

UNIFIED FACILITIES CRITERIA (UFC)

INDOOR RADON PREVENTION AND MITIGATION



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INDOOR RADON PREVENTION AND MITIGATION

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U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by \1\ ... /1/)

Change No.	Date	Location

This UFC supersedes TI 810-91, dated 3 August 1998. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TI 810-91, dated 3 August 1998.

FOREWORD

\1\

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with [USD\(AT&L\) Memorandum](#) dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.


UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCEA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: [Criteria Change Request \(CCR\)](#). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:


- Whole Building Design Guide web site <http://dod.wbdg.org/>.


Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

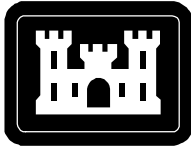
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TI 810-91
3 August 1998

**US Army Corps
of Engineers®**

Technical Instructions

Indoor Radon Prevention and Mitigation

Headquarters
U.S. Army Corps of Engineers
Engineering and Construction Division
Directorate of Military Programs
Washington, DC 20314-1000

FOREWORD

These technical instructions (TI) provide design and construction criteria and apply to all U.S. Army Corps of Engineers (USACE) commands having military construction responsibilities. TI will be used for all Army projects and for projects executed for other military services or work for other customers where appropriate.

TI are living documents and will be periodically reviewed, updated, and made available to users as part of the HQUSACE responsibility for technical criteria and policy for new military construction. CEMP-ET is responsible for administration of the TI system; technical content of TI is the responsibility of the HQUSACE element of the discipline involved. Recommended changes to TI, with rationale for the changes, should be sent to HQUSACE, ATTN: CEMP-ET, 20 Massachusetts Ave., NW, Washington, DC 20314-1000.

TI are effective upon issuance. TI are distributed only in electronic media through the TECHINFO Internet site <http://www.hnd.usace.army.mil/techinfo/index.htm> and the Construction Criteria Base (CCB) system maintained by the National Institute of Building Sciences at Internet site <http://www.nibs.org/ccb/>. Hard copies of these instructions produced by the user from the electronic media should be checked against the current electronic version prior to use to assure that the latest instructions are used.

FOR THE DIRECTOR OF MILITARY PROGRAMS.



KISUK CHEUNG, P.E.
Chief, Engineering and Construction Division
Directorate of Military Programs

CEMP-E

Engineering Instructions
No. EI 15M001

1 November 1996

INDOOR RADON PREVENTION AND MITIGATION

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INDOOR RADON PREVENTION AND MITIGATION

1. **PURPOSE AND SCOPE.** This document establishes design criteria for all U.S. Army facilities to reduce health risks due to indoor radon. The design standards established herein are applicable to all newly constructed and substantially altered Army facilities both inside and outside the Continental United States.
2. **APPLICABILITY.** These instructions are applicable to all elements responsible for the design of military construction.
3. **REFERENCES.**

GOVERNMENT PUBLICATIONS:

Department of the Army

TM 5-805-6	Joint Sealing for Buildings
CEGS-02221	Excavation, Filling and Backfilling for Buildings
CEGS-0790	Joint Sealing

U.S. Environmental Protection Agency (EPA)

EPA 402-R-93-078	Radon Mitigation Standards
EPA 520/1-87-20	Radon Reference Manual
EPA 625/5-87/019	Radon Reduction Techniques for Detached Houses

NONGOVERNMENT PUBLICATIONS:

American Society for Testing and Materials (ASTM)
1916 Race Street
Philadelphia, PA 19103

