



Strength of Masonry Built With Theory Concrete Block System

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ABSTRACT

The "Theory" Concrete block system utilizes recessed channels in the face shells and webs of the units to provide mechanical interlocking at the unit-mortar interfaces and to accommodate horizontal reinforcement. This new system with the reinforcing rods provides an attractive alternative to the conventional concrete block which has horizontal steel in bond beams. Examining the interlocking mechanism that is provided by the mortar in the recesses is of significant particularly when the shear or flexural capacity is controlled by the joint slip or tension debonding. A test program was conducted at Drexel University to determine the compressive and shear strength of the "Theory" concrete block system, and to compare its shear strength with the conventional system. This experimental program contains testing of theory units, prisms for axial compression, and square panels built with theory and conventional blocks for diagonal tension (shear strength). It was concluded that the "Theory" block system has adequate compression and shear strengths that are equal to or exceed those of masonry built with conventional units.

INTRODUCTION

Hollow concrete block is one of the most important developments in concrete masonry and it is the most widely used material for loadbearing masonry construction. It is made of cement sand mix or a concrete mix with dense or lightweight aggregate. Advances in manufacturing methods and quality and uniformity of concrete block as well as availability of necessary raw materials, suitable technology and appropriate equipment for block production and the likely savings due to faster erection, have substantially changes the economics of its use as compared to other structural materials. Thus, there is a demand worldwide for further exploration of this material. Concrete masonry units are manufactured using automated machines. These blocks are proportioned so that their size enables manual laying. Over the years many shapes of blocks were evolved to suit various specific situations which resulted in a buffing array of block shapes to select from.

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Many studies (Shrive et al 1986 & 1987) were conducted to modify the shape of block in order to improve the structural performance of masonry. The new block "Theory Concrete Block (TCB)" with horizontal reinforcing rods provides an attractive alternative to the conventional wall construction which utilizes horizontal steel in bond beams. This system, as compared to conventional blocks, offers a cost-efficient system with many advantages. To evaluate the effectiveness of the theory block system a test program was conducted at Drexel University aiming at determining the compressive and shear strength of theory block system, determining the factor of safety against diagonal tension (shear) failure based on ACI 530/ASCE 5/TMS 402 masonry code and comparing the shear strength of TCB system with conventional system which utilizes bond beams for horizontal reinforcement. The experimental program contains testing of TCB prisms for axial compression, and 4 ft (1.2 m) square panel for diagonal tension (shear strength). Prisms and square wall panels made of conventional units were also included for comparison with the TCB System.

DESCRIPTION OF THE THEORY BLOCK SYSTEM

The new TCB system utilizes recessed channel in the block as shown in Fig. 1 to provide mechanical interlocking at the unit-mortar interfaces and to accommodate horizontal reinforcement in the form of #2 pencil rods. The Channels run parallel to the inner and outer face shells and in the central web at the top of the block only as shown in the figure. The mortar encases the rods and provides the necessary bond for the composite action between the block and the reinforcing steel. The #2 pencil rods provide a steel percentage of 0.16 % for 8 in.(200 mm) masonry walls. The TCB system with the reinforcing rods provides an attractive alternative to the conventional horizontal steel in bond beams (it saves labor). The elimination of bond beams provides clear cells to allow water drainage down to the flashing and weep holes without interruption. This provides a rain screen single wythe masonry wall for water resistance construction. The TCB unit meet the requirement of ASTM C-90.

From a structural engineering standpoint it is important to demonstrate the effectiveness of the new system and to compare its strength with conventional system which utilizes grout bond beams for horizontal reinforcing. Examining the interlocking mechanism provided by the mortar in the recesses is of significance particularly when the capacity is controlled by the joint slip under shear or tension debonding under flexure.

EXPERIMENTAL PROGRAM

The experimental program contains testing of the TCB units, prisms for axial compression tests (ASTM E447) and 4 ft (1.2 m) square wall panels for diagonal tension (shear) tests (ASTM E519-81). Conventional unit, prisms and square panels were included for comparison with the TCB system.

Material Properties

Units. Three conventional units and three TCB units were capped with hydrostone and tested under axial compression to determine unit compressive strength following ASTM C144-88 specification. Unit compressive strength is based on net area. The failure mode is a typical shear failure for the two types of units. The test results are presented in Table 1. As indicated in the table the two types of units have different strength. The conventional unit is a normal weight block whereas the TCB is a lightweight unit. Because of the differences in strength the comparison between the TCB system and the conventional system will not be performed on an absolute basis but rather on the basis of the compressive strength of masonry (i.e. the shear or diagonal strength will be evaluated in terms of the square root of the masonry compressive strength).

