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PREVIEW

**DEVELOPMENT OF PRESTRESSED  
CLAY BRICK MASONRY WALLS**

by

**Ravi K. Devalapura**

**A DISSERTATION**

**Presented to the Faculty of  
The Graduate College at the University of Nebraska  
In Partial Fulfillment of Requirements  
For the Degree of Doctor of Philosophy**

**Major: Interdepartmental Area of Engineering  
(Civil Engineering)**

**Under the Supervision of Professors Gary L. Krause and Maher K. Tadros**

**Lincoln, Nebraska**

**August, 1995**

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DISSERTATION TITLE

Development of Prestressed Clay Brick Masonry Walls

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PREVIEW

# DEVELOPMENT OF PRESTRESSED CLAY BRICK MASONRY WALLS

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University of Nebraska, 1995

Advisers: Gary L. Krause and Maher K. Tadros

Prestressed masonry walls offer various advantages over the current system of veneer construction which has been shown to have several problems. The cracking of masonry walls at service loads, and corrosion of wall ties due to water penetration can be effectively eliminated by the simple technique of post-tensioning. Prestress significantly compensates for the low tensile strength of masonry which is critical at service loads. A new concept of using prestressed masonry for veneer construction has been developed, and a simple yet practical technique of post-tensioning utilizing high strength threaded bars was successfully used in this research.

This study included materials selection, analysis, design, and experimental testing of prestressed masonry wall panels. A total of fourteen panels of 3 x 6 ft were tested in the laboratory in two stages using newly developed two-cored brick units. The post-tensioned panels were tested for flexure to evaluate their capacity to resist out-of-plane loads. Stage I testing included six panels with three grouted and three ungrouted specimens. Results showed that the grouted specimens withstood approximately twice the capacity of the ungrouted specimens. In the Stage II testing, the prestressing force

and the end bearing conditions of the panels were varied to investigate their effects. Also, the post-tensioning was applied at two different ages to investigate how early the prestress could be applied. Prestress loss study was conducted on eight 3 ft x 4 ft panels, where the stress in the prestressing steel and strain in masonry were continuously monitored for 187 days after construction. These panels were exposed to different weather conditions.

This research study showed that the proposed post-tensioned veneer system is feasible. It can eliminate many of the problems associated with the conventional system of veneer construction, and the wall panels have an average factor of safety of 4.0 for cracking under service level wind loads. The results of the prestress loss study showed that moisture expansion of brick masonry significantly reduces the prestress losses in the reinforcing bars.

PREVIEW



**“Dedicated to my parents”**

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## NOTATION

$a$	=	depth of equivalent compression zone at nominal strength
$A_m$	=	cross-sectional area of masonry
$A_n$	=	net cross-sectional area of masonry
$A_{ps}$	=	area of prestressing tendon
$b$	=	width of section
$c$	=	distance from the neutral axis to extreme compression fiber
$C$	=	total compression force acting in the section
$d$	=	distance from the compression face of a flexural member to the centroid of longitudinal tensile reinforcement
$\Delta M_s$	=	Incremental service load moment
$E_m$	=	modulus of elasticity of masonry
$E_{ps}$	=	modulus of elasticity of prestressing tendon
$f_b$	=	stress in the bottom fiber of masonry at cracking stage
$f_{mi}$	=	stress in masonry in the bottom fiber at initial prestress transfer
$f'_m$	=	specified compressive strength of masonry
$f_m (bot)$	=	stress in masonry in the bottom fiber
$f_m (top)$	=	stress in masonry in the top fiber
$f_{me}$	=	stress in masonry due to effective prestress
$f_{ps}$	=	stress in prestressing tendon at nominal strength
$f_{pu}$	=	specified tensile strength of prestressing tendon
$f_{py}$	=	specified yield strength of prestressing tendon
$f_r$	=	modulus of rupture of masonry
$f_s$	=	stress in tendon due to prestress and applied loads
$f_{se}$	=	effective prestress in the tendon
$f_{si}$	=	stress in tendon due to initial prestress
$F_a$	=	allowable average axial compressive stress for concentric applied load

$F_{br}$	= allowable bearing stress
$h$	= overall depth of the member cross section
$I_g, I_{cr}$	= gross, cracked moment of inertia of the wall cross section
$k$	= ratio of depth of the compressive stress in a flexural member to the depth, $d$
$l$	= span length between the supports
$L$	= clear span length between the supports
$M$	= moment at midspan due to uniformly distributed load
$M_a$	= applied moment in the member
$M_{add}$	= additional moment acting in the member
$M_{cr}$	= nominal cracking moment strength
$M_d$	= moment due to dead load of the member
$M_n$	= nominal moment strength
$M_s, M_{ser}$	= service moment at the mid height of the panel
$M_u$	= ultimate moment strength of the member
$M_y$	= nominal moment strength at yield strength
$n$	= modular ratio ( $= E_{ps}/E_m$ )
$P_e$	= effective force in prestressing tendon
$Q$	= applied factored load
$r$	= radius of gyration
$R$	= strength enhancement factor
$R_4$	= interpolation coefficient
$s$	= spacing of reinforcement
$S$	= section modulus
$T$	= total tensile force acting in the cross section
$w$	= uniformly distributed load per unit length of the member
$(1-\alpha)$	= coefficient to account for the variation in member stiffness due to cracking
$\delta_c$	= midspan deflection of the member
$\Delta_{cr}$	= midspan deflection of the member at cracking moment strength, $M_{cr}$

