EXPERIMENTAL STUDY OF THE COMPRESSIVE STRENGTH OF GROUTED CONCRETE BLOCK MASONRY BASED ON NONDESTRUCTIVE DETECTION METHOD

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ABSTRACT

The grouted concrete block masonry is composed of small size hollow concrete block, mortar and grout. To detect the compressive strength of grouted concrete block masonry, the convenient nondestructive detection measures that are used for concrete structures including: rebound method, ultrasonic method, pulling-out method and core drilling method, are proposed in this paper. In this paper, four types of detection tests on 25 grouted concrete block masonry specimens had been made. Experimental results show that these detection methods mentioned above are applicable for grouted concrete block masonry. Based on test results and analysis the formulas of compressive strength for four types of detection measure have been derived respectively, and some detection suggestions for concrete small hollow block, mortar and grout for concrete small hollow block have been given.

KEYWORDS: grouted concrete block masonry; compressive strength; nondestructive detection

INTRODUCTION

The development of small concrete block masonry adequately shows its advantages of “saving soil”,” saving energy” and “re-using waste”. However, there is still no a reliable, convenient and practical detection system, which accounts for the specifications and the actual construction conditions in different countries, and to rapidly and conveniently detects the compressive strength of the grouted concrete-block masonry in small concrete block masonry structures that are in progress or already built. The purpose of this paper is to adopt existing non-destructive or micro-destructive detection methods, to test composed materials of grouted concrete block masonry respectively, combine these test results, and finally find a reliable and comprehensive appraisal method of the compressive strength of grouted concrete block masonry. The existing non-destructive or mirco-destructive test methods explored are the rebound method, pulling-out method, and core drilling method.

It is feasible to use the above mentioned detection methods for testing concrete strength,

however using only one of the methods can not resolve the problem due to the characteristics of the grouted concrete-block masonry itself. Therefore, in this paper, according to suitability of various detection methods and characteristics of grouted concrete block masonry, we consider rebound method to test block and mortar, the pulling-out method to test block strength; and the core drilling method to test the compressive strength of grouted concrete.

DESIGN OF TEST SCHEME AND MATERIAL COMPOSITION

Main factors affecting the compressive strength of grouted block masonry include block strength, mortar strength and grouted concrete strength. According to People's Republic of China national standards "Basic Standard Test Method of Basic Mechanical Properties of Masonry"**(**GBJ 129-90), compressive specimens of small concrete blocks can be made. Main specification of blocks is 390mm×190mm×190mm，the specification of secondary blocks is 190mm×190mm×190mm. When testing, three categories of strength for blocks: MU10, MU15, and MU20 and three categories of strength for mortar: Mb10, Mb15, and Mb20. For grouted concrete, the three categories of strength level are: Cb20, Cb30, and Cb40 See Figure 1 for the specimen, and Table 1 for combination of specimen material strength levels.

Figure 1: Standard Specimen

Table 1: List of Specimen Parameters (each)

Group	Block strength	Mortar strength	Grouted Concrete strength	Ultrasonic And rebound compressive	Core Drilling method	Pulling Out method
Group1	MU10	Mb10	Cb20	3	1	1
Group2	MU15	Mb10	Cb20	3	1	1
Group3	MU20	Mb15	Cb30	3	1	1
Group4	MU15	Mb15	Cb30	3	1	1
Group5	MU20	Mb20	Cb40	3	1	1

Based on Table 1, specimens can be divided into five groups, and every group contains five specimens. As a result, there are 25 specimens in total. The first three specimens of every group are tested with ultrasonic method and rebound method first, then a compressive test is performed on them to directly obtain the compressive strength. The other two specimens are tested with core drilling method and pulling-out method respectively; and the compressive strength of the core column concrete and the block is determined respectively.

TEST RESULTS OF COMPRESSIVE STRENGTH OF STANDARD SPECIMENS

In order to analyze and compare with nondestructive detection results, 5 groups of standard specimens including 15 specimens for compressive strength are tested. The actual values tested are listed in Table 2.

