Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

8th International Conference on Civil and Architecture Engineering
ICCAE-8-2010

Correlation of Post-installed by Adhesive Pullout Test to Estimate In-place Concrete Strength

By

Cui, Shiqi[1, a] Minghai Lee[1, b] Shouxian Wang[1, c] Jinshan Wang[1, d]

Abstract:

Post-installed by adhesive-bonded anchorage pullout method is proposed in this paper to estimate the in-place compressive strength of concrete. In this method, the threaded metal probe is anchored into the concrete by means of a high strength epoxy resin adhesive. To get the best calibration graph, the linear regression models, nonlinear regression models, interpolation, or splines are employed. Experimental and analytical studies conducted on the base of concrete specimens with varying concrete mixes in the 15～80 N/mm^2 strength range. The experimental and analytical results shows that the newly proposed method is an efficient and accurate in estimating the in-place concrete compressive strength.

Keywords:

Post-installed by Adhesive, pullout test, in-place, concrete strength.

[1] Shandong Province Academy of Buildings, Jinan, Shandong province, China.

[a]jiegousuo@gmail.com, [b]sdjky@sina.com, [c]shouxianwang@163.com, [d]wangjinshan@gmail.com

Introduction

Nondestructive testing is essential in the inspection of alteration, repair and new construction in the building industry. Over the years, dozens of nondestructive techniques have been proposed for estimating the in-place strength of concrete, including rebound hammer, probe penetration, pullout, ultrasonic pulse velocity. Although surface hardness and pulse velocity tests cause little damage, are cheap and quick, and are ideal for comparative and uniformity assessments, their correlation for absolute strength prediction poses many problems. Core tests provide the most reliable in-situ strength assessment but also cause the most damage and are slow and expensive. The pullout test depends upon the ability to relate pull-out forces to concrete strengths and a particularly valuable feature is that this relationship is relatively unaffected by mix characteristics and curing history. Pullout tests fall into two basic categories; those which involve an insert which is cast into the concrete, and those which offer the greater flexibility of an insert fixed into a hole drilled into the hardened concrete. Cast-in method must be preplanned and will thus be of value only in testing for specification compliance, drilled hole method will be more appropriate for field surveys of mature concrete, however, this method have not been popularized widely because of its high requirement for the strength of the metal insert and for lack of facilities on the market. In view of such limitations, anchorage pullout method is employed to estimate concrete strength. The anchorage pullout test to the estimate the in-situ concrete compressive strength. In this method, a 25 mm threaded metal probe is anchored into the concrete by means of a high strength epoxy resin adhesive. When the glue has cured sufficiently, a hydraulic jack is used to apply a slowly increasing pullout force. Loading is continued manually until the concrete cone is pulled out. The peak load is recorded and is used to measure the concrete's equivalent cube strength by means of a calibration graph.

Several national and international standards recognize the various NDT methods as suitable. Basically, most test methods measure some others properties of concrete than its mechanical strength. However, the evaluation of insitu concrete strength is carried out by means of an established correlation of these properties with strength. Therefore, the reliability of assessing the concrete strength primarily depends upon the precision of the established calibration. In the non destructive tests used to determine the compressive strength of concrete, the relationship between the NDT measured result, mechanical or physical, and the strength is generally not unique. This arises from the diversity in the existing relations between the measured characteristic and the factors making up concrete strength. In the analysis of the test datas, linear regression models, nonlinear regression models, interpolation, or splines are employed.

Theory of the Failure of Anchorage Pullout Method

There is an assumption that concrete obeys the modified Mohr-Coulomb failure theory and that the extracted cone has the shape of the idealized conic frustum. The analysis assumed "rigid-plastic" behavior and that the normal and shearing stresses were distributed uniformly on the failure surface. It was concluded that, if the friction angle of the concrete equals one-half of the apex angle and if the tensile strength is a constant fraction of the compressive strength, there is a proportional relationship between the ultimate pullout load and compressive strength. The analysis has been criticized as not providing a true behavioral prediction because the conclusions are a direct result of the underlying assumptions rather than from a rigorous assessment of the true behavior during the test.

