SCOPE
This guide provides general information on the construction of prestressed masonry which uses post-tensioning. This is a new method of reinforcing masonry construction which can offer an economical alternative to conventional reinforced masonry by greatly reducing the amount of grouting required. The guide primarily addresses a prestressing system using bar tendons as reinforcement which is available in the United States. However, the concepts presented in this guide generally apply to all post-tensioning systems.

INTRODUCTION
The 1999 edition of the Masonry Standards Joint Committee (MSJC) Code introduced prestressed masonry to the United States. Previously, it has been included in codes in the United Kingdom, Europe, Australia, and New Zealand.

Prestressed masonry does not replace conventional reinforced masonry. It provides another alternative that offers advantages to the owner, designer, and contractor on many projects.

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**Figure 1**
TENDON PLACEMENT
FREQUENTLY ASKED QUESTIONS ABOUT PRESTRESSED MASONRY

1. What is prestressed masonry? It is masonry construction, using either concrete masonry or clay units, which has compression added. This compensates for anticipated tension stresses by either pre-tensioning or post-tensioning the masonry. Pre-tensioning is more suited to prefabricated members; post-tensioning is more applicable primarily to site constructed masonry.

2. What is post-tensioned masonry? It is masonry that is first constructed and then compression is introduced by using tendons. Tendons are steel rods, bars, or strands placed in the cores or cavities of the masonry. See Figure 1. Tendons are typically anchored at the foundation and the top of the masonry. After curing, the tendons are tightened. By placing and tightening the tendons, the masonry is compressed. The compression can compensate for loadings that try to flex the wall and create tension.

3. How do you decide which type of tendon to use? Tendon selection is often based on availability. However, steel rods are the most common in the United States. In some designs, the specifications may dictate a specific type of tendon or corrosion protection.

4. Why is prestressed masonry important to a masonry contractor? It provides options and opportunities. Post-tensioning offers a method for reinforcing masonry without using as much grout as in conventional reinforced masonry. This can reduce cost and it offers contractors opportunities to attract new work.

5. What are the primary uses? One- and two-story buildings and interior masonry partitions in framed buildings are most suited to the use of post-tensioned masonry. However, it has also been used on multi-story veneer construction. Additional uses being developed are prefabricated masonry wall beams, sound barriers, and bracing during construction.

6. Can post-tensioning be used in every building? Not every building is a good candidate. For instance, walls with a large number of openings, small pier areas and columns, and frame buildings with no access to the top of walls are less likely to benefit from using post-tensioning.

7. How does post-tensioning work? Figure 1 shows a schematic wall with various parts. These include a bottom anchor, tendon, and top anchor. Bottom anchors are either cast into the foundation or built into the bottom of the wall. Depending on the tendon system used, the tendons are either installed as the wall is built or installed later. The top anchor is set. Once the wall achieves the desired strength specified by the designer (generally after 3 to 7 days), the tendons are tightened, thereby clamping the wall into compression.

8. Can stack-bonded walls be built with post-tensioning? No, only running bond can be used.

9. Is grouting required for the tendons? In most cases, no. However, tendons for some walls may require grouting; this is a design decision.

10. Can walls be built totally without grout? Generally, no. Grouting will be required in locations where there is mild reinforcement at bond beams, columns, and adjacent to movement joints and openings.

11. Is post-tensioning difficult to learn or harder to construct? No. While it is new, it is not difficult for masons to learn. Once learned, most find it easy to construct. However, added attention must go into the planning and construction of:
   a. anchor alignment and tendon placement
   b. restraint installation
   c. curing the masonry
   d. tensioning the tendons

12. Don't the tendons loosen over time? Yes. Research and experience indicates a tendon will lose 10% to 35% of its initial force over time. The design must take this into account.

13. Are tendons tightened one at a time or in stages; and is it necessary to re-tighten the tendons? Usually, tendons are tightened only once, one at a time along the wall. However, there may be special cases where staged tightening or retightening is advisable.

14. What special equipment and materials are needed? Typically, no special equipment is needed for tightening the tendons. Some post-tensioning systems use hydraulic jacks while others only need a wrench.

15. What happens if the tendons are not tightened properly? If the tendons are not tightened sufficiently, there will not be enough compression in the masonry to overcome tension caused by wind or other loads. If the tendons are over-tightened, they could over-stress the masonry.

16. How long do you have to wait before tightening the tendons? Most designs will require approximately three days. However, the tendons will loosen less if tensioning is delayed until the masonry cures longer and becomes stronger.

17. How big are these tendons? Most will be approximately 1/2-inch diameter; some 3/4-inch tendons are available. Lengths vary dependent upon the manufacturer. Couplers are used to splice short lengths together to get the needed overall tendon length.

18. How much force is in a tendon? One-half-inch tendons will have approximately 7,000 pounds, while 3/4-inch tendons could have 12,000 to 15,000 pounds.

19. Can you use regular reinforcing bars or threaded rods for tendons? Some systems use low-strength bars and rods but most use high-strength (100,000 psi or greater) steel.

