

Concrete in Practice

What, why & how?



CIP 16 - Flexural Strength of Concrete

WHAT is Flexural Strength

Flexural strength is an indirect measure of the tensile strength of concrete. It is a measure of the maximum stress on the tension face of an unreinforced concrete beam or slab at the point of failure in bending. It is measured by loading 6 x 6-inch (150 x 150-mm) concrete beams with a span length at least three times the depth. Smaller beam specimens of cross-section 4 x 4-inch (100 x 100-mm) are also recognized as a standard size. The flexural strength is expressed as *Modulus of Rupture* (MR) in psi (MPa) and is determined by standard test methods ASTM C78 (third-point loading) or ASTM C293 (center-point loading). The specimen size and type of loading does impact the measured flexural strength and comparisons or requirements should be based on the same beam size and loading configuration. The MR measured by third-point loading (ASTM C78) is lower than that determined by center-point loading (ASTM C293), sometimes by as much as 15 percent. It is also observed that a lower flexural strength will be measured with larger beam specimens.

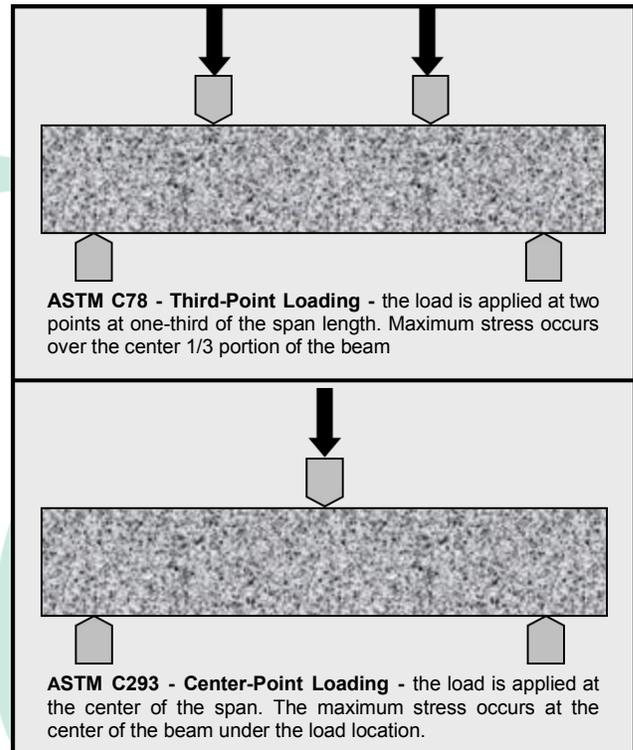
Flexural strength is about 10 to 15 percent of compressive strength depending on the mixture proportions and type, size and volume of coarse aggregate used. For design of building members an estimate of the MR is obtained by:

$$f_r = 7.5\sqrt{f'_c}, \text{ where}$$

f_r is the MR; f'_c is the specified compressive strength. When MR is critical to design, the best estimate is established from laboratory tests for specific mixtures and materials used.

WHY Measure Flexural Strength

Design of the thickness of concrete pavements are based on the flexural strength or MR. Factors include traffic loading and subgrade stiffness. Pavement designers often require validation that the proposed mixture will achieve the MR used in design. Concrete mixtures should be proportioned to achieve the MR as specified in contract documents. When acceptance in the field will be based on flexural strength tests, the concrete mixture should be



ASTM C78 - Third-Point Loading - the load is applied at two points at one-third of the span length. Maximum stress occurs over the center 1/3 portion of the beam

ASTM C293 - Center-Point Loading - the load is applied at the center of the span. The maximum stress occurs at the center of the beam under the load location.

appropriately designed to achieve a higher strength level that will reduce the risk of failing test results. Agencies that do not use MR for field control generally use compressive strength as it is more convenient and reliable to judge the quality of concrete as delivered. A pre-established relationship between compressive and flexural strength may be developed for this purpose. Flexural strength testing is not used for structural concrete.

HOW is Flexural Strength Used

Flexural strength is conservatively neglected in calculating the nominal flexural strength for design of structural members. The flexural strength, estimated from the empirical relationship, is used estimate the tensile stress that causes cracking of non-reinforced concrete and to evaluate deflections at service loads.

Most state highway agencies use compressive strength and not flexural strength tests for acceptance testing of road pavements. Flexural

WHAT are Problems with Flexural Tests

strength tests are useful in research and laboratory evaluation of mixtures, but the sensitivity to testing variations does not lend itself to be used as a basis for acceptance or rejection of concrete in the field. Flexural strength tests for jobsite acceptance is commonly used for airfield pavements.

Beam specimens must be prepared in accordance with ASTM C192 in the laboratory and ASTM C31 in the field. Consolidate by rodding or vibration, tap sides to release air pockets, and spade along the sides. Follow the temperature and moisture retention requirements for standard curing. *Never allow the beam surfaces to dry at any time.* Immerse in saturated limewater for at least 20 hours before testing.

Specifications and investigation of apparent low strengths should take into account the higher variability of flexural strength testing. Standard deviation for concrete flexural strength tests from subsequent loads for projects with good control range from about 40 to 80 psi (0.3 to 0.6 MPa). Standard deviation values exceeding 100 psi (0.7 MPa) may indicate problems with testing.

Where a correlation between flexural and compressive strength has been established, compressive strength of cores determined in accordance with ASTM C42 can be used. Reduced strength measured on cores should be taken into account. Sawing beams for flexural strength tests will show a greatly reduced measured flexural strength and should not be done. Splitting tensile strength of cores by ASTM C496 is sometimes used, but experience is limited.

Another procedure for in-place strength investigation uses compressive strength of cores calibrated by comparison with acceptable placements in proximity to the concrete in question:

Method to Estimate Flexural Strength Using Compressive Strength of Acceptable Lots

	Lot 1	Lot 2	Lot 3
MR, psi	730 (OK)	688 (?)	731 (OK)
Core, psi	4492	4681	4370

Estimated Flexural Strength of Lot 2 =

$$4681 \times \frac{(730 + 731)}{(4492 + 4370)} = 771 \text{ psi (OK)}$$

Flexural tests are extremely sensitive to specimen preparation, handling, and curing procedures. Beam specimens are heavy and can be damaged during handling and transportation. Beams must be cured in a standard manner and tested while wet. *A short period of drying can produce a sharp drop in flexural strength.* Meeting all these requirements on a jobsite is extremely difficult and often result in unreliable and generally low MR test results.

NRMCA, the Portland Cement Association (PCA), and the American Concrete Pavement Association (ACPA) support the use of compressive strength testing as the preferred method of concrete acceptance. ACI Committees 325 and 330 on concrete pavement construction and design also point to the use of compressive strength tests as more convenient and reliable.

The concrete industry and inspection and testing agencies are much more familiar with traditional cylinder compressive strength tests for control and acceptance of concrete. Flexural strength can be used for design, but the compressive strength established by a correlation with laboratory trial batches or empirical relationships should be for quality assurance and acceptance of concrete.

References

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