

EVALUATION OF TENSILE BOND AND SHEAR BOND OF MASONRY BY MEANS OF CENTRIFUGAL FORCE

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INTRODUCTION

Knowledge of the tensile and shear bond strengths of masonry is of great importance in the design and evaluation of masonry structures. Tensile bond strength is the strength developed when a tensile load is applied normal to the bonded faces. Shear bond strength is the strength developed when a mortar masonry joint is subjected to a shear load.

A number of different tests exist for the evaluation of these two strength properties. For tensile bond the modulus of rupture test and the brick couplet test are the most commonly used. These tests are shown schematically in Figures 1a and 1b.

Tensile bond values obtained from tests conducted by various investigators (1,2) have a large scatter. A number of these investigators have pointed out some difficulties in applying these tests to masonry. In determining the tensile bond from the results of the modulus of rupture test a linear bending stress distribution is assumed. However it has been shown by finite element analysis that the stress distribution is not linear. As a result this test overestimates the tensile bond by as much as 70%. Due to possible variations in tensile bond along the

specimen, failure may occur outside the area of constant moment and may thus be influenced by the presence of shear. In the couplet test, it is difficult to assure that the applied load acts through the centroid of the mortar area.

The most common test for determining the shear bond strength is the shear box test shown in Figure 1e. In evaluating the shear bond strength a uniform stress distribution is assumed over the bonded area. However, finite element analysis indicates that this is not the case.

A new test procedure based on centrifugal force has been developed for determining tensile and shear bond strength (3). The limitations of the existing tests for tensile and shear bond strength are eliminated in this new procedure. The present paper describes the test apparatus and principles involved and reports the results of a study of tensile and shear bond strengths of three types of mortar.

TEST APPARATUS AND TEST PROCEDURE

The centrifugal force testing machine is based on the principle that if a mass is rotated about a fixed axis at constant angular velocity it is subjected to a force in the radial direction known as the centri-fugal force.

Tensile and shear bond test specimens, described in Figure 2 are mounted on a metal disk as shown in Figure 3. The disk is then rotated at an angular velocity w . The tensile force acting on the mortar joint of the tensile bond specimen is

$$F = mw^2R$$

where F = centrifugal force

m = mass of that portion of the test specimen between the
mortar joint and the free end

ω = angular velocity

R = distance from the center of rotation to the center of
mass m

For the shear bond specimen, the shear force acting on a mortar joint is:

$$F = \frac{1}{2}m\omega^2R$$

By increasing the angular velocity the force F may be increased until failure occurs when the tensile or shear strength of the specimen is reached. Based on the mass of the separated portion, the distance to the center of that mass and the angular velocity at failure, the stress at failure can be evaluated.

As the angular velocity is increased the resulting tangential acceleration will introduce tangential force to the test specimens. By controlling the rate of change of velocity this tangential force may be reduced to the point where its effect is negligible.

The operation of the centrifugal force machine shown in Plate 1 is based on the above principles. Tensile bond specimens are mounted in the compartment shown in Plate 2. No special clamping device is needed for the shear bond specimens.

STUDY OF TEST SPECIMENS

(a) Tensile bond specimens:

Thirty specimens were prepared for each of the three types of mortar M, S and N. The mortar was mixed by volume with proportions as shown in Table I.

The specimens consisted of two 100x100x100 mm cubes cut from 100x200x400 mm solid lightweight concrete block. Mortar was placed on the factory-produced face used when laying these blocks, and not the saw-cut face. A typical specimen is shown in Plate 3.

(b) Shear bond specimens:

Twenty specimens were prepared for each of two types of mortar M and N. The specimens consisted of three 100x100x100 mm cubes cut from 100x200x400 mm solid lightweight concrete block. The specimens were prepared in a similar manner to that employed in preparing tensile bond specimens.

All specimens were manufactured by an experienced mason using standard construction procedures and they were cured in a laboratory environment at 42% relative humidity and 22° C temperature. All specimens were at least 28 days old at the time of testing.

TEST RESULTS

A summary of test results is given in Table 2. Individual test results are given in the Appendix. A statistical analysis of the data is given in Table 3.

There is a wide range in the test data. The coefficient of variation for the five groups of the test is between 19.8 and 42.5. The standard deviation varies from 9.7 to 21.2.