E 1465	(1992) Guide for Radon Control Options for the Design and Construction of New Low Rise Residential Buildings
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4. **PROPERTIES OF RADON.** Radon is a naturally occurring, chemically inert and water soluble radioactive gas that is undetectable by human senses. It is formed by the radioactive decay of thorium and uranium. These source elements are found in low, but varying, concentrations in soils and rocks. Radon, being a gas, escapes from the ground following paths of least resistance such as through small fissures, gravel, sand, and other porous soils. Normal subsoil investigations do not locate these radon paths with sufficient detail and accuracy to reliably predict points where radon emerges from the earth or probable levels of concentration. Radon-220, derived from thorium, has a half-life of 55 seconds giving it limited time to enter buildings before it decays to a nongaseous element. Radon-222, derived from uranium and having a half-life of 3.8 days, is the primary source of indoor radon. Refer to EPA 520/1-87-20 for more detailed information.
5. **OTHER RISKS.** Health risks associated with radon are from its decay products, not the radon gas. Radon-222 decays in several steps to form non-gaseous radioactive isotopes with short half-lives. Four of these successive decay products have half-lives less than 30 minutes. These isotopes are chemically reactive and attach to building surfaces and airborne dust particles. Both attached and unattached decay products can be inhaled and attach to lung tissue. Further radioactive decay of these isotopes releases

alpha particles that damage lung tissue and leads to lung cancer. EPA recommends the removal of radon gas rather than removal of decay products with high efficiency air filters or air cleaning devices. For more information on the disadvantages of air cleaning as the primary method for radon control, refer to EPA 625/5-87/019. (Most of the research work and publications by EPA have concentrated on single family, detached dwellings. Military facilities are generally larger and of different construction methods than single family residences. The design criteria and details contained in this document are selectively adapted from the EPA data and recommendations.)

6. PRIORITY OF FACILITY TYPES. Priorities for designing various types of military facilities to reduce indoor radon are based upon the USACE Radon Program.

- a. Priority 1: Day care centers, hospitals, schools, living quarters including barracks, unaccompanied personnel housing (officers and enlisted) and family housing, and routinely occupied spaces below grade.,
- b. Priority 2: Offices, work areas, and other facilities having 24-hour operations.
- c. Priority 3: All other routinely occupied structures including morale, welfare and recreational facilities.
- d. Priority 4: All intermittently occupied structures that are used by any military or civilian employee whose total work time in those buildings equals or exceeds 80 hours per year.
- e. Structures occupied less than 80 hours per year by any employee do not require radon preventive measures.

7. INDOOR RADON CONCENTRATION AND ACTION LEVELS. Radon is measured in picocuries per liter (pCi/L or Becquerel per cubic meter (Bq/m^3) of air. EPA studies have assigned relative health risks for various concentration levels of indoor radon based upon periods of exposure; concentration levels below 4 pCi/L (148 Bq/m^3) are negligible.

The action levels given below conform to the USACE Radon Program:

- a. Negligible: 0 to 4 pCi/L (0 to 148 Bq/m^3).
- b. low: 4 to 8 pCi/L (148 to 296 Bq/m^3).
- c. Moderate: 8 to 20 pCi/L (296 to 740 Bq/m^3).
- d. High: 20 to 200 pCi/L (740 to 7400 Bq/m^3).
- e. Very High: Greater than 200 pCi/L (7400 Bq/m^3).

8. DETERMINATION OF RADON POTENTIAL. EPA 402-R-93-078 establishes a program for measuring indoor radon in existing buildings. Radon measurements data should be added to the real property database. Where installations maintain accurate records of radon measurements for existing buildings on army installations, these pre-mitigation measurements may be used as the basis for determining potential radon levels for new facilities. Design criteria will be based upon the highest radon measurements in existing buildings in close proximity to the new facility. Where the new facility is in a remote location, the highest measurements on the installation will determine the design criteria. In cases where existing radon data are not available, soil-based radon and radium measurement may provide useful information in evaluating radon potentials. Procedures for using soil gas measurements to estimate radon potentials are still evolving, contact EPA for the most up-to-date guidance. Indoor radon monitors are available that will measure radon levels automatically and continuously showing current and long term measurements as

recommended by EPA.

9. DESIGN REQUIREMENTS.

a. New Construction. Design requirements consist of passive barriers to seal radon entry routes and active sub-slab suction systems to remove radon gas from the soil under floor slabs and around below grade walls. The objective of both passive and active design strategies is to reduce radon entry to interior spaces. Specific design requirements, based upon facility priority and potential radon concentration, are listed in table 1 by letter codes. The letter codes are described below and indicated on the details shown in appendix A.

