U.S Department of Housing and Urban Development
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Building Concrete Masonry Homes: Design and Construction Issues

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Prepared for

The U.S. Department of Housing and Urban Development
Office of Policy Development and Research
Washington, DC,

and

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and

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Randy MacGillivray
MacGillivray Masonry and General Contractors of Springfield, Ohio

Mark Olson
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EXECUTIVE SUMMARY

Although many home builders use concrete masonry units (CMU) for foundation walls, home builders attempting more comprehensive use of CMU have many questions about the feasibility and appropriate use of concrete masonry construction. In an effort to address a number of these questions the construction of two single-wythe CMU homes in non-traditional CMU markets, i.e., northern climates, were fully documented. Although these case study homes cannot address all of the issues involved in concrete masonry construction, key results are presented below. The case study homes were in Ohio and Minnesota.

- **Building codes and plan preparation:** There are two methods of design used to provide compliance with local building codes, empirical design and engineered design. The empirical design method is often used for single-family dwellings for reasons of simplicity as well as the elimination of engineering costs. The empirical design approach is limited to short buildings (under 35 feet in height) and buildings in low seismic zones and low wind areas. The engineered design approach does introduce additional costs, but can help address special design conditions. The Ohio case study home was empirically designed and the Minnesota case study home employed the engineered design method.

- **Wall thickness:** The three model building codes and CABO prescribe two different minimum requirements for the type of block used for single story buildings. While all four codes prescribe 6-inches as the minimum thickness, CABO and UBC prescribe that the 6-inch block must be of *solid* masonry or 8-inch thick hollow-core block is required. The above-grade masonry walls of the single-story Ohio case study home were built with 8-inch thick hollow-core block. The above-grade masonry walls of the two-story Minnesota home used 6-inch thick hollow-core blocks with the addition of vertical steel reinforcement bars.

- **Lateral support of walls:** Lateral support of walls was not a design issue with the two case study homes, nor will it be an issue for many low-rise residential structures. Homes with tall, unsupported exterior walls or high ceilings, e.g., “great rooms” and entry foyers, as well as buildings with 6-inch thick block will require the attention of a design professional.

- **Crack control:** The case studies illustrated the uncertainty surrounding the need for bond beams, horizontal joint reinforcement, and control joints. While the concrete masonry industry offers recommendations for controlling cracks in masonry walls, the model building codes do not include prescriptive requirements for crack control. Practice in this area varies on an individual basis.

- **Connections to concrete masonry:** The case study homes illustrated several different techniques for detailing building elements such as floor decks, insulation, windows and doors, flashing, and gypsum wallboard. Several photographs and construction drawings from the case studies are provided throughout the body of the report as well as in Appendix A.

- **Energy performance:** The level to which the CABO *Model Energy Code* (MEC) recognizes thermal mass benefits is based on heating degree days and the location of the insulation. The Ohio case study home (in a climate of approximately 5,400 heating degree days) contained insulation in the core of the block, i.e., “integral” insulation as defined in MEC. Therefore some

benefit from thermal mass was achieved, and approval was obtained from the local building department. At the Minnesota case study site the number of heating degree days (approximately 8,200) effectively negated the thermal mass effect and no benefit in reduced insulation was realized.

The empirical design approach in the model building codes is somewhat confusing to the novice user, does not include many common details or fastening requirements, and in some cases may not provide the most cost-effective concrete masonry wall assembly. The home building industry would benefit from a "best practices guide" for residential concrete masonry construction which would simplify key structural items and include support for novice masonry builders.

INTRODUCTION

Objectives

Concrete masonry units (CMU) have a significant percentage of the United States market for foundation walls in homes. CMU also has a long history of use in above-grade walls in Florida, Texas, Arizona and other parts of the southern United States. Strength, durability, fire-resistance, and energy conservation are a few of the benefits to CMU construction. However, there are often difficulties encountered by home builders converting from a traditional above-grade framing material to CMU walls. In most U.S. markets, wood is the predominant framing material and the understanding of CMU construction for above-grade walls is usually limited. Home builders attempting more comprehensive use of CMU have many questions about the feasibility and appropriate use of concrete masonry construction, particularly in relation to insulation placement and connection details.

The objectives of this report are:

- to identify the major issues related to the design, approval, and construction of a home with above-grade concrete masonry walls in non-traditional CMU markets; and

- to identify different approaches to construction details, based on the two case studies in this report, between concrete masonry walls and other structural and non-structural members, including floor framing, gypsum wallboard, insulation, and window and doors.

While cost is an issue foremost in many builders' minds, the emphasis of this report is on technical (rather than financial) decisions and issues.

Structure of the Report

This report is structured around the major sections described below, using the experiences of two case studies as the vehicle to explore those sections. Throughout the report, information on the case studies is highlighted and used as an example.

- **Building design issues** - Issues affecting aesthetic decisions, structural integrity, and energy performance are presented.

- **Construction details** - Photographs and construction drawings from the case studies present building elements such as floor deck connections, and window and door attachments.

- **Conclusions and recommendations** - Summaries of the key evaluations and recommendations for future work complete the report.

The appendices included provide construction details (Appendix A) in support of discussion in the text, and a bibliography (Appendix B).

It is not possible for two case studies to comprehensively address all of the issues that a home builder may face when using concrete masonry for applications not sustained by local tradition. It is important to note that this report does not address all types of residential concrete masonry construction, but rather focuses on the issues facing the construction of above-grade, single-wythe, concrete masonry walls for single-family homes in non-traditional CMU markets. The general geographic focus of this report was on the upper mid-west, with specific case studies in Ohio and Minnesota. Future evaluations should focus on other areas where practices may differ.

Case Study Site Descriptions

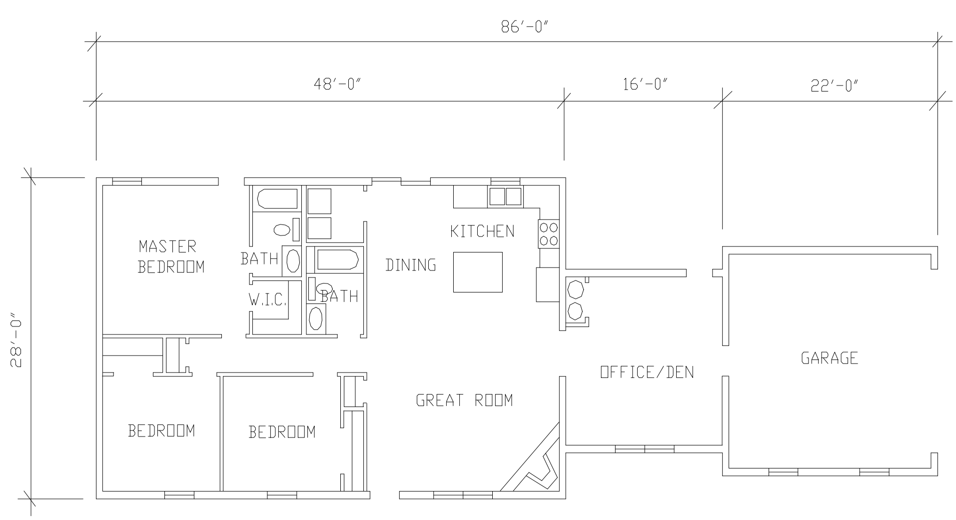
Springfield, Ohio

*Site profile***.** MacGillivray Masonry and General Contractors constructed a concrete masonry house in Springfield, Ohio, which is located approximately 40 miles west of Columbus. The house is the first in a 36-unit development, which is planned to be completely made-up of concrete masonry homes. Although the development is expected to include a broad range of home sizes and prices, the MacGillivrays intend to market the case study home to entry-level buyers. The predominant exterior veneer in the surrounding area is vinyl siding, with a smaller number of homes clad in brick and/or masonry.

Company profile. The MacGillivray masonry business is a family-owned operation--three generations of the MacGillivray family are current employees--which has built primarily commercial structures. However in the last four years the company has built three masonry homes in the Springfield area in addition to its commercial work. In this case, the MacGillivrays provided the masonry construction, the carpentry, and the electrical work, and subcontracted the remaining trades.

House profile. The house is a 1,300 square foot, single-story structure. The house has concrete masonry exterior walls, a wood-framed floor deck over a crawl space, and wood-framed interior walls and roof trusses (see Figure 1 and Photo 1a).

Figure 1 - Ohio Floor Plan



Burnsville, Minnesota

Site profile. The second case study home was built in Burnsville, Minnesota, a suburb of Minneapolis. The house was built in a sub-division where the predominant exterior veneer is vinyl siding and OSB exterior sheathing. The size of the homes in the surrounding area range from 1,800-2,600 square feet.

Company profile. Mark Olson was the mason and general contractor of the home. Although Mark Olson has been in the masonry business building primarily commercial structures for 20 years, he only recently began building homes (the case study house was the second masonry home he has built). In this case, Mark Olson's company provided the masonry construction and a small portion of the framing, and subcontracted the remaining trades.

House profile. The house is a 2,400 square foot, two-story custom-designed, pre-sold structure. The house has a walkout basement, with wood-framing for the second floor deck, interior walls, and roof trusses (see Figure 2 and Photo 1b).

