(60-180)	0.34	0.5	Type 4	1:1.91:2.25	120	43.75	4.83	5.03	2.37
39	59	(30-60)	0.34	0.4	Type 2	1:1.17:1.93	7	42.86	4.72	5.02	2.46
40	59	(30-60)	0.34	0.4	Type 2	1:1.17:1.93	14	43.75	4.75	5.10	2.44
41	59	(30-60)	0.34	0.4	Type 2	1:1.17:1.93	21	53.57	4.80	5.13	2.44
42	59	(30-60)	0.34	0.4	Type 2	1:1.17:1.93	28	53.57	4.82	5.16	2.46
43	59	(30-60)	0.34	0.4	Type 2	1:1.17:1.93	60	52.23	4.87	5.17	2.44
44	59	(30-60)	0.34	0.4	Type 2	1:1.17:1.93	90	50.00	4.90	5.15	2.44
45	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	7	13.07	4.19	3.94	2.39
46	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	90	28.39	4.69	4.70	2.37
47	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	14	22.88	4.54	4.49	2.39
48	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	28	26.47	4.61	4.63	2.37
49	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	60	27.67	4.68	4.67	2.37
50	78	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	7	34.38	4.47	4.67	2.37
51	78	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	14	33.48	4.58	4.79	2.37
52	78	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	21	33.93	4.63	4.89	2.38
53	78	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	28	39.29	4.64	4.93	2.37
54	78	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	60	44.64	4.72	5.02	2.36
55	78	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	90	46.43	4.77	4.99	2.36
56	78	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	120	46.43	4.75	4.99	2.36
57	55	(30-60)	0.34	0.45	Type 3	1:1.4:2.29	7	29.91	4.52	4.59	2.34
58	55	(30-60)	0.34	0.45	Type 3	1:1.4:2.29	14	30.58	4.67	4.77	2.34
59	55	(30-60)	0.34	0.45	Type 3	1:1.4:2.29	21	34.82	4.69	4.87	2.33
60	55	(30-60)	0.34	0.45	Type 3	1:1.4:2.29	28	36.61	4.72	4.93	2.35
61	55	(30-60)	0.34	0.45	Type 3	1:1.4:2.29	60	46.88	4.80	5.02	2.33
62	55	(30-60)	0.34	0.45	Type 3	1:1.4:2.29	90	45.54	4.83	5.02	2.35
63	55	(30-60)	0.34	0.45	Type 3	1:1.4:2.29	120	45.09	4.86	4.99	2.35
64	29	(10-30)	0.34	0.45	Type 2	1:1.51:2.79	7	26.34	4.50	4.70	2.41
65	29	(10-30)	0.34	0.45	Type 2	1:1.51:2.79	14	37.50	4.69	4.98	2.42
66	29	(10-30)	0.34	0.45	Type 2	1:1.51:2.79	21	38.39	4.74	5.03	2.41
67	29	(10-30)	0.34	0.45	Type 2	1:1.51:2.79	28	42.86	4.76	5.10	2.41
68	29	(10-30)	0.34	0.45	Type 2	1:1.51:2.79	60	44.64	4.82	5.18	2.42
69	29	(10-30)	0.34	0.45	Type 2	1:1.51:2.79	90	51.34	4.86	5.18	2.41
70	29	(10-30)	0.34	0.45	Type 2	1:1.51:2.79	120	50.00	4.86	5.18	2.43
71	56	(30-60)	0.34	0.4	Type 1	1:1.17:1.93	90	49.50	4.85	5.05	2.44
72	56	(30-60)	0.34	0.4	Type 1	1:1.17:1.93	7	42.43	4.67	4.92	2.46
73	56	(30-60)	0.34	0.4	Type 1	1:1.17:1.93	14	43.31	4.70	4.99	2.44
74	56	(30-60)	0.34	0.4	Type 1	1:1.17:1.93	21	53.04	4.76	5.02	2.44
75	56	(30-60)	0.34	0.4	Type 1	1:1.17:1.93	28	53.04	4.77	5.05	2.46
76	56	(30-60)	0.34	0.4	Type 1	1:1.17:1.93	60	51.71	4.83	5.07	2.44
77	25	(10-30)	0.34	0.4	Type 1	1:1.26:2.45	90	49.50	4.89	5.09	2.42

Table 1. Continued.

