Development and Evaluation of Hollow Concrete Interlocking Block Masonry System

K. B. Anand[1] and K. Ramamurthy[2]

Traditional masonry construction can be labor intensive and slow due to use of small-sized bricks, which also requires the use of numerous mortar joints. Desire to increase the speed of masonry construction prompted investigations that led to the development of surface-bonded and mortarless masonry using conventional and interlocking blocks. Among these methods, the construction technique adopting interlocking blocks has recently attracted worldwide interest. The geometric features of the individual blocks facilitate interlocking in horizontal and/or vertical directions. This method has significant potential for field adoption due of its inherent advantages such as simplicity in block laying, reduction in mortar consumption and general independence of workmanship variations. Increased output is reported to result in a labor cost reduction of up to 80% [*Hines* (1993)]. Most of the available interlocking blocks vary in geometry, material and dimensional characteristics, and are proprietary systems. Systems can be categorized as those that ensure two-way (vertical and horizontal) interlocking or those that provide only one-way (vertical) interlocking. Many of the developed systems did not progress beyond the design stage because of their intricate configurations [*Crofts* (1993)]. Although a number of interlocking block systems have been reported in the literature, test results on behavioral characteristics are available only for a few of these systems. Classification and a consolidated review of existing systems of interlocking block masonry have been made by *Ramamurthy and Nambiar* (2004). Solid or nearly solid systems like Ytong block [*Sahlin* (1971) *Oh* (1994)], the TASTA system, [*Jasma*(1991), the *Sparfill* system [*Gazzola* (1989)], and the SILBLOCK system [*Anand and Ramamurthy* (2000)] have the limitation that they cannot be adapted to seismic applications. Some of the systems that enable reinforcing and have been recommended for adoption in earthquake resistant construction are Mecano system [*Gallegos* (1988)], the Haener system, [*Drysdale and Gazzola* (1991)], the Modified H-block system [*Harris* (1992) and *Hamid, Harris, and Oh* (1993)], the WHD block system [*Harris* (1992) and *Hamid, Harris, and Oh* (1993)], Azar block [*Technical brochure* 1998)], Faswall system and the IMSI system [*Vander Werf* (1999)].

RESEARCH SIGNIFICANCE

Many of the interlocking block systems do not have effective physical interlocking features and some have very complex shapes. Such intricacies in block geometry (tongue and groove, projecting nibs, and dovetail arrangement) necessitate highly sophisticated production techniques and machinery. In addition, as majority of the hollow interlocking blocks are closed-cell units, the construction of vertically reinforced masonry requires the block units to be lifted over the top of the vertical reinforcement. Such required lifting indirectly leads to usage of relatively short reinforcing bar lengths thereby requiring frequent splicing. In order to overcome the above shortcomings, it was felt essential to develop a system of simple hollow interlocking block masonry and study its performance characteristics with different construction methods.

DEVELOPMENT OF HOLLOW INTERLOCKING BLOCK SYSTEM

Criteria for Design

From the above discussion, the following design criteria were established for the development of system, namely, (i) two-way interlocking in both vertical and horizontal directions, (ii) minimum number of basic blocks in the system, (iii) open-ended unit for ease in construction when reinforced in the vertical direction, (iv) core and web alignment in the system without taper of web and face shells and (v) adequate cell size to provide ease in grouting and adequate cover over reinforcement.

Features of IITM-HILBLOCK System

The dimensional details of the stretcher, jamb and corner units of IITM-HILBLOCK (Hollow Inter-Locking BLOCK developed at Indian Institute of Technology Madras) system developed satisfying the above criteria are shown in Figure 1. Though the individual block as such is not hollow, the uniqueness of the system design is such that, when assembled with staggered bed joints on the inner and outer faces, completely self-aligning hollow cores (30% hollow) are formed. The salient feature of this

---

[1] Assistant Professor at N.S.S. College of Engineering, Palakkad-678008, India. His current research area is accelerated masonry construction.

[2] Professor in Building Technology and Construction Management Division, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai-600 036, India. He has been involved in research on Structural Masonry for the past 15 years. His research interests include analytical and experimental investigations on unreinforced, reinforced and interlocking block masonry. (Corresponding Author) E.mail: vivek@iitm.ac.in

