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LOK-test and CAPO-test development and their applications

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Two pull-out systems for testing the in situ compressive strength of concrete are presented, LOK test and CAPO test. With the LOK test, 25 mm of the concrete (usually the surface layer) is tested by pulling a pre-embedded disc towards a counterpressure ring placed on the testing surface. With the CAPO test the concrete is tested at random on the same principle, but by drilling and expanding a special insert in the concrete which is then pulled out. In this configuration, failure of the concrete is due to compression, and hence the pulling force is a direct measure of the compressive strength. Calibration data from 19 major projects in Denmark, Sweden, Norway, the Netherlands, the USA and Canada are presented, totalling 4774 pull-outs and 4202 compression tests (cylinder and cube). Based on experience so far, general relationships for cylinder strength and cube strength are recommended for normal concrete with maximum aggregate size not greater than 38 mm. Variation in the pull-out tests is shown to be of the same order as for the standard cylinder or the standard cube.

LOK test

The patented LOK-test system, developed in Denmark in the past ten years, consists of different types of insert being cast into the concrete, portable pulling equipment operated by hand, and a statistical system for evaluating in situ concrete quality.

2. The pull-out insert is a 25 mm dia. special steel disc held 25 mm from the testing surface by a removable shaft, which may be attached to the formwork using a circular hardboard plate nailed into place, or through the formwork using an adjustable screw (Fig. 1(a)). It can also be placed in unformed surfaces of concrete using a flotation cup or a steel plate.

3. During testing, all parts of the insert except the disc are removed (Fig. 1(b)). A special pullbolt is threaded into the disc and attached to the testing instrument, a hand-powered hydraulic precision pulling machine, which has a 55 mm dia. counterpressure ring placed centrally on the testing surface (Fig. 1(c)). Pulling force is applied by turning the instrument handle. The equipment automatically ensures correct centring and constant correct loading perpendicular to the testing surface. A small truncated cone between the disc and the counterpressure ring is released and compressed, and the pulling force is recorded. Load is applied to a required proof load and then released, in which case there is no damage to the concrete surface at all. Alternatively, load may be applied until compressive failure of the concrete and, if released immediately afterwards, only slight damage occurs to the concrete (Fig. 1(d)). All that shows on the surface, if anything, is a slightly raised ring the size of the counterpressure ring. The instrument and the pulling bolt are

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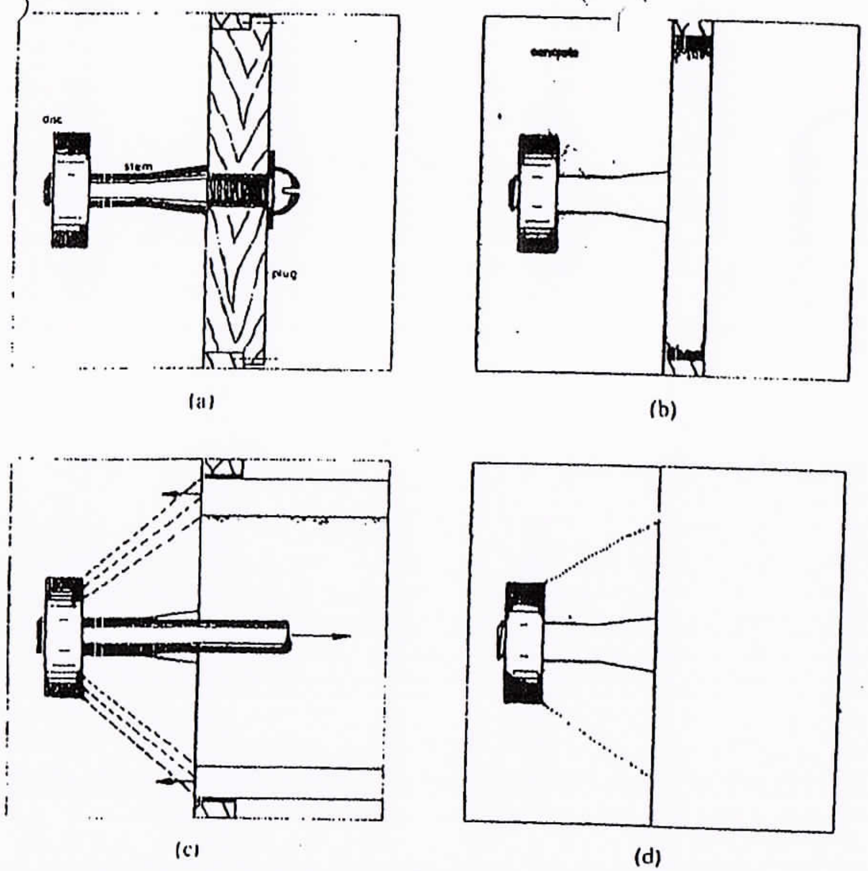