Table 1. Design requirements for radon prevention

PRIORITIES FOR FACILITY TYPES	NEGLIGIBLE 0 to 4 pCi/L (0 to 148 Bq/m ³)	LOW 4 to 8 pCi/L (148 to 296 Bq/m ³)	MODERATE 8 to 20 pCi/L (296 to 740 Bq/m ³)	HIGH 20 to 200 pCi/L (740 to 7400 Bq/m ³)	VERY HIGH over 200 pCi/L (7400 Bq/m ³)
1	A	A,B	A,C	A,D,E	A,D,F
2	A	A,B	A,B	A,D,E	A,D,F
3	A	A,B	A,B	A,C	A,D,E
4	A	A	A	A,B	A,C

(1) Passive Barriers, Letter Code A. Passive barriers are required for facility priorities 1 through 4 and for all potential radon concentration levels. Passive barriers include 6 mil polyethylene sheet in crawl spaces and under floor slabs on grade, capillary water barrier below floor slabs on grade, dampproofing or waterproofing and protection board on below grade walls, sealants in all joints in floor slabs, below grade walls and around all pipe and conduit penetrations. Provide solid courses in hollow masonry walls to prevent gas passage through the internal voids. Joint sealants will be selected and installed according to TM 5-805-6 and CEGS-07920. Polyethylene sheets will be lapped 12 inches and sealed with adhesives or pressure sensitive tape and sealed at foundation walls with mastic. Capillary water barrier will be according to CEGS -02221 except that capillary water barriers will be installed without regards to site conditions.

(2) Sub-slab Suction Systems, Letter Codes B, C, and D. Sub-slab suction systems consist of 4-inch diameter perforated PVC pipe laid in the capillary water barrier below floor slabs which are used to create negative pressure fields under the floor. Provide a suction stack connection, using non-perforated PVC pipe, stubbed through the floor slab and capped. The suction stack should be near the middle of the under slab pipe run and be located where it can be extended through the building roof with minimum changes of direction. Requirements for letter codes B, C, and D are identical except for the spacing for under slab pipe runs. In structures with basements or other below grade spaces, connect the sub-slab piping to the foundation drainage system so that the negative pressure field is extended to the earth side of below grade walls. Where the foundation drainage has gravity outfall, provide an interior suction stack and a water trap. Where foundation drains discharge to a sump, seal the sump cover and provide a suction stack connection to the sump; large buildings will require additional suction stacks remote from the sump. Building sites with seasonally high ground water may require a high water sensor at the suction stack connection to shut off the suction fan. Radon gas is water soluble. It is reasonable to assume that a

properly designed sub-soil drainage system will remove radon from sites with severe ground water problems.

(3) Passive Suction Stack, Letter Code E. Extend non-perforated PVC pipe suction stack through the roof with as few changes in direction as possible. Passive stacks are more effective in colder climates and during winter months than during warm weather. During warm weather they will be most effective in naturally ventilated, non air conditioned buildings.

(4) Active Suction Stack, Letter Code F. Extend the suction stack as described above for the passive stack and install an exhaust fan near the stack discharge. Preferred location for the exhaust fan is above the roof. Condensation of moisture in soil gases will be minimized if the fan is located in a heated space, however, any air leakage that may occur at the fan discharge connection will blow concentrated radon into the building. Any air leakage at the fan intake connection will reduce the suction in the stack.

(5) Design of Sub-Slab Suction System. Pipe sizing for the suction system should be designed similar to any exhaust system utilizing round duct. The under slab perforated pipe should be no larger than 4-inch diameter. In very large structures, do not increase the pipe diameter in order to increase the length of pipe runs, this may reduce uniformity in the pressure field. The quantity of air flow in a sub-slab suction system is effected by a number of variables. The most significant are porosity of the soil, permeability of the capillary water barrier, and air leakage from the building into the soil. In most locations, the air flow per 1,000 sq. ft. of slab area will be 20 cfm or less. Multiple under slab pipe runs may be cross connected below the floor using non-perforated pipe of sufficient diameter to maintain uniform pressure in all pipe runs. Multiple stacks may be connected to a common exhaust fan. Pipes for stacks and any manifolds will be sized according to air flow and pressure losses due to pipe length and number of turns.