20. How do you know the tendons are adequately tightened? In the system shown in this guide, a special load-indicator washer (DTI) is used. It has dimples which are calibrated to compress under a specified load. A standard wrench is used to turn the nut until the dimples of the washer are compressed. Feeler gauges are used to measure how much the dimples compress. In addition, the tendons must be checked for elongation by measuring the tendon extension above the bearing plate both before and after tensioning.

   Other systems use hydraulic jacks with calibrated gauges in combination with measuring tendon elongation.

21. Are all DTI washers the same? No, there is a specially calibrated DTI washer for each tendon diameter; washers must not be mixed. This is one good reason that all tendons on a project have the same diameter.
CONSTRUCTION SEQUENCE

Bottom Anchor and Layout

There are various types of bottom anchors and details. The most common is a cast-in-place anchor (Figure 2). However, for specific designs, adhesive anchors (Figure 3) or a bottom bond beam and anchor (Figure 4) may be appropriate.

The layout is critical because the tendons must be in alignment. Placement tolerances are generally ± 1/2 inch over ten feet.

Placement accuracy can be better controlled by the mason using the anchors shown in Figures 3 or 4. The selection of bottom anchor however, is often a design, and not a construction, choice. Substitutions should not be made in the field without the written permission of the engineer of record.

Tendon Installation

When using threaded rods or bars, most tendons are installed as the masonry work proceeds. However, lengths of tendons can be installed after the wall is built if access is provided. Figure 5 shows a coupler used to join individual pieces of bar tendon. When using strands, a pipe sleeve is installed with the masonry; full-length tendons are installed once the wall is built full height.

Tendon Restraint

When required by design, tendons are built with lateral restraints. Figure 6 shows an example of a grout restraint used with hollow units. Mechanical methods are becoming available. These are often installed at quarter points of the wall height.

Top Anchor

Figure 7 shows a possible detail for a top anchor. The top element must be concrete or a grouted unit. A bond beam distributes the top anchor load and ties the wall together.

Once the wall and the bond beam have cured as specified, the tendons are tightened and the elongation of the tendons checked.
CONCLUSION

Prestressing masonry using post-tensioning is new in the United States and offers additional opportunities for constructing masonry. While the initial interest involves walls, prestressing is being evaluated for use in masonry beams, sound barriers, and bracing during construction.

DISCLAIMER

This document is intended to assist the industry in avoiding design and construction problems with masonry construction. It is intended for masonry contractors, field personnel, architects, engineers, building officials, general contractors, construction managers, students, suppliers, manufacturers and other industry representatives. It is not the intent of this report to cover every aspect of masonry construction, but to focus on issues that may lead to problems. This document should not be used as the sole guide for designing and constructing masonry. It is imperative to refer to relevant codes and standards and other industry-related documents. As such, the IMI assumes no liability for consequences that may follow from the use of this document.
Prestressed Masonry Design

Prestressed masonry design is dealt with in Chapter 4 of ACI-530. The general design requirements of Chapter 1 and design requirements of Specification 2.1 apply to prestressed masonry. The notable exception is the eccentricity requirements for columns found in Specification 2.1.4.2.

Prestressed masonry components are designed by the allowable stress method presented in Chapter 2. Thus, prestressed masonry components are designed based on an elastic analysis utilizing load combinations set forth in Specification 2.1.2.1.

Allowable stresses in prestressing tendons are specified for three conditions:

1. Under jacking force:
   \[ \text{Tendon Stress} < (0.94) f_y \]
   \[ < (0.80) f_u \]

   \( f_y \) = Yield stress of tendon
   \( f_u \) = Ultimate tensile strength of tendon

2. Immediately after transfer of the prestressing force to the masonry:
   \[ \text{Tendon Stress} < (0.82) f_y \]
   \[ < (0.74) f_u \]

3. For post-tensioned masonry (tendons and couplers):
   \[ \text{Tendon Stress} < (0.78) f_y \]
   \[ < (0.70) f_u \]

When computing prestressing tendon stress include all short term prestress losses, i.e., jacking stress loss.
ON A LONG TERM BASIS THE ENGINEER MUST ACCOUNT FOR
TENON LOAD CARRYING CAPACITY ASSOCIATED WITH

- Anchorage Seating Loss
- Elastic Shortening of Masonry
- Creep of Masonry
- Shrinkage of Masonry
- Relaxation in Prestressing Tendon
- Function Loss
- Clay Masonry Expansion (Net Gain)