Figure 2 - Minnesota Floor Plan

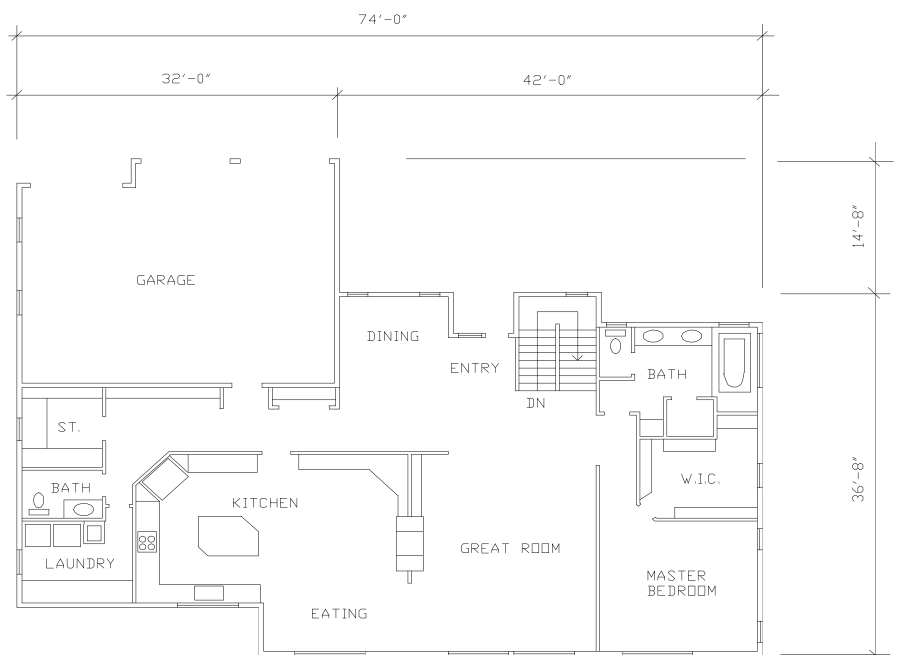


Photo 1a: Completed House at Ohio Site

Photo 1b. Completed House at Minnesota Site

BUILDING DESIGN ISSUES

Building Codes and Preparing Construction Drawings

A major issue that affects the economics of masonry construction is the method of design used to provide compliance with the local building codes. All of the model building codes[1] prescribe that masonry structures be designed using one of two methods, an engineered design or an empirical design. Engineered masonry design is based on an analysis of the structure to determine all of the forces acting on the various building components. It considers live and dead loads, lateral loads, as well as other forces to determine the size of the building components.

Empirical masonry design, on the other hand, is a design method based on "accepted practice" rather than detailed analysis of loads and stresses. Empirical design relies on historical precedent and is based on wall height- (or length-) to-thickness ratios to determine the required section of a wall. The empirical design method is often used for single-family dwellings for reasons of overall efficiency including simplified building code approval and elimination of engineering costs. However, in general the empirical design approach is limited to buildings:

- in low seismic performance categories (Seismic Zones 0 and 1 in UBC);
- in low wind areas (25 psf in ACI 530, and 80 mph in UBC); and
- less than 35 feet in height.

Importantly, the 1995 edition of CABO *One and Two Family Dwelling Code* does include provisions for empirical design in high seismic performance categories and high wind areas, and therefore does not impose limitations such as those listed above. In fact, CABO states that when its empirical design provisions are used to design project drawings, the seal of a licensed architect or engineer is not required.

> *Ohio. As an experienced mason, Randy MacGillivray prepared the construction plans with masonry in mind from the start. The house was designed empirically and therefore no architectural or engineering stamp was required. By eliminating the steps of converting stick-frames plans and acquiring engineering support, the construction plans could be more easily prepared by staff in the MacGillivray office. The local building department evaluated the plans for compliance with the local code, which included requirements for empirical masonry design.*

[1] The *Standard Building Code* (SBC), the *National Building Code* (BOCA), and CABO *One and Two Family Dwelling Code* all prescribe the use of *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402) and the *Specifications for Masonry Structures* (ACI 530.1/ASCE 6/TMS 602) for designing masonry structures. The *Uniform Building Code* (UBC) includes its own detailed requirements for structural masonry based on ACI 530/ASCE 5/TMS 402 and ACI 530.1/ASCE 6/TMS 602.

Minnesota. Although the preparation of the plans included work by a local architect, engineer and block supplier, the builder relied primarily on his masonry experience to convert a set of wood-framing plans. A local architect designed the original house plans with wood-framing in mind. However, because the architect's experience with concrete masonry was limited, Mark Olson contracted a local engineering firm (LHB) with masonry experience to design the desired construction details. Concurrently, a local supplier, Anchor Block, offers a concrete masonry system which incorporated the cost of engineering into the cost of the block. Although the cost of the engineering was approximately $1,500, Mark Olson was willing to absorb this cost for three reasons: 1) the local supplier offered to offset some of these costs (built into the cost of the block); 2) Mark Olson planned to use the design details for future homes; and 3) the engineer's stamp would help reassure any skeptical building officials who may have been unfamiliar with residential block construction. The local building department evaluated the plans for compliance with the 1994 UBC which includes requirements for both empirical and engineered masonry design.

Pennsylvania. Although not a featured case study of this report, the Research Center worked closely with a conventional wood-frame home builder, Stephen Black, during the early stages of this project. The initial approach was to convert a set of existing wood-frame plans with the aid of the home owner's own architect and engineer. Stephen Black typically prepares his own plan modifications with the assistance of a draftsperson, using engineering support only in rare cases. However, because the preparation of plans required more coordination time than the builder expected, the plans were sent to an out-of-state professional design and plan service for preparation. The cost for this service was approximately $2.00 per square foot. Given the demonstration nature of the project, a local block supplier was willing to sponsor the cost of the plan preparation. However, the plans were never taken to the approval stage. The builder's primary reason for not continuing was the potential increase in construction cost, relative to wood framing, estimated by the builder. It is important to note that in conventional CMU markets a builder's decision may be very different because of local trade availability, labor costs, design conditions (i.e. high wind) and other factors.

Wall Thickness

All building walls need sufficient strength and lateral support to resist buckling from compressive loads, wind loads and other forces. Empirically designed concrete masonry buildings rely on the thickness of the wall to resist loads, and the codes prescribe a minimum wall thickness that cannot be reduced or changed without engineering analysis.

Ohio. For empirically designed buildings, all of the model building codes contain similar requirements for the minimum thickness for masonry bearing walls, and these are listed in Table 1 below.

Table 1 - Minimum Thickness for Empirically Designed Walls

Wall Type	*Minimum Thickness*	
	CABO & UBC	*SBC & BOCA*
Bearing walls more than one story high	*8 inches*	
Bearing walls in one story buildings	*6 inches[1] (solid masonry)*	*6 inches*
Non-bearing walls	*none prescribed*	

1. *Assumes wall is not greater than 9 feet in height. When gable construction is used, an additional 6 feet is permitted to the peak of the gable.*

Given that the house was one story high and empirically designed, the builder could have used a 6-inch thick block. However, the builder chose to use an 8-inch wide, half-high, split-face block for all of the above-grade walls (both bearing and non-loadbearing). If a 6-inch thick block with similar appearance (half-high, split-face) were used, reduced material and labor costs (through smaller and lighter block) could lower the total construction costs. The gable ends (above top plate height) were wood-framed and clad with vinyl siding.

Minnesota. Because a licensed engineer designed the masonry walls, the walls were not limited by the requirements of Table 1. The engineer designed the masonry walls with reinforcement bars, which permitted the use of a 6-inch thick wall (the minimum thickness for walls two-stories or greater as prescribed by Table 1 is 8-inches). Because the site was sloped (creating a walk-out basement), the height of the masonry walls above grade varied to a maximum height of approximately 19 feet, with an intermediate lateral support proved by the second floor. Six-inch thick hollow block was used in all above-grade walls, and 12-inch thick hollow block was used for all below-grade walls. The 6-inch thick block walls were reinforced with #5 re-bars placed vertically and spaced at 32" o.c., and the 12-inch blocks were reinforced with 2-#4 vert. at 48" o.c.

Lateral Support of Walls

In addition to wall thickness, the other primary factor for the design of concrete masonry walls is limiting the spacing between lateral supports. All building walls need sufficient strength and lateral support to resist buckling from compressive loads, wind loads, and other horizontal forces. Lateral support can be provided horizontally (by limiting the distance between intersecting walls, pilasters, or buttresses) or vertically (by limiting the height of the masonry wall between roof structures, floor diaphragms, and footings)[2].

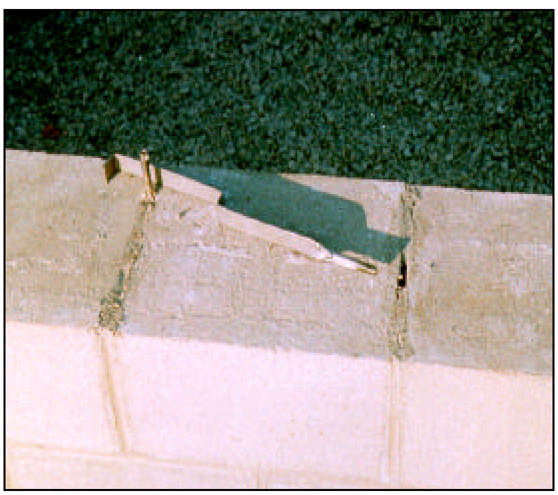
[2]Where lateral support is provided by the walls of the masonry structure itself, i.e., following the 'horizontal' lateral support approach, interior masonry walls (or pilasters) is generally required. These requirements are prescribed in the codes, but they are rarely applied to one- and two-family dwellings because lateral support is more efficiently provided by floor and roof framing, i.e., following the 'vertical' lateral support approach. Therefore the 'horizontal' approach to lateral support is not addressed in this document, nor was it used in the case study homes.

