FIELD INVESTIGATION OF CONCRETE QUALITY USING THE WINDSOR PROBE TEST SYSTEM

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Extensive application of the Windsor probe test system has been made in investigations of in-place compressive strengths of concrete and in determinations of concrete quality. The system drives with a constant energy a steel probe into concrete; the depth of probe penetration is a measure of resistance to penetration. This probe penetration is thus indicative of compressive strength. Comparisons of these compressive strengths with those of cores or cylinders have been made. The Windsor probe has been used in investigations of compressive strengths of reinforced concrete pipe, highway bridge piers, abutments, and pier caps whose strengths were in question; of concrete pavements whose strengths were suspected of being weakened by lightning strikes; and of concrete surfaces damaged by fire.

•AN INVESTIGATION of the Windsor probe test system as a means of determining the in-place compressive strength of concrete in a quick, relatively nondestructive manner was begun in 1967. The system consists of a driver and a steel probe. The probe is driven into the concrete by 600 ft-lb of energy imparted by an accurately loaded, center-fired cartridge. The probe tip is machined to pierce the aggregate as well as the cement-sand mixture, yielding an average strength determination. A locating template is also provided that allows positioning of the 3 triangular "shots" constituting a test, and the accompanying gage plates allow the averaging of the 3 probe heights above the concrete surface. Measurement of this averaged exposed height above the concrete surface is made by using a calibrated depth gage.

The actual compressive strength of the concrete is determined by using a table, provided by the manufacturer and shown in Figure 1, that relates exposed height of the probe to compressive strength of concrete. Several columns in the table cover the range of Mohs' hardness of the aggregate, and a Mohs' hardness kit is also supplied to allow this determination to be made in the field at the site of testing. A probe withdrawal kit is provided for use in removing test probes from the concrete. A hole remains with a diameter of about ¼ in. and an average depth of 1 in. in standard cured concrete. Although some spalling may occur around the hole, the system is relatively nondestructive when compared to a core drill.

FIELD TESTS AND RESULTS

An initial evaluation of the system evolved in conjunction with an investigation to determine whether reinforced, cement concrete pipe being produced met the material specifications of the Pennsylvania Department of Transportation. Relations to be investigated were (a) cylinder strength and concrete mixes, (b) cylinder strength and nonreinforced core strength, (c) cylinder strength and reinforced core strength, (d) cylinder strength and 3-edge bearing test, and (e) core strength and 3-edge bearing test.

For this investigation, a study of the application of the Windsor probe system was obvious. The investigation required that cores be taken from sections of the pipe under test (48-in. reinforced concrete pipe, class 5) and broken after 14 days. Corresponding strengths were determined on the cored pipe samples by using the Windsor system. Alterations to the system were made so that probes could be fired into the curved surface of the pipe. A hand-held fixture similar to a single, raised boss of the locating tem-

Figure 1. Values of compressive strength Mohs' hardness numbers for exposed Windsor probe height.