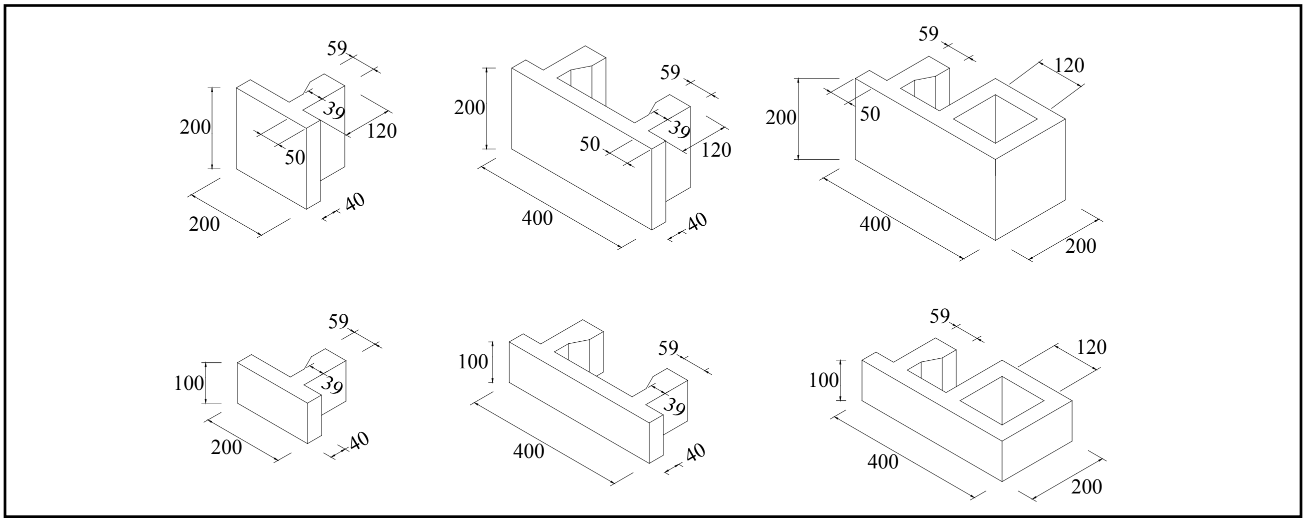


Figure 1—Dimensional Details of HILBLOCK

system is the single type of corner unit that allows formation of *T*, *L* and cruciform wall joints by placing it in the appropriate orientation in each layer. Typical corner details of L and cruciform wall system are shown in Figures 2(a) and 2(b) respectively.

The HILBLOCK system can be adopted for ungrouted or partially/fully grouted (that is either plain (non-reinforced) or reinforced with vertical and/or horizontal reinforcement) construction. HILBLOCK masonry facilitates grouting to cater to structural requirements although grouting is not required for constructional stability. Because the block has an open-ended side, it can be laterally placed around vertical reinforcing steel rather than having to be lifted over such reinforcement as is required with other systems. Thus frequent splicing of vertical reinforcement is not needed, thereby reducing labor and material costs. Though this paper deals with the behaviour of unreinforced masonry, typical detailing for placing vertical and horizontal reinforcement is shown (Figures 3a and 3b) in order to illustrate the potential features of the system. Horizontal reinforcement with the aid of bars bent to match the shape of the core, followed by grouting of the course/layer provides the system equal efficiency in resisting lateral loads acting on either face of the wall.

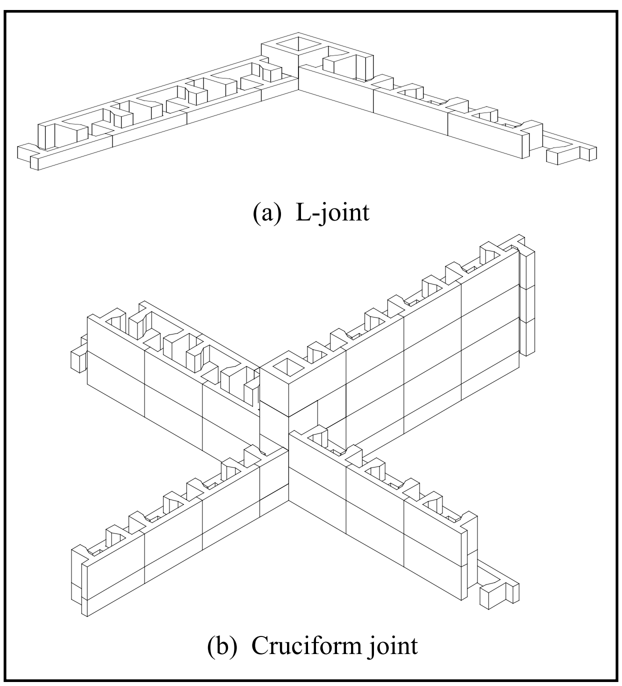


Figure 2—Typical Corner Detail

EVALUATION OF STRUCTURAL PERFORMANCE

Evaluation of the structural performance of the system was undertaken to study the performance of unreinforced (ungrouted and grouted) HILBLOCK masonry under concentric, eccentric, and flexural loading. The scope of the study was restricted to small specimens, such as masonry prisms subjected to concentric and eccentric compression, and wallettes under flexural loading. The required number of blocks was cast using a semi-mechanized process, adopting one mix of concrete.

