INTRODUCTION OF FRICTION TRANSFER: AN INSITU TEST METHOD FOR ESTIMATION OF CONCRETE STRENGTH AND BOND STRENGTH

S.M. Zahrai[1], S. Mehrdad Hosseini[2], S. Mehran Hosseini[3], A. Akbarpour Nahani[2] and S.A. Dibaji[4]

[1] *Associate Professor, Dept. of Civil Engineering, Islamic Azad University, Central Branch, Tehran. Iran*
[2] *Master of Science, Precast/Prestressed Components (P.P.C.) Co., Tehran. Iran*
[3] *Bachelor of Science, Dept. of Civil Engineering, Iran University of Science and Technology, Tehran. Iran*
[4] *Master of Science, Dept. of Mechanical Engineering, Islamic Azad University, Central Branch, Tehran. Iran*

Email: hosseini_seyedmehrdad@yahoo.com

ABSTRACT :

Real concrete strength can be assessed using in situ test methods and is essential for rehabilitation of old and damaged structures and bridges to resist induced loads due to earthquakes, etc. Recently, a newly invented method is applied on concrete elements in structures and bridges to determine the in situ strength of hardened concrete. Friction Transfer test methods as an innovative test method is investigated in different situations and its inherent significant properties and ease of usage is going to be focused on in this paper. Estimation of concrete strength is generally accomplished by testing of cubic or cylindrical specimens that are usually cured under conditions different from the in situ curing conditions. Accurate estimation of concrete strength usually differs from the cubic or cylindrical specimen strength and this is due to several discrepancies: different heat transfer in concrete mass and in discrete specimens, different vibration quality and its effectiveness, humidity of laboratory and site condition and many more. Effectiveness of friction transfer method has been investigated in the past and used in different situations. This paper is going to clarify the detailed properties of this method and the achieved results and also its usage as two separate categories which include testing of concrete strength and testing of bond strength between repaired layers of concrete. In both usages, friction transfer test method showed a better correlation in comparison to other in situ test methods as well as its enhanced flexibility and ease of application.

KEYWORDS: In situ assessment, Friction-transfer test, Adhesion strength, Marshal Stability

1. INTRODUCTION

Assessment of concrete strength usually contains uncertainties due to different conditions; inhomogeneous properties of concrete lead to various discrepancies in its strength and quality. Cement, aggregate and water each should meet district requirements and minimums in order to form a specified concrete strength. Nevertheless, not all mentioned properties and requirements in conforming to their specified codes and standards, can guarantee a desired strength and durability of concrete to be achieved. Curing of concrete is a crucial matter which would be taken into account in order to a concrete with desired properties is resulted.

Standard method of concrete sampling usually includes cubic or cylindrical specimens which are prepared from fresh concrete in site. Compressive strength of concrete as a result of specimen loading at age of 28 days is reported, determining the standard strength of concrete. This method of strength measurement addresses an estimation of strength of concrete in site. In situ and cubic/cylindrical strengths of concrete are different and are due to different conditions in which each sampling and testing method of concrete is carried out. Curing condition, relative humidity and of course transportation methods and equipments used for concrete supply are the keys of discrepancies between in situ and standard cubic/cylindrical strength of concrete from a same batch.
There are three major types of in situ test methods; nondestructive, partially destructive and destructive test methods. Ultrasonic assessment and maturity test are instances of nondestructive test methods. Partially

destructive methods, such as pull-out test, pull-off test and break-off test. Destructive test methods usually involve with drilled cores which significantly affect the element bearing capacity. Partially destructive tests bring more interest than others which eliminate data processing stage as exist in nondestructive ones in addition to no significant affection on bearing capacity of the target element.

Friction transfer test method (Naderi, 2004) is a partially destructive method which is used recently in strength assessment of concrete and bituminous pavements. Strong correlation is observed between estimated and standard strength of concrete. This method is never used in site, instead is hired on cubic specimens. Lotfiani (2001) prepared different cubic specimens with various strength levels as his thesis test program. He concluded that this method gains enough accuracy to be used practical. He prepared additional cubic specimens in order to friction transfer test method get applied on. Curing condition was the same for all specimens. Hosseini (2005) and Akbarpour (2005) used this method on asphalt and concrete pavements and structures as a part of their M.Sc. thesis.

2. FRICTION TRASNFER TEST

Naderi (2004) reported application of an innovative apparatus to evaluate in situ concrete strength. This method is based on cracking torsional shear stress which would be related to concrete strength. After application of this method, negligible damage is resulted in the target member in site which can be repaired using high cement mortar easily and no significant defect would be arisen due to application of friction transfer test method. A partial core with a depth of 25 mm and diameter of 50 mm is drilled in concrete. An iron cast is designed in a manner that would sit on the core and clamped to it using the nuts and bolts. The cast consists of five discrete part which are assembled to form the whole cast.