Ohio. For empirically designed structures (such as the Ohio case study), all of the model building codes prescribe essentially the same methods for providing lateral support, including maximum spacing (see Table 2) and the method of anchorage to lateral supports.

Table 2 - Maximum Spacing of Lateral Support for Empirically Designed Walls (all Model Codes)

Wall Type	***Maximum Ratio: Wall Length to Thickness or Wall Height to Thickness***
Bearing Walls	
Solid or solid grouted	*20*
All other	*18*
Non Bearing Walls	
Exterior	*18*
Interior	*36*

With the 8-inch thick, hollow-core block used at the Ohio site, Table 2 prescribes that the maximum spacing (measured either vertically or horizontally) of lateral support is 12 feet (8 inches x 18 = 144 inches or 12 feet). The floor diaphragm is anchored to the wall with ½" diameter bolts in the sill plate at 4'-0"o.c. (see Photos 2a and 2b below), and the roof is anchored to the wall with anchor bolts in the top plate at 32"o.c., and wind tie-down straps). As a single story house with an unsupported height between the floor and roof of 8 feet, adequate lateral support in compliance with the code has been provided. For most empirically designed homes, the location of lateral support is not a design issue, except when using 6-inch thick block or high ceilings.



Photos 2a and 2b. Tie-Down (Anchor Bolt) at Ohio Site

Minnesota. As stated earlier, the house was designed and stamped by a local engineer and not empirically designed, and therefore was not subject to the prescriptive requirements of the building codes (i.e., Table 2). The 6 inch thick reinforced, above grade, walls were designed with lateral support at the footings, the second level floor assembly, and the roof system. Although the methods of anchorage at the footings and roof were typical, i.e., prescribed in the model building codes, the second level floor assembly was anchored with expanding bolts into grouted cells at 32" o.c. (the methods of anchorage at these three areas are shown in Figures A4, A5, A6, and A7). The unsupported height between the footing and the first floor deck was 8'-8." Between the second floor deck and the roof it was 9 feet.

Crack Control

Cracking can occur in concrete masonry walls due to tensile stresses associated with temperature and moisture change (expansion and shrinkage) or differential settlement of foundation soils. There are two methods of controlling cracking in masonry walls described below.

1) *Provide horizontal steel reinforcement to increase crack resistance*. Steel reinforcement, in the form of bond beams and horizontal joint reinforcement, increases concrete masonry's resistance to the tensile stress of shrinkage. The most common method of shrinkage crack control is horizontal joint reinforcement, which uses the steel to minimize the width of the crack. The standard horizontal joint reinforcement is 9-gauge wire in either a "ladder" or "truss" formation, and is available in standard lengths of 10 and 12 feet. Bond beams which serve both as structural elements and as a means of crack control are a course or courses of a U-shaped masonry block into which reinforcing steel and grout can be placed.

2) *Provide control joints to accommodate movement*. Control joints relieve horizontal tensile stresses by providing separations or weakened joints in the wall at controlled locations or spacings. This is done with special "control joint" units which provide a shear key to permit free longitudinal movement.

Given that there is more than one method of controlling cracks, it is important to distinguish between what is *required* by model building codes and what is *recommended* by the concrete masonry industry. For low-rise buildings in most regions of the United States there are no provisions in the model building codes prescribing the use of steel reinforcement or control joints[3]. The concrete masonry industry does offer recommendations for controlling cracks (see NCMA TEK 10-1 and 10-2) and these guidelines are introduced below.

- Bond beams are typically presumed to offer tensile resistance to an area 24" above and below its location in the wall.
- Horizontal joint reinforcement is usually placed in joints at a vertical spacing ranging from 8-inches to 24-inches.

[3] The exception to this are high wind and high seismic zones, although in these cases the steel reinforcing is required for structural reasons, not for controlling cracks.

- A control joint is often placed at one side of an opening less than six feet in width, and at both sides of openings over six feet wide. For long walls without openings or other points of stress concentrations, the spacing of the control joints depends upon wall height and the amount of horizontal reinforcement.

Ohio. Randy MacGillivray used 9-gauge horizontal joint reinforcement every 32 vertical inches throughout the entire house (see Photo 3). This is not a local code requirement, but Randy chose to use the joint reinforcement as good practice.

Minnesota. Cracking is not as critical in reinforced masonry because the steel reinforcing resists the tensile stress. Bond beams were provided every 8 vertical feet, and the 6-inch thick block walls were reinforced with vertical re-bar and grout at 32-inches o.c.(see Photo 4 below and Figures A5 and A6). Mark Olson felt this would adequately control cracking and therefore did not provide control joints or additional horizontal reinforcement. Mark Olson prefers not to use horizontal joint reinforcement, claiming that it compromises the strength of the bond between units.

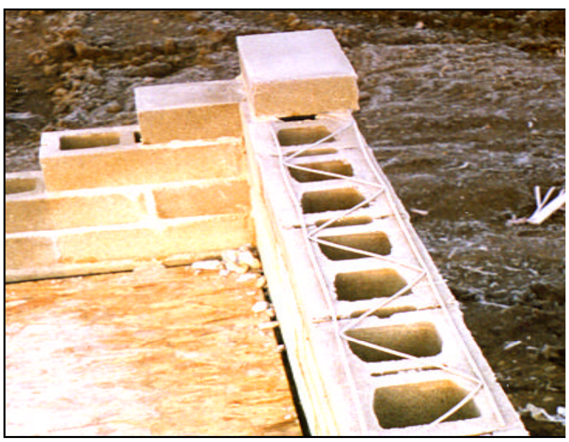


Photo 3. Horizontal Truss-Type Joint Reinforcement at Ohio Site

Photo 4. Bond Beam at Minnesota Site

Wall Assembly

In addition to structural performance, the design of any exterior wall assembly requires consideration of several important elements including interior and exterior finish material, insulation, and weather resistance. In masonry wall design, more so than stick-framed walls, many of the design solutions for one element involves consideration of other elements as well, i.e., the masonry wall is designed as a system. The primary issues are outlined below.

Exterior Finish Materials. The options include:

1) Architectural block. Many options are now available in the appearance of concrete masonry units, including the face type, the size, and the color. Use of this option can eliminate the need for additional exterior finish materials.

2) Cementitious coatings. Troweled-applied, cementitious coatings such as stucco lend themselves to concrete masonry because the stucco can be applied directly to the masonry wall or, in the case of the exterior insulation finish systems (EIFS) products, over a layer of rigid board insulation.

3) Siding. Wood and vinyl siding are typically attached using furring strips which have been fastened to the concrete masonry. The siding and furring strips approach can also accommodate the exterior insulation strategy described below, but does result in additional labor and material costs.

Water Repellency. If concrete masonry is chosen as the exterior finish material, a water repellent should be used to effectively control water penetration. There are two general types of water repellents – surface treatments and integral water repellents.

1) *Surface treatments*. Surface treatment repellents are applied to the weather-exposed side of the wall after the wall is constructed. Surface treatments can be categorized as appearance-altering treatments such as cementitious coatings (stucco) and colored paints, and clear surface treatments such as silicone or acrylic films.

2) *Integral treatments*. Integral treatments, or admixtures, are specified for the concrete masonry blocks and the mortar before the wall is constructed. The water repellent is incorporated into the concrete mix at the block manufacturing plant, and for mortar the admixture is added to the mix on the jobsite. The same admixture should be used in the mortar as was used in the block to ensure compatibility, bond, and performance.

Insulation Strategies - Concrete masonry walls can be insulated on either the exterior or interior face of the block, or in the cores of the block. In addition, the thermal performance of masonry walls can take advantage of the thermal mass of the masonry, depending on many factors including the location of the insulating material in the wall assembly (thermal mass is discussed in the Energy Codes section of this document). The three options are discussed below.

1) *Exterior insulation*. Rigid board such as polystyrene or polyisocyanurate is typically used for exterior insulation and can be adhered or mechanically attached to the masonry. Because the insulation must be protected from weather and impact, this approach lends itself to either a cementitious coating or siding, and would not be used with architectural block.

2) *Integral insulation*. Under this approach, the cores of the hollow masonry units are filled with insulating material such as vermiculite, polystyrene inserts, or an expanding foam such as polyurethane[4]. Depending on the shape of the insert, and the level of grouting and reinforcing in the masonry wall, the integral insulation strategy may reduce the cold bridges (breaks in the insulation) through the thermal envelope. This approach can be used with any of the exterior finish materials described above.

[4] The polystyrene inserts are either placed in the cores of conventional masonry units or are part of an integrated system used in proprietary blocks. The inserts may be installed in the masonry units at the jobsite or in the case of the proprietary blocks, installed at the manufacturing plant.

3) Interior insulation. Similar to exterior insulation, interior insulation is typically a rigid board product such as polystyrene or polyisocyanurate, and is adhered or mechanically fastened. To accommodate an interior finish (typically gypsum wallboard), studs, furring, specially-designed clips and metal channels can also be used. One example of the clip/channel approach involves a "kerfed-edge" insulation board which reduces the thermal bridging.