Table 2: Actual Tested Values of Compressive Strength of Standard Specimens（MPa）

Group	1	2	3
Group1（MU10,Mb20,Cb20）	25.80	26.73	23.39
Group2（MU15,Mb10,Cb20）	23.25	23.95	22.96
Group3（MU20,Mb15,Cb30）	25.40	26.10	27.04
Group4（MU15,Mb15,Cb30）	27.18	30.20	28.65
Group5（MU20,Mb20,Cb40）	25.96	34.51	28.74

REBOUND DETECTION OF SPECIMENS AND THE RESULTS

The test includes rebound on the block and mortar. Using the rebound method to test compressive strength is rapid, simple, convenient, and applies to large area field detection of strength.

REBOUND OF THE BLOCK AND RESULTS

The block rebound apparatus used is the ZC3-A type with a 2.207J standard energy and pointer-direct-reading type indication system. When making rebound tests of the block, 16 spots are tested in every test area. The representative rebound value of every test area should be the arithmetic average of the remaining 10 rebound values after eliminating the 3 largest and 3 smallest values from the 16 rebound values of the area and expressed with R. When testing, the standard specimen is placed vertically on the compressor and preload a force of 100 kN is applied, (see Figure 2). Table 3 for contains the compressive strength values and rebound values of blocks of various standard specimens.

Figure 2: Rebound of Block

Table 3: Compressive Strength and Rebound Values of Blocks

No.	Compressive Strength (MPa)	Rebound Value R	Carbonized Depth (mm)
A-1(MU10)	17.60	44.67	3.0
A-2(MU10)	17.60	42.35	3.0
A-3(MU10)	17.60	40.39	3.0
B-1(MU15)	20.00	41.97	3.0
B-2(MU15)	20.00	43.73	3.0
B-3(MU15)	20.00	46.36	3.0
C-1(MU20)	26.43	46.42	2.0
C-2(MU20)	26.43	50.02	2.0
C-3(MU20)	26.43	52.37	2.0
D-1(MU15)	20.00	43.96	2.0
D-2(MU15)	20.00	42.25	2.0
D-3(MU15)	20.00	41.85	2.0
E-1(MU20)	26.43	53.09	1.0
E-2(MU20)	26.43	49.67	1.0
E-3(MU20)	26.43	47.13	1.0

In the Chinese Ministry of Construction standards "Technical Specification for Inspection of Concrete Compressive Strength by Rebound Method" (JGJ/T23-2001), the universal form of strength test curve is:

$$f_{cu}^{c} = A \times R_m^B \times 10^{Cd_m} \quad (1)$$

In the regression equation of the universal strength test curve, the rebound value R_m and carbonized depth value d_m are taken as the main variables.

From Table 3, the strength testing formula can be derived from the regression equation of the universal strength test-curve (Equation 1) by the rebound method as follows:

$$f_{cu}^{c} = 1.06 \times R_m^{0.86} \times 10^{-0.04 d_m} \quad (2)$$

According to the formula: the correlation coefficient r = 0.875, relative standard deviation e = 11.89% <12%, the average relative error δ=0.0071, the coefficient of variation C_v = 11.92%.

REBOUND TEST OF MORTAR AND THE RESULTS

The mortar rebound apparatus used is the ZC5 type with a 0.196J standard energy and pointer-direct-reading type indication system. A side of the specimen is taken as one test area of the mortar rebound test. In every test area, 12 rebound spots are evenly set out. The maximum and the minimum are eliminated to get the arithmetic average of the remaining 10-rebound values and are expressed with R. The rebound values from tests of various specimens and the compressive strength value of standard compressive blocks of mortar left beforehand are

summarized, and then regression analysis is performed as per the principle of the least square method. The data used to fit are listed in Table 4.