Behavior Under Concentric Compression

Ungrouted specimens: Three-course high prisms (with a *h*/*t* ratio of 3) were dry-stacked, capped and, after curing, tested under axial compression in accordance with ASTM C 1314-97. The ratio of ultimate prism strength to the average block strength (efficiency factor) is given in Table 1. The dry-stacked HILBLOCK masonry exhibits high efficiency factors (0.62 - 0.68) similar to conventional concrete block masonry, and higher efficiency factors than that of brick masonry (0.3 - 0.4, wherein the failure is initiated by vertical splitting of bricks due to biaxial tensile stresses caused by the bedding mortar) [*Drysdale, et al.* (1994)]. Though the dry-stacked HILBLOCK masonry

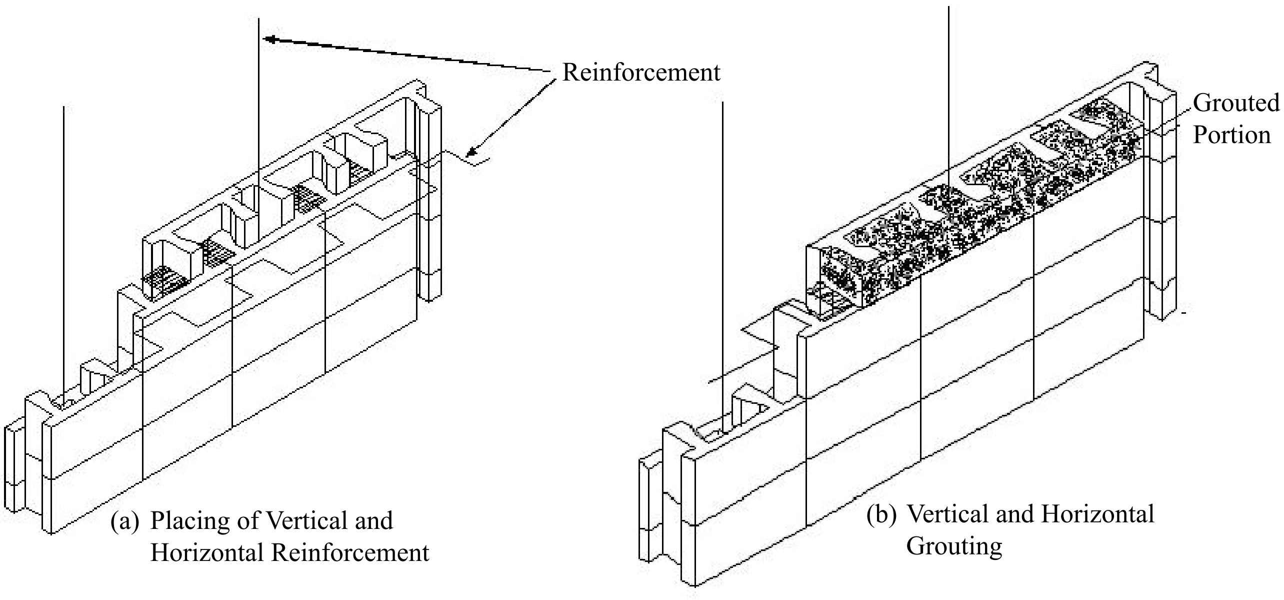


Figure 3—Details of Partially Grouted Masonry

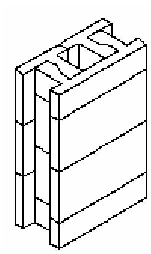
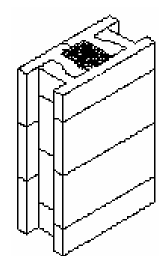
resulted in a higher efficiency factor, the final failure was by a combination of block crushing and splitting caused by the minor unevenness of the block surfaces.

In order to further enhance the efficiency factor by ensuring uniform seating between block surfaces of successive layers, a thin-jointed HILBLOCK masonry was attempted. Cement-fine sand mortar of proportion 1:3 was laid with a scoop on the top surface of the block that had already been laid. The next layer of block was then placed and any excess mortar was forced out of the joint due to the self-weight of the block. The resulting mortar bed joint thickness was 2 to 3 mm thick. Compressive strength results show that a higher efficiency factor of about 0.85 was observed for the thin-jointed HILBLOCK masonry as compared to dry-stacked masonry. Failure was predominantly by crushing.

Grouted specimens: Both dry-stacked and thin-jointed prism specimens were grouted as per the guidelines of ASTM C 476-95 using coarse grout with water-cement ratio adjusted to obtain a slump of 240 mm. The grout had a block-molded compressive strength (tested as per ASTM C 1019-89a16) of 11.84 MPa using 90 x 90 x 180 mm prisms. As the grout strength was compatible with block strength, the capacities of grouted HILBLOCK

Table 1. Specimen Details and Test Results of Axial Compression

Block strength = 10.71 MPa Grout strength = 11.84 MPa

Description		Type of construction			
		Ungrouted		Grouted	
Specimen size -	400mm long; 600mm high				
Type of bedding		Dry-stacked	Thin-jointed	Dry-stacked	Thin-jointed
Prism strength on net area (MPa)	Mean of 6 specimens	6.69	8.84	7.28	9.15
	CoV	0.126	0.093	0.089	0.077
Efficiency factor (Prism/block strength)		0.62	0.83	0.68	0.85
Allowable stresses on gross area (MPa)		1.25	1.66	1.66	2.08
CoV = Coefficient of variation					

prisms were closer to superposed capacities of a hollow prism and a grout column formed in the cells. Testing some of the grouted specimens indicated that the grout infill remained intact, despite failure of the block shells. The grouted specimens also resulted in a higher efficiency factor when the prisms had a thin mortar bedding rather than simply dry-stacked (Table 1).

