Test cores

The fundamental purpose of measuring the strength of concrete test specimens is to estimate the strength of concrete in the actual structure. The emphasis is on the word 'estimate', and indeed it is not possible to obtain more than an indication of the strength of concrete in a structure because this is dependent, *inter alia*, on the adequacy of compaction and on curing. As shown earlier in this chapter, the strength of a test specimen depends on its shape, proportions, and size, so that a test result does not give the value of the *intrinsic* strength of the concrete. Nevertheless if, of two sets of similar specimens made from two concretes, one set is stronger (at a statistically significant level), it is reasonable to conclude that the concrete represented by this specimen is stronger, too, There exist some methods of determining the strength of concrete in situ, but the limitations on the interpretation of test results must be remembered.

If the strength of standard compression test specimens is found to be below the specified value, then either the concrete in the actual structure has too low a strength as well, or else the specimens are not truly representative of the concrete in the structure. This latter suggestion is often put forward in disputes on the acceptance, or otherwise, of a suspect part of the structure: the test specimens may have been disturbed while setting, they may have been exposed to frost before they hardened sufficiently or have otherwise been improperly cured, or simply the results of the compression test are doubted.

The argument is often resolved by testing a core of concrete taken from the suspect member. If it is intended to determine the *potential* strength of the concrete mix used, corrections for the actual conditions have to be applied. Cores can also be cut in order to determine the *actual* strength of concrete in the structure. The distinction between the two purposes must be clearly borne in mind when the test results are being evaluated. The selection of the location of cores also depends on the purpose of testing. This may be: to estimate the strength of a critical part of a structure, or of a part suspected of having been damaged, for example, by frost; or alternatively, to estimate a representative value for the entire structure, in which case a random selection of locations is appropriate.

Cores can also be used to detect segregation of honeycombing or to check the bond at construction joints or to verify the thickness of pavement.

Cores are cut by means of a rotary cutting tool with diamond bits. In this manner, a cylindrical specimen is obtained, sometimes containing embedded fragments of reinforcement, and usually with end surfaces far from plane and square. The core should be soaked in water, capped, and tested in compression in a moist condition according to BS 1881 : Part 120 : 1983 or ASTM C 42-90, but ACI 318-02[12.124] specifies a moisture condition corresponding to the service environment. Japanese tests[12.116] indicate that testing in a dry state yields strength values typically about 10 per cent higher than when the cores are tested wet.

The influence of the height/diameter ratio of the cylinder on the recorded strength was considered on p. 591. If the strength of cores is to be related to the strength of standard cylinders (height/diameter ratio of 2) then, in the core, this ratio should be near 2. When cubes are the standard test specimen, there is some advantage in using cores with a height/diameter ratio of 1 because cylinders with this ratio have very nearly the same strength as cubes. For values of the ratio between 1 and 2, a correction factor has to be applied. Meininger *et al.*[12.83] found the factor to be the same for wet- and dry-tested cores, but lower than specified by ASTM C 42-90 (see Table 12.1).

Cores with height/diameter ratios lower than 1 give unreliable results, and BS 6089 : 1981 prescribes a minimum value of 0.95 prior to capping but, according to BS 1881 : Part 120 : 1983, the cap thickness must not exceed 10 mm at any point. This limitation must be observed although in practice, the length of the core may be governed by the thickness of the concrete. Glueing cores which are too short is possible.[12.96]

Use of small cores

Both British and ASTM Standards specify a minimum core diameter of 100 mm (4 in.) with the proviso that the core diameter be at least 3 times the maximum size of aggregate; however, ASTM C 42-90 allows, as an absolute minimum, the ratio of the two sizes to be 2.

