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A COMPARATIVE STUDY OF PENETRATION RESISTANCE APPARATUS ON CONCRETE

Sérgio M. R. Lopes** and Miguel C. S. Nepomuceno*

Introduction

The existence of a relationship between the compression strength of a given concrete and its resistence to penetration by a steel probe fired into the concrete is well known; the depth of penetration will be inversely proportional to the compressive strength. Since the theoretical description of this phenomenon was not explained up to the present, the relationship between penetration resistance and concrete strength has to be established experimentally. The knowledge of this empirical relationship allows, for a given concrete and a given test apparatus, the assessment of in-place concrete strength, by measuring of the exposed lengths of probes which have been driven into the concrete. A test apparatus, designed for this purpose, using a special probe and standardised powder charge, was developed in the USA during the 1960s' and is known as Windsor Probe Test and covered by the ASTM Standards (ASTM-C803-90). In Europe, similar standards are the British Standards (BS 1881: Part 207: 1992). The technique of firing steel nails or bolts into a concrete surface is also used in the construction industry in order to provide fixings and, of course, the above mentioned relationship and its reliability can be investigated for different firing apparatus.

The aim of this work is to perform studies concerning to a new apparatus application in comparison with the WPT System.

The standardised tests were performed by using the Windsor Probe Test System machine. This system allows the use of two kind of probes: the silver coloured probe, for use in concrete with natural aggregate; and the gold coloured probe, for use with lightweight concrete. Two different power levels are also possible, using the same power load, by an adjustment in the instrument: the standard power and low power. For the purpose of this study, it was decided to use the silver coloured probe (of hardened steel alloy with 6,35 mm diameter, 79.5 mm length, a blunt conical end and a plastic guide) associated with the standard power. Probes were fired into concrete using the driver unit and the triangular device. In spite of a triangular device has been used, the exposed length was measured individually by using a rectangular plate, placed over probe and pressured against the concrete by a knurled spring-nut, and a measuring cap threaded on top of probe. The distance was measured from top of cap to plate with the micrometer depth gauge.

(**) University of Coimbra, U.B.I. - Portugal
(*) University of Beira Interior (U.B.I.) - Portugal

The Alternative Firing Apparatus enables the control of the level of energy delivered to the probe by the driver, as well as different dimensions and geometries for the probe. Therefore, a preliminary study was carried out in different concrete strengths in order to define the parameters, which, of course, should remain fixed during the present investigation.

The probe was made of steel alloy with 4,5 mm diameter and 52 mm length, a conical end and a plastic guide. The exposed length was directly measured, by using a depth gauge, relatively to the original surface of the concrete.

The way of deliver the energy to the probe by Alternative Firing Apparatus has little difference from the WPT System previously mentioned. Both systems use a powder cartridge and probes, but while in the first apparatus (WPT System) detonation resultant energy of the powder cartridge is transmitted directly to the probe, which is accelerated and projected into the concrete surface, in the Alternative Firing Apparatus this energy is transmitted to a piston, which is projected in high velocity against the probe, like a hammer, thrust in the probe by the impact.

In both systems, all the operation instructions, concerning to the use of the apparatus, follow the technical manual supplied with the instruments.

The test specimen consists in sets, each one comprising a 750x550x170 mm slab and 4 cubs of 150 mm, all obtained by using metallic moulds. Each slab should be able to support 6 tests of WPT System and, at least, 12 tests by the Alternative Firing Apparatus. The dimensions were determined in order to obtain, for standard power, the recommended edge distances, member thickness and minimum distances between tests, following the ASTM standards, to prevent splitting of the member under test, structural cracking and also to avoid overlapping of zones of influence. However, in the previews studies made for Alternative Firing Apparatus, it was found that the surface damage was minor in comparison with the WPT System, which means that probably the distances between tests could be reduced.

Procedure

Five different mix proportions were produced in order to obtain five sets of specimens with five different classes of compression strength. The specimens were cured together at approximately 12°C and relative humidity of 65%. The mix proportions were established in order to fix the maximum number of parameters. Therefore, the Faury modules of fineness remain exactly the same and the workability of fresh concrete, measured by slump test, was fixed between 80 mm and 120 mm. Also the operations of mixing and compacting (type and frequency) were kept constant in all the cast specimens. The coarse aggregates were crushed rock brittle from granite with the maximum dimension of 25 mm and the fine aggregate was natural sand from the river.