Table 1 Unit Compressive Strength

| Type of unit | Individual | Compressive strength Mean psi | COV |
|--------------|----------------------|----------------------------------|------|
| TCB | 2090 2030 1930 | 2020 | 2.7% |
| Conventional | 2610 2810 3020 | 2810 | 3.8% |

Note: 1 psi = 0.0069 MPa

Mortar. Cement-lime mortar consisting of type I portland cement, 3/8 part hydrated lime and 3.5 parts sand, conforming to requirements for type S mortar described in ASTM C270-82, was used in the construction of the prisms and panels. An average water/cement ratio of 0.75 was used to obtain an average initial flow of 110 percent. Mortar cubes 2 in. (51 mm) were used as control specimen and were prepared following procedure described in ASTM C109-88. The test results are presented in Table 2. The average compressive strength obtained for the mortar specimen was 2940 psi (20.3 MPa).

Table 2 Compressive Strength of Mortar Cubes

| Specimen | Individual | Compressive strength Mean psi | COV |
|----------|------------|----------------------------------|------|
| 1 | 3180 | 2950 | 2.5% |
| 2 | 3000 | | |
| 3 | 2940 | | |
| 4 | 2780 | | |
| 5 | 2870 | | |

Note: 1 psi = 0.0069 MPa

Grout. Coarse grout consisting of 1 part type I portland cement, 3 parts sand and 2 parts 3/8 in. (10 mm) pea gravel, conforming to ASTM C476-83, was used in the construction of the reinforced panels. Block molded specimens prepared according to ASTM C1019-89 was used as control samples. The average compressive strength of the block molded grout was 4780 psi (33 MPa) as indicated in Table 3.

Table 3 Compressive Strength of Grout Prisms

| Specimen | Compressive strength psi | | COV |
|----------|--------------------------|------|------|
| | Individual | Mean | |
| 1 | 4760 | 4780 | 1.0% |
| 2 | 4740 | | |
| 3 | 4840 | | |

Note: 1 psi = 0.0069 MPa

Reinforcement. No. 5 Grade 60 steel was used for vertical reinforcement in unit cells and horizontal reinforcement in bond beams (conventional block). No. 2 pencil rods provided by the Blue Prince Corporation was used in the TCB system as horizontal reinforcement.

Prism Test

A total of 6 two coarse prisms, three built with conventional units and joint reinforcement and three with TCB system, were constructed with full mortar bedding as shown in Fig. 2. Type S mortar was used and the joint were struck flush. The prisms were built conforming to ACI 530/ASCE 5/TMS 402 masonry code and specifications. The prisms were capped and tested under axial compression using a 300 kips (1335 KN) universal testing machine available at the Structural Testing Laboratory at Drexel University. The testing procedure followed the ASTM E447 specification for determining compressive strength of concrete masonry. The load was applied gradually till failure occurred. Failure modes of the two types of prisms are typical where localized splitting failure of the face shells was observed. Table 4 summarizes the strength results of the prisms. The efficiency which is expressed as prism/unit strength for the TCB System and conventional masonry are 0.94 and 0.91, respectively. The higher value of the TCB system may be attributed to the lower stress concentration due to larger mortar bedded area.

Table 4 Prism Compressive Strength

| Type of Prism | Compressive strength psi | | Efficiency | |
|---------------|--------------------------|------|------------|------|
| | Individual | Mean | Individual | Mean |
| Theory | 1870 | 1880 | 0.93 | 0.94 |
| | 1960 | | 0.97 | |
| | 1810 | | 0.91 | |
| Conventional | 2470 | 2560 | 0.87 | 0.91 |
| | 2570 | | 0.91 | |
| | 2640 | | 0.94 | |

Note: 1 psi = 0.0069 MPa

The prism compressive strength results of the TCB system is compared with the ACI 530/ASCE 5/TMS 402 code values for compressive strength in terms of unit strength and mortar type as indicated in Fig. 3. As can clearly seen in this figure, the TCB system results in a compressive strength in excess of the code assigned values which demonstrates the adequacy of the system for loadbearing masonry construction.

Diagonal Tension (Shear) Test

Fabrication. A total of Nine square panels were built with TCB and conventional units using face shell mortar bedding. Two different types of reinforcement were employed for TCB system; one with horizontal steel rods only and the other with additional vertical steel. The details of reinforcement of the panels are shown in Fig. 4. Wire mesh was used to confine the grout in the bond beams of the conventional masonry as shown in Fig. 5. Grouting was applied after 24 hours of completing of the wall construction and was consolidated with a vibrator. It was noted that installing the wire mesh and grouting the bond beams consumed some time and delaying the construction process.