CONCRETE COMPRESSIVE STRENGTHS FOR USE IN WINDSOR PROBE TEST

EXPOSED PROBE (in.)	COMPRESSIVE STRENGTH (p.s.i.) MOH'S NO. 3	MOH'S NO. 4	MOH'S NO. 5	MOH'S NO. 6	MOH'S NO. 7	EXPOSED PROBE (in.)	COMPRESSIVE STRENGTH (p.s.i.) MOH'S NO. 3	MOH'S NO. 4	MOH'S NO. 5	MOH'S NO. 6	MOH'S NO. 7
1.000	-	-	-	-	-	1.850	6000	5400	4875	4200	3437
1.100	1000	-	-	-	-	1.875	6167	5625	5062	4400	3656
1.125	1167	-	-	-	-	1.900	6334	5800	5250	4600	3875
1.150	1333	-	-	-	-	1.925	6500	5975	5437	4800	4093
1.175	1500	-	-	-	-	1.950	6667	6150	5625	5000	4312
1.200	1667	900	-	-	-	1.975	6833	6325	5812	5200	4531
1.225	1833	1075	-	-	-	2.000	7000	6500	6000	5400	4750
1.250	2000	1250	-	-	-	2.025	7167	6675	6187	5600	4968
1.275	2167	1425	-	-	-	2.050	7334	6850	6375	5800	5187
1.300	2334	1600	-	-	-	2.075	7500	7025	6562	6000	5406
1.325	2500	1775	900	-	-	2.100	7667	7200	6750	6200	5625
1.350	2667	1950	1100	-	-	2.125	7833	7375	6937	6400	5843
1.375	2834	2125	1300	-	-	2.150	8000	7550	7125	6600	6062
1.400	3000	2300	1500	-	-	2.175	8167	7725	7312	6800	6281
1.425	3167	2475	1687	-	-	2.200	8334	7900	7500	7000	6500
1.450	3334	2650	1875	1000	-	2.225	8500	8075	7687	7200	6718
1.475	3500	2725	2062	1200	-	2.250	8667	8250	7875	7400	6937
1.500	3667	3000	2250	1400	-	2.275	8834	8425	8062	7600	7156
1.525	3834	3175	2437	1600	-	2.300	9000	8600	8250	7800	7375
1.550	4000	3350	2625	1800	814	2.325	9167	8775	8437	8000	7593
1.575	4167	3525	2812	2000	1032	2.350	9334	8950	8625	8200	7812
1.600	4334	3700	3000	2200	1250	2.375	9500	9125	8812	8400	8031
1.625	4500	3875	3187	2400	1468	2.400	9667	9300	9000	8600	8250
1.650	4667	4050	3375	2600	1687	2.425	9834	9475	9187	8800	8468
1.675	4834	4225	3562	2800	1906	2.450	10000	9650	9375	9000	8687
1.700	5000	4400	3750	3000	2125	2.475	-	9825	9562	9200	8906
1.725	5167	4575	3937	3200	2343	2.500	-	10000	9750	9400	9125
1.750	5334	4750	4125	3400	2562	2.525	-	-	9937	9600	9353
1.775	5500	4925	4312	3600	2781	2.550	-	-	10125	9800	9562
1.800	5667	5100	4500	3800	3000	2.575	-	-	-	10000	9781
1.825	5834	5275	4687	4000	3218	2.600	-	-	-	-	10000

NOTES:

1. If in doubt as to Moh's Number, confirm with Windsor Scratch Test Set.
2. Moh's Hardness Rating: No. 3 - Limestone (Calcite)
   4 - Limestone (Fluorite)
   5 - Limestone (Apatite)
   6 - Trap Rock (Microcline)
   7 - Gravel (Quartz)
3. Control Strength: A.S.T.M. 39 Cylinders
   A.S.T.M. 42 Cores

Table 1. Average core and Windsor probe strengths in tests of pipe produced by various plants.

Plant	Core (psi)	Windsor (psi)	Plant	Core (psi)	Windsor (psi)
1	6,672	7,550	4	6,699	6,525
2	4,857	5,400	5	5,936	6,500
3	6,787	6,600	6	6,453	5,975

Table 2. Core and Windsor probe strengths in lightning-damage tests.

Core	Core (psi)	Windsor (psi)	Core	Core (psi)	Windsor (psi)
1	3,451	3,475	4	4,746	4,833
2	3,998	3,475	5	3,748	4,082
3	3,884	—			

plate was made, and tests consisted of individual shots at sites near the core locations instead of the 3-shot group used on flat test surfaces. Reliable exposure heights for the individual probe can be made by using the apparatus provided with the system.

Tests were run at 6 pipe manufacturing plants where various manufacturing methods were used. Because this application was made prior to the development of the table shown in Figure 1, a curve supplied by the manufacturer of exposed probe height versus compressive strength was used (Fig. 2). This curve was supposedly developed by the U.S. Bureau of Public Roads using several hundred controlled cylinder breaks. A comparison of the core strength and the Windsor probe strength is given in Table 1. Each core compression value given is an average of 12 core breaks, and each Windsor value is an average of approximately 25 shots with usually 2 shots taken near each core location. These data reduce to a mean core strength of 6,234 psi with a standard deviation of ±677 psi and a coefficient of variation of 10.9 percent. The Windsor results show a mean strength of 6,425 psi with a standard deviation of ±681 psi and a coefficient of variation of 10.6 percent. Tests with the probe were taken 1 to 2 weeks after the core tests; the cores were tested at 14 days age.

The favorable results of the initial application of the Windsor system to the concrete pipe tests opened possibilities of its use in other concrete testing areas.