Sample no.	SLUMP (mm)	SLUMP range (mm)	SO_3 % in fine agregate	W/C	Coarse Aggregate	Mix proportions	Age (day)	Comp. str. (Mpa)	Ult. V(km/s) direct	Ult. V(km/s)surface	Density (gm /cm3)
78	25	(10-30)	0.34	0.4	Type 1	1:1.26:2.45	100	34.47		4.55	
79	8	(0-10)	0.34	0.45	Type 2	1:1.6:3.4	7	24.11	4.61	4.73	2.45
80	8	(0-10)	0.34	0.45	Type 2	1:1.6:3.4	14	34.82	4.81	4.99	2.46
81	8	(0-10)	0.34	0.45	Type 2	1:1.6:3.4	21	37.95	4.87	5.11	2.48
82	8	(0-10)	0.34	0.45	Type 2	1:1.6:3.4	28	41.52	4.92	5.18	2.46
83	8	(0-10)	0.34	0.45	Type 2	1:1.6:3.4	60	53.13	4.95	5.25	2.46
84	8	(0-10)	0.34	0.45	Type 2	1:1.6:3.4	90	53.57	5.00	5.23	2.45
85	8	(0-10)	0.34	0.45	Type 2	1:1.6:3.4	120	52.68	5.01	5.20	2.43
86	70	(60-180)	2.05	0.48	Type 1	1:1.32:2.18	28	26.12	4.51	4.55	
87	70	(60-180)	2.05	0.48	Type 1	1:1.32:2.18	7	22.32	4.34	3.90	2.38
88	70	(60-180)	2.05	0.48	Type 1	1:1.32:2.18	28	40.40	4.66	4.70	2.36
89	70	(60-180)	2.05	0.48	Type 1	1:1.32:2.18	60	39.29	4.67	4.76	2.43
90	105	(60-180)	0.34	0.5	Type 3	1:1.71:1.93	7	33.59	4.46	4.68	2.38
91	105	(60-180)	0.34	0.5	Type 3	1:1.71:1.93	14	38.45	4.55	4.79	2.39
92	105	(60-180)	0.34	0.5	Type 3	1:1.71:1.93	21	38.45	4.59	4.83	2.39
93	105	(60-180)	0.34	0.5	Type 3	1:1.71:1.93	28	42.87	4.58	4.89	2.41
94	105	(60-180)	0.34	0.5	Type 3	1:1.71:1.93	60	45.52	4.63	4.94	2.37
95	105	(60-180)	0.34	0.5	Type 3	1:1.71:1.93	90	46.41	4.63	4.94	2.39
96	105	(60-180)	0.34	0.5	Type 3	1:1.71:1.93	150	50.38	4.68	4.96	2.39
97	65	(60-180)	0.34	0.48	Type 1	1:1.32:2.18	7	20.98	4.51	4.21	2.38
98	65	(60-180)	0.34	0.48	Type 1	1:1.32:2.18	28	29.46	4.67	4.62	2.39
99	65	(60-180)	0.34	0.48	Type 1	1:1.32:2.18	60	35.49	4.66	4.71	2.40
100	65	(60-180)	0.34	0.48	Type 1	1:1.32:2.18	90	41.52	4.69	4.67	2.42
101	65	(60-180)	0.34	0.48	Type 1	1:1.32:2.18	120	25.45	4.70	4.65	2.48
102	65	(60-180)	0.34	0.48	Type 1	1:1.32:2.18	150	35.27	4.92	5.22	2.49
103	9	(0-10)	2.05	0.5	Type 2	1:1.69:4.82	7	25.89	4.78	4.11	2.31
104	9	(0-10)	2.05	0.5	Type 2	1:1.69:4.82	28	30.36	4.89	5.03	2.47
105	9	(0-10)	2.05	0.5	Type 2	1:1.69:4.82	60	38.39	4.90	5.28	2.48
106	9	(0-10)	2.05	0.5	Type 2	1:1.69:4.82	90	38.39	4.97	5.18	2.48
107	9	(0-10)	2.05	0.5	Type 2	1:1.69:4.82	120	32.14	5.01	5.18	2.48
108	15	(10-30)	2.05	0.5	Type 2	1:1.52:3.92	7	16.96	4.47	4.42	2.43
109	15	(10-30)	2.05	0.5	Type 2	1:1.52:3.92	28	22.32	4.70	4.69	2.42
110	15	(10-30)	2.05	0.5	Type 2	1:1.52:3.92	60	30.36	4.71	4.72	2.41
111	15	(10-30)	2.05	0.5	Type 2	1:1.52:3.92	90	39.29	4.71	4.70	2.40
112	15	(10-30)	2.05	0.5	Type 2	1:1.52:3.92	120	36.16	4.75	4.71	2.40
113	45	(30-60)	2.05	0.5	Type 2	1:1.39:3.26	7	21.65	4.46	4.59	2.38
114	45	(30-60)	2.05	0.5	Type 2	1:1.39:3.26	28	30.36	4.64	4.91	2.43
115	45	(30-60)	2.05	0.5	Type 2	1:1.39:3.26	60	29.02	4.69	4.96	2.43
116	45	(30-60)	2.05	0.5	Type 2	1:1.39:3.26	90	38.17	4.71	4.97	2.40
117	45	(30-60)	2.05	0.5	Type 2	1:1.39:3.26	120	37.05	4.74	4.96	2.40
118	85	(60-180)	2.05	0.5	Type 2	1:1.42:2.75	7	22.32	4.44	4.01	2.42
119	85	(60-180)	2.05	0.5	Type 2	1:1.42:2.75	14	33.71	4.75	4.51	2.41
120	85	(60-180)	2.05	0.5	Type 2	1:1.42:2.75	21	28.57	4.74	4.97	2.41
121	85	(60-180)	2.05	0.5	Type 2	1:1.42:2.75	28	32.81	4.76	5.00	2.44
122	85	(60-180)	2.05	0.5	Type 2	1:1.42:2.75	60	38.84	4.77	5.10	2.43
123	85	(60-180)	2.05	0.5	Type 2	1:1.42:2.75	90	41.07	4.81	5.11	2.39
124	85	(60-180)	2.05	0.5	Type 2	1:1.42:2.75	120	49.55	4.83	5.08	2.41
125	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	7	31.25	4.76	4.94	2.39
126	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	14	33.04	4.84	5.11	2.41
127	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	21	35.71	4.87	5.14	2.42
128	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	28	40.40	4.91	5.19	2.42
129	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	60	42.86	4.98	5.25	2.42
130	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	90	49.11	4.97	5.27	2.42
131	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	120	46.43	4.95	5.26	2.42
132	20	(10-30)	0.34	0.5	Type 2	1:2.37:3.87	150	43.30	4.98	5.27	2.42
133	77	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	14	32.24	4.72	4.95	2.33
134	77	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	21	44.19	4.79	5.05	2.35
135	77	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	28	43.74	4.80	5.07	2.35
136	77	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	60	49.15	4.89	5.13	2.36
137	77	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	90	46.89	4.88	5.09	2.35
138	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	7	29.24	4.61	4.75	2.34
139	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	14	35.71	4.77	4.92	2.36
140	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	21	41.07	4.78	5.00	2.37
141	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	28	38.39	4.82	5.08	2.37
142	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	60	41.96	4.84	5.10	2.37
143	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	90	52.68	4.89	5.13	2.36
144	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	120	46.88	4.89	5.10	2.36
145	58	(30-60)	0.34	0.5	Type 2	1:1.9:2.74	150	41.07	4.91	5.12	2.36
146	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	7	28.35	4.68	4.81	2.36
147	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	14	29.91	4.74	4.93	2.33
148	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	21	31.70	4.80	4.96	2.38
149	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	28	38.84	4.80	5.03	2.39
150	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	60	43.75	4.85	5.06	2.38
151	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	90	40.63	4.87	5.08	2.37
152	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	120	44.20	4.87	5.08	2.37
153	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	150	44.20	4.90	5.10	2.38
154	72	(60-180)	0.34	0.5	Type 2	1:1.91:2.25	120	39.78	4.90	5.07	2.37

Table 1. Continued.