Fig. 1. LOK-test sequence for early form stripping

dismantled, and the stem (the removable shaft) is reinserted in the disc leaving the surface almost untouched.

4. Each test takes approximately two minutes and it is recommended that a minimum of six inserts be placed in each structural element to be tested. Ten inserts per 100 m^3 of concrete placed are recommended in slabs for early stripping purposes.

5. Results are averaged, and the standard deviation calculated. The characteristic pull-out strength of the element is calculated by deducting the standard deviation multiplied by a constant (which varies with the number of tests made) from the mean value. This strength, the characteristic LOK strength, is used to evaluate whether in situ specifications have been met.

6. Precompression of the concrete due to direct load, or as a result of prestress, has been shown to have no effect on the LOK strength.[1] Experimentally the LOK strength in kN pulling force has been correlated to 150 × 300 mm standard cylinder or 150 × 150 × 150 mm standard cube strength.[2-18]

7. Theoretically the conversion equation has been substantiated by Coulomb's criterion for sliding failure[19] and by a finite element analysis of the failure.[20] Both analyses conclude that the LOK-test failure is caused by crushing of the concrete released during pull-out between the cast-in disc and the counterpressure ring, and hence the pulling force, the LOK strength, is a direct measure of the compressive strength.

Correlation data, LOK strength to cylinder strength

8. Most of the calibrations in Denmark from 1970 to 1977 were made in the strength range 20–60 MPa. Parameters considered were curing conditions, time of curing, water/cement ratio, air content, type of cement, shape, type and maximum size of aggregates (8 mm, 16 mm and 32 mm). Compared with 150 × 300 mm cylinder strength no significant difference between the four major calibrations was found. The conversion equation was

$$L = 0{\cdot}8 \times f_c + 5{\cdot}0 \qquad (1)$$

with the LOK strength L in kN and the cylinder strength f_c in MPa. The equation is based on 1716 LOK tests and 1066 cylinders. The coefficients of correlation for the four calibrations ranged between 0·95 and 0·98 and the standard deviations between 1·9 MPa and 3·5 MPa, depending on the strength level and the type of calibration procedure used. A summary is given in ref. 15. Later investigations[4] have shown the LOK test to have an in-test variation of the order 1·0 MPa for normal concrete at normal testing levels, when care is taken in the laboratory to make as uniform a compacted concrete as possible, while the standard deviation of well controlled in situ concrete is about 2·8 MPa for LOK tests made at the same horizontal level of a structural element.

9. Canadian[4] as well as Dutch investigations[13,14] conclude that the LOK-test in-test variation is of the same order as the standard cylinder or cube test. Danish investigations[7,8] and testing practice support these findings if LOK tests are made on the specimens used for later reference compression tests, that is in the bottom of a standard 150 × 300 mm cylinder or on one of the vertical faces of a 150 mm cube. If LOK tests are performed on separate specimens, e.g. 200 mm cubes, Danish and Swedish experience shows a higher variation in the LOK test compared with cylinders or cubes—almost double.[11,12] This is probably caused by different compaction of the part of the specimen where the LOK test is pulled out compared with the reference compression specimen.

