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Autor: Bungey, J.H. / Madandoust, R.
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In-situ Strength Assessment of Lightweight Concrete

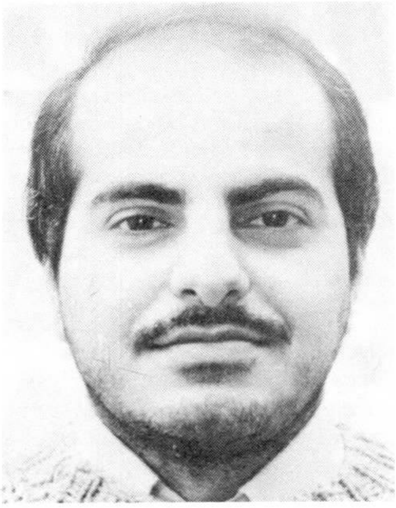
Evaluation in situ de la résistance du béton léger

Festigkeitsbestimmung an Bauwerken aus Leichtbeton

J. H. BUNGEY
University of Liverpool
Liverpool, England

Dr. John H. Bungey, graduated in Civil Engineering at the University of St. Andrews, Scotland in 1966. He worked in design and construction for 4 years and took a M. Sc. at Imperial College, London. Currently a Senior Lecturer at Liverpool University he has research interests in non-destructive testing of concrete.

R. MADANDOUST
University of Liverpool
Liverpool, England



Rahmat Madandoust, born 1959, received his B. Sc. and M. Sc. degrees in Civil Engineering from University of Southwestern Louisiana in the USA. He is currently involved in the assessment of in-situ strength of lightweight concrete.

SUMMARY

A range of non-destructive and partially-destructive test methods have been examined in terms of their reliability when used for in-situ strength assessment of lightweight concrete. These may be used with confidence provided that specially developed correlation curves are available. Testing variability has been found to be generally lower than for concrete with normal weight aggregates, possibly due to differences in failure mechanisms associated with the use of relatively weak aggregate particles.

RÉSUMÉ

Plusieurs méthodes d'essai non-destructives et partiellement destructives ont été examinées selon leur fiabilité lorsqu'elles sont utilisées pour l'évaluation in-situ de la résistance du béton léger. Celles-ci peuvent être utilisées avec confiance pourvu que des courbes de corrélation spécialement développées soient disponibles. Les variations obtenues lors des essais sont généralement de moindre importance que celles obtenues avec du béton normal, cela peut être lié aux différences dans les mécanismes de rupture associés à l'utilisation de particules d'agrégats relativement faibles.

ZUSAMMENFASSUNG

Untersucht wurden verschiedene nicht-zerstörende und teilweise-zerstörende Testmethoden im Hinblick auf ihre Verlässlichkeit bei der Bestimmung der Festigkeit von Ortbeton und Leichtbeton. Die Methoden können ohne weiteres angewendet werden, sofern für diesen Zweck entwickelte Korrelationskurven zur Verfügung stehen. Es wurde festgestellt, dass die Testabweichungen insgesamt niedriger sind als für Beton mit normalen Gewichts-Zuschlagstoffen, möglicherweise aufgrund der Unterschiede bei Fehlermechanismen, die mit der Verwendung relativ schwacher Zuschlagkörner einhergehen.

1. INTRODUCTION

It is now recognized that insitu strength evaluation of concrete by means of non-destructive and partially destructive methods has an important role to play in the building and civil engineering industries. These techniques have a wide range of applications when evaluating structural deficiencies and details of their use are given elsewhere [1].

Assessment of the strength of the concrete in structures has received considerable attention relating to natural dense aggregates, whilst concrete made of lightweight aggregates has received only limited attention. Lightweight concrete has proved itself to be a useful structural material, and applications are becoming more numerous as Engineers gain confidence. Most lightweight aggregates are artificially manufactured, and in the UK the most widely available material suitable for structural concrete is Lytag. This is produced from pulverised fuel ash (Pfa), by a sintering process [2].

A comprehensive experimental programme is being undertaken to examine the reliability and mechanisms of different methods applied to a range of lightweight concretes. In this paper the most important results obtained by six different test methods applied to fully lightweight concrete are presented.

