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High-Strength Concrete Cores

By

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by Tarun R. Naik*

A number of factors are discussed to explain different effects they have on core strength. These factors should be considered when evaluating cores tested to determine "true" in-situ compressive strength. Whenever there is a strength problem at a construction site, cores are generally obtained to determine the in-situ compressive strength. However, the cores may not always give you the "true" picture, because there are factors, which indeed do affect the core strength test results.

If a nondestructive test method is used, then it is generally accepted that it may not give us a perfectly accurate answer. Then the cores do not give us a perfectly accurate answer either. Therefore, as long as we can substitute an equally "accurate" test method, such as the maturity, the pullout, or the pulse velocity, etc. vs. the core test then we are not sacrificing core testing for NDT methods for expediency and cost efficiency. However, it is important to recognize various factors that affect the core strength results. These factors must be considered in evaluating core test results. The information published in the ACI-214, and other publications, gives us a summary of compressive strength test variables for concrete cylinders.

There is a variety of factors which can influence the strength, ranging from the materials for concrete making, e.g., cement, type and composition, manufacturing control, etc. to testing machines, centering of test specimen, speed of loading, etc. There are varieties of such factors, which influence the cylinder compressive strength, which also influence the core compressive strength. Therefore, unless the core testing is done correctly, carefully, accurately, and according to ASTM standards, additional variables would have been introduced. For example, when a core is drilled from a concrete element that core will have aggregates cutoff on its surface. This is not the same as a cylinder (for cylinder there is a layer of mortar surrounding the aggregate). As the core is loaded in compression, and, therefore, as the core diameter increases, the aggregates cutoff on the surface tends to pop-out. So what happens when the core diameter suddenly decreases due to an aggregate which has popped out? Certainly, the core is going to have stress concentration and, therefore, the apparent strength would be actually lower than the real strength of the core. In other words, the indicated strength value will lower. Another

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factor influencing core test results is how the core is obtained. When drilling the core, if the drill bit is not very sharp, or if the machine is not rigidly fastened, then wobbling of the drill bit occurs. This wobbling tends to create markings on the core, sort of corrugations, and this leads to additional stress concentration and, therefore, a lower apparent strength than the actual strength.

Test specimen dimensional effect, usually discussed in reference to cylinders, is also a consideration in evaluating cores. If the standard 6 x 12-in. cylinder strength is indicated as 100, and from the same concrete a 2 x 4-in. cylinder is cast and tested, then the indicated strength value would be 109 for the 2 x 4 cylinder, (9% greater value); or if the cylinder is 24 x 48, then the value would be smaller (66%) for the same concrete. For the above cylinders, 1/d is 2 but each cylinder has a different diameter. or to look at the dimensional effect in a slightly different manner, with 1/d ratio of 2, which is typical, the strength factor is I (i.e., the strength correction compared to so called "actual" standard strength). On the other hand, if the 1/d ratio is I (i.e., the length is equal to the diameter), then the indicated strength would have to be corrected by applying a factor of 0.85, the apparent strength would be about 15% higher than the "actual" strength. Furthermore, for the same 1/d ratio, but for different strength levels of concrete I/d ratio corrections would be different for different strengths. If the 1/d ratio is even greater than 2, then a lower relative strength is obtained. But this problem does not arise in the concrete testing because if the 1/d ratio is greater than 2, then the extra length of the core can be cut-off to obtain a core with 1/d of two. But if the I/d ratio is less than 2, then a higher apparent strength would be obtained, and, therefore, the apparent strength should be corrected (decreased) to get the strength equal to that at which the 1/d ratio equals two.

Testing of dry concrete cores at the University of Wisconsin - Milwaukee (UWM) serves to illustrate the influence of the I/d ratio as it varies from 0.5 to 2 (2 being the standard). Comparing a 2-in. diameter core for 1/d ratio equal to 2, the strength was 6500 psi. When the I/d ratio was 1, the 2-in. core had a strength of about 7500 psi. Similarly, for a 4-in. diameter core, the strength was slightly more than the 2-in. diameter core, about 6600 psi, and for the I/d of 1, it was about 8600 psi. Thus, there is an increase in strength that is dependent upon the diameter for the same I/d ratio. For a 3-in. diameter core, there was a significant difference. For a 3-in. diameter core with an I/d equal to 2, the strength is about 6700 psi; and when I/d is 1, the strength is about 7600 psi. It is apparent from this data that for different diameter cores as the 1/d ratio changes, standard (two) to less than 2, the corrections required are also different. ASTM C-42 does not make this recognition (or distinction).

In the ASTM C-42, one set of correction values is given for cores tested, whether they be dry or wet. The cores data obtained at UWM were for cores tested dry and a different correction value was obtained vs. wet tested cores.

