

Assessing the in situ strength of concrete, using new twist-off method

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Abstract: This paper introduces an innovative partially destructive method, called "Twist-off", for the assessment of in situ concrete strength. In this method a 40mm diameter metal probe is bonded to a concrete surface by means of a high strength epoxy resin adhesive. To measure the concrete compressive strength, a torque is applied using an ordinary torque-meter and the maximum shear stress at failure is used to estimate the cube compressive strength by means of a calibration graph. The relationship between the results of this new method and compressive strengths of concrete cores is also presented in this paper. The average coefficient of variation of the results of this method was seen to be of the order of 8 percent and the correlation coefficients of its comparative results with concrete cube and core compressive strengths were found to be 0.97 and 0.90 respectively. In order to assess the performance of this method on site, tests were undertaken on a number of buildings. Although the method was found to perform well but with some of the structures tested, the differences between the strengths of sample cubes and estimated in situ compressive strength of concrete were seen to be significant.

Keywords: Concrete strength; In situ testing; Twist-off method

Introduction

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the test. The destructive methods, which provide the most reliable strength estimates, involve removal of parts of the concrete, by coring or sawing, and testing these in a laboratory in a standard manner. The chief disadvantages include: considerable damage to the structure, safety problems (especially when pre-tensioned tendons are involved), limited number of non-repeatable tests that can be performed on a member without seriously reducing its

strength, and the high cost of performing the tests (including work stoppage, preparation, etc.). It is due to these disadvantages that destructive tests are generally only used in a fault diagnosis situation when other methods of assessing in situ strength are unsuitable or do not yield conclusive results.

The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination. Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually

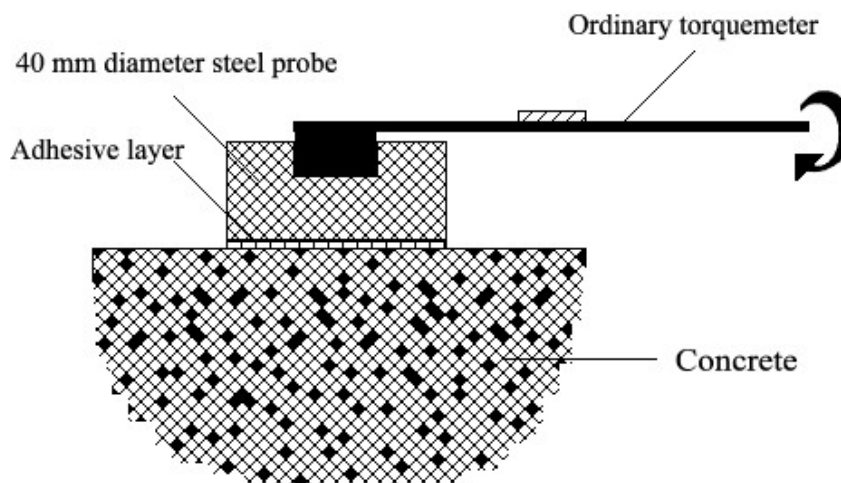


Fig. 1. Twist-off method

related to an assessment of structural integrity or adequacy. Non-destructive methods involve the measurement of some property of the concrete, which can be obtained without the need for destructive forces, and can be used to estimate the concrete's strength by the use of suitable calibration relationships. These methods can normally be performed quickly and inexpensively [1,2,3,4,5,6,7,8,9]. Although large numbers of results can be obtained from single members, it is often difficult to estimate the compressive strength of the concrete accurately, due to the highly indirect nature of the tests and the non-unique relationships between the properties measured and compressive strength. The advantages and disadvantages of non-destructive methods are widely known [10].