2. EXPERIMENTAL PROGRAMME

An Ordinary Portland cement together with coarse and fine Lytag satisfying the relevant British Standards were used for all the mixes. The 24 hour water absorptions (based on oven-dried condition) for coarse and fine Lytag were 12% and 15% respectively. Four different mixes were designed with 28-day cube strengths between about 23 - 47 N/mm^2. For each mix, the following specimens were cast in four batches; 650 x 225 x 120 mm beams for 50 mm cores, 225 mm cubes for pull-out, 150 mm cubes for internal fracture and pull-off, and 100 mm cubes for pulse velocity testing.

All specimens were compacted on a vibrating table and left in the laboratory. Two curing regimes were adopted, wet and dry. Tests were carried out at ages of 7 and 28 days, except for the core tests which were performed at 28 days only.

Pull-out tests were performed on 25 mm diameter cast-in inserts using commercially available Lok test apparatus with procedures following the manufacturer's recommendations, whilst through transmission pulse velocity measurements were taken with widely used 'Pundit' equipment. The internal fracture tests using 6 mm diameter expanding wedge anchor bolts were carried out by using torquemeter apparatus (B.R.E.) as well as a modified form based on a direct pull. Pull-off tests were performed by gluing a 50 mm diameter aluminium disk to the surface of concrete followed by loading with commercially available Limpet apparatus. The 50 mm nominal diameter cores were cut vertically from the specified beams at the age of 28 days followed by trimming and capping to give overall length/diameter (L/D) ratios of 1.0, 1.4, 1.6 and 2.0. Detailed test procedures for all these methods are given elsewhere [1].

3. TEST RESULTS AND DISCUSSION

3.1 General

Table 1 summarises the average test results based on three readings for cores, pulse velocities and cube crushing strengths, and on six readings for the remaining methods. The cube compressive strengths have also been plotted against test results in figures 1 to 4. In all cases the relationship was found to be dependent on the age and curing conditions. With the exception of pulse velocities this dependency is small, and a single relationship could be adopted for practical purposes.

Mix	Age	100mm Cube Strength N/mm²		Core Strength L/D=2.0 N/mm²		Pull-Out Force kN		Internal Fracture B.R.E. N-m		Internal Fracture Direct Pull kN		Pull-Off Stress N/mm²	Pulse Vel. km/sec	
		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Dry	Wet	Dry
1	7	15.5	17.3	-	-	9.2	9.5	2.05	2.10	3.22	3.70	2.77	3.39	3.39
	28	23.9	29.4	25.0	28.0	14.9	17.4	2.33	2.56	4.40	5.07	3.11	3.53	3.47
2	7	19.7	21.7	-	-	10.5	10.6	2.33	2.45	3.90	4.05	2.86	3.53	3.51
	28	32.0	34.2	26.1	30.3	15.4	17.7	2.73	3.00	5.18	5.31	3.38	3.64	3.59
3	7	23.1	27.5	-	-	13.5	14.1	2.55	2.80	4.52	4.64	3.51	3.57	3.57
	28	35.0	39.7	28.8	37.2	19.4	22.5	3.40	3.70	5.70	6.11	3.88	3.68	3.60
4	7	29.0	33.3	-	-	16.4	16.9	2.88	3.03	5.26	5.33	3.54	3.56	3.60
	28	41.5	46.9	39.1	42.7	22.9	23.5	3.48	3.75	6.64	6.73	4.15	3.68	3.61

Table 1 Summary of test results on fully lightweight concrete

Test Method	Coefficient of Variation % Test Result	Coefficient of Variation % Normal Concrete	Correlation Coefficient	95% Confidence Limit on Estimated Strength
Core	4.3	8.8	0.985	±12%
Pull-Out	5.6	7.0	0.968	±17%
Internal Fracture				
B.R.E.	9.0	15.9	0.978	±34%
Direct Pull	9.8	15.6	0.987	±16%
Pull-Off	5.7	8.0	0.986	±24%

Table 2 Statistical evaluation for partially destructive tests

Statistical analyses based on the coefficient of variation have been summarized in table 2. It can be seen that these values are significantly less than those anticipated for normal weight concrete [1], however there are indications that within member material variability may be higher due to compaction differentials. Correlation coefficients given in table 2 based on single practical curves show that in general each test method applied to lightweight concrete gives a better correlation to cube strength than expected for normal weight concrete [1]. The accuracies of strength estimations based on 95% confidence limit for strength level of 30 N/mm^2 are also given in table 2. It is clearly seen that of the six insitu testing methods, the core test along with pull-out and direct pull internal fracture tests demonstrate the best ability to assess the insitu equivalent cube strength.

