# FLEXURAL STRENGTH OF PLAIN CEMENT CONCRETE

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The flexural strength of cement concrete at different periods during curing is affected by water used in mixing and aggregate proportion in a similar way as the compressive strength. The best water-cement ratio in the usual mix of 1:2:4 cement, fine and coarse aggregate (by volume) is 0.7. The flexural strength is directly proportional to the compressive strength and is roughly 21% of the latter.

## Introduction

The flexural strength is rarely used to measure the quality of the portland cement concrete. It is important for designing roads and runways as the slabs in these constructions seldom fail in compression. In an earlier communication,[1] the use of this strength has been suggested in designing the reinforced concrete roof slabs. The mild steel was reduced from 170 lbs. to 34 lbs. for a room of 10′ × 11′ (inside dimensions). Flexural testing is very easy and can be handled more conveniently than compression testing in the field. The factors affecting the compressive strength, as described by D.A. Abrams,[2] also affect the flexural strength. It has also been reported by him that the flexural strength is relatively higher in weak mixes than in the rich concretes and hence the relation between the two strengths is not uniform in concretes with varying cement-aggregate ratios. For usual concrete mixes, the modulus of rupture was given as about 22% of the compressive strength when the plain concrete beams were loaded at the 1/3 points of a 36″-span. The results of the tests carried out at the Road Research Laboratories in the U.K.[3] show the relation between two strengths approximately parabolic in form for rich and weak mixes. The flexural strength is given by an equation $Fb = 9.2\sqrt{Fc}$ where Fb is the modulus of rupture and Fc the crushing strength, both in lbs./sq. in.

The present paper describes the two strengths of usual concrete mixes using local Malir river aggregate and the Dalmia portland cement.

## Effect of Water-Cement Ratio on Flexural Strength

The gradings of the fine and coarse aggregate (locally termed as double screened 'bajri') are given in Fig. 1. The aggregate is mostly calcareous in nature. The concrete beams 4″ × 4″ × 18″ were made in the proportion of 1:2:4: cement, fine and coarse aggregate by volume. Uniform

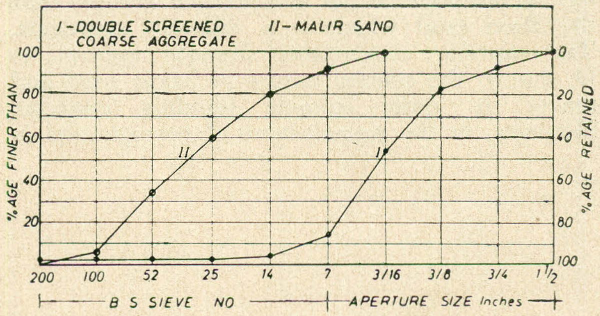


Fig. 1.—Grading of fine and coarse aggregate from Malir river bed.

tamping was given to all beams as is generally done in the field. The water-cement ratio was varied from 0.5 to 0.8 to find out the best ratio for the strength in these conditions. This was inclusive of the water absorbed by the dry, fine and coarse aggregates which was about 2% of the dry weight. The beams were stored in stacks under the shade and were cured by sprinkling water twice a day. The above two conditions are not according to the various national standard specifications but correspond with the general practice in the field in this country.

The beams 4″ × 4″ × 18″ were centrally loaded on a span of 15″ and the results are given in Table 1. For dry strength the samples were kept in the oven at about 110°C. for 24 hours. The flexural strength was calculated as the modulus of rupture Fb, defined by equation Fb=M/Z, where M is the bending moment in the beam at failure, and Z is the section modulus of the beam calculated on the basis of elastic material. The modulus of ruputre is higher than the extreme fibre stress at failure as the cement concrete is not truly elastic owing to the nonlinearity of the stress/strain relation. The maximum strength, in these conditions, was obtained when water-cement ratio was kept at 0.70. The flexural strengths obtained on spans of 9″ and 12″ are reported in Table 2. The best strength again was obtained when water-cement ratio was