Sample no.	SLUMP (mm)	SLUMP range (mm)	SO_3 % in fine agregate	W/C	Coarse Aggregate	Mix proportions	Age (day)	Comp. str. (Mpa)	Ult. V(km/s) direct	Ult. V(km/s)surface	Density (gm /cm3)
155	72	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	7	23.20	4.56	4.71	2.35
156	72	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	41	35.36	4.71	4.92	2.37
157	72	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	21	35.80	4.76	4.95	2.36
158	72	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	28	38.89	4.79	5.03	2.34
159	72	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	60	45.74	4.84	5.08	2.36
160	72	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	90	52.59	4.87	5.12	2.35
161	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	7	33.93	4.51	4.73	2.38
162	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	14	38.84	4.59	4.84	2.39
163	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	21	38.84	4.63	4.88	2.39
164	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	28	43.30	4.63	4.94	2.41
165	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	60	45.98	4.68	4.99	2.37
166	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	90	46.88	4.68	4.99	2.39
167	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	120	46.88	4.70	4.99	2.39
168	92	(60-180)	0.34	0.5	Type 4	1:1.71:1.93	150	50.89	4.73	5.01	2.39
169	98	(60-180)	2.05	0.5	Type 4	1:1.24:2.412	7	14.51	4.01	3.95	2.33
170	98	(60-180)	2.05	0.5	Type 4	1:1.24:2.412	14	17.86	4.24	4.38	2.33
171	98	(60-180)	2.05	0.5	Type 4	1:1.24:2.412	21	22.77	4.32	4.46	2.33
172	98	(60-180)	2.05	0.5	Type 4	1:1.24:2.412	28	23.66	4.39	4.58	2.33
173	98	(60-180)	2.05	0.5	Type 4	1:1.24:2.412	60	32.14	4.45	4.65	2.66
174	98	(60-180)	2.05	0.5	Type 4	1:1.24:2.412	90	32.14	4.47	4.68	2.31
175	98	(60-180)	2.05	0.5	Type 4	1:1.24:2.412	120	30.80	4.52	4.72	2.31
176	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	7	19.84	4.72	4.75	2.39
177	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	14	27.96	4.81	5.04	2.43
178	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	21	29.31	4.87	5.10	2.42
179	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	28	35.62	4.94	5.13	2.43
180	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	60	41.48	4.96	5.17	2.41
181	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	90	41.93	4.98	5.14	2.41
182	70	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	7	23.44	4.61	4.76	2.35
183	70	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	41	35.71	4.76	4.97	2.37
184	70	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	21	36.16	4.81	5.00	2.36
185	70	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	28	39.29	4.84	5.08	2.34
186	70	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	60	46.21	4.89	5.13	2.36
187	70	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	90	53.13	4.92	5.17	2.35
188	70	(60-180)	0.34	0.5	Type 5	1:1.91:2.25	120	40.18	4.95	5.12	2.37
189	90	(60-180)	2.05	0.5	Type 5	1:1.41:2.75	7	8.93	4.13	3.47	2.40
190	90	(60-180)	2.05	0.5	Type 5	1:1.41:2.75	14	13.84	4.24	3.66	2.37
191	90	(60-180)	2.05	0.5	Type 5	1:1.41:2.75	21	12.95	4.32	4.03	2.40
192	90	(60-180)	2.05	0.5	Type 5	1:1.41:2.75	28	13.84	4.38	4.06	2.42
193	90	(60-180)	2.05	0.5	Type 5	1:1.41:2.75	60	20.54	4.44	4.13	2.38
194	90	(60-180)	2.05	0.5	Type 5	1:1.41:2.75	90	22.77	4.50	4.46	2.35
195	90	(60-180)	2.05	0.5	Type 5	1:1.41:2.75	120	21.43	4.51	4.46	2.33
196	10	(0-10)	0.34	0.5	Type 1	1:1.82:4.21	14	24.55	5.01	5.14	2.45
197	10	(0-10)	0.34	0.5	Type 1	1:1.82:4.21	21	31.70	5.11	5.25	2.49
198	10	(0-10)	0.34	0.5	Type 1	1:1.82:4.21	28	34.38	5.10	5.28	2.46
199	10	(0-10)	0.34	0.5	Type 1	1:1.82:4.21	60	40.63	5.14	5.32	2.47
200	10	(0-10)	0.34	0.5	Type 1	1:1.82:4.21	90	39.29	5.19	5.30	2.46
201	27	(10-30)	0.34	0.5	Type 1	1:1.76:3.74	7	21.88	4.64	4.81	2.43
202	27	(10-30)	0.34	0.5	Type 1	1:1.76:3.74	14	30.36	4.80	5.04	2.45
203	27	(10-30)	0.34	0.5	Type 1	1:1.76:3.74	21	32.59	4.89	5.11	2.45
204	27	(10-30)	0.34	0.5	Type 1	1:1.76:3.74	28	41.52	4.91	5.15	2.44
205	27	(10-30)	0.34	0.5	Type 1	1:1.76:3.74	60	38.39	4.91	5.15	2.44
206	75	(60-180)	0.34	0.45	Type 2	1:1.47:1.86	120	45.96	4.70	4.94	2.36
207	75	(60-180)	0.34	0.45	Type 2	1:1.47:1.86	7	34.03	4.42	4.62	2.37
208	75	(60-180)	0.34	0.45	Type 2	1:1.47:1.86	14	33.15	4.53	4.74	2.37
209	75	(60-180)	0.34	0.45	Type 2	1:1.47:1.86	21	34.27	4.67	4.94	2.38
210	75	(60-180)	0.34	0.45	Type 2	1:1.47:1.86	28	39.68	4.69	4.98	2.37
211	75	(60-180)	0.34	0.45	Type 2	1:1.47:1.86	60	45.09	4.76	5.07	2.36
212	75	(60-180)	0.34	0.45	Type 2	1:1.47:1.86	90	46.89	4.81	5.04	2.36
213	55	(30-60)	0.34	0.5	Type 1	1:1.71:3.18	7	20.09	5.02	4.69	2.38
214	55	(30-60)	0.34	0.5	Type 1	1:1.71:3.18	14	27.23	4.83	4.92	2.42
215	55	(30-60)	0.34	0.5	Type 1	1:1.71:3.18	21	30.80	4.89	5.04	2.38
216	55	(30-60)	0.34	0.5	Type 1	1:1.71:3.18	28	33.48	4.91	5.11	2.40
217	55	(30-60)	0.34	0.5	Type 1	1:1.71:3.18	60	41.96	4.92	5.12	2.39
218	55	(30-60)	0.34	0.5	Type 1	1:1.71:3.18	90	37.05	4.96	5.11	2.39
219	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	7	19.64	4.67	4.70	2.39
220	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	14	27.68	4.76	4.99	2.43
221	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	21	29.02	4.82	5.05	2.42
222	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	28	35.27	4.89	5.08	2.43
223	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	60	41.07	4.91	5.12	2.41
224	85	(60-180)	0.34	0.5	Type 1	1:1.75:2.63	90	41.52	4.93	5.09	2.41
225	5	(0-10)	2.05	0.56	Type 2	1:2.1:5.99	21	30.36	4.82	5.14	2.47
226	5	(0-10)	2.05	0.56	Type 2	1:2.1:5.99	28	29.91	4.89	5.18	2.47
227	5	(0-10)	2.05	0.56	Type 2	1:2.1:5.99	60	35.71	4.92	5.26	2.48
228	5	(0-10)	2.05	0.56	Type 2	1:2.1:5.99	90	41.96	4.92	5.25	2.47
229	5	(0-10)	2.05	0.56	Type 2	1:2.1:5.99	120	42.41	4.93	5.27	2.47
230	5	(0-10)	2.05	0.56	Type 2	1:2.1:5.99	150	25.00	4.93	5.26	2.47
231	115	(60-180)	0.34	0.8	Type 2	1:3.33:3.33	7	5.26	3.73	3.06	2.34