(6) Fan Selection. The fan selected will have cfm and horse power ratings adequate to maintain 1 inch wc static pressure at the slab penetration under constant operation. This will be mounted directly in or to the vertical riser with air tight connections and will be of such design that condensation of soil gas moisture will drain either back down the stack or onto the roof. Fans may be an in-line configuration and installed in the stack or a standard curb mounted exhaust fan.

(7) Naturally Ventilated Buildings. Naturally ventilated buildings that are neither heated or cooled by mechanical systems and are in any of the facility priorities 1 through 4 will be designed to include passive barriers (letter code A) only.

b. Existing Buildings. Radon mitigation requirements incorporated into the design of building alterations will be based upon the facility priority and actual radon measurements in the building. The design-requirements in table 1 will be evaluated according to life cycle cost/benefit analysis and engineering judgment. For example, removal of slab-on-grade floors to install a sub-slab suction system may not be cost effective when compared to the differential in equipment and operating-costs to increase interior air pressure or the outside-air exchange rate. EPA publication 402-R-93-078 provides guidelines to ensure effective mitigation.

10. POST CONSTRUCTION RADON MEASURE.

a. After completion of construction, indoor radon measurements will be made with all HVAC systems operating on normal cycles. Radon detectors and laboratory analytical services will be obtained through suppliers that are currently certified under EPA's Radon Measurement Proficiency program.

b. The severity of potential indoor radon concentration cannot be accurately predicted. The time duration for post construction radon measurement(s) and the extent of mitigation work that may be required is not quantifiable for inclusion in construction contracts. Therefore, the installation or user agency will be responsible for post construction radon measurement and mitigation.

11. POST CONSTRUCTION RADON MITIGATION. When post construction radon measurements are greater than 4 pCi/L, mitigation systems designed into the facility will be activated incrementally until the radon level is reduced to less than 4 pCi/L. The incremental steps are as follows:

a. Activate sub-slab suction systems or power ventilate crawl spaces.

(1) Install passive vent stack(s) to sub-slab systems for low and moderate radon levels. If subsequent radon measurements are greater than 4 pCi/L, then install exhaust fans for active vent stack.

(2) Install active vent stack(s) with exhaust fans for high and very high radon levels.

b. Increase interior positive air pressure.

c. Increase the outside-air exchange rate.

12. DESIGN DETAILS.

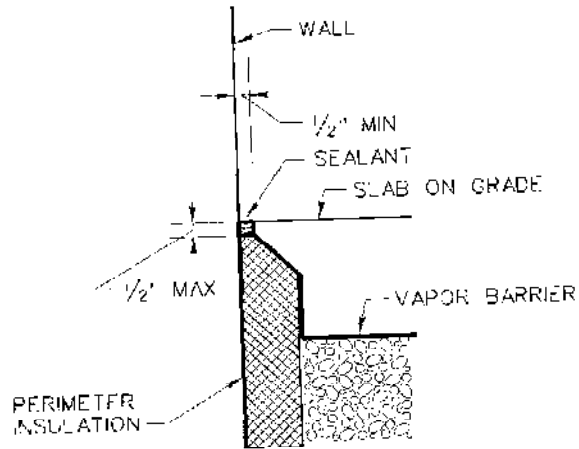
a. Design details are included in appendix A. The design details are generic in nature to depict a variety of typical conditions that are adaptable to specific building designs. Some details may not be applicable to every building; unique conditions are not included. Each detail and/or portions thereof are identified with letter codes that relate to table 1. Additional design guidance may be found in ASTM E 1465 and the EPA publications listed in the references.

b. Reinforcing for concrete and masonry construction shall be provided according to specific design requirements and is not indicated in the details. Minimum reinforcement to control shrinkage cracks in concrete slabs on grade will be 6x6-w1.4xw1.4 welded wire fabric.