All the tests were performed at 28 days age for each group of specimens and, at the time of testing, the specimens presented dry.

Results analysis

The obtained results (table 1) were analysed and plotted us shown in the figures 1 and 2 and are valid for these particular aggregates and conditions of test.

As an additional information, the aggregate hardness was determined on the basis of the Mohs' hardness scale. For the coarse aggregates used to produce mix concrete, a Mohs' scale level 7 was found.

		A	B	C	D	E
Cubes of 15 cm cured at 12ºC, R.H. 65%, tested dry, at 28 days	f_{cm} [MPa]	17.70 (4)	23.80 (3)	37.43 (4)	42.33 (4)	53.18 (4)
	Δ [MPa]	0.47	2.62	0.87	1.74	1.94
	δ [%]	2.66	11.0	2.32	4.11	3.65
Penetration Test Resistance by WPT System	E [mm]	39.14 (6)	43.59 (6)	51.52 (6)	52.97 (6)	54.70 (5)
	Δ [mm]	3.34	1.54	1.65	1.64	2.34
	δ [%]	8.53	3.53	3.20	3.10	4.27
Penetration Test Resistance by the Alternative Firing Apparatus	E [mm]	16.40 (17)	19.82 (13)	24.53 (12)	25.08 (13)	26.92 (17)
	Δ [mm]	1.40	0.85	1.65	0.80	1.13
	δ [%]	8.54	4.29	6.73	3.19	4.20

Table 1 - Results obtained (between parenthesis it is shown the number of executed measurements).
E [mm] is the mean value of the exposure length.

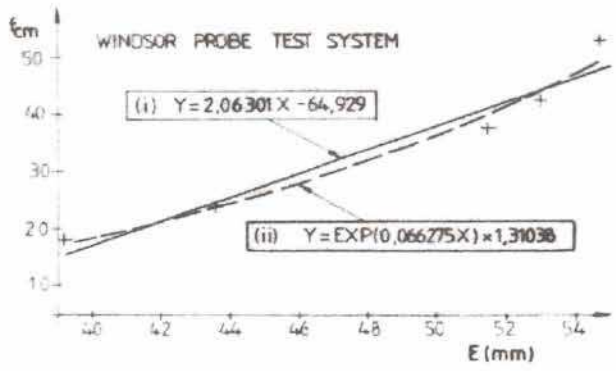

Figure 1- Results obtained from the Windsor Probe Test

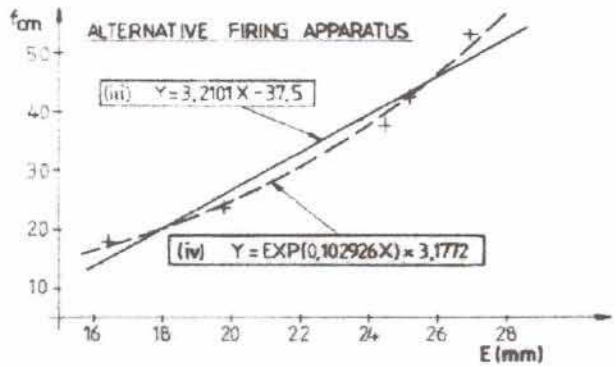

Figure 2 - Results obtained from the Alternative Firing Apparatus

The correlations, linear or curve, were drawn through the points plotted from the mean near-to-surface test results (exposure length), and the mean strength of each corresponding set of identical specimens. Those equations were determined by using the best linear and exponential fitting procedure.

Conclusions

It is clear and mentioned by different authors that, as most other non-destructive tests, aggregate characteristics and other factors may have a considerable influence on the results and, therefore, the validity of calibration tables has to be carefully analysed for each situation. So, the results presented on figures 1 and 2 are valid for the established conditions of this investigation.

The obtained results show that the Alternative Firing Apparatus could be a suitable mean for the assessment of in-place strength.

The main physical limitation of penetration resistance tests is the surface damage and the danger of splitting of members, which limits the zones of testing. However, it was found that the Alternative Firing Apparatus causes less damages than WPT System. Consequently, minor distances between probes are possible.

Other aspect that cannot be ignored is the higher cost of WPT System equipment and probes in Europe when compared with the Alternative Firing Apparatus.

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