A uniform increasing torque is applied to the cast until the concrete is cracked. Toque can be applied using a conventional torque meter. The cracking torque (or torsional shear stress) is recorded and can be related to strength of concrete under test. Strength of concrete can be estimated using pre-calculated correlation equation by a minimum level of accuracy which depends on the properties of hired correlation. Figure 1a shows a typical scheme of friction transfer test and Figure 1b shows it in use.

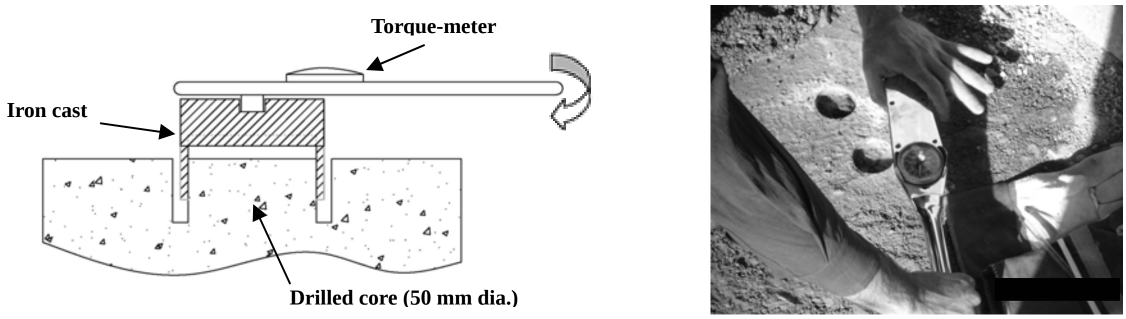

Figure 1 Friction-transfer test, a) Schematic view, b) Application of torque

2.1. Comparison to Other Test Methods

There are other methods which are based on a partial core. Pull-off test method is a partial destructive method which is more practical having strong correlation relative to other test methods. In this method, the drilled core is pulled off using a “steel handle” bonded to the top of the core using an adhesive material such as epoxy resins. Friction transfer method is superior than pull off test method regarding the limitations of epoxy resin usage in humid climate or wet conditions. Another preference would be the speed of result achievement in comparison to other methods such as pull off test or those tests based on transferring a wave inside the body of target element which final results are accessible after drying of adhesive material or processing the transmitted wave properties, respectively.

2.2. Effectiveness of Friction-Transfer Test

Relatively high correlation coefficients obtained from previous research projects indicates that friction transfer method can be used successfully to predict the concrete strength. Other material such as stone and asphalt are also assessed using friction transfer method, however the main objective during innovation of this method was based on concrete evaluation.

Another superiority of friction transfer method would be its multi-tasking abilities of this method. Not all the other in situ methods can measure various mechanical properties of materials. In addition to concrete strength, friction transfer method can be used to measure quality of the adhesion between different layers of cementitious materials. This method also can be extended to measure shear strength of a material or shear adhesion between different layers of materials. Latter is accomplished by the inherent property of friction transfer method in which the cracking shear stress of a material is measured. Figure 2a shows the internal stress induced to the section of concrete core due to friction transfer application.

2.3. Weakness of Friction-Transfer Test

On the other hand, the friction transfer test method is incorporated with inherent potential for uncertainty in some cases. Friction transfer test method referring to its nature inducing unpredicted internal forces to the whole body of the drilled core, provides a potential of weakness in correlation with real material strength. The most significant source of unpredicted forces certainly would be the radial pressure exerted to the core due to fastening of iron cast to the core. In order to exerting torsional torque to the section, it is necessary to be certain of enough friction between internal cast surface and the core body to avoid any slip during loading of the core (this is why the name of this method is “Friction Transfer”).

This is accomplished by fastening of nuts and bolts incorporated into the cast body which provide a radial pressure to the core body. There is no way to make sure if the cast is enough fastened to the core or not. The user of this method cannot predict that the level of fastening one is going to use is enough or even might crack the concrete core. There were many examples of slips due to insufficient friction between cast and the core and on the other hand examples of cracked and semi-cracked cores which all resulted in weak correlation or contradiction in correlation with real concrete strength. As shown in Figure 2b it is obvious that in case of pure torsional moment exerting to the section, the cracking shear stress would be different from case of radial pressure and torque combination.