TABLE 1.—RELATION BETWEEN MODULUS OF RUPTURE OF 4 INCH SQ. BEAMS CENTRALLY LOADED ON SPAN OF 15 INCHES AND WATER/CEMENT RATIO OF 1:2:4 (BY VOLUME) PLAIN CONCRETE.

| No. | Water/cement ratio (by weight) | Dry flexural strength in lbs. per sq. inch at | | Wet flexural strength in lbs. per sq. inch at 28 days | Wet F.S. / Dry F.S. |
|---|---|---|---|---|---|
| | | 7 days | 28 days | | |
| 1. | 0.50 | 93.9±7.8 | 108.5±3.9 | 67.3±15.9 | 0.62 |
| 2. | 0.55 | 93.9±19.9 | 158.4±11.7 | 117.3±15.6 | 0.74 |
| 3. | 0.60 | 211.2±30.2 | 253.9±35.8 | 222.9±15.6 | 0.87 |
| 4. | 0.70 | 304.50±24.0 | 359.9±21.9 | 321.2±39.6 | 0.89 |
| 5. | 0.80 | 228.8±35.2 | 340.3±31.3 | 246.4±23.5 | 0.72 |

TABLE 2.—MODULUS OF RUPTURE OF 4 INCH. SQ. BEAMS CENTRALLY LOADED ON 9 AND 12 INCHES SPANS OF 1:2:4 (BY VOLUME) PLAIN CONCRETE.

| No. | Water/cement ratio (by weight) | Dry flexural strength on a span of 9 inches in lbs. per sq. inch at | | Dry flexural strength on a span of 12 inches in lbs. per sq. inch at | |
|---|---|---|---|---|---|
| | | 7 days | 28 days | 7 days | 28 days |
| 1. | 0.60 | 306.0±7.1 | 320.1±406 | 276.0±15.6 | 299.9±15.6 |
| 2. | 0.70 | 316.6±7.6 | 347.0±15.4 | 328.3±50.0 | 365.6±37.5 |

TABLE 3.—MODULUS OF RUPTURE OF 4 INCH SQ. BEAMS CENTRALLY LOADED ON A SPAN OF 15 INCHES OF 1:2:4 (BY VOLUME) PLAIN CONCRETE AT DIFFERENT PERIODS.

| Samples | Flexural strength in lbs. per sq. inch at | | | |
|---|---|---|---|---|
| | 28 hours | 7days | 14 days | 28 days |
| Dry | 258.1±15.6 | 304.5±24.0 | 343.2± 5.9 | 359.9±21.9 |
| Wet | 193.6±11.7 | 228.8±23.5 | 299.6±17.6 | 321.2±39.6 |

TABLE 4.—EFFECT OF WATER/CEMENT RATIO ON CRUSHING AND FLEXURAL STRENGTH IN DIFFERENT MIXES OF CEMENT CONCRETE.