3.2 Core tests

As expected, core strengths were generally found to increase with decreasing length/diameter (L/D) ratio, although for dry cores the effect was not as large and not always as consistent as anticipated. This may be due to lack of uniformity in moisture content resulting from air drying, and emphasizes the importance of use of standardised specimens soaked for at least 48 hours. Correction factors to obtain the equivalent strength of a core with L/D = 2.0 are given in table 3. Comparison with the data for small cores of normal weight concrete reported by Bungey [1] suggests that considerably less correction is required for fully lightweight concrete. A similar finding has been obtained by Swamy [3] for semi-lightweight concrete. Recommended correction factors according to A.S.T.M. [4] and British Standards [5] are also included in table 3 and it can be seen that widely accepted British Standard values overestimate those required, even for wet specimens of lightweight concrete. Analysis of correction factors related to strength level also suggests that some dependency is present, as for normal weight concrete [1]. From the limited number of results at present available this relationship is however not clearly defined and it would be prudent to keep the L/D ratio as close to 2.0 as possible. The correlation between crushing strength of lightweight cores of this ratio and cube compressive strength agrees closely with that anticipated for comparable normal weight concrete cores.

L/D Ratio	Core L/D Correction Factor				
	Lightweight Test Results		Bungey [1]	ASTM C42-82 [4]	BS 1881 pt 120 [5]
	Wet	Dry			
2.0	1.00	1.00	1.00	1.00	1.00
1.6	0.97	0.98	0.91	0.97	0.94
1.4	0.94	0.96	0.86	0.95	0.90
1.0	0.86	0.90	0.77	0.87	0.80

Table 3 Comparison of core correction factors

3.3 Ultrasonic Pulse Velocities

It is well known that correlation between pulse velocity and compressive strength will be influenced considerably by factors such as mix proportions, aggregate type and curing regime. A relationship may however be developed for a particular concrete of specific proportions under defined conditions of age, moisture and curing. It can be noted from Table 1 that pulse velocities are significantly lower than expected with normal weight concrete of comparable strengths. Table 1 also shows that the influence of curing is less significant at early ages, possibly due to the large reservoir of water absorbed in the aggregate. It is thus considered inappropriate to use a strength/pulse velocity relationship developed during early stages for longer term strength assessment since the drying out effects may be misleading. Nevertheless, insitu pulse velocity measurements may provide valuable information concerning concrete uniformity within structural members.

3.4 Pull-out, Internal fracture and Pull-off tests

Fig. 1 shows that, although of the same general form, the relationship between pullout strength and compressive strength for lightweight concrete is significantly different to that for normal weight concrete. To permit inspection of the failure mechanism some truncated cones of concrete were completely extracted following testing, and visual examination of the failure surface showed that this mostly passed through the relatively weak aggregate particles. Behaviour of the overall system is thus more homogeneous than normal weight concrete with strong aggregates and may explain the lower variability of testing. The reduced pull-out force achieved at a given strength level may also be explained by the differences in failure mechanism, with no aggregate interlock occurring [6]. It is clear from Fig. 2 and Fig. 3 that the failure force for both internal fracture loading methods applied to lightweight concrete is also reduced. This feature, coupled with the much