Nevertheless, there exist circumstances where only very small cores can be drilled, either because of the risk of structural damage or because of congestion of the reinforcement or for aesthetic reasons. In such cases, some standards allow the use of 50 mm (2 in.) diameter cores. These small cores may violate the requirement of a minimum ratio of core diameter to aggregate size, and the drilling operation can affect the bond between the aggregate and the surrounding hardened cement paste.[12.98] Tests[12.127] have shown that, when the maximum size of aggregate is 20 mm ($\frac{3}{4}$ in.), 50 mm (2 in.) cores have a strength about 10 per cent lower than 100 mm (4 in.) cores; other tests[12.110] on concretes with 28-day cube strengths between 20 and 60 MPa (or 3000 and 9000 psi) indicate that the difference is between 3 and 6 per cent. A good correlation between the strength of 28 mm ($1\frac{1}{8}$ in.) diameter cores and the cube strength was obtained in laboratory tests on concrete with a maximum size of aggregate of 30 and 25 mm ($1\frac{1}{4}$ and 1 in.)[12.78] (see Fig. 12.22).

Overall, in view of the numerous factors influencing the strength of cores, as compared with the relative uniformity of cast standard compression test specimens, the effect of core size can be considered to be unimportant. However, small cores have a higher variability than standard-size cores; typical values[12.100] of the coefficient of variation are 7 to 10 per cent for 50 mm cores, and 3 to 6 per cent for 150 mm cores. It follows that, for a given precision of the estimate of strength, the required number of 50 mm cores is probably 3 times larger than the number judged adequate for 100 mm (4 in.) or 150 mm (6 in.) cores. Likewise, when the core diameter is less than three times the maximum size of aggregate, an increased number of cores has to be tested.

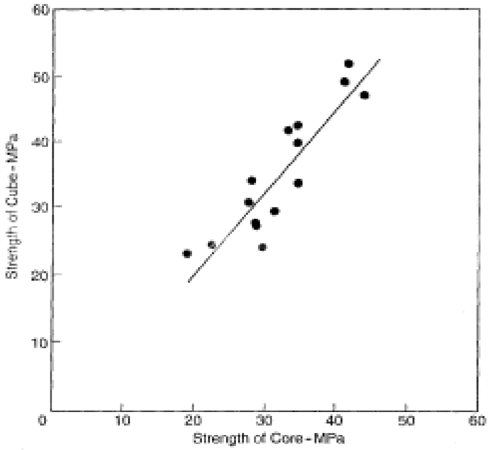

Fig. 12.22 Relation between the strength of 28 by 28 mm (1⅛ by 1⅛ in.) cores and the strength of 150 mm (6 in.) cubes; maximum aggregate size 25 and 30 mm[12.76]

Factors influencing strength of cores

The strength of cores is generally lower than that of standard cylinders, partly as a consequence of the drilling operation and partly because site curing is almost invariably inferior to curing prescribed for standard test specimens. However careful the drilling, there is a high risk of slight damage. The effect appears to be greater in stronger concrete, and Malhotra[12.99] suggests that the reduction in strength can be as high as 15 per cent for 40 MPa (6000 psi) concrete. A reduction of 5 to 7 per cent is considered reasonable by the Concrete Society.[12.100]

There is, however, a difficulty in separating out the effect of drilling because the curing history of cores is perforce different from the curing history of cast test specimens. The difficulty is exacerbated by the fact that the exact curing history of a structure is usually difficult to determine so that the effect of curing on the strength of cores is uncertain. For structures cured in accordance with the recommended practice, Petersons[12.67] found that the ratio of core strength to standard cylinder strength (at the same age) is always less than 1, and decreases with an increase in the concrete strength level. Approximate values of this ratio are: just under 1 when the cylinder strength is 20 MPa (3000 psi) and 0.7 when it is 60 MPa (9000 psi).