Table 4: Mortar Compressive Strength and Rebound Data

No.	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	D-1	D-2	D-3	E-1
Compressive strength（MPa）	14.20	14.20	14.20	15.07	15.07	15.07	22.14	22.14	22.14	21.61	21.61	21.61	25.67
Rebound value R	39.80	36.40	37.55	36.25	35.20	33.35	40.15	42.35	39.70	38.05	39.40	36.55	41.70

Give the regression equation in the form of index:

$$f_{cu}^{c} = A \times R_{m}^{B} \tag{3}$$

According to data in Table 5 and Equation 3, the index curve regression equation is:

$$f_{cu}^{c} = 0.00296 \times R_{m}^{2.4068} \tag{4}$$

The correlation coefficient of the formula: r =0.861 ＞ 0.85 which can meet the precision requirement.

PULLING-OUT METHOD DETECTION AND THE RESULTS

The principle behind the pulling-out method to test strength is mainly based on the correlation between concrete tensile strength and compressive strength. In Chinese Specification " Technical Specification for Inspection of Concrete Strength by Pull-Out Post-Insect Method" (CECS69: 94) specifies that: when testing concrete strength with the pulling-out method, the counterforce supporting the inner diameter of the three-point type pulling-out test apparatus is d_3=120mm, the anchoring depth of the anchorage h=35mm,the drilling hole diameter d_1=22mm， and the enlarged trough diameter d_2=30mm(see figure 3 for detailed dimensions). The pulling-out device is the SHJ-40 model multifunction testing device manufactured by Beijing Chinese Coal Mine Engineering Company Ltd.

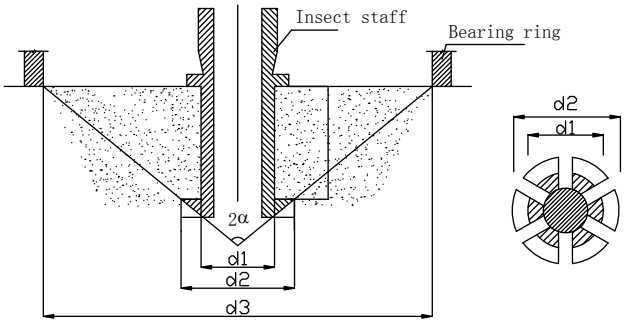

Figure 3: Sketch of Three-point Type Pulling-out Test Device

The pulling-out forces and block compressive strength obtained from tests of various standard specimens were summarized and the fitting data are listed in Table 5. As per the principle of the least square method, the regression analysis can be made using straight line regression equation:

$$f_{qk} = a \times F_p + b \tag{5}$$

Where a , b =regression coefficient;

f_{qk} =representative value of small concrete blocks;

F_p =representative value of limit pulling-out force.

Thus, the linear regression strength testing formula of pulling-out method is as follows:

$$f_{qk} = 0.7861F_p + 4.5737 \tag{6}$$

The correlation coefficient r = 0.966, the relative standard deviation e = 3.84%<12%, the average relative error δ＝0.030, the coefficient of variation C_v = 3.86%.

Table 5: Block Compressive Strength and Pulling-out Force

No.	A-1	A-2	A-3	A-4	B-1	B-2	B-3	B-4	C-1	C-2
Compressive strength（MPa）	17.60	17.60	17.60	17.60	20.00	20.00	20.00	20.00	26.43	26.43
Pulling-out force（kN）	16.56	18.08	18.18	17.76	19.41	19.10	19.49	20.48	26.97	27.70
No.	C-3	C-4	D-1	D-2	D-3	D-4	E-1	E-2	E-3	E-4
Compressive strength（MPa）	26.43	26.43	20.00	20.00	20.00	20.00	26.43	26.43	26.43	26.43
Pulling-out force（kN）	29.89	26.87	20.24	18.80	19.51	17.60	29.37	26.69	25.21	27.81

DATA TREATMENT AND ANALYSIS OF CORE DRILLING METHOD

The HILTI DD130 drilling hole machine with 102 mm diameter drilling bit was used. The core column dimension of grouted block masonry was 125×115～145×125mm which meets the dimension requirement of taking cores. In this paper, the stipulations in Chinese Specification "Technical Specification for Inspection of Concrete Strength by Core Drilling Method" (CECS03:2007) were adopted. The concrete compressive strength of core specimens can be calculated as per the following equation:

$$f_{cu,cor} = \frac{F_c}{A} \tag{7}$$

Where $f_{cu,cor}$ =concrete compressive strength of core specimens (MPa);

F_c =the maximum pressure from compressive test of core specimens (N);

A =compressive section area of core specimens (mm^2)

The detailed calculation results of grouted concrete compressive strength and core specimen compressive strength are listed in Table 6.