10. Equation (1) is used today by Danish State Railways and the National Road Department of Denmark, and is regarded as the reference calibration. According to the Danish code of practice at least 90% of the specified characteristic cylinder strength has to be met if the structure is tested in situ with the LOK test. In this case a special equation between characteristic strength values is used.[21,22]

11. Although the original main purpose of the LOK test in Denmark was to test the quality of the finished concrete structure in the critical 25 mm layer of the surface cover, another major interest in the late 1970s was in stripping formwork early or in loading structural elements as early as possible. This interest was especially pronounced in North America, where the LOK test was introduced in 1976. Since most of the Danish calibrations were made above 20 MPa, and the need was to correlate LOK strength to cylinder strength below this level, a new series of calibrations was made, both in North America and in Denmark. Recently,

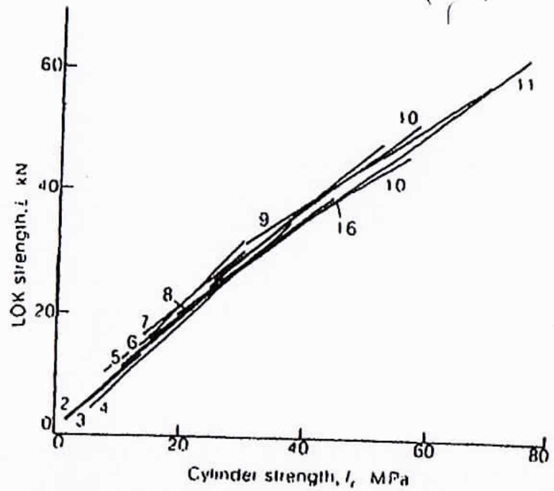

Fig. 2. Correlations between LOK strength and 150 × 300 mm standard cylinder strength (numbers refer to references)

special high-strength concretes attracted interest, and additional calibrations in the very high-strength area have been carried out in the USA as well as in Denmark.

12. Figure 2 summarizes the twelve major calibrations made in the period 1970–1983. The total number of LOK tests was 2701 and the number of cylinders

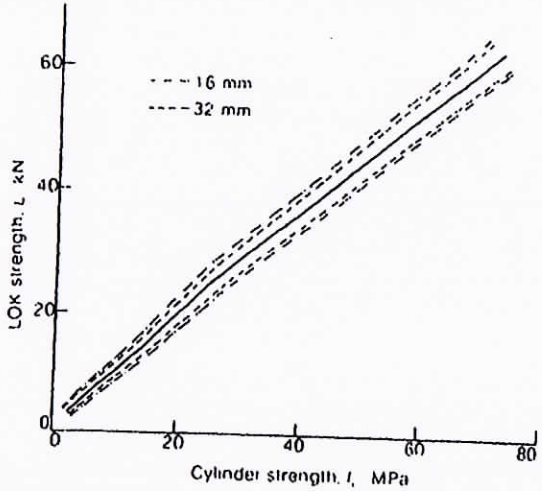

Fig. 3. Recommended calibration LOK strength to 150 × 300 mm standard cylinder strength; upper and lower 95% confidence limits related to an average of four LOK tests and two cylinders for 16 mm and 32 mm maximum aggregate size[5]

1941. Coefficients of correlation are between 0·95 and 0·98. Standard deviations range from 1·5 MPa to 3·5 MPa. Based on the present amount of data, a linear relationship in the strength range 3–25 MPa is recommended:

$$L = 0{\cdot}96 \times f_c + 1{\cdot}0 \qquad (2)$$

with the LOK strength L in kN and the cylinder strength f_c in MPa, while the conversion equation (1) is confirmed for strengths between 25 MPa and 75 MPa as measured on standard cylinders.

13. Figure 3 illustrates the recommended average conversion equations (1) and (2) together with the 95% confidence limits related to an average of four LOK tests and of two cylinders for maximum aggregate sizes 16 mm and 32 mm.[5] Confidence limits are based on 490 LOK tests and 250 cylinders with LOK tests made on the vertical faces of 200 mm cubes, two in each. As stated in §§ 8–9, this kind of calibration procedure maximizes deviations between LOK tests as well as between the LOK test and cylinders due to different compaction of the tested concrete. The confidence limits may therefore be regarded as conservative.