Table 1. Continued.

Sample no.	SLUMP (mm)	SLUMP range (mm)	SO_3 % in fine agregate	W/C	Coarse Aggregate	Mix proportions	Age (day)	Comp. str. (Mpa)	Ult. V(km/s) direct	Ult. V(km/s)surface	Density (gm /cm3)
232	115	(60-180)	0.34	0.8	Type 2	1:3.33:3.33	21	22.98	4.36	4.49	2.38
233	115	(60-180)	0.34	0.8	Type 2	1:3.33:3.33	28	23.76	4.37	4.52	2.37
234	115	(60-180)	0.34	0.8	Type 2	1:3.33:3.33	60	25.95	4.44	4.61	2.36
235	115	(60-180)	0.34	0.8	Type 2	1:3.33:3.33	90	26.01	4.48	4.61	2.37
236	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	7	11.61	4.42	4.07	2.43
237	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	14	15.18	4.50	4.44	2.37
238	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	21	16.07	4.57	4.58	2.37
239	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	28	16.07	4.59	4.58	2.33
240	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	60	19.20	4.65	4.71	2.36
241	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	90	17.41	4.67	4.74	2.36
242	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	120	26.79	4.75	4.79	2.36
243	20	(10-30)	2.05	0.56	Type 2	1:2.:4.9	150	16.96	4.72	4.81	2.36
244	25	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	14	9.06	4.13	4.11	2.40
245	25	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	21	12.82	4.35	4.42	2.38
246	25	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	28	16.00	4.36	4.42	2.37
247	25	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	60	19.67	4.41	4.47	2.34
248	25	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	90	16.57	4.39	4.45	2.34
249	35	(30-60)	2.05	0.56	Type 2	1:1.92:4.09	7	13.39	4.27	3.97	2.40
250	35	(30-60)	2.05	0.56	Type 2	1:1.92:4.09	14	16.96	4.38	4.50	2.36
251	35	(30-60)	2.05	0.56	Type 2	1:1.92:4.09	21	16.96	4.46	4.62	2.42
252	35	(30-60)	2.05	0.56	Type 2	1:1.92:4.09	28	18.08	4.49	4.66	2.43
253	35	(30-60)	2.05	0.56	Type 2	1:1.92:4.09	60	25.89	4.52	4.75	2.41
254	35	(30-60)	2.05	0.56	Type 2	1:1.92:4.09	120	19.87	4.58	4.79	2.40
255	110	(60-180)	0.34	0.8	Type 3	1:3.33:3.33	7	6.76	3.70	3.03	2.34
256	110	(60-180)	0.34	0.8	Type 3	1:3.33:3.33	21	17.13	4.32	4.45	2.38
257	110	(60-180)	0.34	0.8	Type 3	1:3.33:3.33	28	17.58	4.33	4.48	2.37
258	110	(60-180)	0.34	0.8	Type 3	1:3.33:3.33	60	21.19	4.40	4.56	2.36
259	110	(60-180)	0.34	0.8	Type 3	1:3.33:3.33	90	20.29	4.44	4.57	2.37
260	70	(60-180)	2.05	0.56	Type 2	1:1.96:3.5	7	12.95	4.13	3.93	2.61
261	70	(60-180)	2.05	0.56	Type 2	1:1.96:3.5	28	18.75	4.41	4.61	2.45
262	70	(60-180)	2.05	0.56	Type 2	1:1.96:3.5	60	23.21	4.44	4.71	2.44
263	70	(60-180)	2.05	0.56	Type 2	1:1.96:3.5	90	26.79	4.50	4.74	2.38
264	70	(60-180)	2.05	0.56	Type 2	1:1.96:3.5	120	20.54	4.53	4.73	2.42
265	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	14	31.28	4.58	4.80	2.33
266	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	21	42.88	4.65	4.90	2.35
267	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	28	42.44	4.85	5.12	2.35
268	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	60	47.69	4.94	5.18	2.36
269	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	14	31.28	4.77	4.99	2.33
270	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	21	42.88	4.84	5.10	2.35
271	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	28	42.44	4.85	5.12	2.35
272	62	(60-180)	0.34	0.4	Type 1	1:1.13:1.7	60	47.69	4.94	5.18	2.36
273	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	7	39.29	4.95	5.16	2.42
274	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	14	40.18	4.99	5.26	2.46
275	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	21	44.64	5.02	5.31	2.46
276	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	28	41.07	5.06	5.35	2.47
277	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	60	57.59	5.06	5.39	2.46
278	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	90	49.55	5.10	5.42	2.46
279	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	120	62.05	5.10	5.39	2.45
280	10	(0-10)	0.34	0.5	Type 2	1:2.27:4.22	150	42.41	5.11	5.42	2.47
281	22	(10-30)	0.34	0.4	Type 3	1:1.26:2.45	7	38.89	4.37	4.94	2.44
282	22	(10-30)	0.34	0.4	Type 3	1:1.26:2.45	14	43.75	4.75	4.97	2.41
283	22	(10-30)	0.34	0.4	Type 3	1:1.26:2.45	21	46.41	4.79	5.00	2.43
284	22	(10-30)	0.34	0.4	Type 3	1:1.26:2.45	28	47.73	4.83	5.06	2.44
285	22	(10-30)	0.34	0.4	Type 3	1:1.26:2.45	60	45.96	4.89	5.09	2.43
286	22	(10-30)	0.34	0.4	Type 3	1:1.26:2.46	120	49.50	4.81	5.07	2.43
287	5	(0-10)	2.05	0.6	Type 2	1:2.49:6.72	7	11.16	4.26	3.36	2.42
288	5	(0-10)	2.05	0.6	Type 2	1:2.49:6.72	16	15.63	4.58	4.03	2.42
289	5	(0-10)	2.05	0.6	Type 2	1:2.49:6.72	21	17.86	4.54	4.51	2.39
290	5	(0-10)	2.05	0.6	Type 2	1:2.49:6.72	28	14.73	4.60	4.68	2.41
291	5	(0-10)	2.05	0.6	Type 2	1:2.49:6.72	60	18.75	4.65	4.80	2.43
292	5	(0-10)	2.05	0.6	Type 2	1:2.49:6.72	90	24.78	4.69	4.79	2.39
293	5	(0-10)	2.05	0.6	Type 2	1:2.49:6.72	120	19.64	4.70	4.81	2.40
294	15	(10-30)	4.45	0.6	Type 2	1:2.02:4.71	7	17.86	4.47	4.53	2.34
295	15	(10-30)	4.45	0.6	Type 2	1:2.02:4.71	14	20.09	4.57	4.63	2.35
296	15	(10-30)	4.45	0.6	Type 2	1:2.02:4.71	21	21.43	4.59	4.65	2.35
297	15	(10-30)	4.45	0.6	Type 2	1:2.02:4.71	28	18.08	4.64	4.73	2.37
298	15	(10-30)	4.45	0.6	Type 2	1:2.02:4.71	60	30.80	4.70	4.80	2.37
299	15	(10-30)	4.45	0.6	Type 2	1:2.02:4.71	90	37.05	4.73	4.85	2.33
300	15	(10-30)	4.45	0.6	Type 2	1:2.02:4.71	120	24.55	4.75	4.84	2.35
301	40	(30-60)	4.45	0.6	Type 2	1:1.91:3.88	7	12.50	4.19	3.94	2.40
302	40	(30-60)	4.45	0.6	Type 2	1:1.91:3.88	14	16.52	4.62	4.06	2.36
303	40	(30-60)	4.45	0.6	Type 2	1:1.91:3.88	21	17.86	4.36	4.45	2.35
304	40	(30-60)	4.45	0.6	Type 2	1:1.91:3.88	28	15.63	4.41	4.58	2.37
305	40	(30-60)	4.45	0.6	Type 2	1:1.91:3.88	60	22.32	4.45	4.64	2.37
306	40	(30-60)	4.45	0.6	Type 2	1:1.91:3.88	90	26.34	4.51	4.65	2.35
307	40	(30-60)	4.45	0.6	Type 2	1:1.91:3.88	120	23.21	4.51	4.67	2.33
308	70	(60-180)	4.45	0.6	Type 2	1:1.87:3.33	7	14.73	4.17	3.95	2.34

