Seventh Canadian Masonry Symposium
McMaster University
Hamilton, Ontario

June 4-7, 1995

A BRIEF INTRODUCTION TO "THE SHANGHAI DESIGN CODE FOR BUILDINGS OF HOLLOW CONCRETE BLOCKS"

Zhang Guanfu[1], Liu Yongfeng[2] and Liu Jifen[3]

ABSTRACT

The applications for hollow concrete blocks in the Shanghai area and an abstract of the "Design Code for Buildings of Hollow Concrete Blocks" are presented.

SURVEY OF APPLICATION

In 1987, the General Housing Group in Shanghai introduced a production line from Europe which could manufacture 5.2 million concrete blocks per year. The line began production that same year. The main dimensions of the blocks are 390×190×190mm (16×8×8 in.). Since 1987 we have successfully designed more than 30 masonry buildings using these concrete blocks. Designs include multi-storey office buildings, masonry buildings with first-storey frames, residential buildings, educational facilities, commercial buildings and buildings used for storage. By the end of 1994, floor space of buildings constructed from masonry had nearly reached 200,000 m^2. Now concrete blocks are popular in large-scale housing construction.

1 Chief Engineer, Vice-President, China Housing Shanghai Architectural Design Institute, No. 1293 Lujia Bang Rd., Shanghi, 200011, China

2 Vice-President, Senior Engineer, the same as above

3 Chief Architect, the same as above

ASPECTS OF THE DESIGN CODE

In order to promote continued design of buildings using concrete blocks in the Shanghai area, we published "The Shanghai Design Code for Buildings of Concrete Block". This publication summarizes the experience of engineering practice in the Shanghai area and draws on advanced Chinese techniques. The Code covers the following topics: general discussion, materials, basic design requirements, loadbearing-capacity calculation, earthquake resistance verification, structure construction and architectural design. The following is a brief introduction to earthquake design, crack-resistance design and architectural design of concrete block buildings.

STATIC CALCULATION AND EARTHQUAKE RESISTANCE VERIFICATION

Routine methods are used in the static calculation of buildings of concrete block. Some main principles on earthquake resistance verification are introduced as follows. According to the standards published by the National Earthquake Bureau, the seismic intensity in a great part of the Shanghai area is 7 (roughly equal to 0.1 g), while in the other parts it is 6. The method of horizontal seismic-action calculation for multi-storey buildings of concrete block prescribed in the code is the base shear method, which requires checks in two principal directions.

Total horizontal seismic action at the base of the structure is expressed as follows

$$F_{Ek} = \alpha_1 \, G_{eq} \tag{1}$$

where:

- F_{Ek} - Characteristic value of total horizontal seismic action on the structure.
- α_1 - Influence coefficient of horizontal seismic action corresponding to the natural period of vibration of a structure. For buildings of concrete block, the value of α_{max} shall be used. (i.e. where earthquake intensity is 7, $\alpha_{max} = 0.08$).
- G_{eq} - Total equivalent gravity load on the structure. When it is a single mass-point system, the representative value of the total equivalent gravity load shall be used. When it is multi mass-point system, 85% of the above-mentioned representative value shall be used.

Total seismic force is distributed linearly along the height of the structure. Then, in the longitudinal and transverse directions respectively, the assigned seismic action (force) on a certain floor is distributed on each masonry wall in proportion to its relative lateral stiffness (flexural, shear or both).

The earthquake resistance capacity of concrete block with reinforced cells should be verified as follows

$$V \leq \frac{1}{\gamma_{RE}} [f_{VE} A + (0.03 f_c A_c + 0.05 f_y A_s) \zeta] \qquad (2)$$

where:

V - shear design value on the wall section

γ_{RE} - modified coefficient for earthquake resistance capacity

shear wall with reinforced cells at both ends	0.9
self-supporting wall	0.75
other kinds of shear walls	1.0

f_{VE} - design value of the shear strength of a masonry wall when crushed along a stepped section

f_c - design value of the centrally compressive strength of the concrete in reinforced cores

A - horizontal section area of a masonry wall

A_C - the sum of section areas of the reinforced cells

A_S - the sum of section areas of steel bar

ζ - influence coefficient of reinforced cells

Table 1 Influence coefficients for reinforced cells

Ratio of Filled Cores	$\rho<0.15$	$0.15\leq\rho0.25$	$0.25\leq\rho<0.5$	$\rho\geq0.5$
ζ	0	1.00	1.10	1.15

Note: The ratio of filled cores is the ratio of the number of reinforced cores to the total number of cells in a section of masonry wall.