The correction factors for lightweight concrete are different than those for normal weight concrete. It is not suggested that ASTM should account for all such differences but the fact is that the differences do exist and the standard ASTM procedures do not account for these factors. The 1/d ratio for normal weight concrete and lightweight concrete has different sets of correction factors.

Wall concrete cores are taken perpendicular to the direction of the casting and slab cores are taken in the direction of the casting. This also makes a difference. Concrete is not as homogeneous as it is assumed. Concrete at the top of a column versus the bottom of the column is also different. At the bottom of the column, the concrete is stronger than that at the top of the column. Among other reasons, because the bottom of the column concrete is going to consolidate more because it would support more weight, when the concrete is still wet. So the bottom concrete strength is greater than the top concrete strength. Top concrete also tends to have a higher w/c ratio. This point is also illustrated in Figure 1 (from controlled lab experiments).

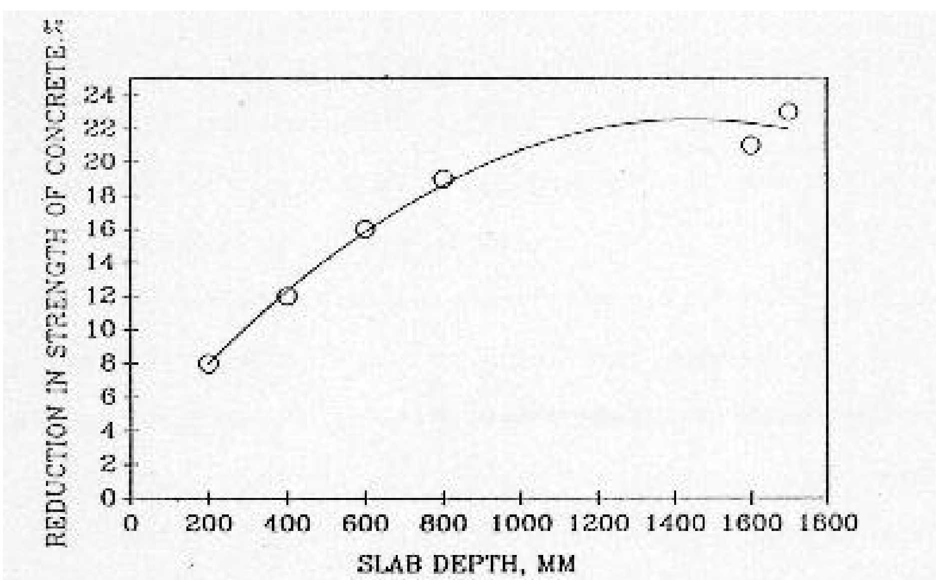

Figure1: Effect of depth of slab on strength reduction in concrete between the top and bottom of the slab

One of the other ASTM C-42 requirements says that once the core is obtained, and if the concrete that is being investigated is going to be remaining in a dry environment, then the core should be dried out for seven days before testing. But if the testing agency waits for seven days, then the core will most probably gain strength. So it is preferable not to want to wait for seven days. Normally cores are obtained with a water-cooled drill bit and that is why it may be necessary to dry the core if the concrete is going to be dry during the use (because dry concrete will give greater strength, 10-20% greater than the same concrete tested wet). But if the concrete is dried by waiting for seven days, and the cores are already 45 days old, then in the seven days the strength is increasing, because the concrete from the outside where the building might be in a colder environment while the cores brought inside for seven days (inside the lab) would be in 73OF ± ambient environment. This would not give the correct picture of the strength of the concrete on the day the core were taken, because not only will the cores be older but during the seven days they will be subject to much "better" curing temperatures than the outside concrete. Generally, the objective is that once a core is taken and brought to the lab, it should be tested as soon as possible. A study was undertaken, therefore, at UWM to find out that once the core becomes wet from drilling then how much water it could lose in drying operations, and how fast. Therefore, a batch of freshly drilled cores was obtained and was weighed to find their initial wet weight. Then after lab (air) drying, the percentage difference in the weight was recorded. At 1, 2 or 3 days there was a significant weight loss (differences). But from 3 days to 5 days of drying, the percentage difference in the moisture loss was about a quarter percent. There was about 2/10 of a 1% greater loss between the 3 and 5 days, going from 0.6% for the 3-day to 0.8% for 5-day drying. At about 3 days, therefore, pretty much most of the moisture, loss had taken place and the cores were pretty much dry by then. Therefore, 7-day waiting is not necessary and such cores can be tested at the 3-day age.
A similar conclusion was reached from observing moisture loss from many additional cores.