When the question arose as to the strength of certain sections of concrete pavement on the Pennsylvania Turnpike at Harrisburg and on Interstate 83 across the Susquehanna River, the Windsor system was again applied to obtain a possible answer; but again it was used in conjunction with cored samples for comparison. For these tests, the Mohs' hardness data shown in Figure 1 were used to determine the Windsor strengths. The Turnpike tests yielded a Windsor probe value, averaged for 6 test sites, of 6,098 psi with a standard deviation of ±477 psi. Five cores taken in close proximity to the probe tests showed an average compressive strength of 5,255 psi with a standard deviation of ±567 psi. On the Interstate bridge, the average compressive strengths were 5,100 psi with a standard deviation of ±648 psi for 6 Windsor test sites and 5,515 psi with standard deviation of ±1,390 psi for only 2 cores.

When the results of these tests became known to Department of Transportation personnel, requests for the use of the Windsor probe system increased. Many of these applications required only that a "ball-park" figure of compressive strength be determined, for in some cases cores were difficult or impossible to obtain.

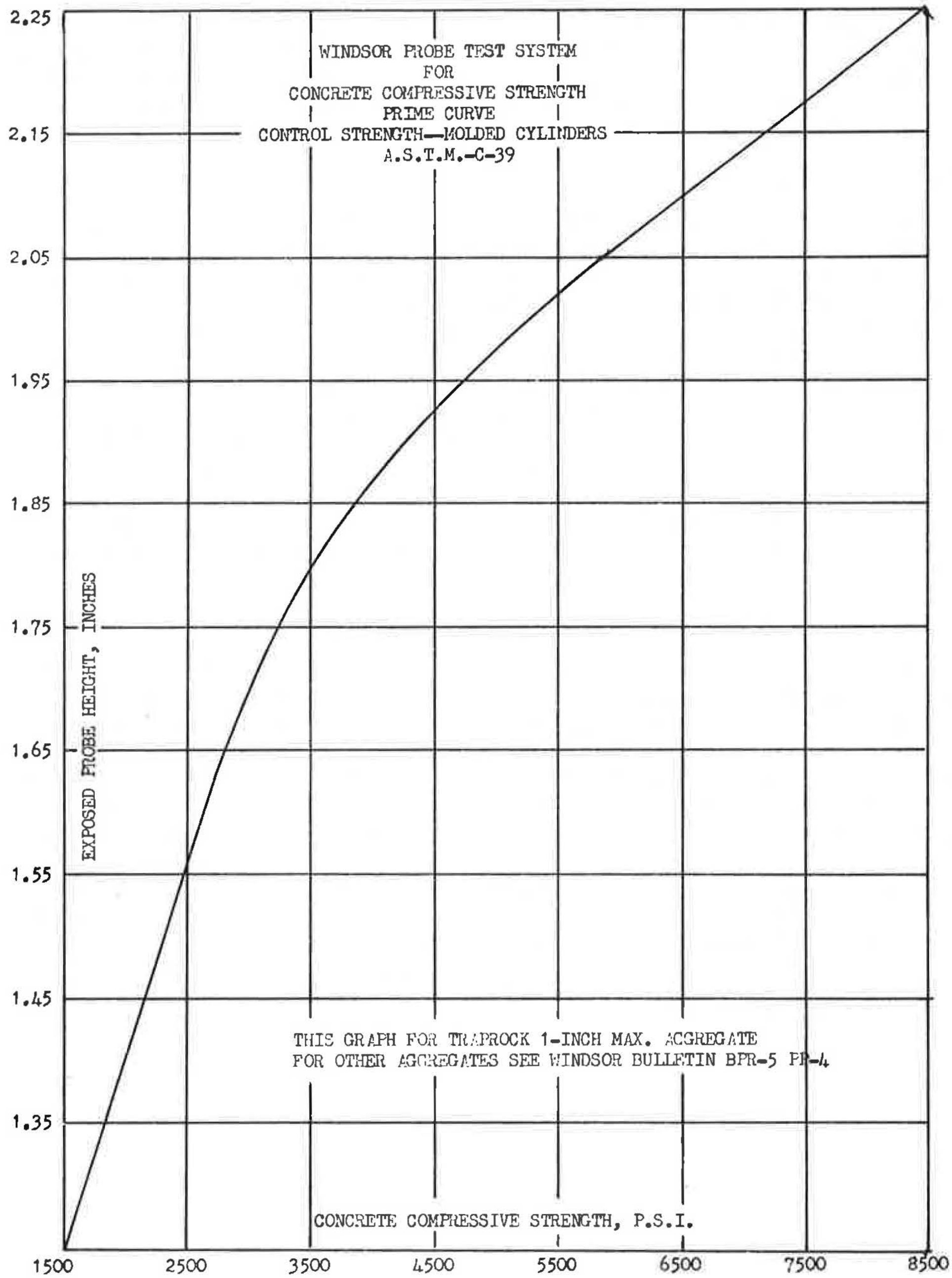
Pier Erosion

One such application was the testing of vertical bridge piers on a section of a Schuylkill Expressway Bridge across the Schuylkill River in Philadelphia. A major portion of some piers had been eroded by the river, and a question as to the strength of other apparently good piers arose. More than 100 piers were individually tested. Good piers showed strengths exceeding 8,500 psi in some cases, and many piers that appeared visually good had strengths of less than 1,800 psi. Some piers were even found to be hollow as the steel Windsor probe went into the pier column completely such that no exposure height was measurable. Thus, the Windsor probe system provided a quick and relatively accurate check of the compressive strengths, where measurable, and the general quality of the piers.

Lightning Damage

The damage caused by lightning striking a section of a reinforced concrete highway resulted in an investigation of damage not visible from the pavement surface. Nondestructive techniques, including the Windsor probe, were used in areas other than where sections of pavement as large as 2.5 by 3.2 by 0.4 ft deep were blown out at joint locations to obtain an overall damage pattern. Five cores were taken from the 500-ft damaged area of pavement, and core 4 was used as a standard inasmuch as it was taken from an area of no visible damage. The results of the Windsor and the core compressive strengths are given in Table 2. The average compressive strength of the concrete cores was 3,986 psi with ±478 psi standard deviation; the average Windsor strength was 3,966 psi with ±558 psi standard deviation. Core 3 was not included because no