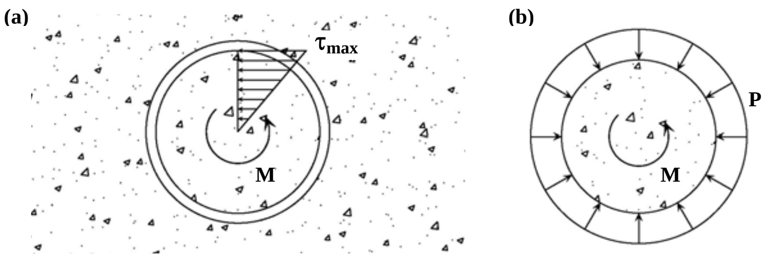

Figure 2 Drilled core section, a) Pure torsion condition and consequent shear stress (initial loading concept), b) Combination of torsion and radial pressure (real loading concept)

The virgin concept of Naderi for this method was based on pure torsional torque. In most of the cases, fastening the cast into the core causes micro cracks in the drilled core; subsequently lower strength will be predicted by this method. It is noticeable that extent and influence of micro cracks on the measured cracking shear stress can not be estimated in order to eliminate them, because the magnitude of fastening level is not considered in the relations Naderi proposed, in addition to the different magnitude of fastening level that one uses in each application of friction transfer test.

3. APPLICATION

As previously noted friction transfer test method can be effectively used to estimate bonding strength between two layers of different materials. On concrete structures there are cases that an element would be repaired or strengthened by addition of a new layer of concrete to previous element state. In such cases this method can be used to evaluate the adhesion between old and new concrete. Also in bridges, or concrete pavements, it is possible to apply this method for estimation of bonding effectiveness by measuring shear resistance between two layers. Naderi also has used this method to evaluate adhesion between two layers of stone but it seems that no effective correlation resulted. As discussed earlier, this problem can be addressed to the fact that there are unforeseen forces in the section which are more critical in the case of stones which express less elastic behavior. This method is also used to assess strength of stones expected to face the same problem.

This method also has been applied to asphalt pavements in which suitable correlations have been resulted. This method was just used to assess the Marshal Stability of the asphalt pavements. Hosseini (2005) prepared various shallow cylindrical specimen with various strengths, according to the Marshal test method published in ASTM, in a manner that each set of strength included six specimens; three of them were used to provide Marshal Stability of asphalt and friction transfer test method was applied to the remained specimens to provide corresponding cracking shear stresses (Figure 3a and 3b). No report of application of this method is still published to assess adhesion between to asphalt layers.

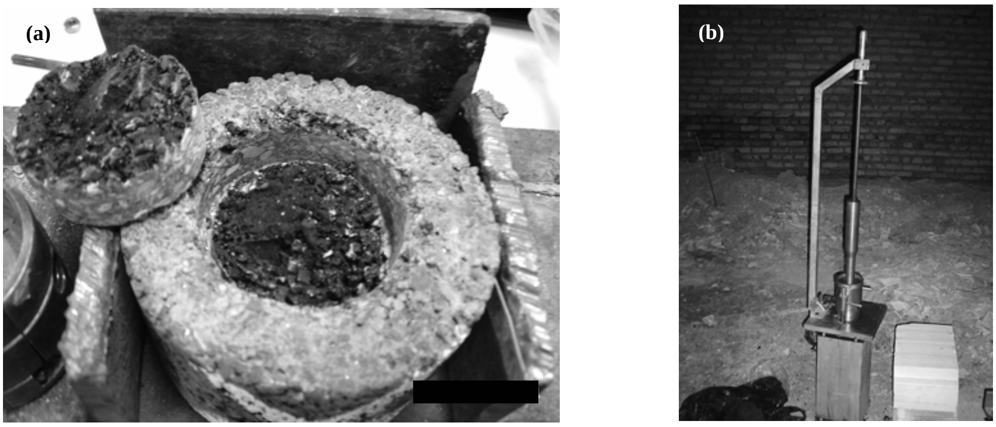

Figure 3 Drilled core section, a) Friction-Transfer test is applied on a Marshal Stability test specimen, b) Standard apparatus used to prepare Marshal Test specimens, (Hosseini, 2005)

Akbarpour (2005) in his Master's thesis, applied friction transfer test method to various elements in a concrete structure. A large project in eleven stories and more than 70,000 sq. meters area was selected as the target. Valuable results were achieved in this research which was the first application of this method in a real and practical aspect. Correlations were achieved for various elements of structure which was different from each other. It is noteworthy that elements included floor (slab), beam and column (Figure 4a and 4b).