> *Ohio. Randy MacGillivray used a split-face, half-high masonry block as the exterior veneer on all four facades, chosen primarily for its appearance and durability. The exterior side of the masonry walls were sprayed with a silicone surface treatment to provide a layer of water repellency. The surface treatment will require periodic reapplication to maintain water repellency. The cavity of the block was insulated with expanding polyurethane. The interior finish was gypsum wallboard, which was attached directly to the masonry with adhesives. See Figure A1 for a complete wall section.*
>
> *Minnesota. Mark Olson also used a half-high, split-face block on all four sides of the house, chosen primarily for its appearance and durability (see Photo 5). The exterior side of the masonry walls were sprayed with a siloxane surface treatment to provide an layer of water repellency. An integral water repellent treatment was not used as the builder felt this would compromise the bond between the unit and the mortar. The Minnesota house was insulated on the interior side of the block with 2½" of polyisocyanurate, which was glued to the face of the block. A narrow cavity (1-5/8" deep) was framed with light-gauge metal studs to provide a cavity for running electrical wiring. This thin metal stud wall was fastened to the floor and ceiling assemblies (bottom of floor trusses and roof trusses, slab, etc.). A small bead of adhesive at mid height (glued to the insulation boards) provided additional stiffness to the metal stud assembly. The interior finish was gypsum wallboard which was fastened to the interior side of the metal stud walls with screws. See Figure A4 for a complete wall section.*

Photo 5. Half-High Split-Face Block at Minnesota Site

Energy Codes

Although concrete masonry walls do not have a large cavity which can be filled with insulation, i.e., stick-frame walls, designing a concrete masonry wall for compliance with energy codes can take advantage of the thermal mass of the masonry. Thermal mass is the ability of a material to store heating and cooling energy, and masonry, because of its high density and specific heat, can provide effective thermal mass. Thermal mass slows the response time and moderates the indoor temperature fluctuations in a building, and can reduce heating and cooling loads. The effectiveness of thermal mass, however, varies with factors such as climate, building design, and insulation position. Thermal mass is most effective when insulation is placed on the exterior of the masonry (because the masonry is most directly in contact with the interior conditioned air), and in climates where the outdoor daily temperature fluctuations are above and below the indoor temperatures.

The CABO *Model Energy Code* (MEC), which is referenced by all model building codes recognizes the thermal mass benefits of masonry construction. As a result, the amount of insulation (R-value) required for a masonry wall may be less than that required for a wall with less mass in the same climate, giving the designer additional flexibility to achieve compliance for the entire building envelope. Although a comprehensive examination of the thermal mass provisions and a comprehensive computation of the case studies' compliance with their local code are too lengthy for this document, two important considerations are listed below.

- To qualify for the thermal mass provisions in MEC, the exterior wall assembly is required to have a heat capacity greater than or equal to 6 Btu/ft^2/^{o}F. Generally, a wall with an average thickness of 2 ½-inches of normal weight concrete, or a 6-inch thick, hollow-core concrete masonry unit of normal weight meets the MEC heat capacity requirement.

- The level to which MEC recognizes thermal mass benefits is based on heating degree days, i.e., climate, and the location of the insulation, i.e., on the interior of the wall, the exterior, or "integral". Situations where the insulation is located on the exterior of the wall mass and located in moderate climates will result in the largest reduction in insulation requirements for the wall assembly. In climates where heating degree days are greater than 8,000, no reduction in insulation due to thermal mass is realized.

> *Ohio. The state energy code recognizes MEC and the provisions for thermal mass. Given that the block used in the wall (8-inch thick, hollow-core, normal weight masonry) meets the MEC requirement for thermal mass, the required insulation is permitted to be decreased to a level based on the number of heating degree days in the area (approximately 5,400 for Springfield, Ohio). By using an expanding polyurethane in the core of the blocks, i.e., "integral" insulation as defined in MEC Table 502.1.2c, the builder obtained approval from the local building department.*
>
> *Minnesota. Because the number of heating degree days in Minneapolis is approximately 8,200 the thermal mass is effectively negated and no benefit in reduced insulation was realized. However, the builder was able to meet the*

energy code requirements using 2½” of polyisocyanurate installed on the interior side of the masonry block providing an insulation value of approximately R-17.5.

CONSTRUCTION ISSUES AND DETAILS

Staging of the Block

Scaffolding will be required for any masonry wall above about four feet high, or chest height of a mason. Although establishing an efficient flow of materials on a jobsite is often very straightforward, the staging of masonry block and mortar on some sites requires additional consideration. For example, the construction of some two story concrete masonry walls may require either the use of a hydraulic lift, or significant manual hoisting and/or carrying of block. In any case, whenever laying block while working on a framed floor deck (as opposed to a slab), the weight and location of the block staged on this floor deck should be considered so as not to exceed the maximum allowable load for the deck.

> *Ohio. The house was one story high with a wood-framed floor deck, and the 8-inch thick, half-high block wall was laid from the interior side of the wall. Full pallets of block were periodically placed on the floor deck using a fork lift, and then placed on the scaffold planks by a laborer. The mortar was mixed in a gas-powered mixer, and wheelbarrowed from the mixer to the floor deck.*
>
> *Minnesota. Mark Olson had two different approaches for laying block. At ground levels (the basement level and the main floor at the front of the house) Mark chose to lay the block wall while working from the exterior side of the wall, stating that when working with an architectural block he can tool a better joint from the exterior side. However, at upper levels (the main level on the downhill side was 19 feet above grade), Mark chose to lay the block from the interior side. For these walls, full pallets of block were staged on the second level floor deck over bearing walls below. The mortar was mixed in a gas-powered mixer and wheelbarrowed to the work area.*

Windows and Doors

Beams, lintels and arches are used to span openings in masonry walls. Large openings are typically spanned with steel or cast-in-place, reinforced concrete lintels. To span small openings, steel angle, reinforced concrete masonry units (CMU), and precast concrete are most commonly used. In general, the model building codes do not offer detailed prescriptions for lintels--most lintel manufacturers offer supporting calculations.

Virtually any of the windows and doors available today can be installed in a masonry wall. Although in some cases the jamb of doors and windows can be set in place in the wall and the masonry is laid up to the jamb, typically doors and windows are installed as a unit after the wall is complete. When the door or window is installed as a unit, it is often attached to a sub-frame, or buck, consisting of 2x lumber.

> *Ohio. The door and window openings (other than the garage door) are all either three feet or six feet wide, supporting roof and wall loads only. The builder used 2-3 ½” x 3 ½” steel angles as a lintel, as shown in Photos 6a and 6b and Figure*

A2. This required cutting the block to accept the vertical flange of the steel lintel creating a "beam pocket", also shown in Photos 6a, 6b, and Figure A2. This beam pocket, along with the cores of the block above it (which is the top course of the wall), was fully grouted for added strength and bonding of the lintel and the supported block. The windows (units without interior or exterior casings) were fastened directly through the window frame to the block with TAPCON™ screws.

Minnesota. The door and window openings (other than the garage door) range from three feet to eight feet wide, supporting wall loads, and in some cases, roof loads as well. Mark Olson used half-high blocks which were cut on-site to the required size as concrete block lintels, creating a soldier course header detail (see Photos 7a and 7b and Figure A6). The half-high block were set on temporary steel lintels which are removed later (also shown in Photos 7a and 7b). To install the windows Mark Olson used a modified buck approach, where a pressure-treated 2x lumber buck is attached to the inside face of the masonry wall with glue and TAPCON™ screws. The window is then nailed to the 1½" dimension of the buck, and trimmed-out with 2x4s ripped to the desired width (as shown in Photo 7c and 7d).

Photos 6a and 6b. Steel Lintel at Ohio Site

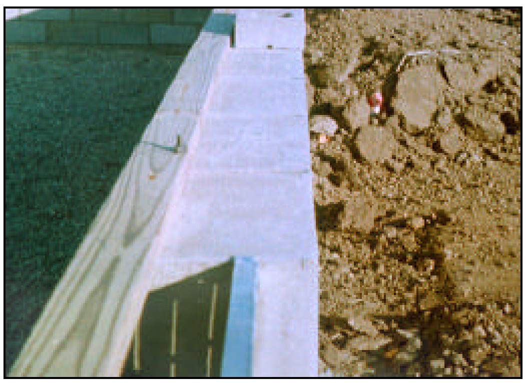
Photos 7a and 7b. Reinforced CMU Lintel at Minnesota Site (with and without temporary steel lintel).

Photo 7c and 7d. Modified Window Buck at Minnesota Site

Floor Deck Connection

Two sections of the CABO code prescribe floor deck connections: 1) the "Floors" chapter (section 502.4) prescribes minimum bearing of floor joists (3-inches); and 2) the "Masonry" chapter (section 604.8.2.2) prescribes how floor diaphragms are to be anchored to masonry walls to provide vertical lateral support for the wall. The Masonry chapter (section 604.2.3) also prescribes that where walls of hollow masonry units are decreased in thickness (for example, at floor deck connections between stories), a course of solid masonry (or special units or construction) shall be used to transmit the loads from wythes above to those below.

Ohio. The floor deck bears on a 2x4 treated sill plate (shown in Photo 8a), which is anchored to the 12-inch thick foundation walls (Photos 8a and 8b). The ¾" OSB rim joist is notched to avoid the anchor bolts (Photo 8b). In addition to photos 8a and 8b below, this detail is shown in Figure A3.



Photos 8a and 8b. Floor Deck Connection at Ohio Site.

Minnesota. The floor trusses are supported by 2x4 wood stud walls, and are not supported by the masonry wall. The floor deck assembly is connected to the masonry wall, but this connection provides lateral support to the wall and does not support the floor deck (see Photo 9 and Figure A6). Although this detail allowed Mark Olson to create a thermal envelope without breaks, this essentially creates a "dual" wall[5].