Type M mortar specimens had the highest mean tensile bond strength - 517 kPa. The mean strength for Type S specimens was 87% of that for Type M and the mean strength for Type N specimens was 65% of that for Type M. Type M mortar specimens had the highest mean shear bond strength - 324 kPa. The mean strength for Type N specimens was 82% of that for Type M specimens.

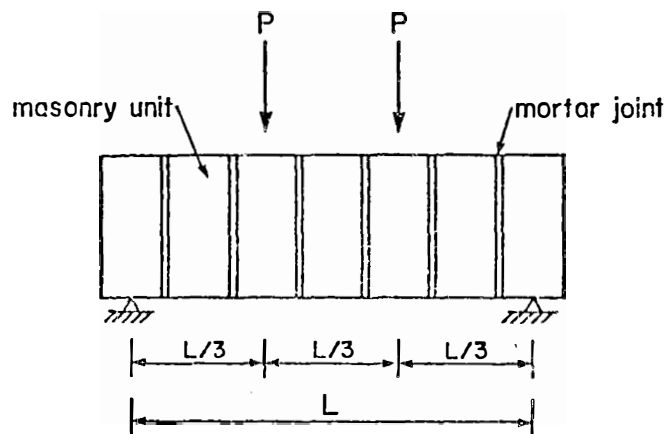
The large spread of the test data is not attributed to any inherent fault of the testing procedures. This is not borne out by tests carried out by the authors (4) on specimens for evaluation of the tensile bond developed between concrete block and grout. Results of these tests had a coefficient of variation of 5.2%.

CONCLUSIONS

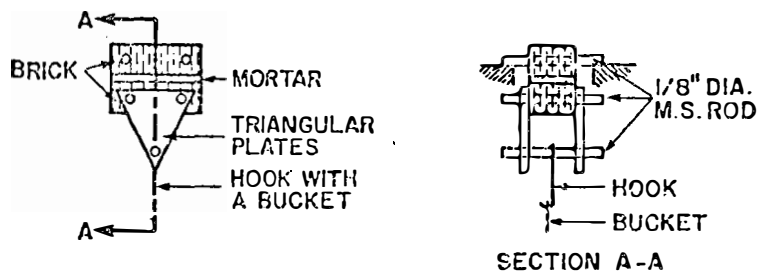
1. The centrifugal force machine provides an acceptable means of evaluating tensile and shear bond strengths of masonry. This method eliminates some of the uncertainties of existing test methods.
2. Based on the tests performed in this study the tensile bond of concrete block masonry with Types M, S and N mortars is of the order of 517, 448 and 345 kPa respectively.
3. Based on tests performed in this study the shear bond strength of concrete block masonry with Type M and N mortars is of the order of 324 and 262 kPa respectively.

REFERENCES

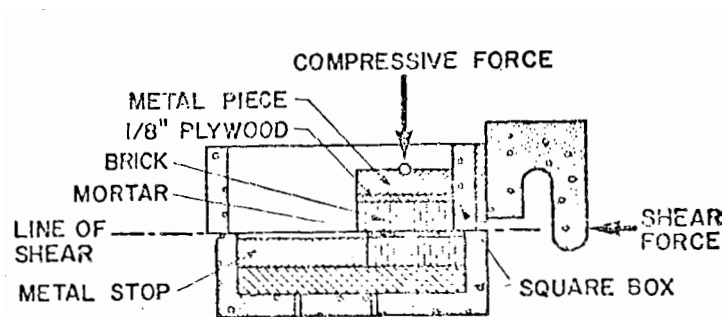
1. Mayes, R.L., Clough, R.W., "Compressive, Tensile Bond and Shear Strength of Masonry". A literature survey, National Technical Information Service, U.S. Department of Commerce, PB 246 292, Springfield, Va., 22151.
2. Kampf, L., "Factors Affecting Bond Between Brick and Mortar", Symposium of Masonry Testing ASTM, STP 320, February 1963.
3. Hatzinikolas, M., Longworth, J., Warwaruk, J., "The Use of the Centrifugal Force for Determining the Tensile Bond Strength of Masonry", Proceedings of the 6th International Masonry Conference, London, England, December 1977.
4. Hatzinikolas, M., Longworth, J., Warwaruk, J., "Concrete Masonry Walls" Structural Engineering Report No. 70, The Department of Civil Engineering, The University of Alberta, Edmonton.



la. Modulus of Rupture test.