Table 6: Grouted Concrete Strength and Core Specimen Compressive Strength

Design Value of Grouted Concrete strength	Core specimen compressive Strength (MPa)	Grouted concrete Compressive strength (MPa)	Core specimen/grouted -core concrete
Cb20	28.28	20.1	1.41
Cb30	35.01	36.1	0.97
Cb40	44.30	46.8	0.95

From the values in Table 6, it can be seen that the compressive strength of grouted concrete obtained by drilling core method well conforms to the compressive strength of standard blocks of grouted concrete, and can reflect real compressive strength of grouted concrete. Only the strength of the Cb20 concrete is higher than compressive strength of standard blocks of grouted concrete. The higher compressive strength may have resulted from the preparation process of standard blocks left beforehand. Thus, the drilling-core method is an effective method to test concrete strength directly and is feasible for testing grouted concrete block strength.

COMPARING AND ANALYZING OF COMPRESSIVE STRENGTH OF GROUTED CONCRETE BLOCK MASONRY

In Chinese Code "Code for Design of Masonry Structures"(GB50003-2001), calculation formula for average compressive strength of grouted concrete block masonry is as follows:

$$f_{g,m} = f_m + 0.63\alpha f_{cu,m} \tag{8}$$

$$f_m = 0.46 f_1^{0.9}(1 + 0.07 f_2)K \tag{9}$$

Where $f_{g,m}$ =average compressive strength of grouted concrete block masonry.

f_m =average compressive strength of hollow concrete block masonry.

$f_{cu,m}$ =compressive strength of concrete cubic block.

f_1 =average compressive strength of the block (N/mm^2).

f_2 =average compressive strength of mortar (N/mm^2).

K =corrective coefficient of masonry strength, When $f_2 > 10\text{MPa}, K = 1.1 - 0.01 f_2$.

α =rate of grouted cores; for tests in this paper, it is 0.43.

The results in Table 7 were obtained by putting the data outputs of compressive strength of blocks from the pulling-out method, the data outputs of compressive strength of mortar from the rebound method, and the data outputs of compressive strength of the core column concrete from the drilling-core method into the formulas (8) and (9), and then adopting the results from compressive tests for the compressive strength of standard specimens.

Table 7: Comparative Analysis of Compressive Strength of Concrete Block Masonry

No.	f_1 (MPa)	f_2 (MPa)	K	f_m (MPa)	$f_{cu,m}$ (MPa)	$f_{g,m}$ (MPa)	Actual compressive Strength (MPa)	Compressive/(8)
	Pulling-out	Rebound	-	(9)	Drilling-core	(8)	Compressive	—
A-1	18.44	20.98	0.89	13.93	28.28	21.59	25.80	1.19
A-2	18.44	16.93	0.93	12.89	28.28	20.55	26.73	1.30
A-3	18.44	18.24	0.92	13.24	28.28	20.91	23.39	1.12
B-1	20.00	16.76	0.93	13.81	28.28	21.47	23.25	1.08
B-2	20.00	15.61	0.94	13.47	28.28	21.13	23.95	1.13
B-3	20.00	13.71	0.96	12.87	28.28	20.53	22.96	1.12
C-1	26.47	21.43	0.89	19.43	35.01	28.92	25.40	0.88
C-2	26.47	24.37	0.86	20.33	35.01	29.82	26.10	0.88
C-3	26.47	20.86	0.89	19.24	35.01	28.73	27.05	0.94
D-1	19.54	18.83	0.91	14.11	35.01	23.60	27.18	1.15
D-2	19.54	20.48	0.90	14.55	35.01	24.03	30.20	1.26
D-3	19.54	17.09	0.93	13.63	35.01	23.11	28.65	1.24
E-1	26.01	23.48	0.87	19.76	44.30	31.76	25.97	0.82
E-2	26.01	21.56	0.88	19.17	44.30	31.17	34.51	1.11
E-3	26.01	25.56	0.84	20.34	44.30	32.34	28.75	0.89