Allowable stresses on gross cross-sectional area of HILBLOCK masonry has been proposed (Table 1) by applying a modification factor for the *h*/*t* ratio of the prism ([*ACI 530 ACI 530/ASCE 5/TMS 402* (1999)] which uses, for *h*/*t* = 3, a multiplication factor of 1.07) and a factor of safety of 4. It is observed that, the HILBLOCK masonry provides adequate compressive strength values as compared with the allowable compressive stresses for empirical design [*ACI 530/ASCE 5/TMS 402* (1999)] of conventional masonry.

Behavior Under Eccentric Compression

Dry-stacked and thin-jointed prisms (ungrouted and grouted) with an *h*/*t* ratio of 3 were constructed with HILBLOCK. Test results of prisms subjected to compressive loading applied at eccentricities of 0, *t*/6, and *t*/3 (equal both at top and bottom) for 'hinged end condition' (*t* = thickness of specimen and *e* = eccentricity of the applied load in the thickness direction with respect the center line of specimen as shown in Table 2. For ungrouted prisms, failure was initiated by vertical opening at the junction of the web and the face shell, prior to face shell splitting. For grouted prisms tested with an eccentricity of *t*/6, failure on the compression face occurred along with tensile separation at the joints on the tension side of the specimen. At an eccentricity of *t*/3 separation along the joints on the tension side preceded the crushing failure on the opposite side. Most of the cracks were observed along lines corresponding to the grout core on the compression face shell. As prisms failed gradually, a large portion of the face shell separated from the grout.

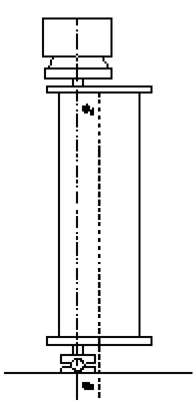
Test results in Table 2 show, as expected, i) decreasing capacities associated with increasing eccentricities, and ii) reduction in capacity of hollow prisms at higher eccentricities is not as pronounced as that of grouted masonry. Figures 4a and 4b show the capacity reduction factor (ratio of eccentric to axial capacity) obtained from tests on HILBLOCK masonry (both dry-stacked and thin-jointed) for the ungrouted and grouted cases respectively, along with the test results of *Drysdale and Hamid* (1983) 18 (applicable for short specimen without consideration of slenderness effects). The reduction in load carrying capacity under eccentric loading for both ungrouted and grouted HILBLOCK masonry is less than that of conventional hollow and grouted block masonry. The relatively high capacity of HILBLOCK masonry is attributed to the flexural and frictional resistance between interlocking shells prior to failure, whereas the failure in conventional masonry is governed by the bond failure at mortar-block interface on the tension face.

Flexural Behavior

Because the construction of interlocking block progresses with insertion/sliding of the units, a certain amount of tolerance is essential between the interlocking shells. The tolerance to be provided in manufacture will depend on the degree of surface finish that can be obtained in

Table 2. Specimen Details and Test Results of Eccentric Compression

Block strength = 10.71 MPa   Grout strength = 11.84 MPa

Loading Arrangement	Type of Construction		Ultimate load at eccentricity of					
			e = 0		*e* = t/6		*e* = t/3	
			Mean* (kN)	CoV	Mean* (kN)	CoV	Mean* (kN)	CoV
	Dry stacked	Ungrouted	360	0.138	273	0.082	195	0.094
		Grouted	555	0.054	398	0.069	235	0.11
	Thin-jointed	Ungrouted	510	0.089	428	0.056	308	0.063
		Grouted	690	0.117	556	0.074	342	0.07
* Mean of 6 specimens; CoV = Coefficient of variation								