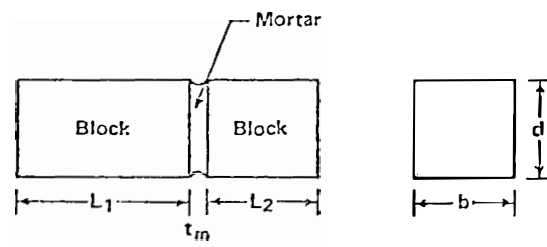


lb. Brick Couplet test.

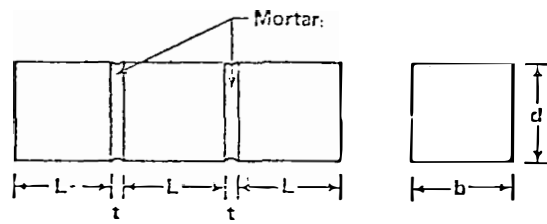


le. Shear Box test.

Figure 1 Tensile bond and shear bond tests



a) Tensile bond specimen



b) Shear bond specimen

Figure 2 Test specimens

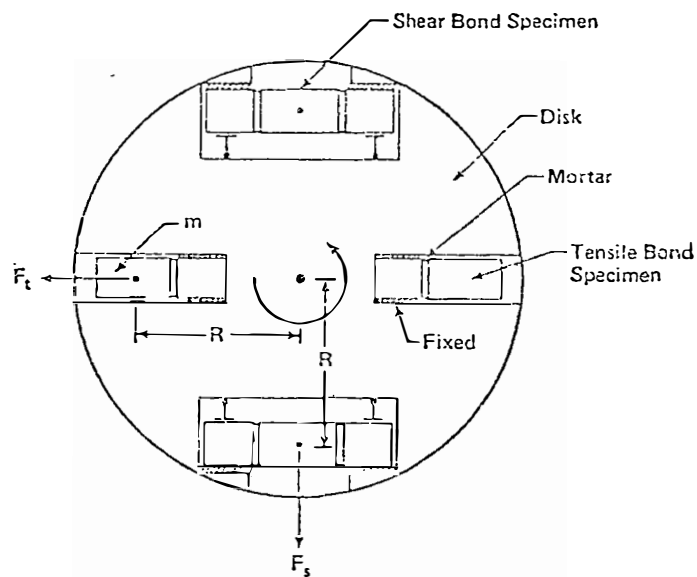


Figure 3 Schematic diagram of test apparatus

Table I - Mortar Composition

Type of Mortar	Composition in Parts by Volume		
	Portland Cement	Lime	Aggregate*
M	1	1/4	3 7/16
S	1	1/2	4 1/8
N	1	1	5 1/2

* Volume (cement + lime) x 2 3/4

TABLE 2 - Summary of Test Results

Mortar Type	Mean Bond Strength	
	Tensile kPa	Shear kPa
M	323.4	517.0
S		444.7
N	264.8	343.4

TABLE 3 - Statistical Analysis of Test Data

Test	Type of Mortar	Number of Specimens	Min.-Max. Values Obtained (kPa)	Mean kPa	Standard Deviation kPa	Coefficient of Variation %
Tensile Bond	M	30	703.0 - 242.7	512.0	118.5	22.9
	S	30	589.5 - 268.2	450.9	88.9	19.8
	N	30	620.5 - 115.8	343.4	146.2	42.5
Shear Bond	M	20	486.7 - 196.5	323.4	86.9	26.9
	N	20	429.5 - 144.8	264.8	66.9	25.3