Table 1. Continued.

Sample no.	SLUMP (mm)	SLUMP range (mm)	SO_3 % in fine agregate	W/C	Coarse Aggregate	Mix proportions	Age (day)	Comp. str. (Mpa)	Ult. V(km/s) direct	Ult. V(km/s)surface	Density (gm /cm3)
309	70	(60-180)	4.45	0.6	Type 2	1:1.87:3.33	14	19.20	4.25	4.38	2.35
310	70	(60-180)	4.45	0.6	Type 2	1:1.87:3.33	21	20.09	4.32	4.51	2.37
311	70	(60-180)	4.45	0.6	Type 2	1:1.87:3.33	28	20.09	4.38	4.54	2.37
312	70	(60-180)	4.45	0.6	Type 2	1:1.87:3.33	60	22.10	4.43	4.64	2.37
313	70	(60-180)	4.45	0.6	Type 2	1:1.87:3.33	90	28.13	4.44	4.64	2.47
314	70	(60-180)	4.45	0.6	Type 2	1:1.87:3.33	120	26.34	4.47	4.64	2.33
315	45	(30-60)	0.34	0.6	Type 1	1:2.05:3.21	120	22.61	4.51	4.53	2.33
316	45	(30-60)	0.34	0.6	Type 1	1:2.05:3.21	9	9.08	4.19	3.82	2.40
317	45	(30-60)	0.34	0.6	Type 1	1:2.05:3.21	14	10.59	4.62	3.94	2.36
318	45	(30-60)	0.34	0.6	Type 1	1:2.05:3.21	21	17.24	4.36	4.32	2.35
319	45	(30-60)	0.34	0.6	Type 1	1:2.05:3.21	28	20.12	4.41	4.44	2.37
320	45	(30-60)	0.34	0.6	Type 1	1:2.05:3.21	60	21.61	4.45	4.49	2.37
321	45	(30-60)	0.34	0.6	Type 1	1:2.05:3.21	90	22.06	4.51	4.51	2.35
322	50	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	14	18.30	4.39	4.62	2.33
323	50	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	21	20.98	4.22	4.66	2.33
324	50	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	28	23.66	4.48	4.70	2.33
325	50	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	60	28.57	4.55	4.74	2.32
326	50	(30-60)	0.34	0.65	Type 2	1:2.31:3.47	90	27.68	4.58	4.77	2.33
327	20	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	14	9.15	4.18	4.15	2.40
328	20	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	21	12.95	4.39	4.46	2.38
329	20	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	28	16.16	4.40	4.47	2.37
330	20	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	60	19.87	4.46	4.51	2.34
331	20	(10-30)	0.34	0.8	Type 2	1:3.37:5.06	90	16.74	4.43	4.49	2.34
332	28	(10-30)	0.34	0.45	Type 3	1:1.51:2.79	7	26.08	4.46	4.61	2.41
333	28	(10-30)	0.34	0.45	Type 3	1:1.51:2.79	14	37.13	4.64	4.88	2.42
334	28	(10-30)	0.34	0.45	Type 3	1:1.51:2.79	21	38.01	4.70	4.93	2.41
335	28	(10-30)	0.34	0.45	Type 3	1:1.51:2.79	28	42.43	4.71	5.00	2.41
336	28	(10-30)	0.34	0.45	Type 3	1:1.51:2.79	60	44.20	4.78	5.08	2.42
337	28	(10-30)	0.34	0.45	Type 3	1:1.51:2.79	90	50.83	4.81	5.08	2.41
338	100	(60-180)	0.34	0.8	Type 1	1:3.33:3.33	7	6.70	3.66	3.00	2.34
339	100	(60-180)	0.34	0.8	Type 1	1:3.33:3.33	21	16.96	4.28	4.40	2.38
340	100	(60-180)	0.34	0.8	Type 1	1:3.33:3.33	28	17.41	4.28	4.44	2.37
341	100	(60-180)	0.34	0.8	Type 1	1:3.33:3.33	60	20.98	4.36	4.52	2.36
342	100	(60-180)	0.34	0.8	Type 1	1:3.33:3.33	90	20.09	4.40	4.52	2.37
343	72	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	7	33.69	4.38	4.58	2.37
344	72	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	14	32.81	4.49	4.69	2.37
345	72	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	21	33.25	4.53	4.79	2.38
346	72	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	28	38.50	4.55	4.83	2.37
347	72	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	60	43.75	4.62	4.92	2.36
348	72	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	90	45.50	4.67	4.89	2.36
349	72	(60-180)	0.34	0.45	Type 1	1:1.47:1.86	120	45.50	4.66	4.89	2.36
350	28	(10-30)	0.34	0.6	Type 3	1:2.25:4.6	120	27.79	4.75	4.68	2.35
351	28	(10-30)	0.34	0.6	Type 3	1:2.25:4.6	7	18.96	4.47	4.39	2.34
352	28	(10-30)	0.34	0.6	Type 3	1:2.25:4.6	14	21.49	4.57	4.49	2.35
353	28	(10-30)	0.34	0.6	Type 3	1:2.25:4.6	21	22.07	4.59	4.51	2.35