EARTHQUAKE DESIGN

It is pointed out in the code that plan and vertical designs conducive to earthquake resistance should be adopted in the design of concrete block buildings. It is also affirmed that confined masonry structures, with bond beams at each floor and reinforced cells, is an effective approach to increasing the deformation capacity of masonry buildings during earthquakes.

Plan Design

The plan of a structure should be as simple, regular and symmetrical as possible. The center of rigidity should be close to the center of mass. Irregular plans such as Type L, E, T, and π can lead to torsional vibrations. In order to reduce the probability of failures due to weak links and stress concentrations, highly irregular plans should be avoided. The projected length of a plan shall be less than half of the width of the projection.

Distance Between Walls

To transfer lateral seismic forces effectively, the maximum distance between adjacent loadbearing transverse walls is determined in accordance with Table 2.

Table 2. Maximum Distance Between Seismic-Resistant Transverse Walls (m)

Type of Floor and Roof	Seismic Intensity	
	6	7
Cast-in-place or Prefabricated Monolithic Structures	15	15
Precast Reinforced Concrete	11	11
Masonry Loadbearing Walls with First-Storey Frames	25	21

Local Dimensions of Walls

To avoid structural collapse due to local damage of walls during earthquakes, the dimensions of masonry walls should conform to the limits specified in Table 3.

Table 3. Limitations of Local Dimensions of Masonry Walls (m)

Position	Seismic Intensity	
	6	7
Minimum Width of Loadbearing Walls Between Window Openings	0.8	1.0
Minimum Distance Between the Ends of Exterior Bearing Walls and the Edge of Window or Door Openings	0.8	1.0
Minimum Distance Between the Ends of Exterior Nonbearing Walls and the Edge of Windows or Door Openings	1.0	1.0
Minimum Distance Between the Outside Corner of Interior Walls and the Edge of Windows or Door Openings	0.8	1.0
Maximum Height of Unanchored Parapet (Except at the Exit)	0.5	0.5

Notes: When the width of a loadbearing wall between window openings is less than the limitations given above, reinforced cells shall be included in the design and the wall width shall not be less than 600 mm (24 in.).
If the width of walls between window openings is less than 600mm, other measures ought to be taken.

Total Height, Number of Storeys, and Height-To-Width Ratio
To avoid flexural damage of masonry structures, the maximum height-to-width ratio of a building should not be greater than 2.5. The total height and the number of storeys shall comply with Table 4.

Table 4. Height Limitations for Hollow Concrete Block Structures Due To Seismic Intensity and the Number of Storeys

Building Type		Seismic Intensity			
		6		7	
		Total Height(m)	Number of Storeys	Total Height(m)	Number of Storeys
Single-Storey		6		5	
Multi-storey	Masonry	21	7	19	6
	With First-storey Frame	19	6	19	6

Notes: Generally, the total height of a building is the distance from the outdoor ground to the eaves, but for buildings with semibasements it is taken from the basement floor to the eaves.
If the transverse walls are relatively sparse, the number of storeys in Table 4 should be reduced by one storey.

Vertical Rigidity And Mass
The vertical rigidity of masonry shall not change rapidly but gradually. In addition, the rigidity of adjacent storeys should be almost equal and the rigidity ratio must not be greater than 2. Moreover, structures which are rigid in upper storeys and relatively flexible in lower storeys are prohibited in design.