From Table 7 we can find that when putting the corresponding testing data of compressive strength of composed materials of grouted concrete block masonry into Equations (8) and (9) to calculate the whole compressive strength, in the Table, the average ratio of actual compressive strength to the calculating value as per the specifications is 1.074，the standard deviation is 14.35%，and the variance coefficient is 14.35%. This shows that using this combination of methods of nondestructive or micro-destructive methods to test the compressive strength of grouted concrete block masonry is feasible, and the calculated compressive strength value well conforms to the actual compressive strength value.

CONCLUSIONS

In this paper, the rebound, pulling-out and drilling-core nondestructive or micro-destructive detection methods were used to test the compressive strength of 25 grouted concrete block masonry specimens. Large quantities of testing data on blocks, mortar, and grouted core concrete were obtained and a comparison and analysis with the compressive test results of standard specimens was made. Finally a calculating method for the compressive strength of grouted concrete block masonry by nondestructive or micro-destructive detection methods was determined. The main conclusions are as follows:

1. The compressive strength of both concrete blocks and mortar can be tested by using the rebound nondestructive detection method. The compressive strength of blocks can also be tested by the micro-destructive pulling-out method. The testing results of the pulling-out method are better than those of the rebound method. In this paper, the strength testing formula for blocks and mortar respectively were set up.

2. It is convenient, feasible, direct and reliable to use the drilling-core method in testing compressive strength of grouted concrete block. In this paper, data from drilling-core method well conformed well to the compressive strength obtained from tests of standard blocks of core column concrete.

3. The calculating method for the compressive strength of grouted block masonry is: Enter the compressive strength results from the nondestructive or micro-destructive tests for blocks, mortar and core column concrete into the calculating formula of average compressive strength in the masonry specifications to calculate the compressive strength of grouted concrete block. The calculated results compare well with the actual compressive strength.

Through tests and analysis, it can be seen that under existing technical conditions, the nondestructive detection of the compressive strength of grouted block masonry can be determined completely. The data from the nondestructive tests are accurate, and the calculated results are believable. We recommend incorporating the nondestructive detection methods of compressive strength of grouted concrete block masonry into corresponding detection specifications.

REFERENCES

1. Cui shuang-shuang. Experimental study on inspection of merchandise concrete strength by pull-out method .Master's thesis in Harbin Institute of Technology 2007
2. WANG Yu-din. Test intensity of concrete by rear-extraction method & experimental research for local curve. Shanxi Architecture. 2005, (15)
3. SHI Cheng-ming, HU Xing-min, SHAO Shi-sheng, ZHANG ling. How to improve the repercussion test accuracy of concrete compressive strength. Journal of Shanxi University of Technology (Natural Science Edition) 2007(03)
4. Han Jian-ping, Wang Fei-xing, Wang Zhi-hua. Discussion on Several Issues of Testing and Evaluating Concrete Strength by Drilling Core Method. Earthquake Resistant Engineering and Retrofitting.2008(02)
5. Basic Standard Test Method of Basic Mechanical Properties of Masonry (GBJ 129-90). China Architecture & Building Press.1991
6. Technical Specification for Inspection of Concrete Compressive Strength by Rebound Method (JGJ/T23-2001). China Architecture & Building Press.2001
7. Technical Specification for Inspection of Concrete Strength by Pull-Out Post-Insect Method (CECS69: 94).China Planning Press.1994
8. Technical Specification for Inspection of Concrete Strength by Core Drilling Method (CECS03:2007). China Architecture & Building Press.2007
9. Code for Design of Masonry Structures (GB50003-2001). China Architecture & Building Press.2002