Photo 9 Floor Deck Connection at Minnesota Site

[5] Mark Olson's supplier (Anchor Block) recommends joist hangers tied directly into the bond beam as part of their system. Mark Olson stated at the end of the project that the hanger approach is better than using wood bearing walls.

Fastening into Concrete Masonry

As the primary structural system of a building, the concrete masonry wall will be used to support numerous building elements including furring strips for siding or drywall, windows and doors, or insulation and electrical boxes. Each of these elements will require fastening, and many of the fastening options are listed below. Depending on how they are used, fasteners may be subjected to tension (withdrawal) loads, shear loads, or a combination of the two. Most concrete/masonry fasteners work in one of four ways:

1.) Masonry nails, masonry screws, and various mechanically-driven pins;
2.) Wedge and sleeve anchors, and expansion bolts;
3.) Hollow-wall fasteners, such as toggle bolts and hollow wall screws; and
4.) Chemical fastening systems, or adhesive anchoring.

> *Ohio. The elements fastened to the concrete masonry were the window frames, door frames, and the nailers for the gypsum wallboard, which were all fastened with TAPCON™ screws (see #1 above). Descriptions of these connections are detailed in the "Windows and Doors" and "Gypsum Wallboard Connections" sections of this report.*
>
> *Minnesota. The elements fastened to the concrete masonry walls were the window bucks, door frames, and second level floor deck assembly. The window bucks and door frames were fastened with glue and TAPCON™ screws (see #1 and 4 above), as described in the "Windows and Doors" section of this report. The floor deck was fastened with 5/8" diameter expanding bolts (see #2 above), as described in the "Lateral Support of Walls" section of this report and Figure A6.*

Flashing and Weepholes

Water can enter into any wall type by wind driven rain, and in concrete masonry walls, weepholes and flashing can be used to provide protection against this moisture. While flashing prevents moisture from wind-driven rain entering the wall around window and door openings, the weepholes provide a means of escape should moisture enter the wall. Although CABO, UBC, and ACI 530 do not prescribe the use of weepholes or flashing, both BOCA and SBC require that weepholes be provided [6].

[6] BOCA requires a maximum spacing of 33 inches on center, and that weepholes shall not be less than 3/16-ich in diameter. SBC prescribes maximum spacing of 48" on center, and shall be located in the first course above the foundation wall or slab, and other points of support, including structural floors, shelf angles, and lintels.

Ohio. Although weepholes were not used in the masonry walls, flashing was used at the base of the 8-inch thick masonry walls to protect the wood floor deck assembly from potential moisture (see Photo 10).

Photo 10. Moisture Barrier at Ohio Site

Minnesota. The builder chose not to use flashing and weepholes. Mark Olson stated that when using masonry lintels in single-wythe construction, flashing is not necessary in most cases (Mark added that in some single-wythe applications, e.g., where metal lintels are used, flashing is necessary). Mark also stated that when the wall is water-proofed with siloxane, weepholes are also not necessary.

Gypsum Wallboard Connections

Gypsum wallboard is typically attached to concrete masonry walls via an intermediate frame, such as furring strips or a narrow stud-wall.

Ohio. At three courses of the concrete masonry wall (approximately the 2', 5' and 7' heights), the half-high block was offset about ½-inch to the exterior side, providing a narrow channel (see Photo 11). Strips of OSB sheathing (1/2-inch thick) were placed into this channel, and screwed to the CMU block with TAPCON™ screws. The gypsum wallboard was then screwed to the OSB nailers. The narrow channel can also be used as an electrical raceway.

Minnesota. On the lower-story side walls of the house the gypsum wallboard was fastened to the 2x4 wood stud walls supporting the floor deck. On the front and back walls of the house (as well as the entire second floor), 1-5/8" metal stud walls were framed (attached to the ceiling and floor assemblies), to which the gypsum wallboard was attached using sharp-point screws.

Photo 11. Channel for Drywall Nailers at Ohio Site

CONCLUSIONS & RECOMMENDATIONS

Conclusions

- A major decision that affects the efficient use of masonry construction is the method of design used to provide compliance with the local building codes, i.e., empirical design and engineered design. The empirical design method is often used for single-family dwellings for reasons of simplicity, as well as the elimination of engineering costs. The engineered design approach, as illustrated in the Minnesota case study, does introduce additional costs, but can help reassure skeptical building officials who may be unfamiliar with residential block construction.

- As seen in the Minnesota and Pennsylvania case studies, local suppliers can be integral and supportive players in the development of plans. In fact, as illustrated in the Pennsylvania case study, a high level of support may be *required* before some conventional stick-frame home builders convert to concrete masonry construction. Home builders considering concrete masonry above grade should seek support from their local supplier.

- The three model building codes and CABO prescribe two different minimum requirements for the type of block used for single story buildings. While all four codes prescribe 6-inches as the minimum thickness, CABO and UBC prescribe that the block must be of *solid* masonry.

- The Ohio and Minnesota case studies illustrated that the weight of concrete masonry blocks requires consideration during the construction of both single- and multi-story walls. In the Ohio case study the block was laid from the interior side of the wall, requiring the staging of the block on a wood-framed floor assembly. In the Minnesota case study the block was laid from the exterior side of the wall at the ground level, and from the interior side at the upper level.

- Lateral support of walls was not a design issue/barrier with the two case study homes, nor will it be an issue for many low-rise residential structures. Because the clear span distance between floors and roof is typically 8 or 9 feet in most single-family detached homes, the masonry walls rely on lateral support in the vertical direction (floors and roofs) and not the horizontal direction. Buildings with tall, unsupported exterior walls or high ceilings, e.g., “great rooms” and entry foyers, as well as buildings with 6-inch thick block (which limit the spacing between lateral support) will require special attention.

- While the concrete masonry industry offers recommendations for controlling cracks in masonry walls, the model building codes do not include prescriptive requirements for crack control. For typical residential construction crack control has not necessarily been "proven" to be a problem. However, as the Ohio and Minnesota case studies illustrated, the uncertainty surrounding the need for bond beams, horizontal joint reinforcement, and control joints results in decisions made on an individual basis. Details and guidance specifically for use by home builders need to be developed, in particular for the novice masonry builder.

- By limiting the "allowable compressive stresses in masonry", the model building codes require that these values be verified. In most cases this level of verification may require either engineering analysis (beyond which the typical builder is capable) or on-site testing by the local code official.

Recommendations

Create a "prescriptive method", i.e., a non-engineered design, for residential concrete masonry construction. The empirical design approach currently in the model building codes is confusing to the novice user, does not include many common details or fastening requirements, and in many cases does not produce the most cost-effective concrete masonry wall assembly. Specific provisions of a "prescriptive method" could address the following issues:

- *Minimum wall thickness*. Providing optimized wall assemblies (which offer options such as block thickness and level of reinforcement), would improve the flexibility and simplicity of the current empirical design approach.

- *The applicability limits of the current empirical design approach*. In general, the current empirical design approach offered in the model building codes is limited to buildings in low seismic and wind pressure areas and less than 35 feet in height. The proposed "prescriptive method" could be developed for high wind and seismic areas as well.

- *The allowable compressive stresses*. The information in the model building codes prescribing allowable compressive stresses of masonry and mortar is confusing and intimidating. The information provided implies that the loads on the block and mortar must be calculated for every empirical design. However, in practice a single minimum or standard block is usually supplied. The code should recognize this simplistic approach to empirical design.

- *Floor deck connections*. With regards to the connection of the floor deck to masonry walls, the empirical design information in the codes offers only a ledger detail, i.e., side bearing. A prescriptive method could provide details for floor deck connection where wall thickness decreases, e.g., between stories, top of foundation, etc.

- *Lateral support of walls.* Although not an issue with the two case study homes, it is apparent that lateral support of the overall building is not addressed in the current empirical masonry code and should be investigated with respect to safety and efficient design limits on the amount of openings in walls to resist racking loads from wind and seismic forces.

Prepare a "best practice guide" for residential concrete masonry construction. In addition to the structural items listed above (which can be codified), a "best practices guide" should offer support for novice masonry builders. Specific provisions of the document could address: water repellency; insulation placement and energy code compliance; window and door installation; fastening into concrete masonry; flashing and weepholes; and interior finish attachment.