Because cores are often taken after the 28-day test cylinders have been tested, cylinders of an age comparable to the age of the cores may not be available, but it is sometimes argued that cores taken from concrete many months old should have a higher strength than at 28 days. This appears not to be the case in practice

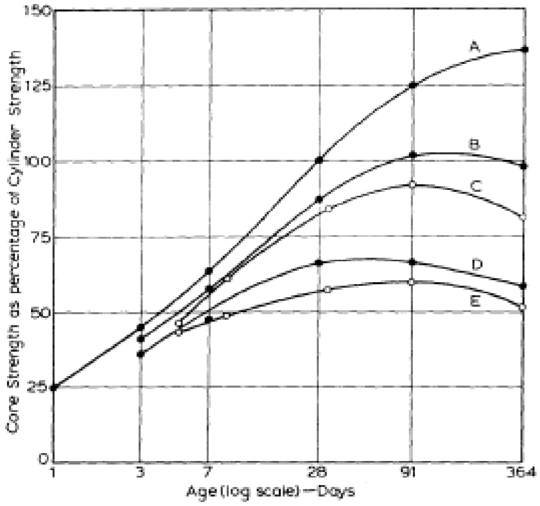

Fig. 12.23 Development with time of strength of concrete cores made with Type I cement expressed as a percentage of 28-day strength of standard cylinder (38 MPa (5500 psi)): (*A*) standard cylinder; (*B*) well-cured slab, core tested dry; (*C*) well-cured slab, core tested wet; (*D*) poorly cured slab, core tested dry; (*E*) poorly cured slab, core tested wet[12.101]

(see Figs 12.23 and 12.24), and there is evidence that in situ concrete often gains little in strength after 28 days.[12.102,12.103] Tests on high strength concrete[12.112] show that, although the strength of cores increases with age, the core strength, even up to the age of 1 year, remains lower than the strength of standard 28-day cylinders; this is shown in Table 12.3.

These results accord with Petersons' view[12.104] that, for average conditions, the increase in strength over that at 28 days is 10 per cent at three months, and 15 per cent at the age of six months. The effect of age is, therefore, not easy to deal with but, in the absence of definite moist curing, no increase in strength should be expected with age and no age correction should be used in the interpretation of the strength of cores.[12.100]

The location in the structure from which the core has been taken may affect the strength of the core. If the core has been taken from concrete in tension, the core strength may be low because of the presence of cracks;[12.114] thus, a false picture of the strength of the concrete in the structure can be obtained.

The position of the core with respect to the height of the lift may also be of relevance. Cores usually have the lowest strength near the top surface of the

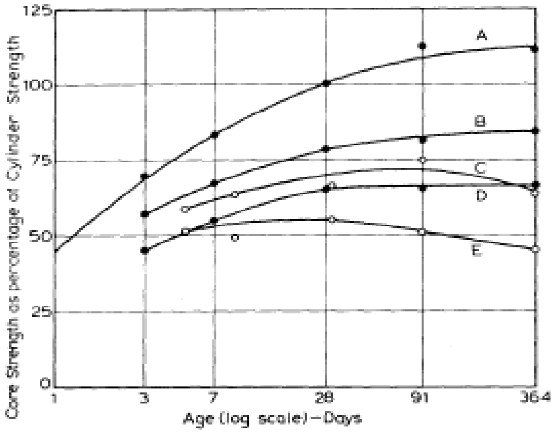

Fig. 12.24 Development with time of strength of concrete cores made with Type III cement expressed as a percentage of 28-day strength of standard cylinder (38 MPa (5500 psi)): (*A*) standard cylinder; (*B*) well-cured slab, core tested dry; (*C*) well-cured slab, core tested wet; (*D*) poorly cured slab, core tested dry; (*E*) poorly cured slab, core tested wet[12.101]

Table 12.3 Development of the Strength of Cores* with Age (based on ref. 12.112)

Age, days	*Strength, MPa*		*Core strength as a proportion of strength of 28-day standard cylinders*
	Standard cylinders	*Cores*	
7	66.0	57.9	0.72
28	80.4	58.5	0.73
56	86.0	61.2	0.76
180	97.9	70.6	0.88
365	101.3	75.4	0.94

* Cores taken from columns cured using a sealing compound.

structure, be it a column, a wall, a beam, or even a slab. With an increase in depth below the top surface, the strength of cores increases,[12.67] but at depths greater than about 300 mm there is no further increase. The difference can be as high as 10 or even 20 per cent. In the case of slabs, poor curing increases this difference. Compressive and tensile strengths are affected to the same degree.[12.105] This pattern of strength is, however, not universal, some tests indicating no significant variation in core strength with height.[12.112] It is likely that the variation in strength with height is the consequence of trapped bleed water, coupled with a variation in compaction: when these factors are absent, there is no variation in strength with height.