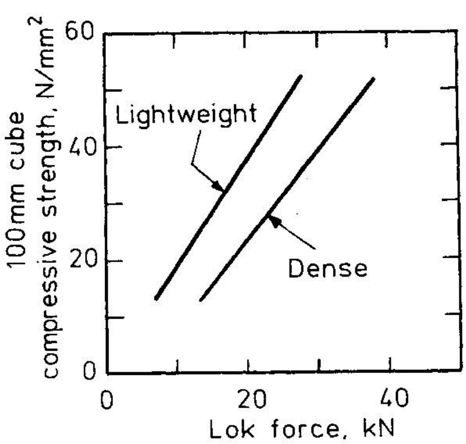


__Fig. 1__ Correlations between compressive strength and pull-out force

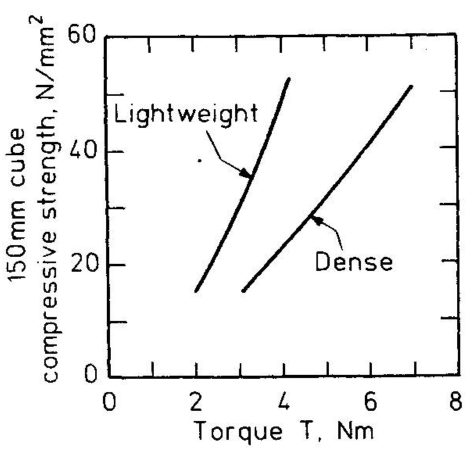


__Fig. 2__ Correlations between compressive strength and B.R.E. Internal fracture torque

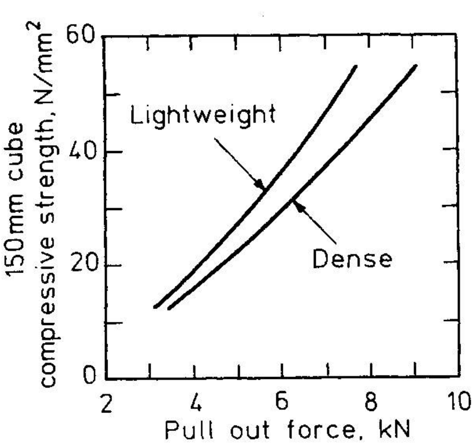


__Fig. 3__ Correlations between compressive strength and direct-pull internal fracture force

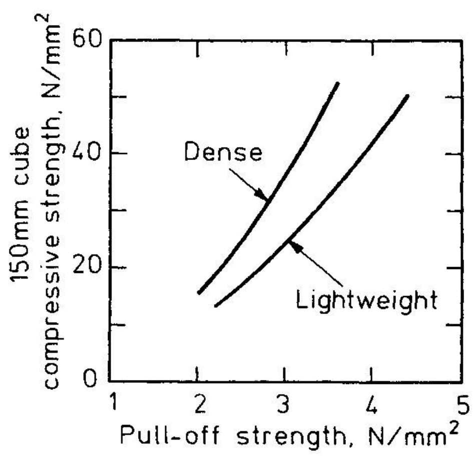


__Fig. 4__ Correlations between compressive strength and pull-off strength

reduced test variability, is likely to be for similar reasons. It can be noted from table 3 that the accuracy of strength estimation is improved significantly by use of the direct pull method, as also found with normal weight concrete [1].

For the pull-off tests a higher force was achieved at a given compressive strength level (Fig. 4). The reason for this is unclear at present but it is suspected that greater surface porosity may permit deeper adhesive penetration below the concrete surface, and hence increased pull-off strength. Possible differences in relationships between tensile and compressive strength may also be a contributory factor.

4. CONCLUSIONS

From the data presented in this paper it can be seen that all insitu tests, with the exception of cores, showed dependency upon the type of concrete under investigation. All also demonstrated lower testing variability for fully lightweight concrete than for that made with natural dense aggregates, possibly as a result of improved homogeneity due to the absence of strong aggregate particles. Correction factors for core length/diameter ratio were also found to be considerably reduced.

Good correlation was found to exist between compressive strength and results of each test, and accuracies of strength estimation by core, pull-out and direct-pull internal fracture methods were marginally better than assumed for normal weight concrete. Practical usage will however depend upon the aesthetic acceptability of surface damage and consequent repairs, as well as the availability of relevant correlations for the materials used.

It is recommended that ultrasonic pulse velocity measurements be confined to comparative situations, whilst any of the partially-destructive tests may be used as an alternative to cores although providing strength estimates of lower accuracy.

5. ACKNOWLEDGEMENTS

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