APPENDIX A-CONSTRUCTION DETAILS

LIST OF FIGURES

Figure A- 1 Ohio Wall Section

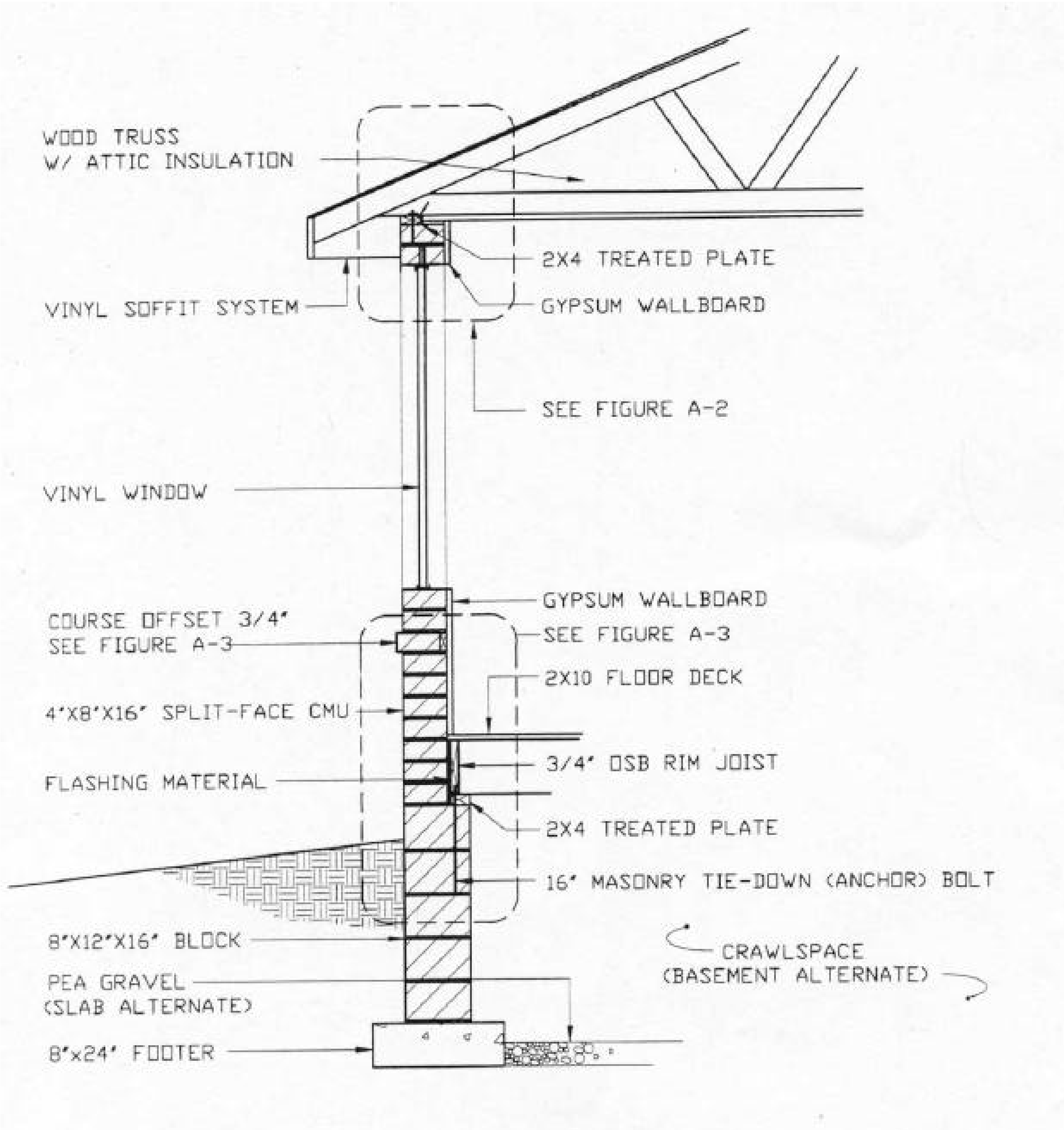


Figure A- 2 Ohio Lintel/Beam Pocket

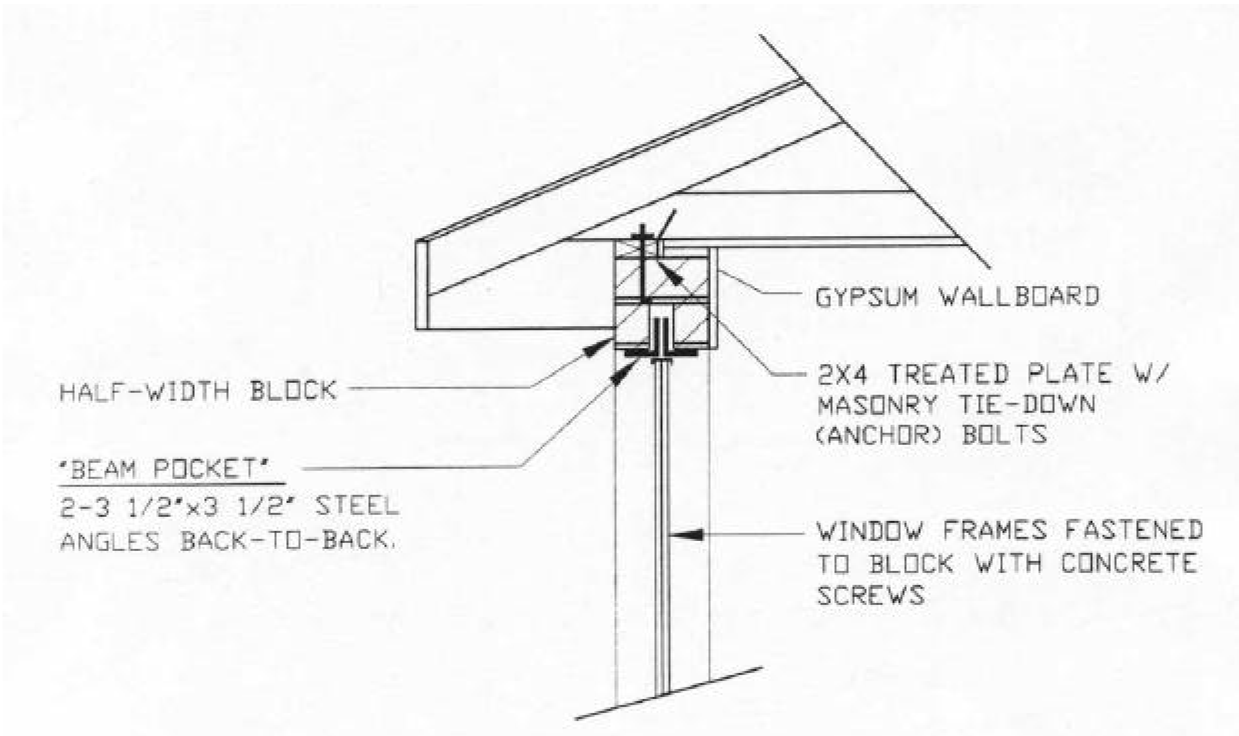


Figure A- 3 Ohio Floor Deck/Foundation Detail

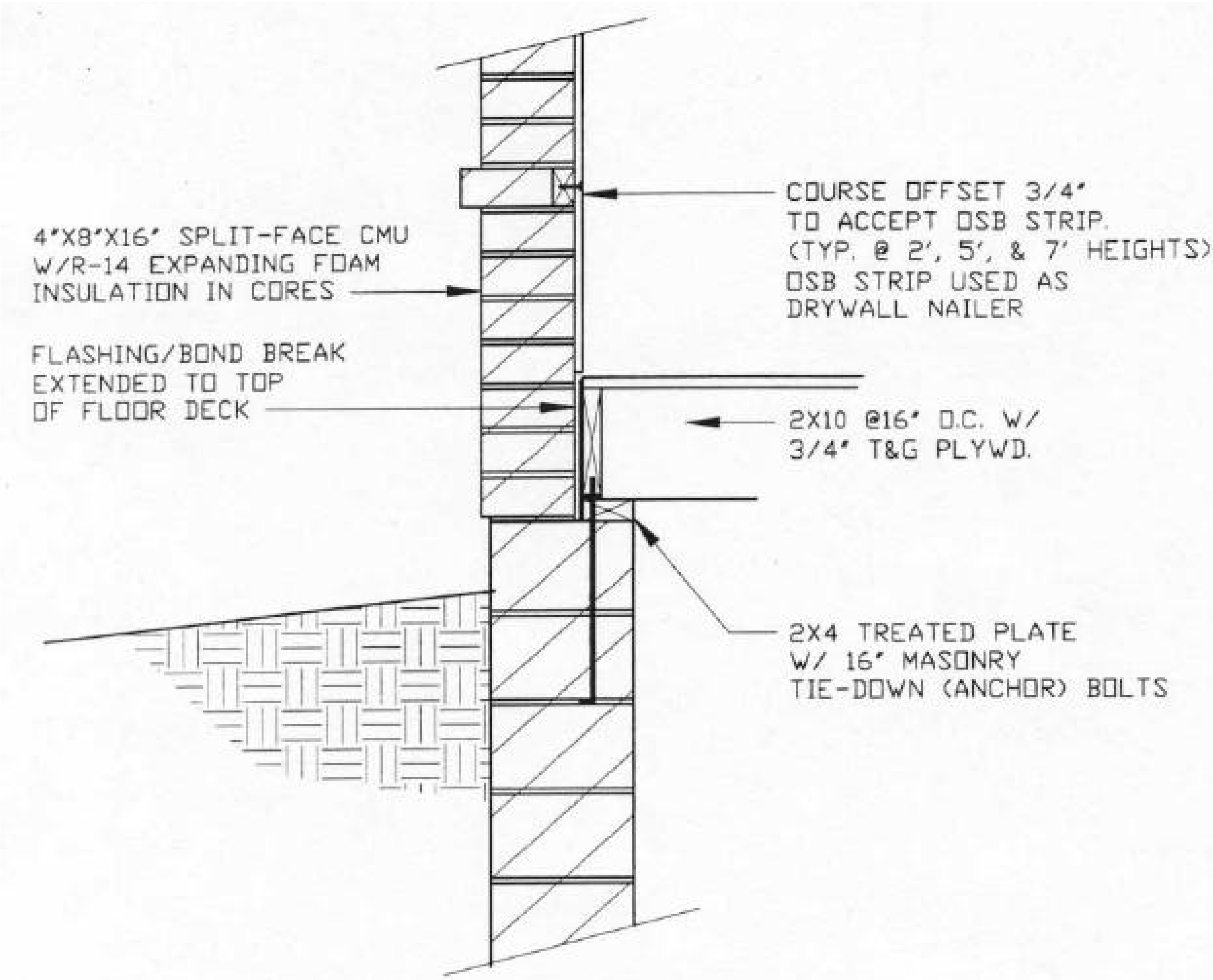


Figure A- 4 Minnesota Wall Section

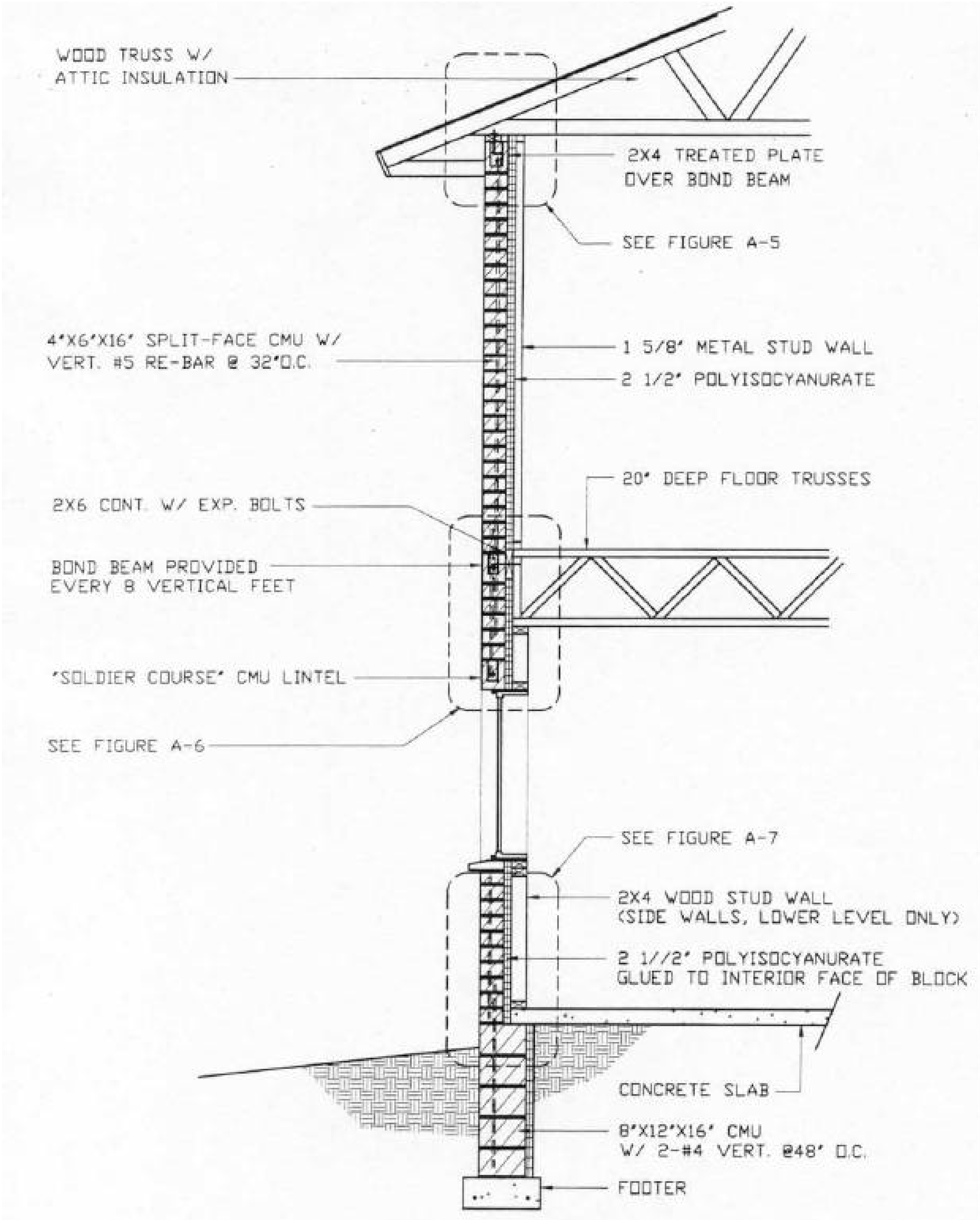


Figure A- 5 Minnesota Roof Truss/Bond Beam Detail

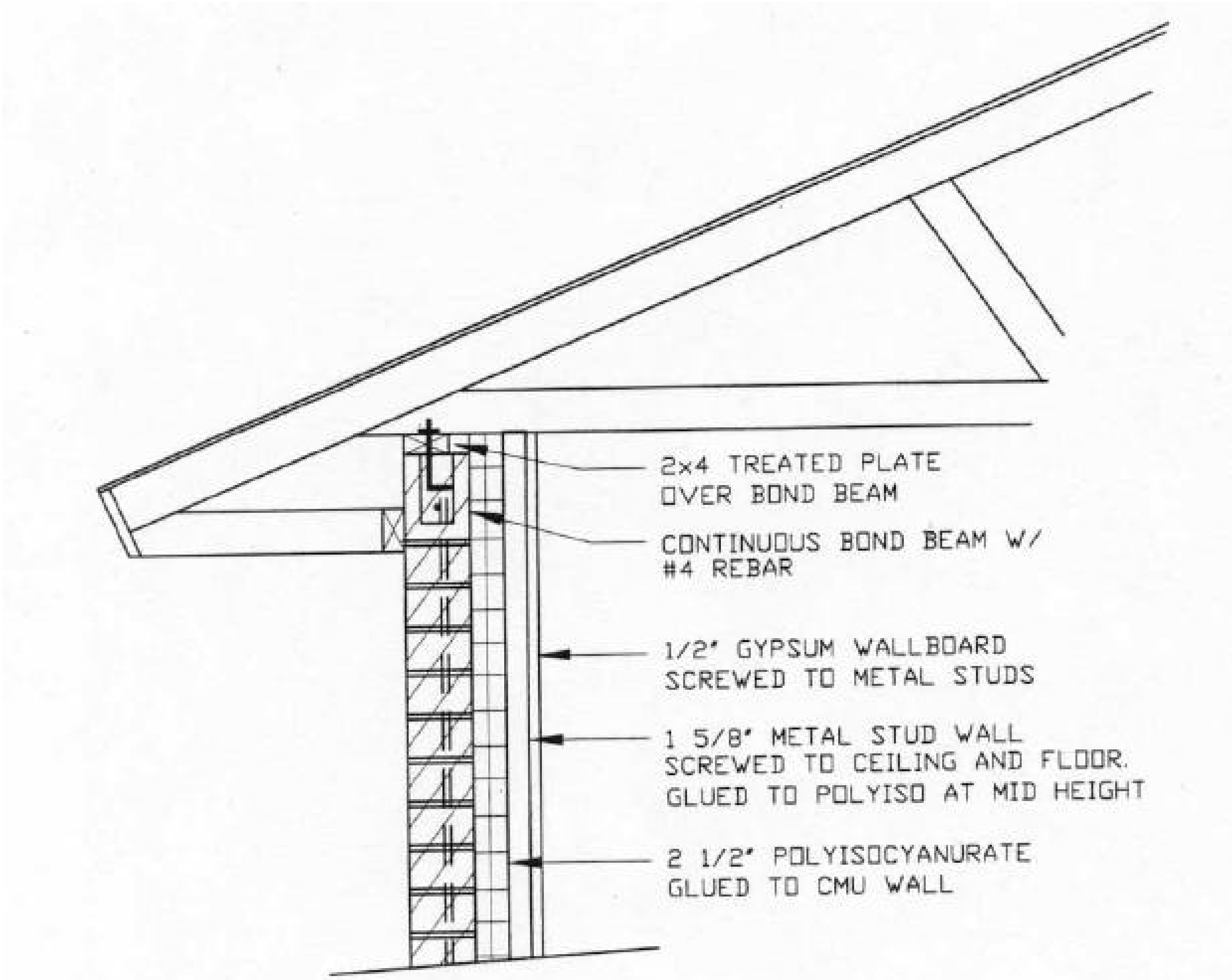


Figure A- 6 Minnesota Floor Deck/Bond Beam/Lintel Detail

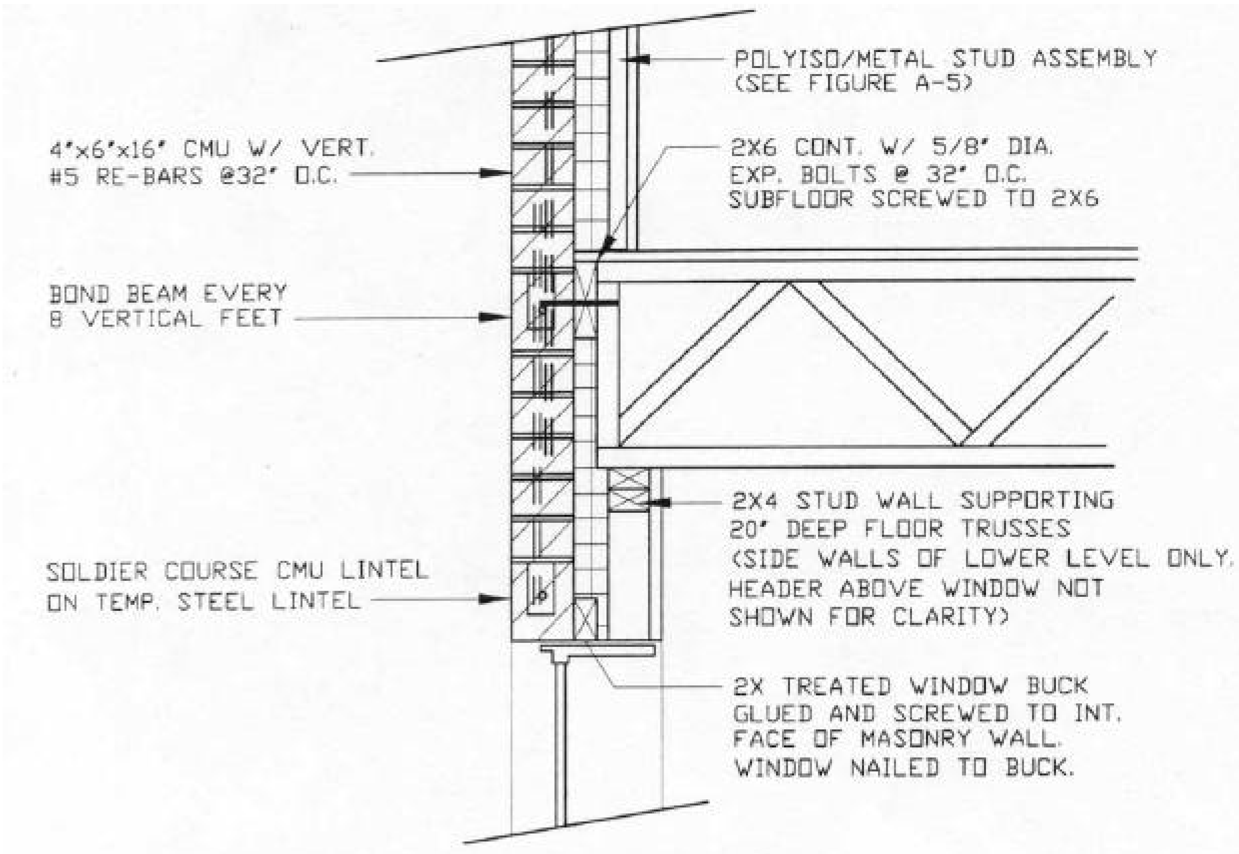
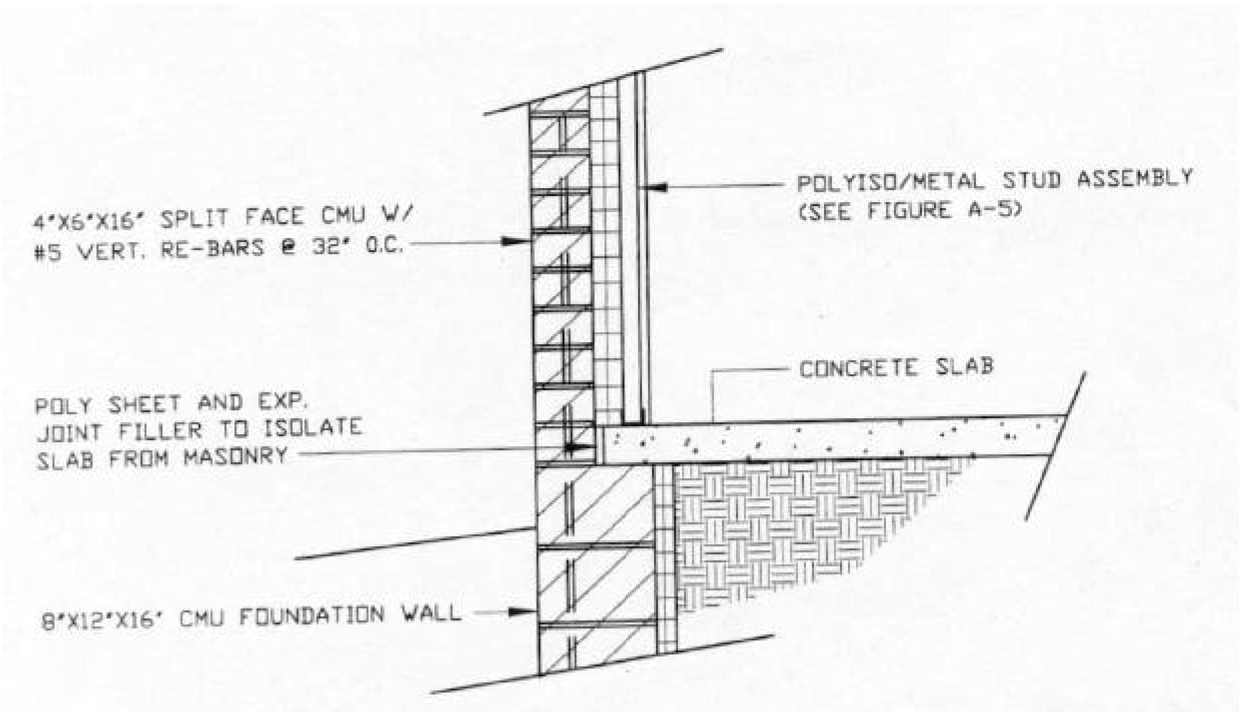


Figure A- 7 Minnesota Slab/Foundation Detail



APPENDIX B

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APPENDIX C

METRIC CONVERSION FACTORS

The following list provides the conversion relationship between U.S. customary units and the International System (SI) units. A complete guide to the SI system and its use can be found in ASTM E 380, Metric Practice.

To convert from	to	multiply by
Length		
inch (in.)	meter (μ)	25,400
inch (in.)	centimeter	2.54
inch (in.)	meter (m)	0.0254
foot (ft)	meter (m)	0.3048
yard (yd)	meter (m)	0.9144
mile (mi)	kilometer (km)	1.6
Area		
square foot (sq ft)	square meter (sq m)	0.09290304E