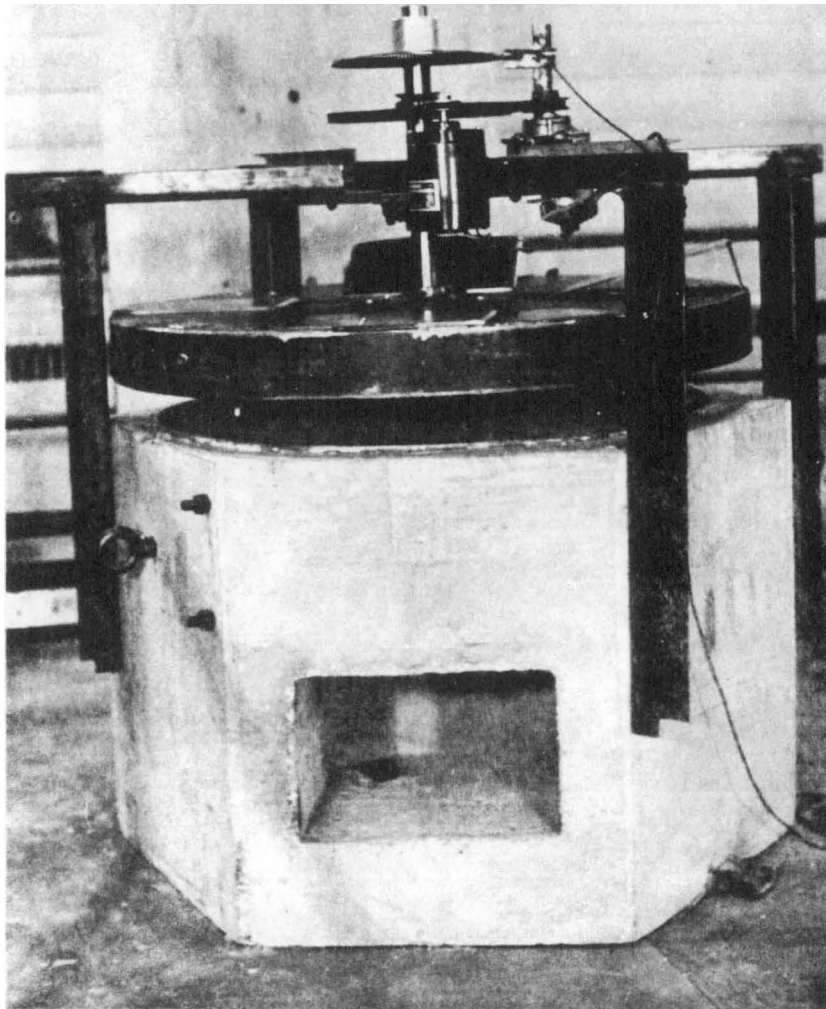


PLATE 1 View of the Testing Machine

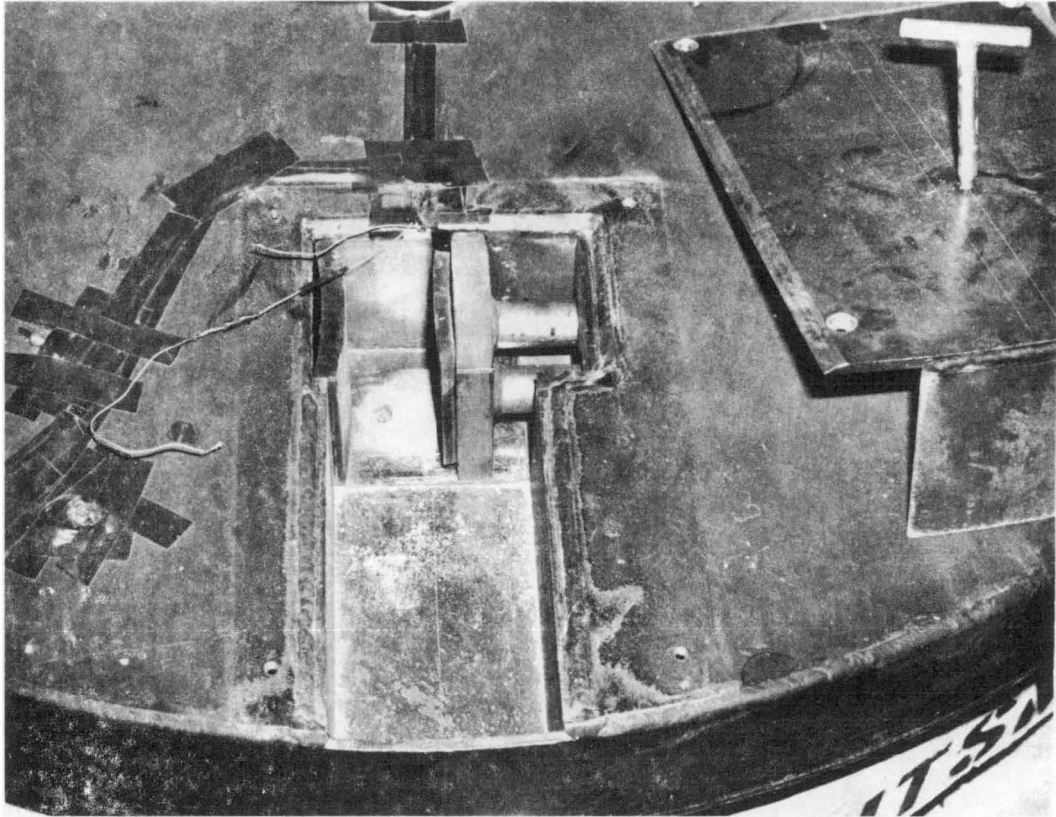


PLATE 2 2 Compartment for Tensile Bond Test

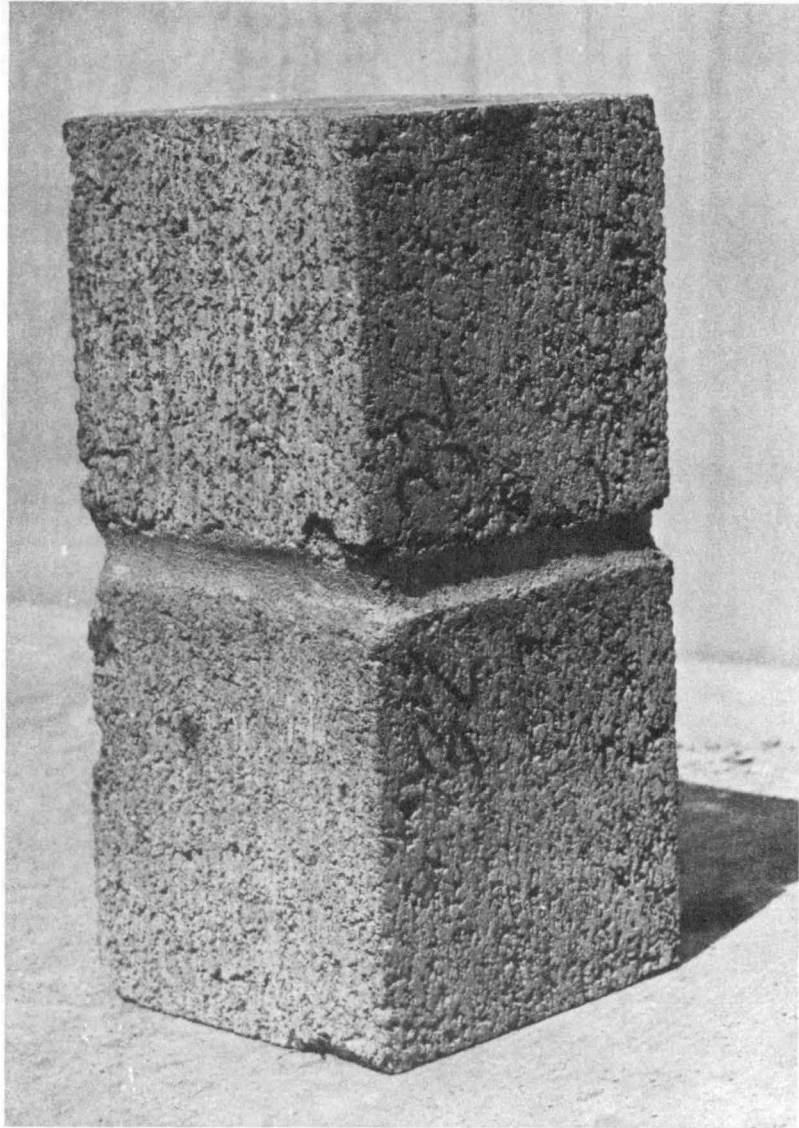


PLATE 3 Specimen for Tensile Bond Strength Test

APPENDIX
TEST DATA

**TABLE AI - Tensile Bond Strength of Type M
Mortar and Concrete Block**

Specimen No.	Angular Velocity at Failure (R.P.M.)	Weight of Separated Portion kg.	Tensile Bond Strength kPa
1	555	2.03	355.8
2	570	2.06	391.6
3	692	2.06	561.9
4	540	2.09	335.8
5	726	2.00	599.2
6	591	2.03	387.5
7	696	1.99	548.8
8	717	2.01	567.4
9	664	2.10	515.0
10	634	2.09	477.8
11	750	2.10	683.9
12	688	2.16	586.7
13	729	2.08	621.2
14	736	2.11	660.5
15	730	2.05	643.3
16	676	2.06	543.3
17	763	2.08	698.5
18	789	1.82	664.0
19	781	2.00	703.3
20	637	2.09	492.3
21	633	1.97	455.0
22	644	1.71	409.6
23	682	2.02	492.3
24	640	2.09	496.5
25	639	2.09	485.4
26	674	2.10	543.3
27	709	2.04	584.0
28	553	2.07	368.9
29	601	1.96	397.8
30	451	2.08	242.7