| No. | Nominal mix of the cement concrete (by volume) | Water/cement ratio (by weight) | Dry crushing strength in lbs. per sq. inch at | | Dry fllexural strength in lbs. per sq. inch at | | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 7 days | 28 days | 7 days | 28 days | |
| 1 | 1:2:4 | 0.500 | 437±31 | 700±62 | 93.9 | 108.5 | |
| 2. | 1:2:4 | 0.550 | 480±31 | 1073±62 | 93.9 | 158.4 | |
| 3. | 1:2:4 | 0.600 | 980±47 | 1400±93 | 211.2 | 253.9 | |
| 4. | 1:2:4 | 0.700 | 1225±163 | 2125±32 | 304.5 | 359.9 | |
| 5. | 1:1.9:3.8 | 0.476 | 490±47 | 723±31 | 100.0 | 125.0 | The cement was increased by 5 per cent of the cement used in the above mix of 1:2:4 without changing the quantities of aggregate and water. |
| 6. | 1:1.9:3.8 | 0.524 | 537±32 | 1293±62 | 105.4 | 175.5 | |
| 7. | 1:1.9:3.8 | 0.574 | 1050±47 | 1400±47 | 221.0 | 316.0 | |
| 8. | 1:1.9:3.8 | 0.670 | 1983±31 | 2427±62 | 386.7 | 457.0 | |
| 9. | 1:1.82:3.64 | 0.455 | 600±47 | 817±31 | 123.0 | 140.61 | The cement was increased by 10 per cent of the cement used in the above mix of 1:2:4 without changing the quantities of aggregate and water. |
| 10. | 1:1.82:3.64 | 0.500 | 670±78 | 1330±47 | 175.5 | 210.8 | |
| 11. | 1:1.82:3.64 | 0.545 | 1377±29 | 1700±31 | 351.0 | 421.0 | |
| 12. | 1:1.82:3.64 | 0.636 | 2170±47 | 2613±124 | 439.4 | 527.3 | |
| 13. | 1:1.74:3.48 | 0.435 | 630±47 | 933±92 | 175.5 | 210.0 | The cement was increased by 15 per cent of the cement used in the above mix of 1:2:4 without changing the quantities of aggregate and water. |
| 14. | 1:1.74:3.48 | 0.478 | 732±31 | 1473±31 | 200.0 | 246.0 | |
| 15. | 1:1.74:3.48 | 0.520 | 1493±78 | 1750±93 | 351.0 | 439.0 | |
| 16. | 1:1.74:3.48 | 0.610 | 2310±47 | 2697±24 | 527.3 | 597.61 | |

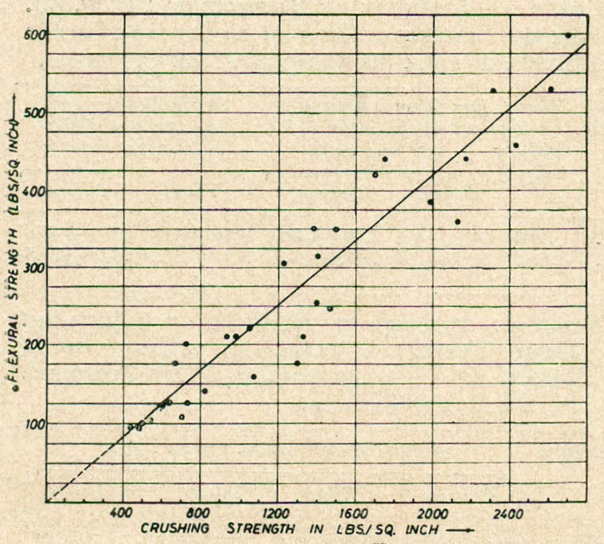


Fig. 2.—Relation between compressive and flexural strength of plain cement concrete.

0.7 and it was nearly the same as obtained when beams were tested on 15″ span. This indicates that the span-depth ratios from 2.25 to 2.75 of the beams centrally loaded did not change the maximum flexural strength of (1:2:4) usual concrete mix. The wet and dry strength of this mix at different periods from 28 hours to 28 days are given in Table 3. The high flexural strength of the cement concrete specially at 28 hours may be due to the calcareous aggregate. It is reported[4] that the limestone has a better bond with portland cement and the bond strength between this aggregate and cement is higher than the tensile strength of the limestone itself.

## Relation between Crushing and Flexural Strengths

The crushing strength was obtained on 4″ cubes and 4″ × 4″ × 18″ beams were loaded at centre on a span of 15″ for flexural strength. Both the strengths were obtained at 7 and 28 days of (1:2:4) cement concrete and recorded in Table 4 for water-cement ratios 0.50, 0.55, 0.60 and 0.70. The compaction and curing was done in a similar manner as mentioned before. The cement was increased by 5, 10 and 15% of the cement used in the previous mix of 1:2:4 without changing the quantities of aggregate and water. The additional cement increased both the strengths as it decreased water-cement ratio without affecting the workability of the mix. Fig. 2 shows the relation of the two strengths at 7 and 28 days for all the mixes mentioned above.

## Conclusion

The previous results indicate that both the strengths are affected by water-cement ratio, age of concrete and the proportion of aggregate in a mix. The relation between the two strengths is uniform and the flexural strengths work out at about 21% of the compressive strength.

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