square inch (sq in)	square centimeter (sq cm)	6.452 E
square inch (sq in.)	square meter (sq m)	0.00064516E
square yard (sq yd)	square meter (sq m)	0.8391274
square mile (sq mi)	square kilometer (sq km)	2.6
Volume		
cubic inch (cu in.)	cubic centimeter (cu cm)	16.387064
cubic inch (cu in.)	cubic meter (cu m)	0.00001639
cubic foot (cu ft)	cubic meter (cu m)	0.02831685
cubic yard (cu yd)	cubic meter (cu m)	0.7645549
gallon (gal) Can. liquid	liter	4.546
gallon (gal) Can. liquid	cubic meter (cu m)	0.004546
gallon (gal) U.S. liquid*	liter	3.7854118
gallon (gal) U.S. liquid	cubic meter (cu m)	0.00378541
fluid ounce (fl oz)	milliliters (ml)	29.57353
fluid ounce (fl oz)	cubic meter (cu m)	0.00002957
Force		
kip (1000 lb)	kilogram (kg)	453.6
kip (1000 lb)	Newton (N)	4,448.222
pound (lb)	kilogram (kg)	0.4535924
pound (lb)	Newton (N)	4.448222
Stress or pressure		
kip/sq inch (ksi)	megapascal (Mpa)	6.894757
kip/sq inch (ksi)	kilogram/square centimeter (kg/sq cm)	70.31
pound/sq inch (psi)	kilogram/square centimeter (kg/sq cm)	0.07031
pound/sq inch (psi)	pascal (Pa) **	6,894.757
pound/sq inch (psi)	megapascal (Mpa)	0.00689476
pound/sq foot (psf)	kilogram/square meter (kg/sq m)	4.8824
pound/sq foot (psf)	pascal (Pa)	47.88

To convert from	to	multiply by
Mass (weight)		