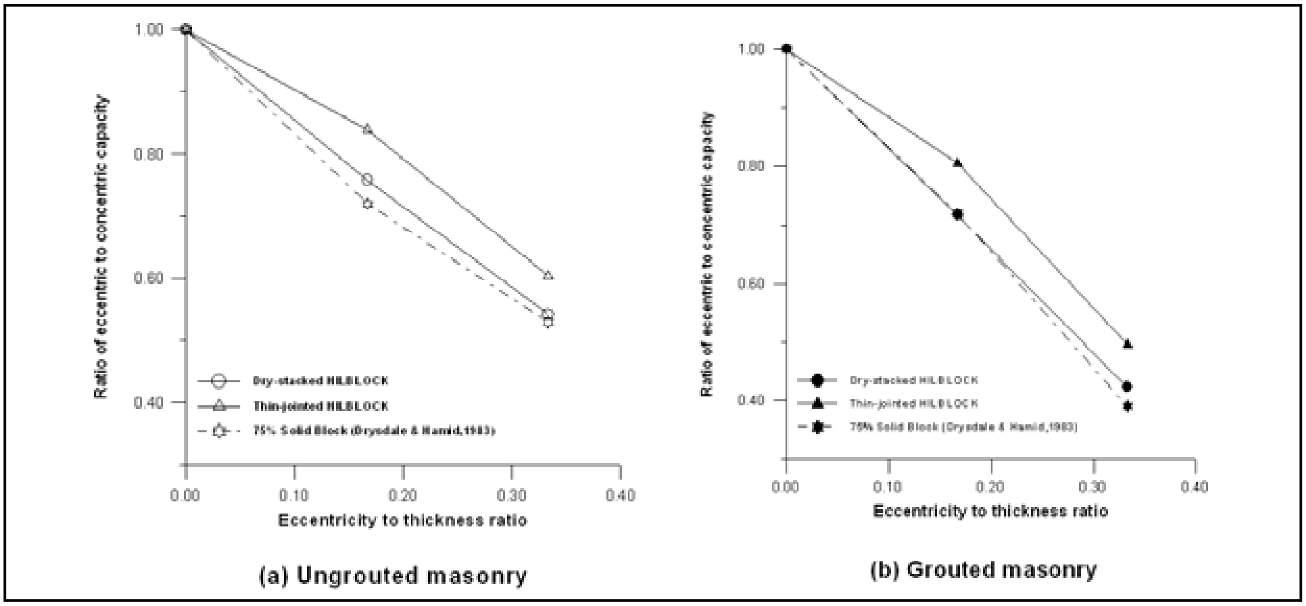


Figure 4—Influence of Construction Method on Capacity Reduction Under Eccentric Compression

molding. In the present investigation a tolerance of 1mm has been provided. This lack of fit results in play in the system and influences the failure mode of masonry, especially under flexure.

In order to overcome the effect of play, surface finishing of the masonry can be provided, which is also beneficial from a rain penetration resistance point of view. Alternatively, the thin-jointed construction procedure suggested also aids in overcoming the effect of play. Surface finishing alternatives such as flush pointing, stucco mortar finish, or plastering indicated that the play resulting from the lack of fit can be restrained.

Based on the supporting conditions, walls without pre-compression are classified as (i) spanning vertically (failure is due to tensile stress normal to bed joint) and (ii) spanning horizontally (failure due to tensile stress parallel to bed joint). For the assessment of flexural strength with bending parallel to bed joints, the flexural load is applied through two rods parallel to the bed joints (Figure 5(a)). For assessing the strength with bending perpendicular to bed joints, the load is applied through two rods normal to the bed joints (Figure 5(b)). Wallette specimens of 800mm long and 800 mm high were constructed for testing under flexural load under two-point loading (at one-third points) applied perpendicular to the bed joints. Wallettes of 1,200 mm long and 800 mm high were used for the flexural loading parallel to the bed joints.

Tests were undertaken on i) ungrouted wallettes without and with surface finishing (plastering and stucco), and ii) grouted wallettes (for loading parallel to the bed joints, the central vertical core of the wallette was grouted, whereas for loading normal to the bed joints, the central horizontal course of 100 mm depth was grouted), as described in Table 3. As these wallettes were unreinforced, the wallettes were tested in a vertical position in a wallette flexure test frame (as recommended in BS 5628) to overcome possible damage due to self-weight if placed and tested horizontally (Figure 5). The flexural strength presented in Table 3 is based on the gross cross-sectional area at the failure plane, even though the net area resisting failure is only part of the cross section (due to the bed joint and cross joint discontinuity from outer to inner face). For this case, the flexural strength = M/Z, where M is the maximum bending moment, $Z = bd^2/6$ (section modulus based on gross cross section at the failure plane), where b (length of failure plane) = 800 mm for both cases of loading, and d (depth of failure plane) = thickness of masonry = 200 mm.

The proposed permissible flexural stresses for HILBLOCK masonry equals the ultimate flexural strength of wallette divided by 3 (i.e. the conventional factor of safety value for flexure).