354	28	(10-30)	0.34	0.6	Type 3	1:2.25:4.6	28	24.42	4.64	4.59	2.37
355	28	(10-30)	0.34	0.6	Type 3	1:2.25:4.6	60	26.59	4.70	4.65	2.37
356	28	(10-30)	0.34	0.6	Type 3	1:2.25:4.6	90	28.30	4.73	4.70	2.33
357	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	7	6.70	4.10	3.18	2.39
358	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	14	13.39	4.45	4.40	2.39
359	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	28	16.74	4.52	4.54	2.37
360	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	60	21.88	4.58	4.58	2.37
361	95	(60-180)	0.34	0.8	Type 4	1:3.35:4.27	90	20.98	4.60	4.61	2.37
362	55	(30-60)	0.34	0.8	Type 4	1:3.2:5.23	10	13.84	4.45	4.00	2.42
363	55	(30-60)	0.34	0.8	Type 4	1:3.2:5.23	21	17.19	4.58	4.57	2.41
364	55	(30-60)	0.34	0.8	Type 4	1:3.2:5.23	28	22.77	4.65	4.56	2.41
365	55	(30-60)	0.34	0.8	Type 4	1:3.2:5.23	60	24.33	4.66	4.63	2.40
366	55	(30-60)	0.34	0.8	Type 4	1:3.2:5.23	90	20.54	4.67	4.58	2.40
367	90	(60-180)	0.34	0.8	Type 1	1:3.35:4.27	7	6.76	4.15	3.21	2.39
368	90	(60-180)	0.34	0.8	Type 1	1:3.35:4.27	90	21.19	4.64	4.65	2.37
369	90	(60-180)	0.34	0.8	Type 1	1:3.35:4.27	14	13.53	4.50	4.44	2.39
370	90	(60-180)	0.34	0.8	Type 1	1:3.35:4.27	28	16.91	4.57	4.58	2.37
371	90	(60-180)	0.34	0.8	Type 1	1:3.35:4.27	60	22.09	4.63	4.63	2.37
372	10	(0-10)	0.34	0.9	Type 2	1:5.29:6.68	14	8.93	4.13	4.19	2.33
373	10	(0-10)	0.34	0.9	Type 2	1:5.29:6.68	21	10.71	4.35	4.45	2.38
374	10	(0-10)	0.34	0.9	Type 2	1:5.29:6.68	28	12.50	4.35	4.50	2.36
375	10	(0-10)	0.34	0.9	Type 2	1:5.29:6.68	60	16.29	4.47	4.53	2.37
376	10	(0-10)	0.34	0.9	Type 2	1:5.29:6.68	90	15.63	4.51	4.52	2.34
377	58	(30-60)	0.34	0.45	Type 2	1:1.4:2.24	120	44.64	4.81	4.89	2.35
378	58	(30-60)	0.34	0.45	Type 2	1:1.4:2.24	7	29.61	4.48	4.50	2.34
379	58	(30-60)	0.34	0.45	Type 2	1:1.4:2.24	14	30.27	4.62	4.68	2.34
380	58	(30-60)	0.34	0.45	Type 2	1:1.4:2.24	21	34.47	4.65	4.77	2.33
381	58	(30-60)	0.34	0.45	Type 2	1:1.4:2.24	28	36.24	4.67	4.83	2.35
382	58	(30-60)	0.34	0.45	Type 2	1:1.4:2.24	60	46.41	4.75	4.92	2.33
383	58	(30-60)	0.34	0.45	Type 2	1:1.4:2.24	90	45.08	4.79	4.92	2.35

Table 2. Grading and characteristics of coarse aggregate used.

Sieve Size mm	Passing Percentage %				
	Type 1	Type 2	Type 3	Type 4	Type 5
37.5	100	100	100	100	100
20	70	100	100	100	100
14	40	70	100	100	100
10	10	40	50	100	0
5	0	0	0	0	0

Table 3. Comparison between SUPV and DUPV

UPV Type	Correlation Factor	R^2 Value
SUPV	0.8329	0.7055
DUPV	0.7389	0.6504

Figures 1 and 2 show that the rate variations of the DUPV are less than the variations of SUPV for the same variation of the compressive strength. Thus, an increase in the DUPV happens at a lesser rate than increasing the compressive strength. The SUPV seems to be more sensitive to the increase in compressive strength. This tendency is noticed since the propagation of surface waves is restricted to a region near the boundaries of the free external surface of the material. The depth of the penetration is on the order of one wavelength thickness. The cement paste content of this layer is greater than the average paste content inside the concrete due to the so-called wall effect. Therefore, the velocity of a surface wave SUPV is influenced more by the paste properties than that of the direct waves DUPV that travel through the whole mass of the concrete. Since the concrete strength is also controlled by the strength of the hardened cement paste, SUPV may be a better indicator of the concrete strength than DUPV.