pound (lb) avoirdupois	kilogram (kg)	0.4535924
ton, 2000 lb	kilogram (kg)	907.1848
grain	kilogram (kg)	0.0000648
Mass (weight) per length		
kip per linear foot (klf)	kilogram per meter (kg/m)	0.001488
pound per linear foot (plf)	kilogram per meter (kg/m)	1.488
Moment		
1 foot-pound (ft-lb)	Newton-meter (N-m)	1.356
Mass per volume (density)		
pound per cubic foot (pcf)	kilogram per cubic meter (kg/cu m)	16.01846
pound per cubic yard (lb/cu yd)	kilogram per cubic meter (kg/cu m)	0.5933
Velocity		
mile per hour (mph)	kilometer per hour (km/hr)	1.60934
mile per hour (mph)	kilometer per second (km/sec)	0.44704
Temperature		
degree Fahrenheit (°F)	degree Celsius (°C)	$t_C = (t_F-32)/1.8$
degree Fahrenheit (°F)	degree Kelvin (°K)	$t_K = (t_F + 459.7)/1.8$
degree Kelvin (°F)	degree Celsius (°C)	$t_C = (t_K -32)/1.8$

* One U.S. gallon equals 0.8327 Canadian gallon

** A pascal equals 1000 Newton per square meter.

The prefixes and symbols below are commonly used to form names and symbols of the decimal multiples and submultiples of the SI units.

Multiplication Factor	Prefix	Symbol
$1,000,000,000 = 10^9$	giga	G
$1,000,000 = 10^6$	mega	M
$1,000 = 10^3$	kilo	k
$0.01 = 10^{-2}$	centi	c
$0.001 = 10^{-3}$	milli	m
$0.000001 = 10^{-6}$	micro	μ
$0.000000001 = 10^{-9}$	nano	n