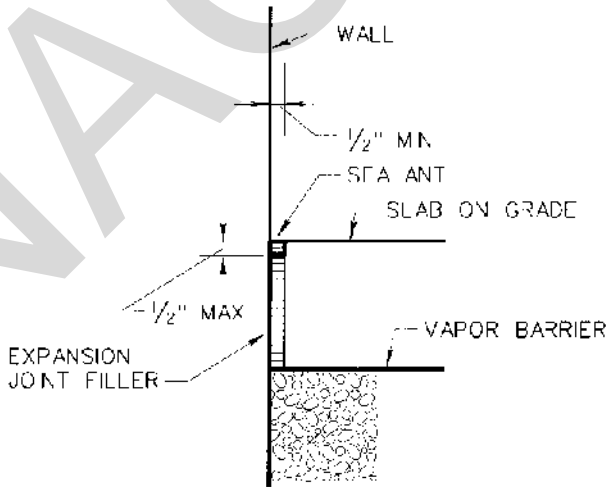
INACTIVE

APPENDIX A

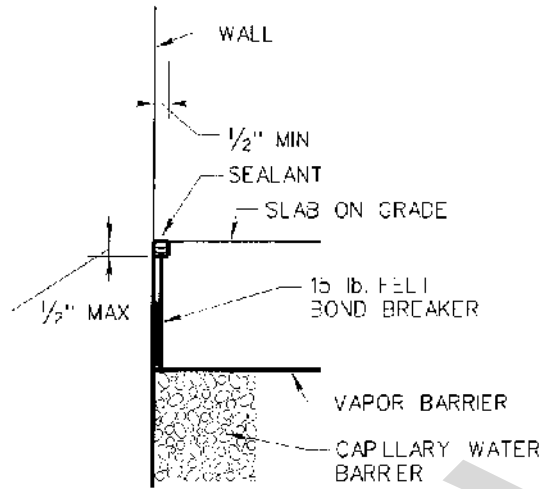
DESIGN DETAILS



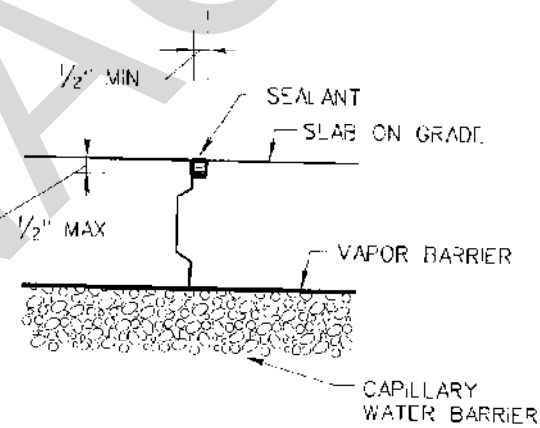
JOINT DETAIL
SLAB EDGE WITH PERIMETER INSULATION XIX
CODE A



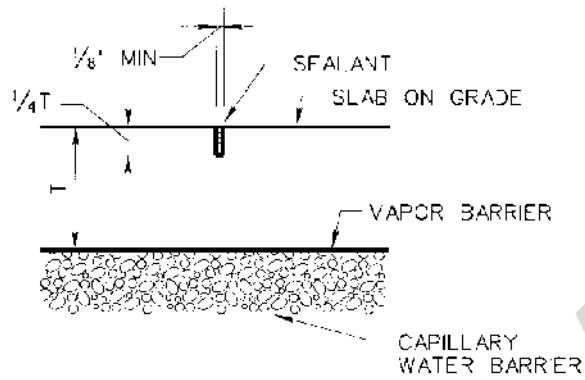
JOINT DETAIL
SLAB EDGE WITH EXPANSION JOINT XIX
CODE A



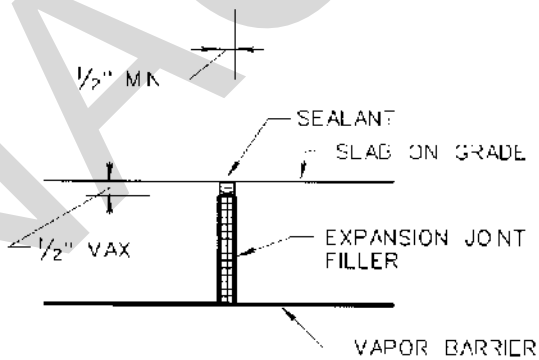
JOINT DETAIL 3
SLAB EDGE WITH BOND BARRIER xix
CODE A