Correlation data, LOK strength to cube strength

14. Comparisons between LOK strength and 150 mm cube compressive strength have been made in seven major calibrations, three in Sweden, three in the Netherlands and one in Norway. Correlations are illustrated in Fig. 4. In total there were 2073 LOK tests and 2261 cube tests. Coefficients of correlation ranged from 0·95 to 0·99 and standard deviations from 1·5 MPa to 3·3 MPa.

15. As noted from Fig. 4, the first six calibrations[12–14, 17, 19] differ significantly from the last calibration. The deviation is especially pronounced at higher strength levels. LOK inserts in calibration 18 were placed and pulled out of 150 mm cubes, also at high strength levels, while the first six were based on pull-outs made on specimens with a minimum 100 mm distance between the insert and the edge of the specimen if tested at higher strength levels.

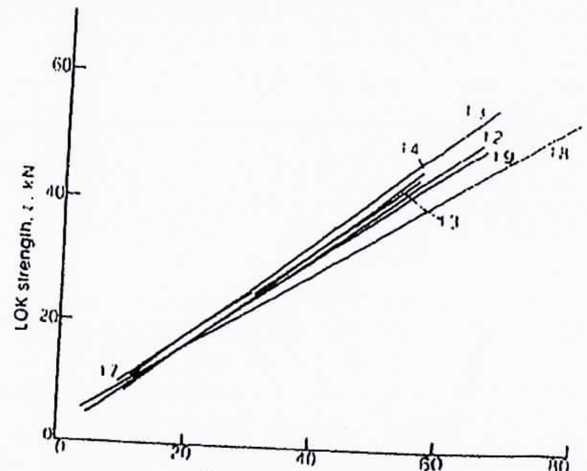

Fig. 4. Correlations between LOK strength and 150 × 150 × 150 mm standard cube strength (numbers refer to references)

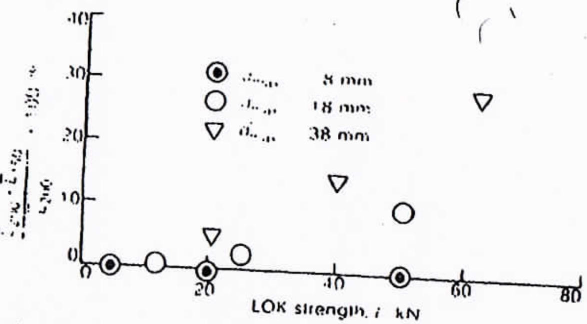

Fig. 5. Reduction in LOK strength due to radial cracking if pulled out of 150 mm cylinders compared with 200 mm cubes for different sizes of maximum aggregate as a function of strength: each measurement is based on an average of three LOK tests on each type of specimen

16. From Danish calibrations it has been known for many years that severe radial cracking occurs during pull-out. This increases with the maximum size of aggregates to be used, the greater the strength level to be tested and the less the distance is from the insert to the edge. This phenomenon happens during all pull-outs, but usually the cracking is not visible.[20] This is the reason all Danish calibrations, as well as the North American calibrations in the higher-strength area, have always been based on pull-outs made on 200 mm cubes placed centrally on the vertical faces. Smaller specimens will more easily severely crack radially during pull-out, giving lower pull-out forces than if no cracks have been observed after pull-outs made on larger specimens.

17. To investigate the influence of this 'edge'-effect on pull-out forces, a number of 200 mm cubes and 150 mm cylinders were cast at the Institute of Technology in Denmark. LOK inserts were placed centrally in the bottom of the steel forms and care was taken to ensure uniform compaction of the concrete during casting, as well as equal maturity of the concrete at the time of testing. Three different maximum aggregate sizes were used, 8 mm, 18 mm and 38 mm, and three different strength levels were applied. The results are summarized in Fig. 5.

18. Although the amount of data is limited, there is a significant trend towards the LOK strength being lower if pulled out of 150 mm specimens compared with 200 mm, when maximum aggregate size is 18 mm or above and concrete strength is higher than 40 MPa. If the data for calibration 18 (Fig. 4) are corrected accordingly, there is no significant deviation between the seven LOK-strength/cube-strength correlations as illustrated in Fig. 6.