Modified Mohr-Coulomb failure criterion :

$$|\tau| = c - \sigma \tan\phi \tag{1}$$

According to the sketch of modified Mohr-Coulomb, the cohesion c of the concrete is obtained as follows:

$$c = \frac{f_c(1-\sin\phi)}{2\cos\phi} \tag{2}$$

in which f_c is the cubic compressive strength of the concrete, substituting the Eq. 2 into Eq. 1, the shear stress is obtained as follows:

$$\tau = \frac{f_c(1-\sin\phi) - 2f_t\sin\phi}{2\cos\phi} \tag{3}$$

Figure 2 is the failure surface of idealized frustum, the surface area of the frustum is calculated as follows：

$$A = \frac{\pi h(D\cos\alpha + h\sin\alpha)}{\cos^2\alpha} \tag{4}$$

Then, from the equilibrium of forces in the vertical direction, we obtain

$$P = (\tau\cos\alpha + \sigma\sin\alpha)A \tag{5}$$

substituting σ、τ、A into Eq. 5, we obtain

$$P = \frac{\pi h[f_c(1-\sin\phi)\cos\alpha + 2f_t\sin(\alpha-\phi)](D\cos\alpha + h\sin\alpha)}{2\cos\phi\cos^2\alpha} \tag{6}$$

In experiment, D=25*mm*, h=30*mm*, α=57.7◦ , it has been accepted that$\varphi=\alpha$, $f_t=0.1f_c$, substituting these data into Eq. 6, we obtain

$$\frac{P}{f_c} = 988.2 \quad (7)$$

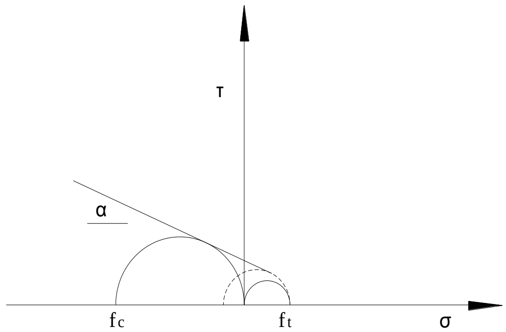

Fig.1 Sketch of modified Mohr-Coulomb

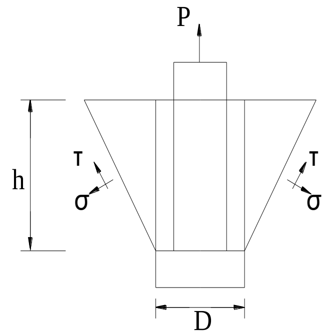

Fig.2 Sketch of frustum

Specimen Preparation and Experimental Study

The equipment of the anchorage pullout method to estimate concrete strength requires load-measuring system with accuracy standard of 0.1kN, the pullout metal anchor, load system, bearing system, reaction ring.

In this research, 76 batches of specimen with different concrete mixes were cast including 152 concrete beams with dimensions of 240mm×750mm×2100mm and 2600 concrete cubes with dimensions of 150mm×150mm×150mm cured under conditions identical to the concrete beam specimens (Fig. 3).

Fig.3 Specimen and frustum of anchorage pullout method

Results and Discussion

For each concrete mix to be tested, four types of correlation are established between the compressive strength of the standard concrete cube and the pullout force index of concrete beam specimens using the adhesive postinstalled method. It was decided that determination of best fit relationships using both linear and geometric regressions should be considered. Therefore, the correlation coefficient for each graph was calculated. These values are listed in Table 1.

Table 1 Specifications of fit curves.