Partially destructive tests involve destructive forces, the damage only takes place on a small scale so that repair work, if required, is superficial and the member under test is not significantly weakened. All of the methods employ calibration relationships to estimate

compressive strength but, as some strength parameter is usually measured, they are regarded as being more reliable than nondestructive alternatives [12,13,14]. As they are generally less expensive than destructive tests they tend to provide a better balance of advantages and disadvantages than any of the traditional in situ methods. The Twist-off test, which is the subject of this paper, is one such partially destructive method, which can be undertaken in the laboratory and on site. As is shown in Fig. 1, the method involves bonding a 40 mm diameter metal probe to the surface of concrete under test and an ordinary torque meter is then situated on the preformed groove on the probe and a gradually increasing torque is applied by hand. Using the shear stress–torque relationship, the failure torsional shear stress is calculated. This can be used to estimate the concrete's equivalent cube compressive strength by means of a previously prepared calibration graph.

It is worth mentioning that, there are two

other methods in which torque is used to produce destructive stresses for failure. One is called "The Internal Fracture Test", developed at the Building Research Establishment for the purpose of testing HAC concrete, but it has since been used to test ordinary portland cement concrete [15]. The testing procedure involves fitting a 6mm wedge anchor bolt, to an accurately measured depth, into a hole, previously drilled in the concrete. A portable apparatus is then used to apply a tensile force to the bolt causing it to open and grip the concrete. The load is applied manually by turning a unit with a torque wrench: the torque at failure being used to estimate the concrete's equivalent cube strength by means of a calibration graph.

The other test method called "The Friction Transfer Method", developed by the author for the purpose of testing in situ concrete strength [16]. The method involves the drilling of a 50 mm diameter partial core with 25 mm depth on the surface of concrete under test and fixing a specially designed gripping device on top of the partial core by fastening its bolts. An ordinary torque-meter is then situated on the gripping device and a gradually increasing torque is applied by hand. As the frictional resistance of the gripping device is higher than the torsional resistance of the partial core, the latter will eventually fail. Using the shear stress-torque relationship, the failure torsional shear stress is calculated. This can be used to estimate the concrete's equivalent cube compressive strength by means of a previously prepared calibration graph.

It is therefore seen that in this new method, no pre-drilling of the concrete is required and the test is carried out by the use of adhesively bonded probe which means less work, less damage to the concrete surface, less

expensive and more accuracy.

Theory of the Twist-off method

The theory behind the Twist-off method is that the twisting of the metal probe produces torsional shear stresses within the adhesive layer and the concrete. Since the strength of the very thin layer of the adhesive is very much higher than the concrete, the failure takes place within the concrete and the ultimate torque or torsional shear stress is calculated. However, as the quality of concrete is usually assessed in terms of its cube compressive strengths, it is necessary to introduce some form of calibration to estimate this parameter. Since the diameter of the probes are kept constant (40 mm), the failure torque can also be used to estimate the equivalent cube compressive strength, without the need for calculating the stresses involved.

Regarding the acceptability of core testing in concrete industry, extensive work on the use of both core and Twist-off methods yielded a very close linear relationship between core compressive and Twist-off torsional shear strengths (Fig. 2). Knowing that the relationship between the core and cube compressive strengths of concrete and therefore between that of the torsional shear and compressive strength of concrete is not unique, it has been found that for a particular type of concrete there is a close relationship between Twist-off torsional shear and cube compressive strength (Fig. 3).

In order to measure the in situ strength of other materials such as mortars; different repair systems (e.g. sand/cement; polymer-modified and epoxy mortars), different calibration graphs are used to relate the failure stress or torque, to the material

n | 43 (cases excluded:56 due to missing values)

r statistic | 0.90
90% CI | 0.84 to 0.94

2-tailed p | <0.0001 (t approximation)

Core compressive strength V. Twist-off stress

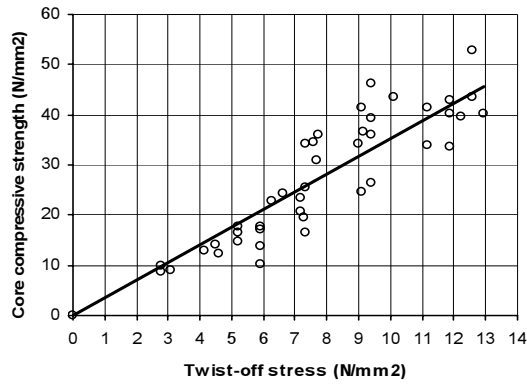


Fig. 2. Core compressive strength V Twist-off shear stress

n | 99

r statistic | 0.97
90% CI | 0.96 to 0.98

2-tailed p | <0.0001 (t approximation)