**TABLE A2:- Tensile Bond Strength of Type S
Mortar and Concrete Block**

Specimen No.	Angular Velocity at Failure (R.P.M.)	Weight of Separated Portion kg.	Tensile Bond Strength kPa
31	700	1.93	525.4
32	617	1.95	428.2
33	636	2.12	483.2
34	586	2.04	395.8
35	560	2.13	381.3
36	673	1.86	484.7
37	725	1.92	571.5
38	695	1.91	534.4
39	675	2.08	520.5
40	666	2.06	511.6
41	685	2.10	559.1
42	690	2.03	536.4
43	543	2.07	348.9
44	692	1.91	520.5
45	689	1.77	484.0
46	563	1.88	342.0
47	663	2.13	546.7
48	543	1.88	304.0
49	649	1.83	419.9
50	646	1.91	448.8
51	637	1.86	428.2
52	607	2.03	424.7
53	744	1.86	589.5
54	733	1.78	535.0
55	672	2.01	497.8
56	502	1.85	268.2
57	577	1.86	343.3
58	577	2.10	402.6
59	566	2.17	395.0
60	501	2.02	290.9

**TABLE A3 - Tensile Bond Strength of Type N
Mortar and Concrete Block**

Specimen No.	Angular Velocity at Failure (R.P.M.)	Weight of Separated Portion kg.	Tensile Bond Strength kPa
1	474	1.42	188.2
2	425	1.41	144.8
3	770	1.30	410.9
4	406	1.27	115.8
5	531	1.32	241.3
6	437	1.37	145.5
7	657	1.31	370.2
8	512	1.39	210.9
9	744	1.37	435.7
10	862	1.36	581.9
11	669	1.32	345.4
12	869	1.42	613.6
13	782	1.41	490.2
14	640	1.37	320.6
15	750	1.41	436.4
16	781	1.28	457.1
17	545	1.39	237.9
18	900	1.33	620.5
19	680	1.34	358.5
20	807	1.32	476.4
21	650	1.37	308.9
22	659	1.33	347.5
23	745	1.33	433.7
24	417	1.35	138.6
25	804	1.46	504.7
26	523	1.31	213.0
27	415	1.41	135.8
28	708	1.37	370.3
29	626	1.28	277.2
30	687	1.36	385.4

**TABLE A4 - Shear Bond Test Results for Type M
and N Mortar and Concrete Block**

Mortar	Specimen Number	Angular Velocity at Failure (R.P.M.)	Weight of Separated Portion (kg.)	Shear Bond kPa
Type M	1	600	2.81	314.4
	2	600	3.25	373.7
	3	701	3.10	486.8
	4	653	3.24	441.9
	5	676	3.34	474.3
	6	676	3.16	455.2
	7	466	3.91	325.4
	8	510	2.96	317.2
	9	500	3.08	322.7
	10	420	3.36	233.7
	11	464	3.40	295.7
	12	444	3.03	238.5
	13	441	3.29	257.9
	14	518	2.78	333.0
	15	438	2.78	222.7
	16	464	3.05	272.3
	17	396	3.05	196.5
	18	432	2.99	225.5
	19	526	2.80	327.5
	20	517	3.37	355.0
Type N	21	488	3.15	299.0
	22	524	3.02	334.4
	23	488	3.39	309.5
	24	506	2.92	291.6
	25	464	3.19	266.8
	26	465	3.16	276.5
	27	486	2.65	264.7
	28	444	2.94	230.3
	29	514	2.79	315.8
	30	421	3.29	233.7
	31	502	3.24	295.8
	32	460	3.31	257.2
	33	402	3.18	166.1
	34	650	3.27	429.5
	35	578	3.20	328.9
	36	376	3.25	144.8
	37	540	2.80	254.4
	38	511	2.57	206.1
	39	500	2.96	233.0
	40	445	2.55	162.0