Type of fit curve	Regression	r^2 (r)	Residual standard	Relative error (%)
$y=ax+b$	$f_c=2.59P-7.88$	0.958 (0.979)	2.95	5.45
$y=ax^3+bx^2+cx+d$	f_c =-0.0017 $P^3+0.0548P^2+2.6586\ P$-	0.964 (0.982)	2.654	3.40
$y=ax^b$	$f_c=0.7894P^{1.3371}$	0.935 (0.967)	3.16	6.04
$y=ae^{bF}$	$f_c=9.6784e^{0.0736\ P}$	0.924 (0.961)	3.367	6.45

From this information it was apparent that, due to the high correlation coefficient (r) values which range from 0.926 to 0.950, almost all forms of the calibration graphs would be suitable. However, with regard to the highest correlation coefficient which belongs to the cubic form, this calibration graph appears to be most suitable. A closer inspection of the best fit lines, however, reveals that, in view of the obvious advantages of having simple calibration factors, the linear calibration graph will be the best fit curve for our purpose. Because according to the values assigned to the parameters related to the statistical analysis and the best fit curves (shown in Table 1), it can be deduced that the effect of cubic curve is very much similar to the linear form, and noting the insignificant difference between the r (i.e., 0.982-0.979=0.003), it seems reasonable to choose the linear relationship for its simplicity.

Summary

On the basis of the extensive experience of the post-installed by adhesive-bonded anchorage pullout method, which has been gained in laboratory and theory of the failure of the concrete frustum, the following conclusions have been reached:

(a) According to Modified Mohr-Coulomb failure criterion, we get the equation 6 which shows that the pullout force of the frustum anchorage method is proportional to the concrete compressive strength.

(b) Based on the analysis of the datas of experiment, the linear relationship between the pullout force and the concrete compressive strength is reasonable and accurate in estimating the in-place concrete strength.

The post-installed by adhesive-bonded anchorage pullout method can provide accurate andreliable estimates of in-place 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 sand or cement mortar. Considering such advantanges comparied with other partial destructive method, we will in nation-wide popularize anchorage pullout method.

Acknowledgments

This research is supported by the Shandong Province Academy of Buildings Research and Shandong Huasen Concrete Corporation Ltd. The writers would like to thank Mr. Huidong Xie for producing the concrete cubes and beams.

References

[1] V.Mohan Malhotra and Nicholas J. Carino, in: Handbook on Nondestructive Testing of Concrete, chapter, 3, CRC Press LLC (2004).

[2] J.H.Bungey and S.G.Millard, in Testing of Concrete in Structures, chapter, 4, Chapman & Hall (1996).

[3] M. Naderi: Journal ofTesting and Evaluation Vol. 35 (2007), p. 2361.

[4] Mustafa Tuncan, Omer Arioz, Kambiz Ramyar, Bekir Karasu: Construction and Building Materials (2008), in press.

[5] F. Indelicato: Materials and Structures Vol. 30 (1997), p. 131-137.

[6] Eligehausen, R., Mallbe, R., and Rehm, G. Betonwerk+ Fertigteil-Technik, 10, 686-692, 1984.

[7] Cook, R. A.,Fagundo, F. E., Biller, M. H., and Richardson, D. E. Structures and materials res. rep. no.91-3, Univ. of Florida, Gainesville, Fla, (1991).

[8] Ronald A. Cook, Journal of Structural Engineering. Vol. 9(119), p. 2744-2762 (1993).

[9] R.A.Cook, G.T.Doerr, and R.E., Klingner, ACI Structural Journal. Vol. 5(90), p. 514-524 (1993).

[10] Ronald A .Cook, Gacob Kunz, Werner Fuchs, and Robert C. Konz, ACI Structural Journal. Vol. 1(95), p. 9-26 (1995).

[11] Shiqi Cui, Jinshan Wang, Lei Shi and Huidong Xie: Structural Engineers Supplement. Vol. 1, p. 82-86 (2007).

[12] Shiqi Cui, Jinshan Wang, Xuwen Kong and Cong Li: Proceedings of International Conference on Health Monitoring of Structure, Material and Environment. Vol. 2, p. 988-990 (2007).

[13] Jinshan Wang, Shiqi Cui, Hongdi Lv and Jing Zhao: Proceedings of International Conference on Health Monitoring of Structure, Material and Environment. Vol. 2, p. 999-1002 (2007).

[14] Shiqi Cui, Jinshan Wang, Zhaozhen Pei and Hongdi Lv: Proceedings of the UK Forum for Structural Integrity's Ninth International Conference on Engineering Structural Integrity Assessment. Vol. 2, p. 1434-1436 (2007).