Specimen without surface finish: Unlike conventional masonry, the HILBLOCK masonry exhibits higher flexural resistance for loading parallel to bed joints than loading normal to bed joints. The ultimate strength of a wall loaded parallel to bed joints is governed by i) flexural resistance offered by the longitudinal cross section of the HILBLOCKs due to staggered bed joint arrangement, ii) friction between interlocking shells and iii) stress transfer through contact bed surfaces of the successive blocks on the compression face. The ultimate strength of a wall loaded normal to bed joints, however, depends only on the flexural resistance offered by the transverse section of the shell (with lesser effective area) of HILBLOCK. The flexural strength of ungrouted HILBLOCK masonry is higher for the thin-jointed case as compared to dry-stacked

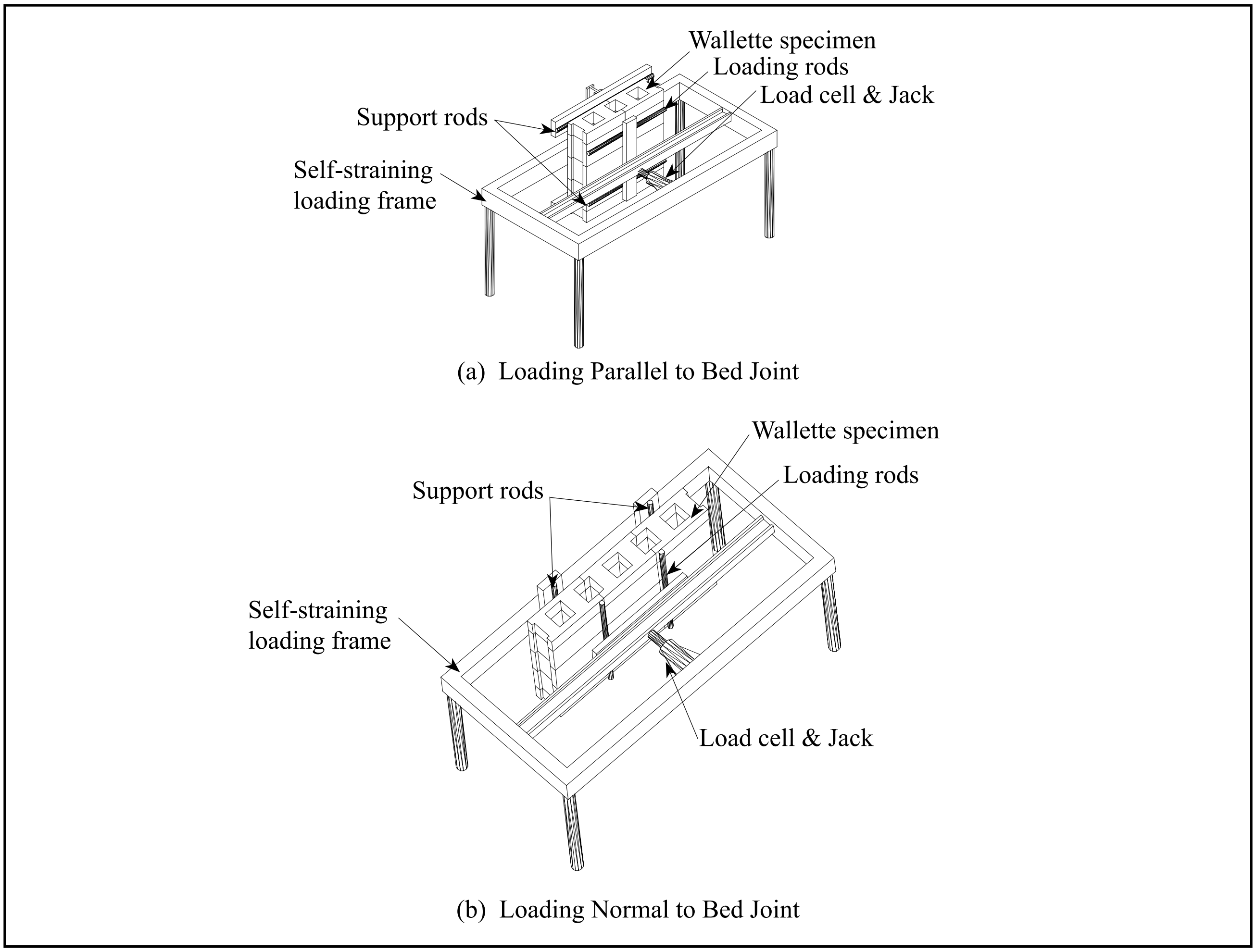


Figure 5— Details of Flexural Load Testing

specimens. This is due to the uniform stress transfer at the contact bed surface on the compression face when the loading is parallel to bedding, and the bond strength at bed joints delaying the failure for the case of loading normal to bedding.

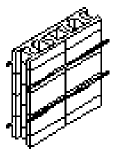
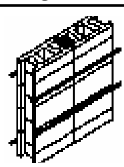
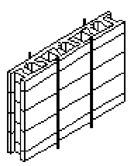
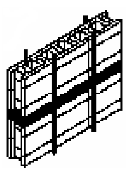
The grouted HILBLOCK masonry also exhibited relatively higher flexural strength for loading parallel to bed joints than loading normal to bed joints. The enhancement in strength due to grouting is marginally higher for loading normal to bed joints than loading parallel to bed joints. The improvement in flexural strength with grouting is higher for dry-stacked masonry as compared to thin-jointed masonry. In ungrouted dry-stacked masonry, minor seating adjustments occur before the interlocking mechanism is developed and grouting makes the specimens act more monolithically.