Figure 2. Compressive strength versus exposed Windsor probe height.



probe test was taken at this core location. The rms deviation of probe versus cores was ±325 psi. A reasonable correlation between the Windsor system and core compressive strengths was obtained (correlation coefficient of 0.829).

Such correlation allows extensive tests of apparently undamaged portions of the highway to be made and the compressive strengths to be determined quickly without the time lag of removing the cores to a laboratory-based compressive machine. No hole patching is required as when cores are taken from the pavement.

Fire-Damaged Abutment Wall

When wooden forms used in the construction of a bridge abutment wall caught fire, the resultant heat was believed to have caused strength problems with the partially cured concrete. Sequences of Windsor tests at various questionable sections of the wall were made and showed the average compressive strength to be 3,500 psi. Sawed samples of flexural test specimens poured from the same concrete were tested in compression and found to have an average strength of 2,400 psi. The discrepancy between the Windsor probe values and the compressive test values was believed to have been caused by improper curing of the test specimens. Windsor probe tests on actual portions of the concrete flexural test specimens resulted in their shattering. It has been noted that "shooting" the Windsor probes into blocks of concrete where concrete surfaces surrounding the target point are less than 8 in. and the concrete thickness is less than 6 in. tends to crack the block. The manufacturer of the Windsor system has established a V-fixture that holds poured concrete cylinders or cored samples in such a manner that probes may be fired into them along their long dimensions.

CONCLUSIONS

The Windsor probe system has generally provided a quick and relatively accurate means of determining the compressive strengths of concrete and has proved useful as a check on the quality of concrete where damage or deterioration was evident but its extent was unknown. The system is also relatively cheaper than coring samples. The initial system cost is approximately $700, and the cost of a 3-shot pattern constituting a complete individual test is about $6. The system is easy to operate, and safety precautions are provided such that accidents can occur only with improper usage. The system has been lent to personnel in Pennsylvania Department of Transportation districts, and, after a training session of 5 hours, individuals who had never seen the system were making tests. Although the Windsor probe test system may not take the place of coring as a check of concrete strength or quality, it does provide meaningful supplementary information of those properties and may in some cases, such as on a bridge pier over water where coring is nearly impossible, provide the only feasible way to obtain quick and accurate concrete compressive strength values.