In a contribution, Hosseini and Akbarpour invented two other test methods which are in progress to eliminate inferring forces in the drilled core which is expected to increase correlation coefficient to have a more accurate result in comparison to the result of friction transfer test. Processing the properties of mentioned test methods is out of scope of this study. (Figure 5)

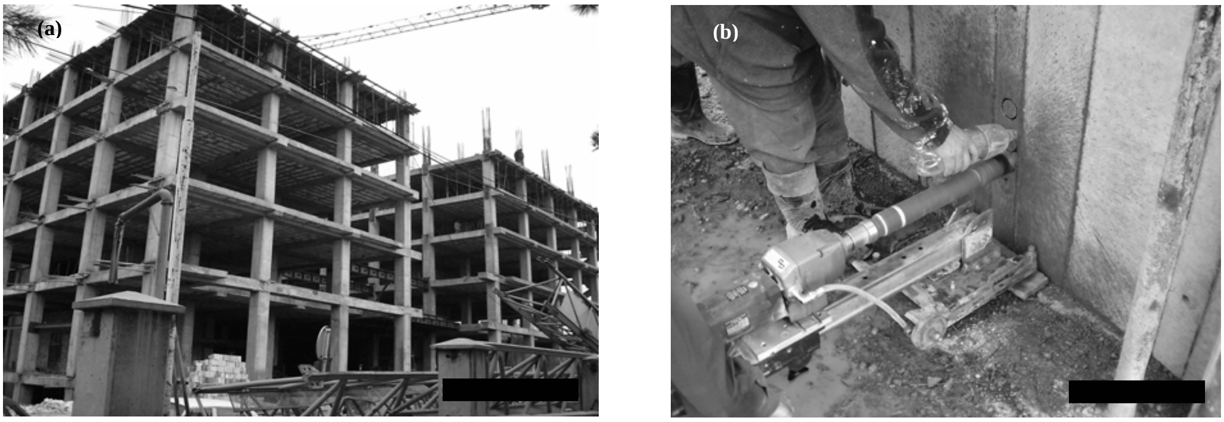

Figure 4 Target building for application of Friction transfer test [Akbarpour, 2005],
a) Overall view, b) Core is being drilled in concrete shear wall for application of Friction-Transfer test

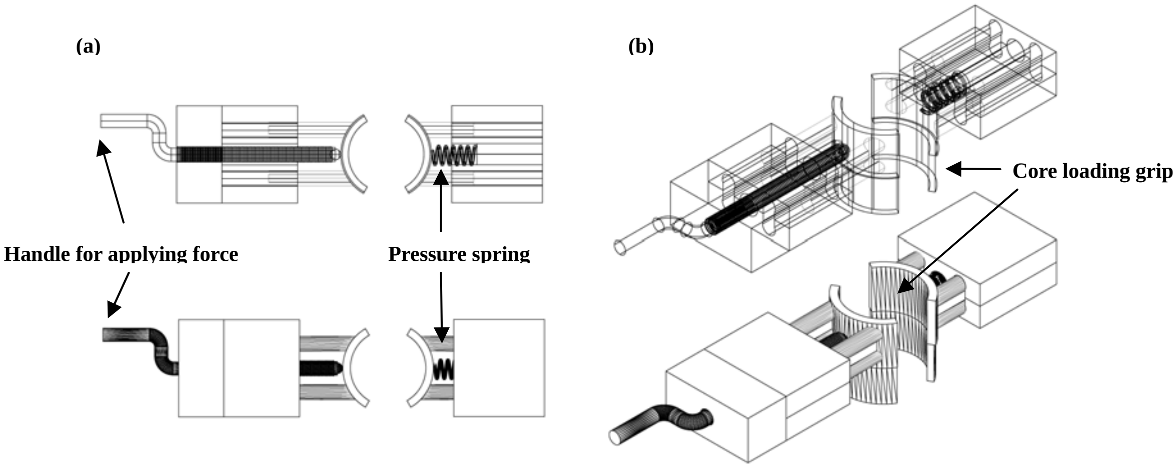

Figure 5 Internal Pressure Apparatus, designed by Hosseini (2007), a) Plan wire-frame and realistic model,
b) 3D wire-frame and realistic model