A comparison of allowable flexural stresses of conventional masonry as per [*ACI 530/ASCE 5/TMS 402* (1999)] is made with that of HILBLOCK masonry (using a factor of safety of 3) in Table 3. For loading parallel to bed joints, the permissible stress of HILBLOCK masonry is higher than that of conventional masonry (wherein the failure is governed by the bond strength between the mortar and block), while for loading normal to bed joints it is comparable with the code values.

Specimens with surface finish: Generally the studies on flexural behavior of conventional masonry are confined to unplastered masonry. The code provisions are for unplastered masonry while specifying the permissible flexural stresses. It is a common practice in many countries to provide surface finish to masonry walls. Earlier studies [*Radhakrishnan and Ramamurthy* (1995)] and [*Rajasekhar and Ramamurthy* (1996)] have indicated that plastering enhances the flexural bond strength of concrete hollow block masonry as well as brick masonry. In view of the above, the influence of the following two types of surface finishing on both sides of ungrouted dry-stacked HILBLOCK masonry were studied: (i) conventional 10 mm thick cement mortar plastering (1:5 cement-sand), and (ii) a 6mm thick layer of stucco mortar 1:3 cement-fine sand slurry sprayed on to the surface of masonry using a stucco gun. Comparison of allowable flexural stresses arrived at based on test results are presented in Table 3. Plastering with medium strength mortar as well as sprayed stucco mortar enhances the flexural strength over that of masonry without surface finish. This increase is introduced by the tensile strength of the surface finishing mortar. The

Table 3. Specimen Details, Test Results and Comparison of Allowable Stress in Flexure

Block strength = 10.71 MPa — Grout strength = 11.84 MPa

Test details	Type of surface finish	Ultimate strength (MPa) (Mean of 3 specimens each)		Permissible flexural stresses (MPa)			
				HILBLOCK masonry		Conventional concrete hollow block masonry	
		Type of bedding		Present study		ACI 530	
		Dry-stacked	Thin-jointed	Dry-stacked	Thin-jointed	Type N mortar (Cement/ lime)	Type N mortar (Masonry cement)
Loading parallel to bed joint							
 Ungrouted	Pointed	0.54	0.73	0.18	0.24	0.13	0.062
	Stucco (6mm)	0.68	0.89	0.23	0.29		
	Plaster (10mm)	0.72	0.97	0.24	0.32		
 Grouted	Pointed	0.79	0.90	0.26	0.30	0.2	0.1
Loading normal to bed joint							
 Ungrouted	Pointed	0.31	0.51	0.10	0.17	0.26	0.13
	Stucco (6mm)	0.40	0.68	0.13	0.23		
	Plaster (10mm)	0.46	0.73	0.15	0.24		
 Grouted	Pointed	0.49	0.66	0.16	0.22	0.28	0.14

surface finishing helps in improving the performance of ungrouted HILBLOCK masonry (especially dry-stacked case) towards meeting the code requirement.

CONCLUSIONS

IITM-HILBLOCK Masonry system developed and proof-tested exhibits efficient structural behaviour similar to conventional mortar-bedded hollow concrete block masonry. The following conclusions have been drawn from the study on HILBLOCK masonry, and they are applicable to the range of parameters investigated.

1. Both ungrouted and grouted HILBLOCK masonry exhibited higher efficiency factors under concentric compression compared to conventional mortar bedded masonry (reported in literature).
2. The relatively higher capacity of HILBLOCK masonry under eccentric compression is attributed to the flexural and frictional resistance between interlocking shells prior to failure, whereas the failure in conventional masonry is governed by the bond failure at mortar-block interface on the tension face.
3. Unlike conventional masonry, the HILBLOCK masonry had higher flexural resistance for loading parallel to bed joints than loading normal to bed joints due to staggered bed joints.
4. The permissible stresses of ungrouted HILBLOCK masonry for loading parallel to bed joints is around 140% higher than conventional masonry, while for loading normal to bed joints, it is comparable with the code requirement for conventional masonry.

ACKNOWLEDGMENTS

This study is a part of the sponsored research project funded by the Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Employment and Poverty Alleviation, Government of India, New Delhi. The financial support provided by the BMTPC is gratefully acknowledged.

REFERENCES

Hines,T., "*Benefits of Drystack Interlocking Concrete Masonry as A Component of Cost Effective Construction*," Proceedings of the Sixth North American Masonry Conference, Philadelphia, Pennsylvania, pp. 849-861, June 1993.