19. However, it will be noticed that there is a tendency towards slightly more conservative correlations in the Netherlands (correlations 13 and 14) than in Sweden (correlations 12, 18 and 19). This difference is probably caused by cube-test-machine deviations and/or different procedures for cube manufacturing. Despite the differences, the maximum deviation from the mean calibration illustrated in Fig. 7 is less than 6%. A similar deviation is found for LOK-strength/cylinder-strength calibrations (Fig. 2).

20. The recommended mean conversion equation is

$$L = 0{\cdot}75 \times f_c' + 2{\cdot}2 \qquad (3)$$

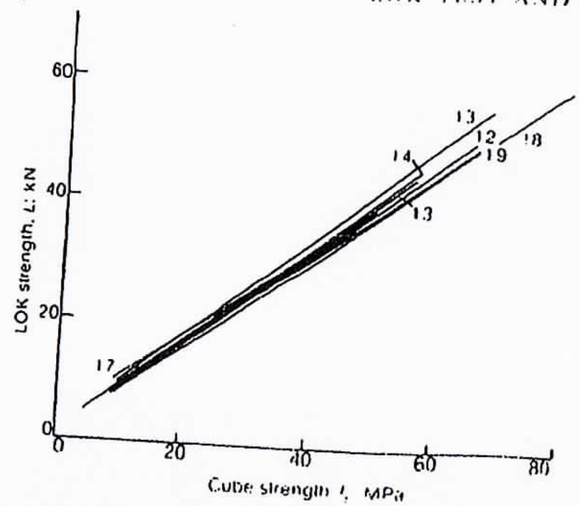

Fig. 6. Correlations between LOK strength and 150 mm cube strength (calibration 18 corrected): numbers refer to references

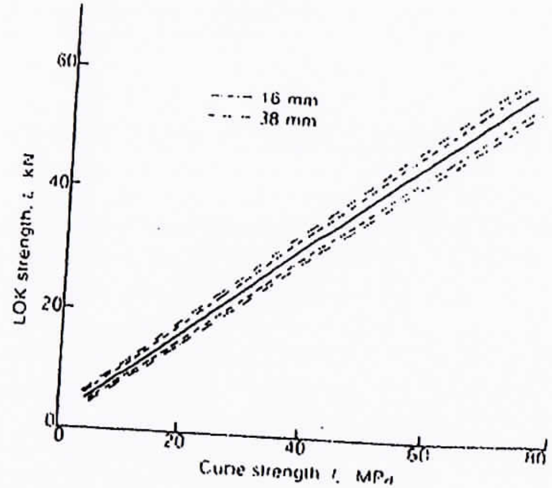

Fig. 7. Recommended calibration LOK strength to 150 mm standard cube strength: upper and lower 95% confidence limits related to an average of three LOK tests and three cubes for 16 mm and 38 mm maximum aggregate size[18]

with the LOK strength L in kN and the 150 mm cube strength f_c' in MPa. If cube strength is measured in lbf/in² the conversion equation based on the present data is

$$L = 0{\cdot}005172 \times f_c' + 2{\cdot}2 \qquad (4)$$

LOK-test applications

21. With the LOK test all factors influencing in-place concrete strength are taken into account, such as the quality of the concrete as delivered to a site, the compaction of the concrete placed, the ambient temperature, the heat of hydration and the curing conditions.

22. A wide range of structures in North America have been and are being form stripped early, using specially designed early high-strength mixes tested reliably and accurately in situ with the LOK test. Typical high-rise structures, cooling towers, slabs being post-tensioned and various kinds of bridges being early loaded, are tested. The system is the ASTM C-900 standard today.

23. In Denmark and Sweden the LOK test is used for control testing of structures equivalent to drilled cores and for early stripping as well. Concrete structures and frames for housing, factories, energy plants, heat transmission systems and highway bridges are being tested. The codes in both countries are encouraging in-place testing of the finished product, and major authorities recommend or demand the LOK test in the specifications.