$\Delta_s$	=	midspan deflection of the member at service load
$\epsilon_{m (top)}$	=	strain in masonry in the extreme top fiber
$\epsilon_{m (bot)}$	=	strain in masonry in the extreme bottom fiber
$\epsilon_{me}$	=	strain in masonry due to effective prestress
$\epsilon_{mu}$	=	strain in masonry at nominal strength
$\epsilon_{ps}$	=	strain in prestressing tendon at nominal strength
$\epsilon_{pu}$	=	strain at specified tensile strength in prestressing tendon
$\epsilon_{py}$	=	strain at specified yield strength of prestressing tendon
$\epsilon_s$	=	strain in the steel due to prestress and applied loads
$\epsilon_{se}$	=	strain in prestressing tendon due to effective prestress
$\phi$	=	curvature of the section
$\rho$	=	ratio of the area of flexural tensile reinforcement, $A_s$ , to the area $bd$

PREVIEW

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 General**

Masonry has been in use for centuries in the construction industry and countless masonry buildings have been built around the world. Its simple method of construction, aesthetic appearance, and durability have popularized its use and applications. It has been favored for non-structural applications such as building claddings (veneers), partitions, infilled walls, etc. and limited structural applications. It is seldom used in load bearing and flexural applications due to its low tensile strength. Clay Bricks are very strong with compression strength normally exceeding 10,000 psi (69 MPa). These bricks when used with even the lowest grade mortar, result in a fairly strong masonry assemblage. The most common use of brick masonry in non-load bearing applications does not utilize the full potential of the engineering properties of the brick. If the engineering properties of brick masonry are exploited, a number of advantages such as better durability, improved efficiency, and greater resistance to impact or accidental loads can be obtained.

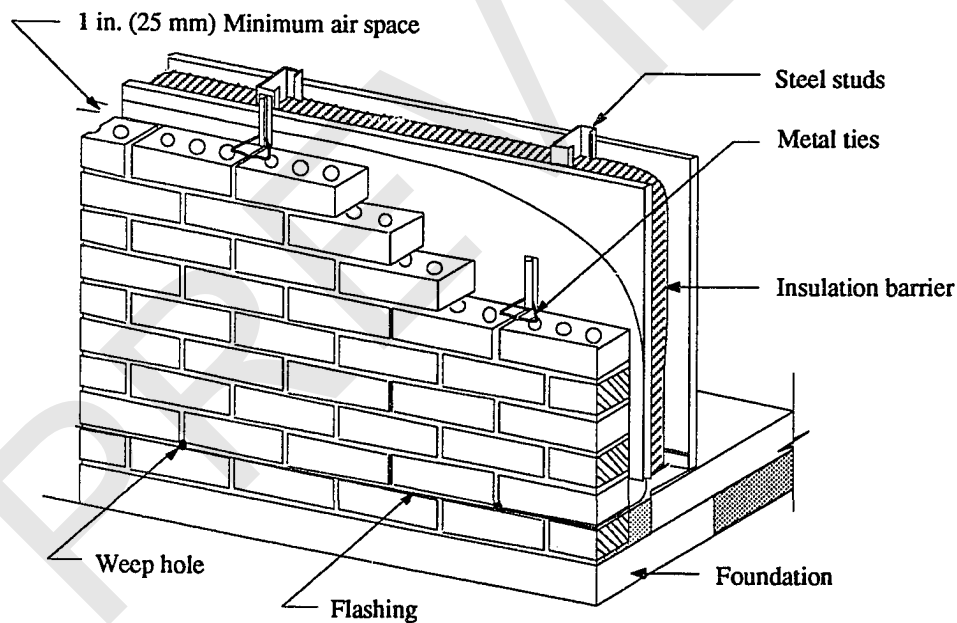
Currently, the most extensive application of clay brick masonry in the United States is in the construction of veneers. A veneer is defined as “a wall having a facing of masonry units, or other weather-resisting, noncombustible materials, securely attached to the backing, but not so bonded as to intentionally exert common action under load” [Brick, 1987]. The primary functions of a veneer are to transfer wind and externally applied loads to the structural components, and to give an aesthetically pleasing appearance to the building. It also provides a means of support to the thermal insulation barriers attached to the exterior walls of the building. A veneer is considered to be a non-structural element which supports no loads other than its own weight. Anchored veneer consists of a single masonry wythe as the exterior finish separated from a backing by an air space. Concrete masonry, steel studs, timber, or light structural steel members are commonly used as the backing. Wind load is transferred from the veneer to the backing by the ties which connect it to the backing at regular spacing. Brochelt [1988] describes the history of anchored masonry veneer and its structural design requirements.

## **1.2. Brick Masonry Veneer Walls**

### **1.2.1 Current System of Construction**

In the current system of construction, the veneer is attached to the back-up system using metal ties at regular intervals. These ties are embedded in the form of a grid behind the wall, and they are permanently secured to both the veneer wythe and the metal stud

back-up system. The UBC [Uniform, 1994] Section 1403 gives the height limitation, and design requirements for backing, anchor ties, and metal studs used in the construction of anchored veneers. Also BIA [Brick, 1987] addresses the considerations and recommendations for the design, detailing, materials selection and construction of brick veneer/steel stud panel walls. Typical brick veneer/steel stud wall construction is shown in Figure 1.1.



**Fig. 1.1 Typical brick veneer/metal stud system**