Testing. Special steel shoes were fabricated as specified in ASTM E519 for gradual load application at the corners as shown in Fig. 5. The vertical compression load was applied via a 328 kips MTS actuator linked to a state-of-the-art computer controlled and data management station. The load was applied gradually till failure took place.

Results and Discussion. Typical failure patterns are shown in Fig. 5 for the three types of panels (Unreinforced and Reinforced TCB panels TH & TR and Reinforced Conventional panel CR). As can be seen, all specimens failed in a diagonal tension along the loaded diagonal of the panel. Summary of the shear strength test results are presented in Table 5. The results show that providing #5 vertical rebars at 24 in. (0.8 m) on center increased the shear strength of the TCB system by about 23%. In addition, the TCB system with vertical reinforcement reveals shear strength comparable to conventional masonry with bond beams. If the shear strength is measured in terms of the square root of the masonry compressive strength, the TCB system reveals better results when compared with shear test results of conventional masonry obtained from other sources, as illustrated in Fig. 6. This may be attributed to the interlocking mechanism of the TCB system where the mortar in the recesses acts as shear keys. In order to fail the joint the keys have to be sheared off as indicated schematically in Fig.7. Examining the crack patterns of the panels shown in Fig. 5 testifies to that effect where the TCB system shows less joint shear than conventional masonry. It is reported (Swinsson et al 1981) that the shear keys provided by the mortar plugs in the cores of the clay brick masonry result in an appreciable increase in the joint capacity. Because the mortar joint is the weak plane where shear failure initiates (Drysdale et al 1993) the increase in the joint shear capacity would result in an increase in the diagonal tension (shear) strength of masonry assemblages.

Because of the high shear strength values obtained for the TCB system it is expected that this system would performed adequately in areas prone to earthquakes, hurricanes and tornadoes. Comparing the shear strength results of the TCB system with the allowable code values (Fig. 6) indicates a margin of safety more than three which is adequate for this type of construction.

Table 5 Diagonal Tension (Shear) Test Results

| Type of unit | Type of panel | Individual | Shear strength Mean psi | COV |
|--------------|---------------|------------|----------------------------|------|
| TCB | TH1 | 170 | 173 | 1.9% |
| | TH2 | 170 | | |
| | TH3 | 180 | | |
| | TR1 | 210 | 213 | 1.0% |
| | TR2 | 220 | | |
| | TR3 | 210 | | |
| Conventional | CR1 | 250 | 243 | 2.9% |
| | CR2 | 250 | | |
| | CR3 | 230 | | |

Note: 1 psi = 0.0069 MPa

CONCLUSIONS AND RECOMMENDATIONS

Based on the test result presented in this research it is concluded that the TCB system has adequate compression and shear strengths that is equal to or exceed those for masonry built with conventional units. The unique interlocking mechanism of the TCB system provides higher joint resistance to shear slip which results in higher diagonal tension (shear) strength and higher resistance to lateral forces induced from earthquakes, hurricanes and tornadoes. The TCB System provides an attractive alternative to conventional reinforced masonry with bond beams. The elimination of the bond beams saves time and money with the added advantages of the uninterrupted cores for adequate drainage of penetrated water through flashing and weep holes which results in a water resistant single wythe masonry walls.

It is recommended to increase the faceshell thickness of the TCB from 1.25 in. (31 mm) to 1.5 in (38 mm) in order to minimize breakage of the parts on either side of the recess. It is also suggested to make the recess half circle instead of the rectangular shape to eliminate high stress concentration that take place at sharp corners. The proposed configuration for the production mold of the 8 in. (200 mm) TCB is shown in Fig. 8. This details complies with the ACI 530/ASCE 5/TMS 402 code minimum cover for protection of reinforcement.