For a standard 1/d ratio of 2, and for a 6-inch diameter core, we have a 6 x 12 core. Compare this core strength to a standard (6 x 12) cylinder strength made from the same concrete. Would we get the same strength? We should, but we don't. That is the point that is being illustrated in showing standard size cylinder strength versus the standard size core strength, Figure 2. As the cylinder strength goes up, the equivalent core strength goes down. When the cylinder strength is about 3,000 psi, the equivalent core strength is about 95%. But when the concrete strength goes up, as for example 7000 psi concrete, the equivalent core strength is only about 15%. Therefore, there is a difference between cylinder strength and core strength, and that difference becomes greater as the concrete strength goes up. That is why, probably, the ACI 318 Building Code says that

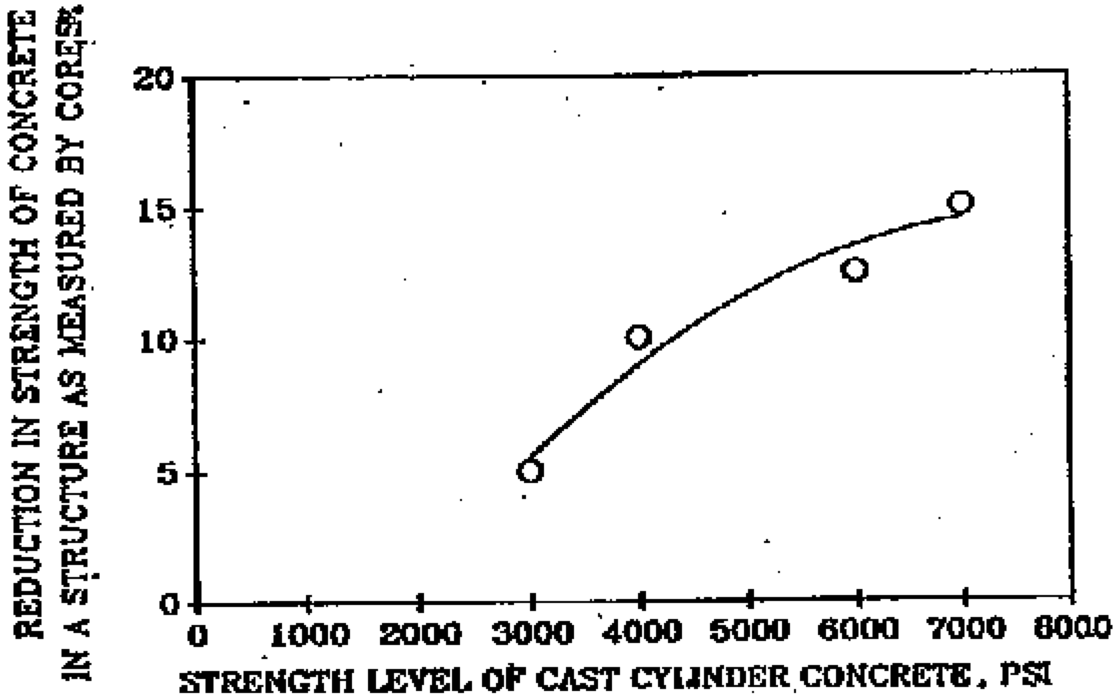

Figure 2: Effect of strength level of cylinder concrete on the strength of cores.

85% of the core strength is sufficient. Among other reasons, all these factors, which are not explicitly accounted for, could potentially reduce the strength also. From the core test, we do not get equivalent cylinder strength exactly at all strength levels. For example, for 3000 psi concrete we have about 95% for the core strength. For a higher strength concrete, such as 15000 psi concrete, the code should require the core to test even lower. It is apparent from this illustration that as the strength of the standard cylinder goes up, the equivalent core strength value goes down. When the cylinder strength was 3000 psi, the core strength was about 95%; versus when the cylinder strength was 6000 psi, the equivalent core strength was about 87% of that. The conclusion is that when a core is tested the indicated strength is always lower than the equivalent cylinder strength. In addition, more importantly, as the strength level goes up, the reduction goes up. Actually, core strength is allowed to be 15% lower than the cylinder strength not only in the U.S. code but also in Canada, Germany, and India. Finland allows 10% to 15% lower core strength depending upon the type of the structure, and Norway allows 30% lower core strength than equivalent cylinder strength. Some people have argued that the cores should consistently give you higher strength results. Exactly the opposite of what is indicated in Figure 2. It is said that core tests result in higher values than cylinders, but they are comparing the equivalent cylinder test value at 28 days and the core test value at 2 or 3 years. Another point according to ACI 318 is that while the core strength may be lower than the cylinder, it should be okay, as long as the cores are 85% of the specified strength. Therefore, cylinders tested at 28 days should come out higher than the core strength at 28 days age. For core strength evaluation, let us assume the concrete is 56 days old when it was tested and it did meet the 85% requirement. If the concrete element is not yet subjected to full load, depending upon the structural element, then taking into consideration the safety margins, this concrete may be acceptable.