THE CODE REQUIREMENTS FOR PRESTRESSED MASONRY COMPONENTS
ARE SEPARATED UNDER TWO CLASSIFICATIONS

1. LATERALLY UNSERAINED TENONS

2. LATERALLY RESTAINED TENONS

LATERALLY UNSERAINED TENONS ARE MORE COMMON, THE
ALLOWABLE MASONRY COMPRRESSIVE STRESSES ARE GOVERNED
BY SPECIFICATION 2.2.3, I.E.,

\[
\frac{f_t}{f_m} + \frac{f_o}{f_0} \leq 1.0
\]

\[
P \leq \left(\frac{14}{h}\right) f_e
\]

\[
h/r < 99 \quad f_e = \left(\frac{14}{h}\right) f_m \left[1 - \left(\frac{h}{140r}\right)^2\right]
\]

\[
h/r \geq 99 \quad f_e = \left(\frac{14}{h}\right) f_m \left(\frac{f_0}{f_0}\right)^2
\]

\[
f_0 = \left(\frac{14}{h}\right) f_m
\]

\[
P_e = \frac{n^2 E_m I}{n^2} \left[1 - 0.59 + \left(\frac{e}{r}\right)\right]^3
\]

THE ALLOWABLE FORCE IN CODE EQUATION 2-11 MAY BE
INCREASED BY 20%. HOWEVER THE APPLIED AXIAL LOAD (P)
MUST INCLUDE THE PRESTRESSING FORCE.

LATERALLY UNSERAINED TENONS ADDRESS TWO DISTINCT LOADING
NARRAVES: STRESSES IMMEDIATELY AFTER TRANSFER OF LOAD TO THE
MASONRY AND LONG TERM LOAD APPLICATION.
TENSION STRESSES ARE NOT PERMITTED IN THE MASONRY UNLESS THE APPLICATION OF THE PRESTRESSING FORCE AND SERVICE LOADS. ADDITIONAL REINFORCEMENT MUST BE SUPPLIED UNDER SPECIFICATION 4.6.

IN ADDITION TO THE WORKING STRESS REQUIREMENTS PROVIDED BY CHAPTER 2 OF THE CODE SPECIFICATION 4.4.3.3 STIMULATES MOMENT STRENGTH REQUIREMENTS. UNDER THIS SPECIFICATION.

\[
\text{DESIGN MOMENT STRENGTH} = (1.08) M_n
\]

\[
M_n = \text{NOMINAL MOMENT STRENGTH}
\]

APPLIED MOMENTS MUST BE COMPUTED USING LOAD FACTORS STIMULATED IN ASCE 7. THE NOMINAL MOMENT STRENGTH IS COMPUTED FROM CODE EQUATION 4-2:

\[
M_n = \left( f_{ps} A_{ps} + f_y A_y + P_u \right) \left( \frac{1}{d} - \frac{1}{d} \right) \quad \text{EQ 4-2}
\]

WHERE

\[
f_{ps} = f_{sy} \quad \text{(BONDED PRESTRESSING TENDONS)}
\]

\[
f_{ps} = f_{se} + (700,000) \left( \frac{d}{L_p} \right) \left\{ 1 - (1.4) \left[ \frac{f_{pu} A_{ps}}{600 f_m} \right] \right\}^{0.5}
\]

\text{(UNBONDED PRESTRESSING TENDONS)}

\[
f_{se} = \text{EFFECTIVE TENDON STRESS (AFTE ACCOUNTING FOR LOSS)}
\]

\[
L_p = \text{CLEAR SPAN BETWEEN TENDONS}
\]

NOTE THAT

\[
\frac{d}{L_p} \leq 0.425
\]

\[
\frac{d}{L_p} \leq 0.425 \quad \text{EQ 4-1}
\]

\[
q = \frac{f_{ps} A_{ps} + f_y A_y + P_u}{(0.80) f_m b} \quad \text{EQ 4-1}
\]

FOR UNBONDED PRESTRESSING TENDONS

\[
f_{ps} = f_{se} + (1,000,000) \left( \frac{d}{L_p} \right) \left\{ 1 - (1.4) \left[ \frac{f_{pu} A_{ps}}{600 f_m} \right] \right\}^{0.5} \quad \text{EQ 4-4}
\]
Shear stresses in pre-stressed masonry components can not exceed any of the following quantities:

\[
F_v = V + (0.45) \left( \frac{N_v}{A_n} \right) \quad 4.4.4
\]

\[
F_v = \left\{ \left( 2.25 \right) f_{m'} + 1.5 \left( f_{m'} \right)^{1/2} \left( \frac{N_v}{A_n} \right) \right\}^{1/2} \quad 4.4.6
\]

\[
F_v = \left\{ \left( \beta f_{m'} \right)^2 - \left( \beta f_{m'} \right) \left( \frac{N_v}{A_n} \right) \right\}^{1/2} \quad 4.4.6a
\]

Where:

\[ N_v = \text{Force acting normal to the shear surface} \]

\[ \beta = 0.25 \ (\text{fully grouted masonry}) \]

\[ \beta = 0.15 \ (\text{partially or ungrouted masonry}) \]

Finally, local bearing stress is computed based on contact surface tile masonry and mechanical anchorage device. Bearing stresses due to jacking face tile following code provision:

\[
\text{Bearing stress} = (0.50) f_{m'}
\]

\[ f_{m'} = \text{Initial masonry strength} \]

Under specification 4.4.4