ACKNOWLEDGEMENT

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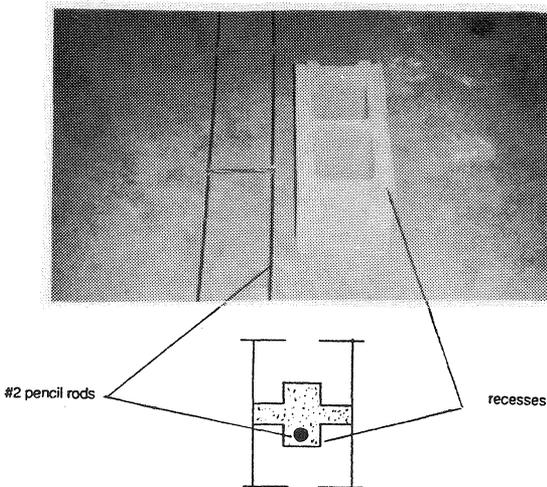


Figure 1. The Theory Concrete Block System

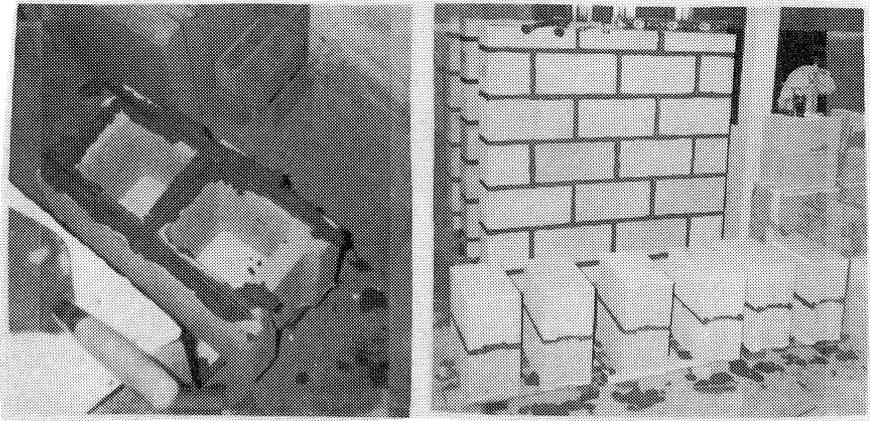


Figure 2. Construction of Masonry Prisms

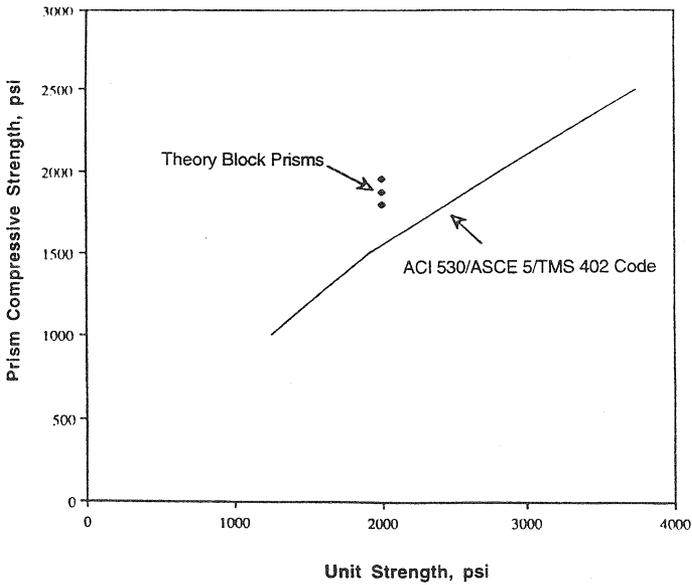
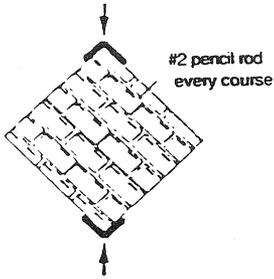
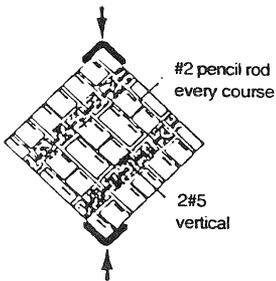


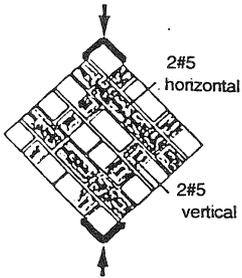
Figure 3. Comparison of Compressive Strength of the Theory Block System with Code Values