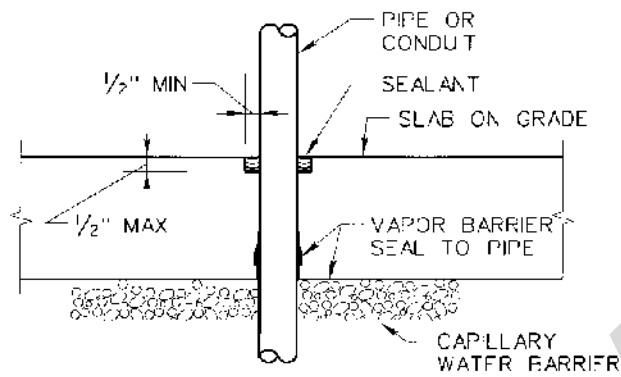
JOINT DETAIL 4
CONSTRUCTION JOINT xix
CODE A



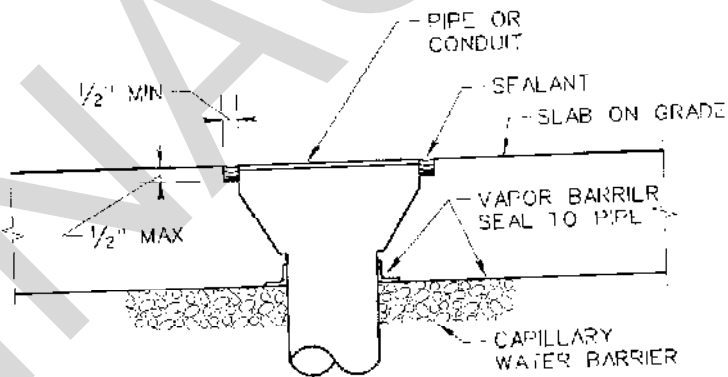
JOINT DETAIL 5
xix
CONTROL JOINT
CODE A



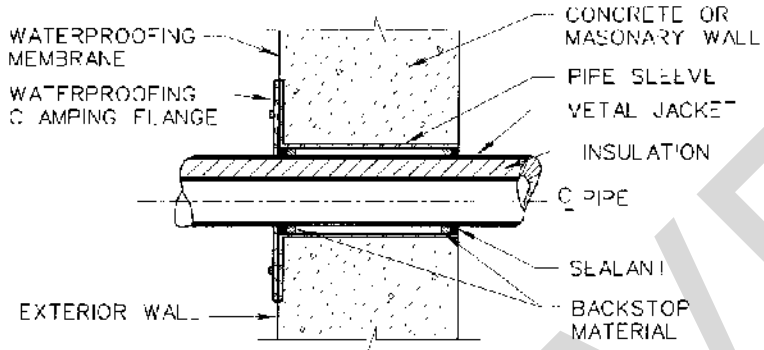
JOINT DETAIL 6
xix
EXPANSION JOINT
CODE A