4. DISCUSSION ON RESULTS ACCURACY

Naderi (2006) reported use of friction transfer method to estimate the in situ shear strength of bituminous pavement layers. As previously noted a specially devised apparatus fits on the top of the partial core and is clamped to it. A torque is applied using an ordinary torque-meter, and the maximum shear stress at failure is calculated. He reported that comparative studies of laboratory Marshall Stability and friction transfer tests produced correlation coefficients of 0.72 and 0.82 for linear and polynomial best-fit curves respectively, and the respective linear correlation coefficient for the in situ tests was found to be 0.84. The measured values for Marshall and friction transfer tests ranged from 750 to 1100 kg and from 1.2 to 1.8 N/mm2 respectively. The average coefficients of variation of eight series of experiments were found to be 11.07% for Marshall Stability tests and 11.39% for the friction transfer method. As the final result he concluded that based on the laboratory experiments, and considering such factors as versatility, simplicity, speed, applicability under any site conditions by untrained operators, very low cost, easily interpreted and understood results, and good accuracy, this new method is strongly recommended for the assessment of the in situ shear strength of bituminous materials. This conclusion would be a bit exaggerated according to the mentioned problems in the basic concept of friction transfer method (the idea of interfering forces in the section, clarified in figure 2a and 2b). This problem would be more critical in application on the bituminous pavements which the rigidity and cracking shear stress can significantly be different for various temperatures and various rates of exerting the torque.

Hosseini (2005), in his thesis applied this method on bituminous pavements and his results were based on the fact that all the specimens were in an equal temperature during the test and rate of torque exerting tried to be the same for all specimens. Naderi, in aforementioned research, did not address these two pivot parameters (effect of temperature and loading rate) which causes that one has doubts in the accuracy of the results reported above as well as his final conclusion on "strongly recommendation" of friction transfer method to assess the in situ shear strength of bituminous materials. The case would be more obvious considering the fact that the apparatus Naderi proposed in his test method can be tightened to a smaller diameter of the standard core which is essential to be clamped on it. This matter in bituminous pavements which are less stiff and express more deformations in comparison to concrete, causes more critical micro cracks in the core section comparing to concrete cores and of course the shape of the asphalt core section alters from ideal circle, depending on the fastening magnitude and consequently the shear stresses in the section would be different from relations Naderi acquired using his basic assumptions based on a circular core section. By these facts, undoubtedly more uncertainties would arise in the test program Naderi (2006) established and results he reported for bituminous pavements.

In the case of concrete strength assessment, Naderi (2003) reached strong correlations for in situ evaluation of concrete. To achieve this fact, he prepared different empirical mixes with various water to cement ratio to attain different concrete strengths which can cover a wide range of compressive cubic strength. For each strength and corresponding cracking shear stress due to friction transfer method application, he prepared four specimens. Three of them used to measure cubic compressive strength and one used for three friction transfer test. The concrete mixes although not reported but obviously are different from those are used in conventional concrete projects which causes that the results would be used with cautions in real projects. In addition, he applied this method on the standard cubes as mentioned before, therefore the curing conditions were the same for standard compressive test and friction transfer test method. In real projects curing conditions are significantly different for elements in site and the specimens taken from them which the former one may be exposed to more sever climate conditions. Application of friction transfer method based on Naderi's correlations on the concrete elements of a real project, would conflict with the initial procedure used to achieve of correlations that is based on the same curing condition for both standard compressive and friction transfer test. Again, the aforementioned problem of interfering forces in the drilled core section still exists.

To wrap up, a set of clarifications would be programmed to be applied into friction transfer method. A series of general solution to mentioned problems is provided in the next section. Some of them involve with laboratory test and the remaining includes analysis of the section to model the real state of the section during loading.

5. CONCLUSION

Friction transfer test was processed in different aspects of concept maturity and ease of use and practicality. It had been observed it has shown good correlation with standard concrete strength. Based on aforementioned topics, this method should be used with care for real projects. The correlations for this method are based on the same curing conditions for both standard compressive and friction transfer test which this case is different in real projects.

In the case of bituminous pavements, available researches do not completely cover all the parameters affecting the shear strength of bituminous pavements. The most crucial parameters which would be considered in interpretations are temperature and rate of exerting torque in friction transfer test.

For both use, the friction transfer method suffers from its sightless initial concepts which does not completely addresses all the existing forces in the drilled section during test of friction transfer. The most pivot force would be the radial pressure acting on the perimeter of the core due to fastening of the iron cast (friction transfer device) on the section in order to application of the increasing torque. As a guide, to overcome the mentioned problems, following general solutions can be advised:

[1] Implementation of an electrical, pneumatic or hydraulic engine to ensure of a uniform rate of exerting the

torque and in parallel, recording the history of loading.

[2] Providing a computer model including the whole forces acting on the section, namely the uniformly increasing torque and radial pressure due to fastened device of friction transfer test. This study would completely address the nonlinear properties of the materials including post-cracked conditions of the section. A mesh-less analysis method can be used to this goal.

[3] Implementation of a gauge to estimate the existing radial pressure on the drilled core section.

[4] Considering the effect of humidity on the cracking shear stress which is not completely addressed in previous studies.

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