I- Theory Block System



II- Theory Block system with vertical steel



III- Conventional Masonry with bond beams

Figure 4. Configurations and Details of Diagonal Tension Panels

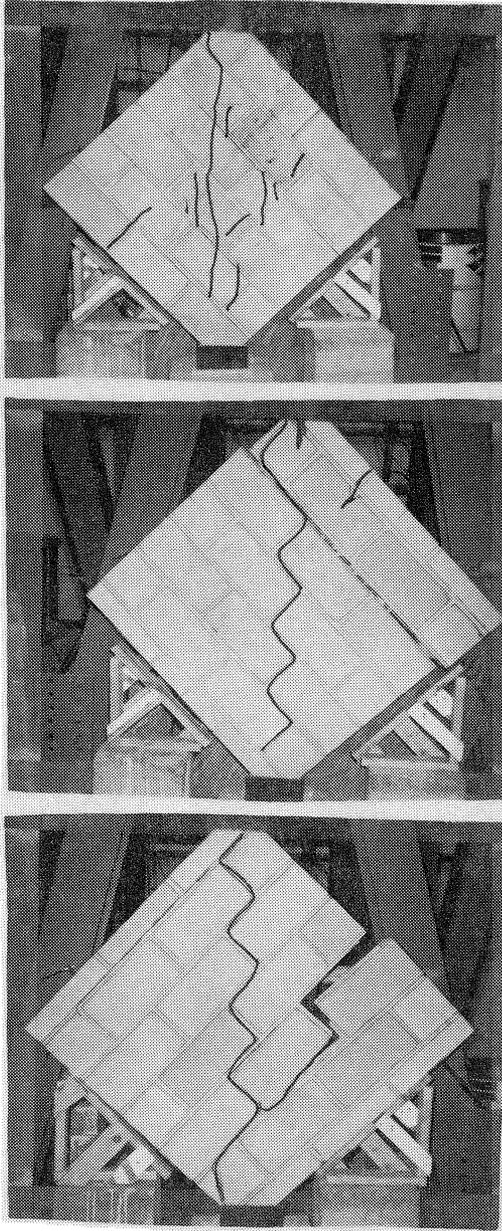


Figure 5. Failure of Diagonally Loaded Panels

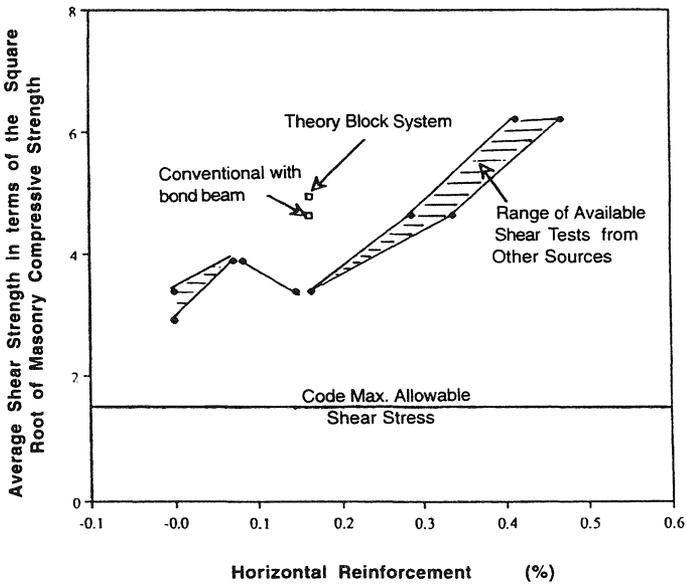


Figure 6. Comparison of Shear Strength of Theory Block System with Conventional Masonry and Allowable Code Values

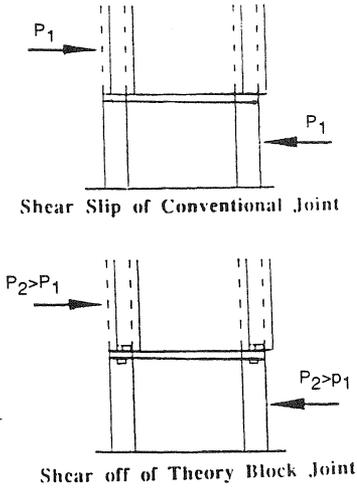


Figure 7. Failure Mechanisms of Mortar Joint Under In-Plane Shear

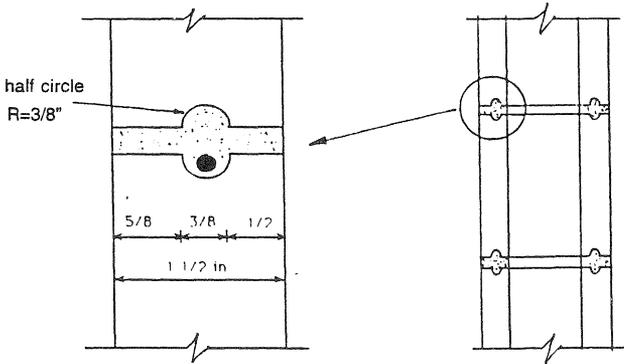


Figure 8. Proposed Configuration of the Production Mold of the 8 in. Theory Block