24. Testing cases are referred to in detail in refs 23–28.

CAPO test

25. For test locations in newly-cast hardened concrete or for testing dubious or damaged concrete structures with pull-outs before repair, a new pull-out test was developed in Denmark in the late 1970s. This patented cut and pull-out test (CAPO test) is similar to the LOK test except that the insert is drilled and expanded wherever required in situ into the hardened concrete.

26. The testing procedure is illustrated in Fig. 8. The first reinforcement is located with a covermeter or a simple metal detector and the testing surface is, if necessary, ground smooth and flat with a heavy grinder in a 100 × 100 mm area. A hole is cut perpendicular to the surface with a special tool 18 mm in diameter, to a depth of 50 mm at least 20 mm from reinforcement position, and afterwards undercut with a diamond miller to a 25 mm hole positioned 25 mm from the concrete surface, to a depth of 10 mm. Fig. 8(a) illustrates the hole at this stage.

27. An expandable insert is placed in the hole and is expanded with a special expansion unit (Fig. 8(b)). The unit and the insert are attached to a pullbolt, which is coupled to a LOK-test instrument with a 55 mm counterpressure ring placed on the testing surface and loaded as with the LOK test (Fig. 8(c)). The CAPO strength is recorded as the maximum reading during pull-out, which in this case is always continued to past failure until the cone of concrete is removed (Fig. 8(d)). This allows the concrete cone to be inspected and analysed, and the expandable insert mechanism to be reused. The cone hole may have to be repaired afterwards.

28. The test takes approximately ten minutes for trained personnel familiar with diamond cutting and testing of in situ concrete. The portable equipment, all kept in two small suitcases, makes it possible to carry out a large number of CAPO tests wherever required on the structure.

Correlation data

29. In 1979 the Technical University of Denmark conducted a research project to evaluate the reliability and the reproducibility of the CAPO test relative to standard cylinder strength and to the LOK-test. The project and the results have been published.[11,15,29] Four types of concrete were investigated: normal concrete with ordinary aggregates (8 mm, 16 mm and 32 mm maximum aggregate size),