Figure 3 shows that for pulse velocity less than (4.5 km/s), the (DUPV) was more significant than the (SUPV) for the same compressive strength. For pulse velocity greater than (4.5 km/s), the (DUPV) was less than the (SUPV) for the same compressive strength. This happens because, at low pulse velocity (less than 4.5 km/s), the ultrasonic wave passing throws the coarse aggregate and gives us high (DUPV) when the compressive strength low. The (SUPV) wave passing throw the cement mortar and will represent the compressive strength more accurately. Besides that, the correlation factor of SUPV was more significant than (DUPV), so using (SUPV) is better than using the (DUPV) to represent the relationship with the compressive strength.

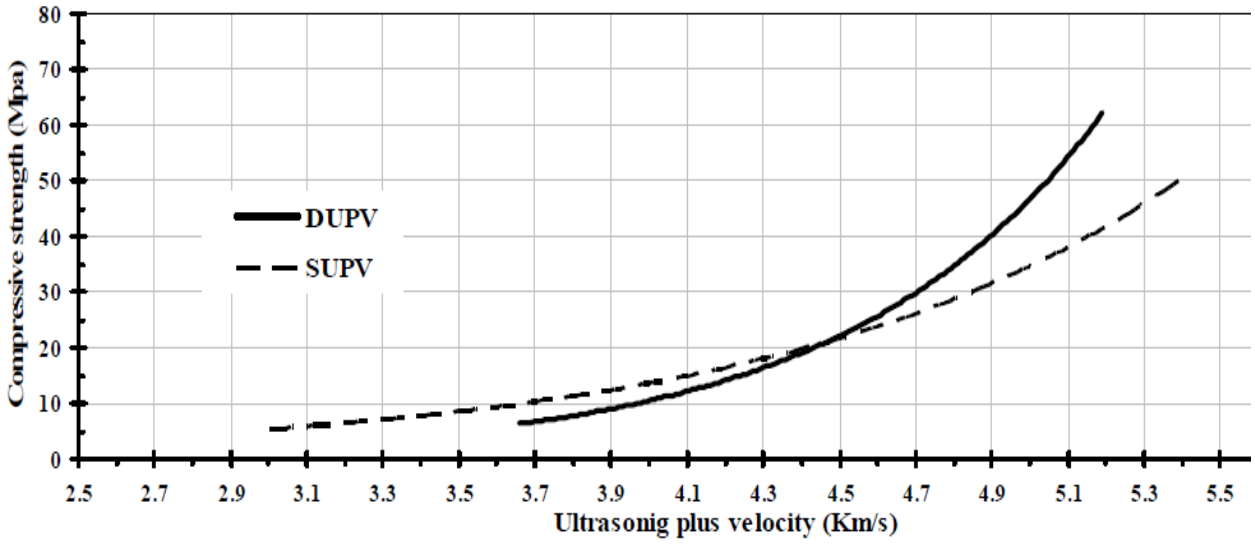

Figure 3. Relation between (DUPV and SUPV) with the compressive strength for concrete samples subjected to normal curing.

Results of Statistical Analysis

The statistical methods can explain the test results and the prediction of concrete strength, in the case of the test that was carried out in a satisfactory way and standard tools. The statistical methods were proved to have good values. The goal of a regression method is to fit a line through points (results) so that the squared deviations of the observed points from that line are minimized. In statistical modeling, the overall objective is to develop a predictive equation relating a criterion variable to one or more predictor variables. In this research, the criterion variables include the compressive strength, the direct ultrasonic wave, and the surface (indirect) waves. The summary of descriptive statistics of all the variables is shown in Table 4, and the correlation matrix for the data are shown in Table 5. The terms shown in Table 4 and 5 are defined as follows: C= Compressive strength (MPa), D=Direct ultrasonic wave velocity (km/s), S= Surface (indirect) ultrasonic wave velocity (km/s)

Table 4. Statistical summary for predictor and criteria variables.

Variable	N	Range	Min.	Max.	Sum	Mean	Mean. Std. Error	Std. dev.
C	383	59.47	5.26	64.73	12248.1	31.979	0.6299	12.3273
D	381	1.53	3.66	5.19	1774.02	4.6562	0.0120	0.2353
S	383	2.42	3	5.42	1830.51	4.7794	0.2032	0.3976

Table 5. Correlation matrix for predictor and criteria variables.

Variable	C	D	S
C	1	0.760	0.810
D	0.760	1	0.880
S	0.810	0.880	1

Compressive Strength Modeling. The relation between compressive strength and the ultrasonic velocity (DandS) is exponential and found from the previous studies [1,3,5] and others. Therefore, to catch these predictor variables in one equation, it's proposed to take the exponential value of the (UPV) data (DandS reading) and choose the linear regression to specify the parameter and select the stepwise.

$$C = 0.128\ e^{1.127\ S} \tag{7}$$

The correlation of the proposed equation is (0.84726), and R^2 is (0.7883). Verification of the proposed equation and previous equations depends on separated data taken from a different source. The data adopted for the study in this part was taken from ref erences[9,10], as shown in Table 6.

Table 6. Comprising data from Neville [9,10].

Compressive Strength (MPa)	17	20.5	21	28	31.5	31	42	51	52.5
Ultrasonic Velocity (km/s)	3.75	3.9	4.1	4.3	4.3	4.4	4.4	4.6	4.7

By using the direct ultrasonic velocity illustrated in Table 6, the compressive strength estimated from some of the previous equations and also estimated from the proposed Eq. (7), which depending on the SUPV. The equivalent surface SUPV was taken from Eq. (8), built only for verification purposes from the research data.

$$S = 1.405\ D^{-1.406} \tag{8}$$

where: S is a surface ultrasonic velocity and D is a direct ultrasonic velocity in km/sec

From Figure 4 one can notice that no equation can satisfy all the points entirely. The proposed equation could be considered the nearest one to the points taken from reference [9], and that agrees with the correlation factor appear in Table 7, which equals (0.9611).