Bond Beam
Bond beams connecting transverse walls and longitudinal walls can ensure structural integrity of a building. They can also increase the seismic-resistance of a building. During earthquakes, bond beams, which are important structural components for seismic-resistance, can effectively control the development of cracks. If the floor or roof is built using prefabricated elements, bond beams shall be set up in every storey and every masonry wall. If the floors and roof are cast in situ and have reliable connections to the walls, bond beams may be omitted. Bond beams shall be placed at the same level as, or closely under the soffit of floors. Bond beams must be enclosed.

Reinforced Cells
Reinforcing cells, which can increase the shear strength of masonry walls by about 10%, can be set in the cells of concrete block. More importantly, the reinforced bond beams

and floors form a common restriction system. This can further increase seismic-resistance. The reinforced cells shall be continuous from the foundation to the roof and the steel bars in the cells shall be anchored into both the bond beam and the foundation. Reinforced cells should be implemented where stress concentrations occur and at other important locations in a building as outlined in Table 5.

Table 5. Requirements of Core-Column Setting

Number of Storeys Seismic Intensity 6	Number of Storeys Seismic Intensity 7	Locations	Number of Reinforced Cells
4,5	3,4	Corners of Exterior Walls, Corners of Bays for Stairs, Intersections of Exterior and Interior Walls of Big Rooms	Reinforce 3 Cells at Corners of Exterior Walls and Fill 4 Cells at Intersections of Exterior Walls and Interior Walls
6	5	Corners of Exterior Walls, Corners of Bays for Stairs, Intersections of Gable and Interior Longitudinal Walls, Every Other Intersection of Exterior Walls and Interior Walls	
7	6	Corners of Exterior Walls, Corners of Stair Bays, Intersections of Exterior and Interior Walls	Reinforce 4 Cells of Exterior Walls, 4 Cells at the Intersections of Interior Walls and Exterior Walls and 3 to 5 Cells at the Inter-section of Interior Walls

Connection of Structural Elements

In order to prevent various structural elements from separating or tilting during an earthquake, the connections between various parts of the building such as the reinforced cells and walls, frame columns and masonry infills, floor slabs and walls or beams, bearing walls and partition walls, cantilever components (such as parapets or handrails) or other nonstructural components and the main structure shall be reliable. Steel bars shall be used to connect them strongly and effectively.

CRACKING RESISTANCE DESIGN

In the Code, the measures to avoid and reduce cracking of hollow concrete block masonry are described in the following sections.

Measures Against Cracks Induced By Imposed Loads
In order to ensure the uniform distribution of loads, it is desirable to use blocks and mortars with rational strength grades. The key to reducing cracks of this kind is to control the stress in uncracked zones. The main specific requirements are as follows: 1. The strength grade of mortar shall not be less than 5MPa (0.725 ksi). 2. The openings of the hollow concrete block under the soffit of the main beams, secondary beams and cantilever beams are to be filled with concrete to form a pad-like solid support, which is 400 to 800 mm in length and 1 to 3 courses of blocks in height. Otherwise, bearing plates are to be used.

Measures to Reduce Cracks Caused By Differential Settlement of the Foundations
In structural design, attention should be given to the uniformity of a structure's rigidity. It is preferable that there be few recesses or changes in building width in a structural plan, the dimensions of which should not be too large. If the imposed loads or plan shape of one part of a structure is significantly different from other parts of the structure, movement joints should be used to separate the different part from the rest of the structure. To ensure the integrity of a structure, it is necessary to establish a sufficient number of bond beams and reinforced cells to strengthen the rigidity of the foundation beams, and to strictly control settlement of the foundations. Necessary ground treatments are required for defective soil stratum where very soft foundation soil, rivers, ancient river courses or liquescent sand layers are discovered. Otherwise, pile foundations are to be used. It is preferable to place horizontal mesh reinforcement over all the length or to set up overall length sill beams under the soffit of the sills of external walls. For spandrel beams on the first floor and for basement walls, solid block masonry is required.