Cube compressive strength

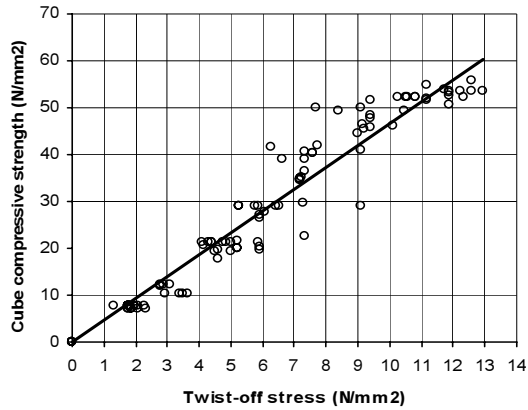


Fig. 3. Cube compressive strength V Twist-off shear stress

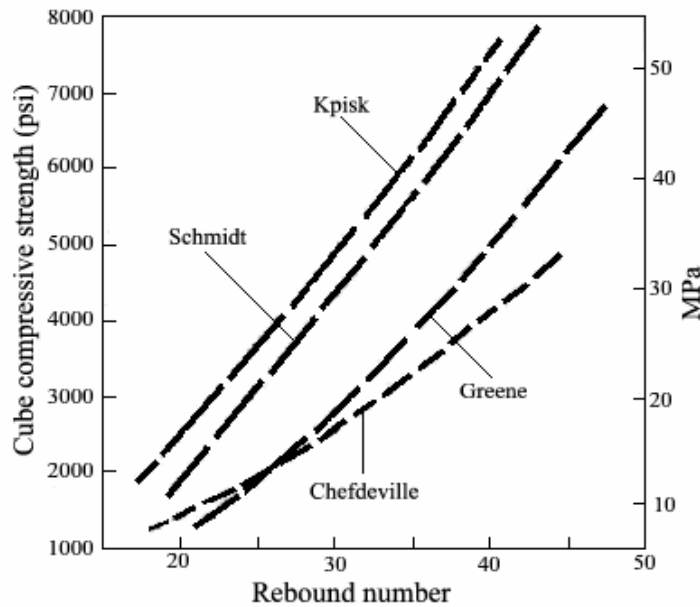


Fig. 4. Schmidt hammer correlation curves produced by different researchers (Ref. 18)

compressive strength.

Accuracy of the Twist-off method

In view of the wide range of in situ tests for concrete, which are currently available, a new method is only likely to gain widespread acceptance if it is accurate, versatile and easy to use. Twist-off, with no need for the advance planning, the only real question over its acceptability was that of accuracy. Several research projects undertaken at Imam Khomeini International University, since 2004, included investigations of the relationships between the Twist-off shear and cube compressive strengths of concrete. In each case, useful relationships were found between the two parameters and the site work also yielded encouraging results. Furthermore, some researches were conducted to examine the relationships between the results of Twist-off method and those of the core tests. In order to see the

actual applicability and the effectiveness of Twist-off method, site tests were undertaken on different structures. Considering the method of application of the required torque (by hand), effect of the direct shear force was also considered but due to the length of the lever arm, its effect was found to be negligible.

In order to see the effect of the rate of loading on the accuracy of the new method, different operators were employed during the testing of samples with different strengths. Having examined the coefficient of variations obtained in this way, it was found that different rate loading exercised by different operators had no significant effect on the accuracy of the method.

Since the probes used in the Twist-off method are adhered to the concrete surface by the use of epoxy adhesives, effects of different epoxies on the accuracy of the results were examined by choosing different

formulas and different thicknesses. The results of these series of studies indicated that provided that the excess of the epoxy is squeezed out of the interfacial space within the probe and concrete, and as long as the failure takes place within the concrete, the accuracy of the results are unaffected by the type of the epoxies used. It should be noted that most of the epoxies are very sensitive to moisture. Therefore with Twist-off method, before the application of the torque, the necessary strength of the hardened epoxy has to be ascertained. Since the decrease in the W/C ratio increases the concrete strength, the adequate strength of the adhesive used, becomes very pronounced with high strength concretes.