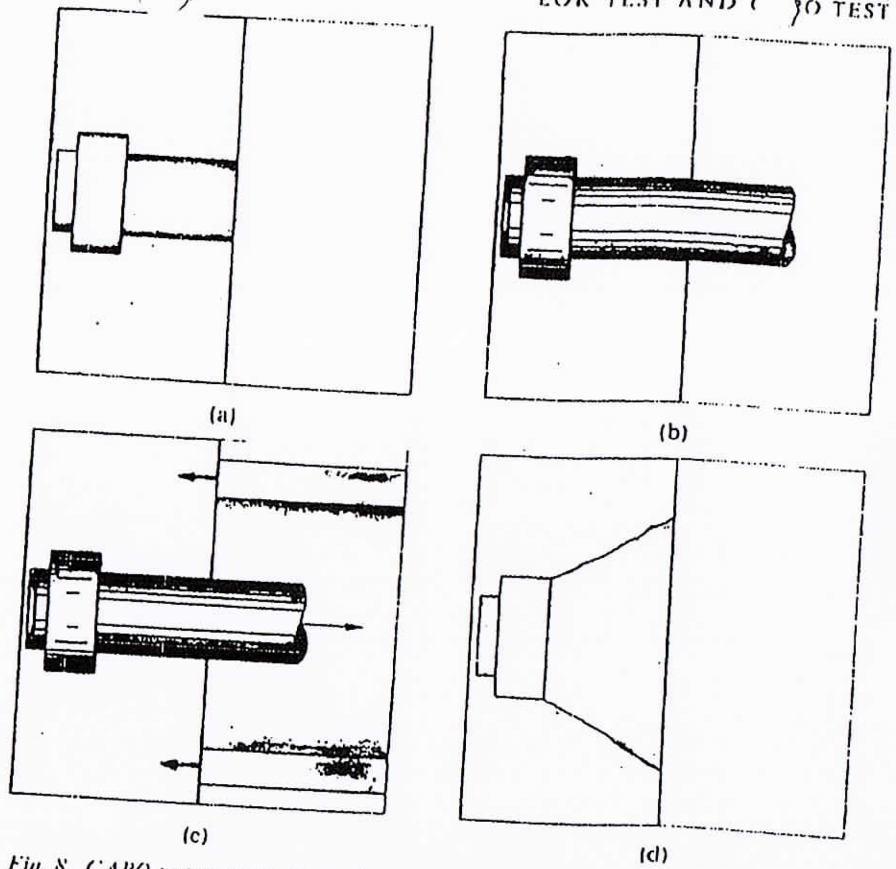

Fig. 8. CAPO-test sequence for testing hardened concrete

gunite concrete, vacuum concrete and lightweight concrete. Only the data for the normal type concrete will be covered here.

30. Thirty mixes were made. Parameters considered were: water/cement ratio, source of aggregate and type of cement, size of aggregates up to 32 mm, curing conditions, age of the concrete and air content. Strength ranged from 4 MPa to 75 MPa as measured on standard cylinders.

31. Within each mix a number of cylinders and a similar number of 200 mm cubes were cast. The numbers depended on the types of parameter investigated, but typically were six or eight. LOK inserts were cast in each cube, and were placed centrally on two opposite vertical faces. Cylinders and cubes were cured under the same conditions, and at the time of testing the cylinders were crushed in compression and the cubes tested with LOK tests and two CAPO tests carried out on the remaining two vertical faces of the 200 mm cubes.

32. In total there were 116 cylinder tests, 216 LOK tests and 214 CAPO tests. In Fig. 9 average values of two cylinders and of two cubes tested with LOK and CAPO tests are reproduced.

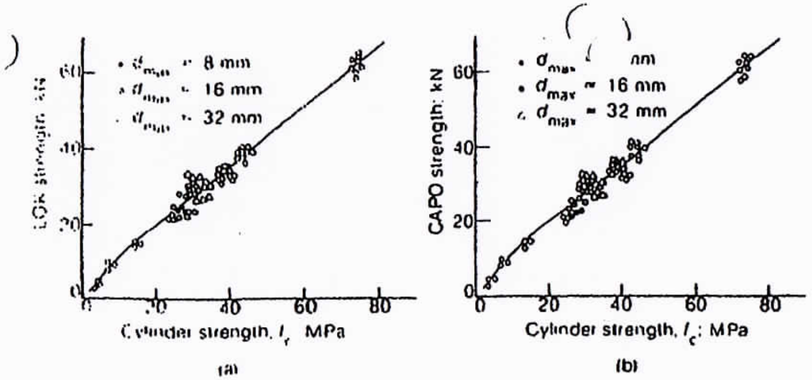

Fig. 9. Pulling force related to 150 × 300 mm standard cylinder strength:[11] *(a) LOK strength; (b) CAPO strength*

33. The coefficients of variation within each mix were calculated on average to be 3·7% for cylinders, 7·2% for LOK tests and 7·1% for CAPO tests. The coefficients of correlation for strengths above 20 MPa were 0·95 for the LOK test and 0·95 for the CAPO test compared with cylinder strength. Calibrations were not significantly different from earlier findings as summarized in Figs 2 and 3 for the LOK or the CAPO test.

34. It is concluded that the CAPO strength correlates with cylinder compressive strength in a similar way to the LOK test, and that the accuracy of the LOK test and CAPO test is of the same order. Recent research in Sweden[18] has reached the same conclusion comparing the LOK test against 150 mm cube strength with the CAPO test against 150 mm cube strength. Identical calibrations were found.

CAPO-test applications

35. The CAPO test has been accepted in Denmark as equivalent to the LOK test and has been used on a number of projects, mainly for investigations of critical parts of dubious or damaged concrete structures such as deteriorated concrete, fire-damaged concrete, a badly consolidated structural element or concrete with low maturity being loaded early. Another major area for the CAPO test is the testing of gunite concrete and vacuum concrete. The CAPO test is increasingly also being used as a supplement to LOK test for control purposes and for permeability testing of the surface layer in a depth up to 60 mm, in which case some extra equipment for compression of carbon-dioxide on the concrete surface is needed.

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