Measures To Reduce Drying Shrinkage Cracks
It is important to control the relative water content of the block within the range of 40% to 50%. Wet blocks shall not be used in block buildings. During the rainy season, waterproof facilities should be provided and blocks are not allowed to be placed instantly on the rain-wetted masonry. To improve the water resistance of blocks, joints are to be pointed in original mortar in summer. Work with internal and external plaster is to be done after complete drying shrinkage of the masonry walls has occurred.

Measures to Reduce Temperature Cracks
The roof of a building should be designed as a sloping roof. The maximum length of a building with cast in situ roof is 40 m. It is necessary that thermal insulation be used. In order to reduce temperature cracks on the top floor of a building with a flat roof, the main measures adopted are as follows: 1. Reinforced concrete sill beams are to be placed under the soffit of the sills on the top floor. 2. On both sides of a window or door openings on the longitudinal walls of the first bay on the top floor, reinforced cells

are to be used and the steel bars are to be imbedded in the top and bottom bond beams. 3. 4 mm diameter full length horizontal mesh reinforcement shall be placed in the gable of the top floor at a vertical spacing of 600 mm. 4. The above-mentioned mesh reinforcement shall be placed in the internal walls (longitudinal only) of the first bay on the top floor at the spacing of 600 mm. 5. It is desirable to use the supported heat insulating layer and the heat reserving layer simultaneously on the roof. 6 The internal plastering is to be done only after setting the thermal insulation is completed. 7. The strength grade of the mortar under the soffit of roof slabs may be lower. 8. The strength grade of the mortar in the masonry walls on the top floor shall be increased.

Measures To Reduce Cracking Due to Defective Block Products And Nonconforming Construction

Full curing shall be given to the block products before delivery to ensure the required design strength. The quality of block products shall conform to standards of product quality. When the products are to be delivered, a certificate of quality and test reports shall be provided. Builders who undertake the work of construction of masonry buildings should have experience in this field and do the job in strict accordance with the operating rules. When a building of concrete block is under construction or in use, unapproved drilling or cutting of holes and chases is strictly prohibited.

ARCHITECTURE DESIGN

Plan Design

Designers should try to make the plan of a building regular and succinct, while still satisfying all of the demands of the building's intended function. Walls and columns should be designed to be plumb and aligned over the height of the building and coigns should be avoided whenever possible. The dimensions of the plan should be in accordance with the module of 100 mm. If this requirement cannot be met, some kind of abnormal concrete blocks and in situ concrete forming will be implemented to fill up the spaces.

Roof Design

The reinforced concrete roof is greatly influenced by the weather. If the deformations caused by temperatures can't be dealt with properly, stresses occur in the roof. As a result, the masonry walls will crack. Therefore, designers should try to use a prefabricated roof in roof design, and to set slipping layers under the roof and thermal insulation on the roof. If stresses are allowed to develop on a roof, the great horizontal stress can cause cracking of the masonry. To avoid this, expansion joints shall be set between the ends of precast slabs at a spacing of 6 m (20 ft.) in the two principal direction. This means that the entire roof is divided into several small parts and each part can deform freely. In a word, the most important principle in roof design is to reduce temperature stresses.

Design of Sound Insulation and Thermal Insulation

In the design of masonry residential buildings in the Shanghai area, thermal insulation shall be applied to the external walls of livingrooms and bedrooms which face east, west or north. The practical method is to place hearth cinders or foam concrete slab in the cells of concrete blocks, and to stick 30 mm (1.2 in.) thick perlite plates on the surface of the internal walls. As a result, the insulation quality of the masonry walls can be as good as that of 240 mm (10 in.) solid brick walls. The heat transmission coefficient can also reach 0.344, which complies with the insulation requirements for residential buildings in the Shanghai area.

The soundproofing effect of the masonry walls in the Shanghai area has already reached 49 dB, which meets general soundproofing requirements. If mineral cotton, foam concrete, slags or perlite are to be filled in the cells of the concrete blocks, the soundproofing effect of masonry walls can be increased to 52-54 dB. This can be increased to 60 dB if gypsum board sheets are set on both surfaces of the masonry wall, while a 60-100 mm (2.4 in.) thick air layer is left between the gypsum plates and the surfaces of the wall.