Regarding the effect of surface texture on the accuracy of the results, since the surfaces tested during both laboratory and site investigations were all faces cast against the formwork, further studies were not carried for this purpose.

In order to see the accuracy if the Twist-off method, Fig. 4 shows different calibration curves obtained by research workers compared to the curve supplied with the hammer identified as "Schmidt". It is important to note that some of the curves deviate considerably from the curve supplied with the hammer.

Specimen preparation and test procedure

In order to study the relationships between the results of Twist-off, core testing and compressive strengths, 150 and 200 mm cubes were prepared. Twenty four hours after casting, all cubes were cured in water. Since the diameter of the cores was meant to be 100mm, three 200mm cubes were chosen to keep the height/diameter ratio of the cores to

2. From each batch of concrete, 3 No. 200mm and 5 No. 150mm cubes were cast. Three of these cubes were used for compression testing and 3 for core testing and two were used for Twist-off tests. One Twist-off tests on each side of the cube produced 4 results per cube. The design compressive strengths of the cubes ranged from about 7 to about 50 N/mm². These cubes were tested at the age of 28 days. In order to choose the best probe dimension, 300 x 300 x 100 mm concrete blocks were cast and at the age of 28 days they were used for assessing the most suitable probe diameter on account of ease of force application and the accuracy of the results. The structures chosen for in situ tests included different multistory buildings. In addition, in some instances, for comparison of the results, 100 mm cores were cut out of the concrete of these structures and tested in a standard manner.

Laboratory tests

The laboratory work involved over 500 Twist-off tests on the cubes cured under standard conditions and tested at the age of 28 days. The initial calibration graphs of Twist-off results plotted against cube compressive strengths (see Fig. 3) were produced using the average results from at least eight Twist-off tests and three cube compressive tests. The coefficients of correlation for the best-fit calibration graphs (restrained to pass through the origin) ranged from 0.903 to 0.969. Although other forms of calibration improved the correlation, but for the simplicity it was decided to use restrained straight lines for the remaining graphs. The relationship between cube and core compressive strengths with the coefficient of correlation of 0.93 is shown in Fig. 5. Working calibration graphs were then

n | 43 (cases excluded:56 due to missing values)

r statistic | 0.93
90% CI | 0.89 to 0.96
2-tailed p | <0.0001 (t approximation)

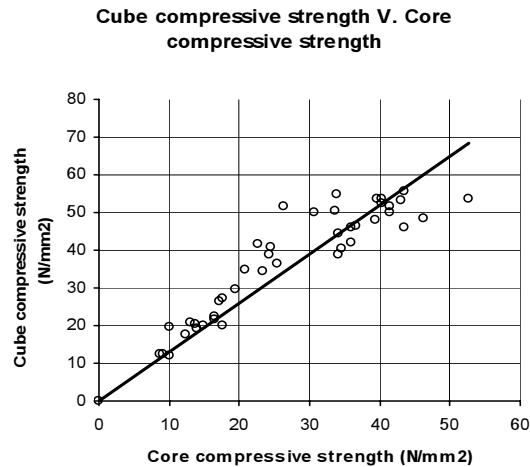


Fig. 5. Cube compressive strength V Core compressive strength

produced with each point representing a single Twist-off result and the appropriate cube compressive strength. The accuracy of the Twist-off method was found to be better than that of all other currently available partially destructive methods [11,17,18]. The reason for this could be the way that the load (torque) was applied and the nature of failure surfaces as well as the destructive stresses involved. For example in pull-off method, a small deficiency or failure around the perimeter of the probe area, would initiate a tearing failure and causes eccentricity to the direct pulling force, with consequent effect on the final result. The results from samples made out of the same batch of concrete and mortar were found to have a coefficient of variation of less than 8%, thus providing the consistency of the test method. Effect of

probe diameter on Twist-off results was examined by studying the coefficient of variation of results obtained for different probe diameters. These results showed that, 40 mm diameter probe not only produced lower coefficient of variations but since the torque is applied by hand, the associated failure torque is easily applied by a normal person.