Table 7. Correlation factor for proposed and previous equations.

Equation	Elvery and Ibrahim [2]	Raouf and Ali [3]	Jones [1]	Nash't et al. [5]	Pundit Manual	Proposed
Cor. Coef.	0.9591	0.9469	0.9447	0.9495	0.9565	0.9611

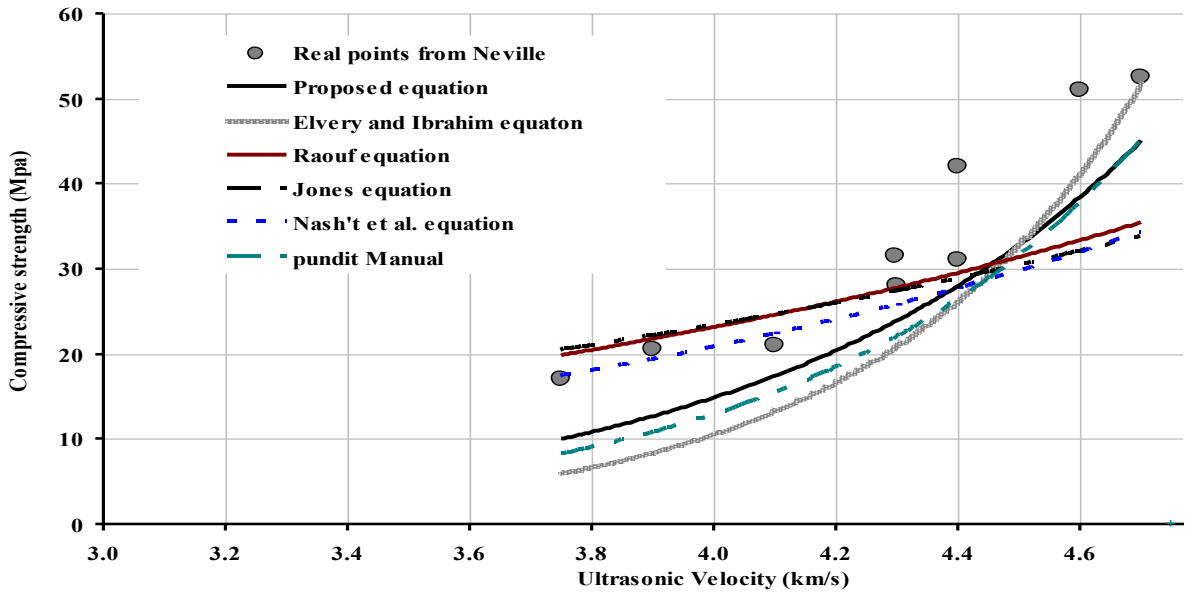

Figure 4. Relation between compressive strength and ultrasonic pulse velocity for proposed and previous equations.

Effect of The Salts on The Proposed Relation. The salt content in fine aggregate affects the relationship between the compressive strength and the (SUPV). Suppose the inspector suspects that there's salt in the tested concrete and to be on the safe side, the following correction of the (SUPV) reading should be used before using Eq. (7). This correction was found from separating the normal curing data for concrete with salt from the data of concrete with no salt. These two groups of data are interred in the SPSS program, and with two equations are found one for the case of high salt content, and the other represents the data for concrete with a bit of salt, as mentioned earlier

$$\mathbf{C = 0.8983\ e^{0.706\ S'}} \tag{9}$$

By equating Eq. (7) with Eq. (8), the relation between (SUPV) for concrete with high salt and concrete with a little salt is found as shown in Eq. (10).

$$\mathbf{S = 0.63\ \ S'\ \ + 1.72} \tag{10}$$

where:

S = Surface (indirect) ultrasonic wave velocity (km/s) (with no salt)

S' = Surface ultrasonic wave velocity (km/s) (with salt)

Conclusions

- The SUPV is more sensitive than the DUPV for assessment of compressive strength where R^2 value equal to (0.7883) and correlation factor equal to (0.84726) for equation depending on surface reading while R^2 value equal to (0.6504) and correlation factor equal to (0.7389) for equation depend on direct reading.
- SO_3 content in fine aggregate effect decreases compression strength while the SUPV reading does not affect the same rate. For using the general proposed equation, the proposed correction of SUPV reading must be used.

- For the same sample, when concrete compressive strength is more than (20.5 MPa), the SUPV reading is more significant than DUPV, while for compressive strength less than (20.5 MPa), the DUPV is greater than SUPV.

References

[1] Jones, R., 1962. Non destructive testing of concrete. London, Cambridge University.
[2] Elvery, R.H., and Ibrahim,L.A.M., 1976. Ultasonic assessment of concrete strength at early ages. Magazine of Concrete Research, 28(97), pp.181-190.
[3] Raouf, Z. and Ali, Z. M., 1983. Assessment of concrete characteristics at an early age by ultrasonic pulse velocity. Journal of Building Research, 2(1), pp.31-44.
[4] Popovics, S., Joseph, L. R., John, S. P., 1990. The behavior of ultrasonic pulses in concrete. Cement and Concrete Research, 20(2), pp.259-270.
[5] Nash't, I. H., A'bour S.H., Sadoon A.A., 2005. Finding an unified relationship between crushing strength of concrete and non-destructive tests. 3rd MENDT - Middle East Nondestructive Testing Conference and Exhibition, Bahrain, Manama.
[6] Jassim, A. K., 2012. Prediction of compressive strength of reinforced concrete structural members by using combined non-destructive tests. M.Sc. Thesis, University of Baghdad, Iraq.
[7] Fawzi, N. M., Said, A. I., and Jassim, A. K., 2013. Prediction of compressive strength of reinforced concrete structural elements by using combined non-destructive tests. Journal of Engineering, 19(10), pp. 1189-1121.
[8] Ali B. A. H, 2008. Assessment of Concrete compressive strength by ultrasonic non-destructive test. M.Sc. Thesis, University of Baghdad, Iraq.
[9] Nivelle, A. M., 1995. Properties of Concrete. 4th Edition Longman Group Limited.
[10] Sturrup V.R. , Vecchio F.J. and Caratin H, 1984. Pulse velocity as a measure of concrete compressive strength, in situ/non-destructive testing of concrete. Ed.V.M. Malhotra, ACI SP-82, Detroit Michigan, pp. 201-227.