The presence of trapped bleed water may also be responsible, in part, for the reported influence of the orientation of the core (vertical or horizontal) on its strength. Cores drilled horizontally were found to have a strength lower by, typically, 8 per cent.[12.106] This effect is similar to the effect of bleed water on the strength of cubes (see p. 588).

The conversion expressions of BS 1881 : Part 120 : 1983 distinguish between cores drilled horizontally and those drilled vertically, the ratio of the strength of the former to the latter being 0.92. However, if there is no trapped bleed water in the concrete, the correction for horizontally-drilled cores may not be valid. It is also possible that difficulties in horizontal drilling contribute to the lower strength of such cores.

British Standard BS 1881 : Part 120 : 1983 gives also correction factors which allow for the weakening effect of transverse reinforcement in the core. Although some effect of embedded steel on strength could be expected, the information on this is contradictory. Reviews by Malhotra[12.99] and by Loo *et al.*[12.132] report some tests showing no reduction in strength, and other tests where the reduction ranged between 8 and 18 per cent; the reduction seems to be higher when the height/diameter ratio of the core is 2 than at lower values of this ratio.[12.132] The Concrete Society[12.100] also reports a reduction in strength as a function of the position of the steel: the effect is greater the further the steel is from the end of the core.

The tests of Loo *et al.*[12.132] confirmed that embedded transverse reinforcement reduces the strength of cores with a height/diameter ratio of 2, but the effect decreases at low values of the height/diameter ratio; at a height/diameter ratio of 1, embedded steel has no effect on the measured strength, regardless of the position of the steel in the core. This effect is linked to the stress distribution in cylinders with various values of the height/diameter ratio (see p. 592). When this ratio is 1, or in a cube, there is no lateral tensile stress in the specimen, and the steel is well able to resist vertical compression.

In view of the various factors involved and of the conflicting data, no reliable factor which allows for the presence of transverse steel can be accepted. The best solution, if possible, is to take cores from a location such that they contain no reinforcement, not only because it complicates the strength assessment, but more importantly, because cutting reinforcement may have highly undesirable structural consequences. In any case, the presence of steel parallel to the axis of the core is unacceptable.

Relation of core strength to strength in situ

It should be emphasized that the core strengths, when converted to the strength of cylinders of standard size or to cube strengths, represent, at best, the strength of in situ concrete. They are not to be *equated* with the strength of *standard* test specimens, which is the potential strength of the given concrete (see p. 582). Indeed, from the preceding review of the various factors influencing the strength of cores, it is apparent that it is not easy to *interpret* the strength of cores in relation to a specified 28-day strength. Various reports[12.99,12.103] suggest that, even under excellent conditions of placing and curing, the strength of cores is unlikely to exceed 70 to 85 per cent of the strength of standard test specimens. This view is supported by ACI 318-02[12.124] which considers that concrete in the part represented by a core test is adequate if the average strength of 3 cores is equal to at least 85 per cent of the specified strength and if no single core has a strength lower than 75 per cent of the specified value; no age allowance is made. It should be noted that, according to ACI 318-95, cores are tested in a dry state if the structure is dry in service, which should lead to a higher strength than when tested to ASTM or British Standards (see p. 600). Thus, the requirements given above are fairly liberal.

It is useful to note that the '85 per cent allowance' is applied also to shotcrete according to ACI 506.2-90.[12.133] However, since shotcrete is accepted on the basis of core strength, and not of moulded specimens, there is no logical reason for this 'allowance'.[12.111]

In some cases, beam specimens can be sawn from road or airfield pavements, using a diamond or silicon carbide saw. Such specimens are tested in flexure in accordance with ASTM C 42-90 but, at least when siliceous aggregate is used, sawn specimens give appreciably lower strengths than comparable moulded beams.[12.23] Cutting of beams is not much used and the means of obviating their use was discussed on p. 597.