On the basis of the laboratory tests and the associated analysis work, it was concluded that the Twist-off method offered an excellent means of estimating the equivalent cube compressive strength of concrete specimens. It was noted that testing could be performed easily using the explained simple apparatus and that accurate and reliable strength estimates could be calculated.

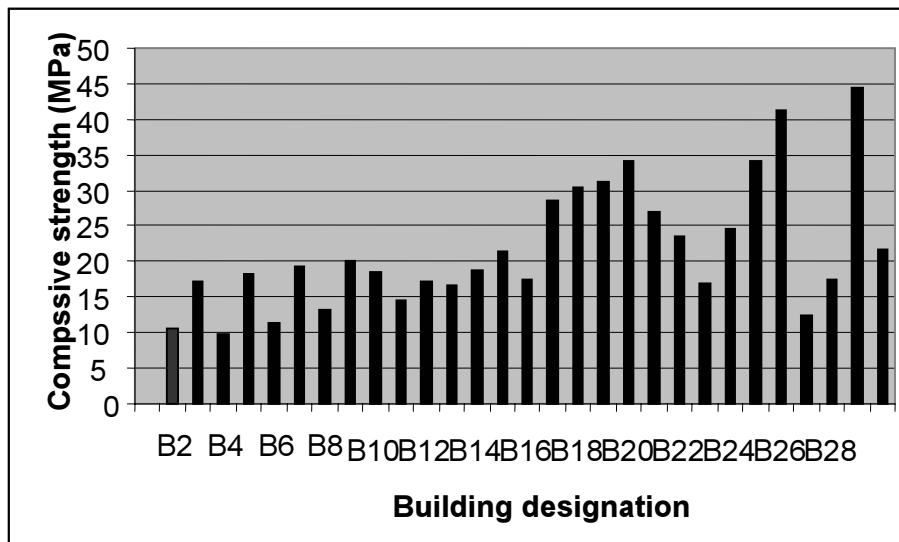


Fig. 6. In situ concrete strengths of 30 concrete structures measured by “Twist-off” method

In situ tests

As the mixing, transformation, placement, compaction and curing systems used in the preparation of the laboratory test samples, completely differ from those of the real concrete structure, it was decided to assess the efficiency of the Twist-off method on site, by comparing its results with the results obtained from current core and cube testing. For this purpose, ordinary cast in place concrete multistory buildings were considered. During these experiments the Twist-off method proved to be a very accurate, versatile and easy to use, in assessing the strengths of in situ concrete.

Since its development, hundreds of in situ tests have been carried out using this new Twist-off method on different concrete structures, the results of which not only proved the success of the method for in situ studies but also showed the real in situ strengths of concrete under different curing,

compaction, and location with different member sizes. In this respect, as an example, the results of Twist-off tests conducted on 30 reinforced concrete structures in Qazvin are depicted in Fig. 6. These series of tests enabled us to evaluate the effects of different parameters such as: ready mix supply; site mixing; inadequate curing and compaction; use of inappropriate machinery; and different pouring height, on the in situ strength of concrete. The ranges of the compressive strengths plotted in Fig. 6 shows the varying standards practiced and implemented within a city. Noting the average strength requirements, the percentage of unacceptable values appears to be very high.

Conclusions

On the basis of the extensive experience of the Twist-off method, which has been gained in laboratory and on site, the following

conclusions have been reached:

(i) The Twist-off test can provide accurate and reliable estimates of in situ concrete strength using very simple and cheap apparatus. The damage caused by this method is trivial and if required can be repaired by hand, using s/c mortar.

(ii) The accuracy attainable using Twist-off method is better than that of any other new partially destructive methods, and it is more versatile than most, requiring no advance planning.

(iii) The Twist-off method can be used successfully for the following:

- (a) Quality control of in situ concrete.
- (b) Evaluation of formwork stripping times.
- (c) Fault diagnosis on existing concrete structures.
- (d) Research work on in situ concrete strength.

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