Crofts, F. S., "*State of the Art of Mortarless Concrete Masonry in South Africa*," Proceedings of the Sixth North American Masonry Conference, June, Philadelphia, Pennsylvania, pp. 875-884, June 1993.

Ramamurthy, K., and Nambiar, E. K. K. "*Accelerated Masonry Construction: Review and Future Prospects*," Progress in Structural Engineering and Materials, V.6, No.1, pp 1-9, January-February 2004.

Anand, K.B. and Ramamurthy, K., "*Development and Performance Evaluation of Solid Interlocking Block Masonry Construction*," Journal of Architectural Engineering, ASCE, V.6, No.2, pp. 45-51, 2000.

Sahlin, S., "*Structural Masonry*," Prentice-Hall, Englewood Cliffs, N.J., 1971.

Oh, K. H., "*Development and Investigation of Failure Mechanism of Interlocking Mortarless Block Masonry Systems*," Ph.D thesis, Drexel University, Pennsylvania, U.S.A, 1994.

Jasma, P. H., "*Tasta-Quick Building System With Cellular Concrete Blocks-Revolution or Elementary Way of Thinking?*," Proceedings of the Ninth International Brick/Block Masonry Conference, Berlin, V. 2, pp. 1034-1041, October 1991.

Gazzola, E. A. and Drysdale, R. G., "*Strength and Deformation Properties of Dry-Stacked Surface Bonded Low Density Block Masonry*," Proceedings of the Fifth Canadian Masonry Symposium, Vancouver, Canada, pp. 609-618, June 1989.

Gallegos, H., "*Mortarless Masonry: The Mecano System*," International Journal of Housing Science and its Applications, V.12, No.2, pp.145-157, 1988.

Drysdale, R. G. and Gazzola, E. A., "*Strength and Deformation Properties of a Grouted, Dry-Stacked, Interlocking, Concrete Block System*," Proceedings of the Ninth International Brick/Block Masonry Conference, Berlin, V. 1, pp. 164-71, October 1991.

Harris, H. G., Oh, K. H. and Hamid, A. A., "*Development of New Interlocking Block Masonry Units for Efficient Building Systems*," Proceeding of Sixth Canadian Masonry Symposium, Saskatchewan, Canada, pp. 723-734, June 1992.

Oh, K. H., Harris, H. G. and Hamid, A. A. "*New Interlocking and Mortarless Block Masonry Units for Earthquake Resistant Structures*," Proceedings of the Sixth North American Masonry Conference, Philadelphia, Pennsylvania, pp.821-836, June 1993.

VanderWerf, P., "*Mortarless Block Systems*," Masonry Construction, pp. 20-24, February, 1999.

ASTM C 1314-03b, "*Standard Test Method for Compressive Strength of Masonry Prisms*," American Society for Testing of Materials, Philadelphia, 2005.

Drysdale, Robert G., Hamid, Ahmad A. and Baker, Lawrie R., "*Masonry Structures: Behavior and Design*," Second Edition, Boulder, Colorado, The Masonry Society, 1999.

ASTM C 476-02, "*Specification for Grout for Masonry*," American Society for Testing of Materials, Philadelphia, 2005.

ASTM C 1019-05, "*Test Methods for Sampling and Testing Grout*," American Society for Testing of Materials, Philadelphia, 2005.

Masonry Standards Joint Committee, *Building Code Requirements for Masonry Structures*, ACI 530-02/ASCE 5-02/TMS 402-02, American Concrete Institute (ACI), Farmington Hills, MI, American Society of Civil Engineers (ASCE), Reston, VA, The Masonry Society, Boulder, CO, 1999.

Drysdale, R. G. and Hamid, A. A., "*Capacity of Concrete Block Masonry Prisms Under Eccentric Compressive Loading*," ACI Journal, Proceedings V.80, No.11, pp.102-108, 1983.

BS 5628 Part-1, "*Code of Practice for Structural Use of Masonry, Part-1: Unreinforced Masonry*," British Standards Institution, London, 1978.

Radhakrishnan, R. and Ramamurthy, K., "*Influence of Plastering on Flexural Bond Strength of Concrete Block Masonry*," Proceedings of CONCET 95, Fourth International Conference on Concrete Engineering and Technology, The Institution of Engineers MALAYSIA (IEM), pp.6-8, June 1995.

Ramamurthy, K. and Rajasekhar, G., "*Flexural Strength of Concrete Hollow Block Masonry*," Jl. of the Institution of Engineers (India), Civil Engineering Division, V.77, pp.29-33, 1996.

Technical Brochure, Azar Dry-Stack Block, Azar Group of Companies, Ontario, Canada, 1998.

NOTATIONS

b	=	length of failure plane.
d	=	depth of failure plane.
e	=	eccentricity of the applied load in the thickness direction with respect the center line of specimen.
h	=	height of masonry prism.
M	=	the maximum bending moment.
t	=	Thickness of masonry specimen.
Z	=	section modulus based on gross cross section at the failure plane.