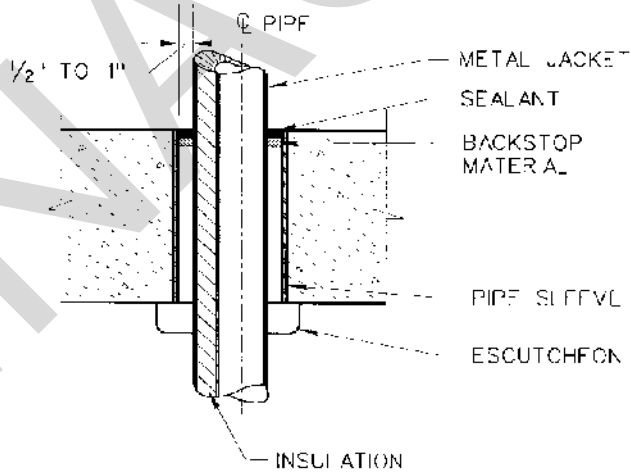
DETAIL 7
PIPE OR CONDUIT PENETRATION XIX
CODE A



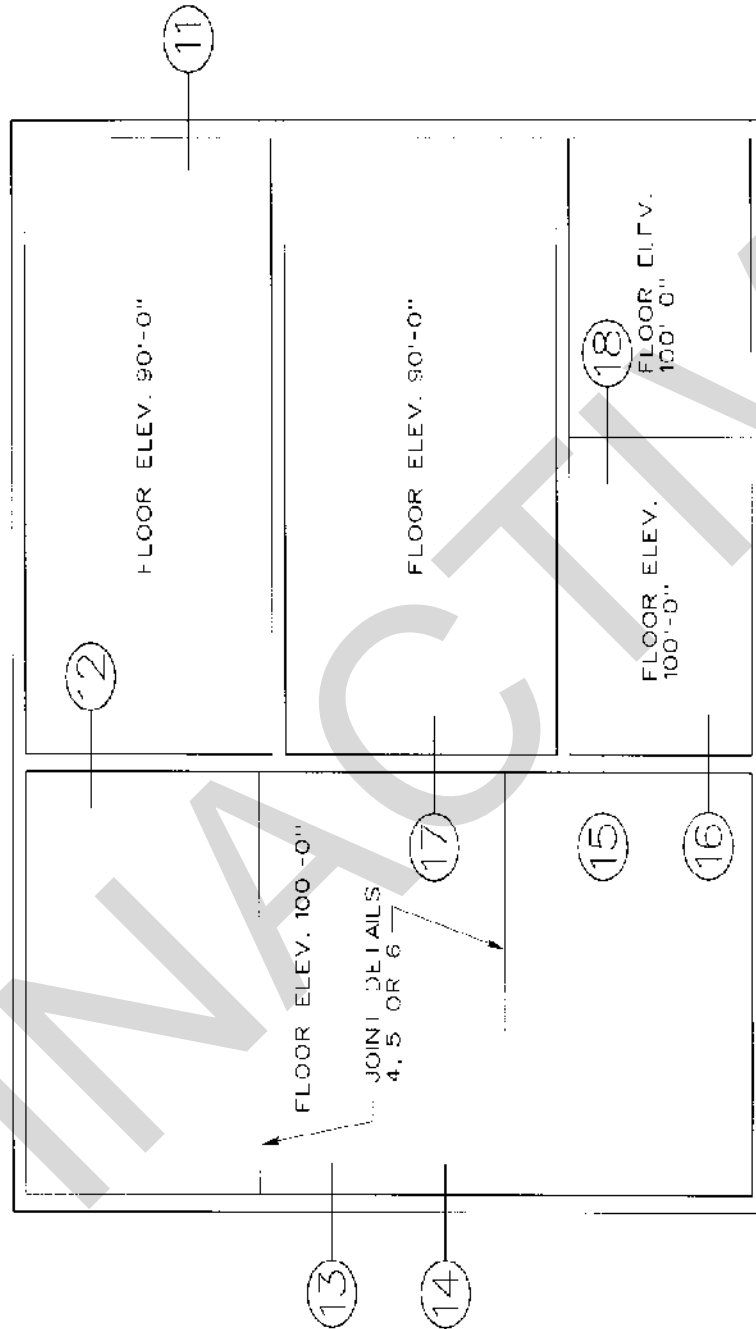
DETAIL 8
AT FLOOR FIXTURES XIX
CODE A



DETAIL 9
XIX
PIPE OR CONDUIT THROUGH
BELOW GRADE WALL
CODE A



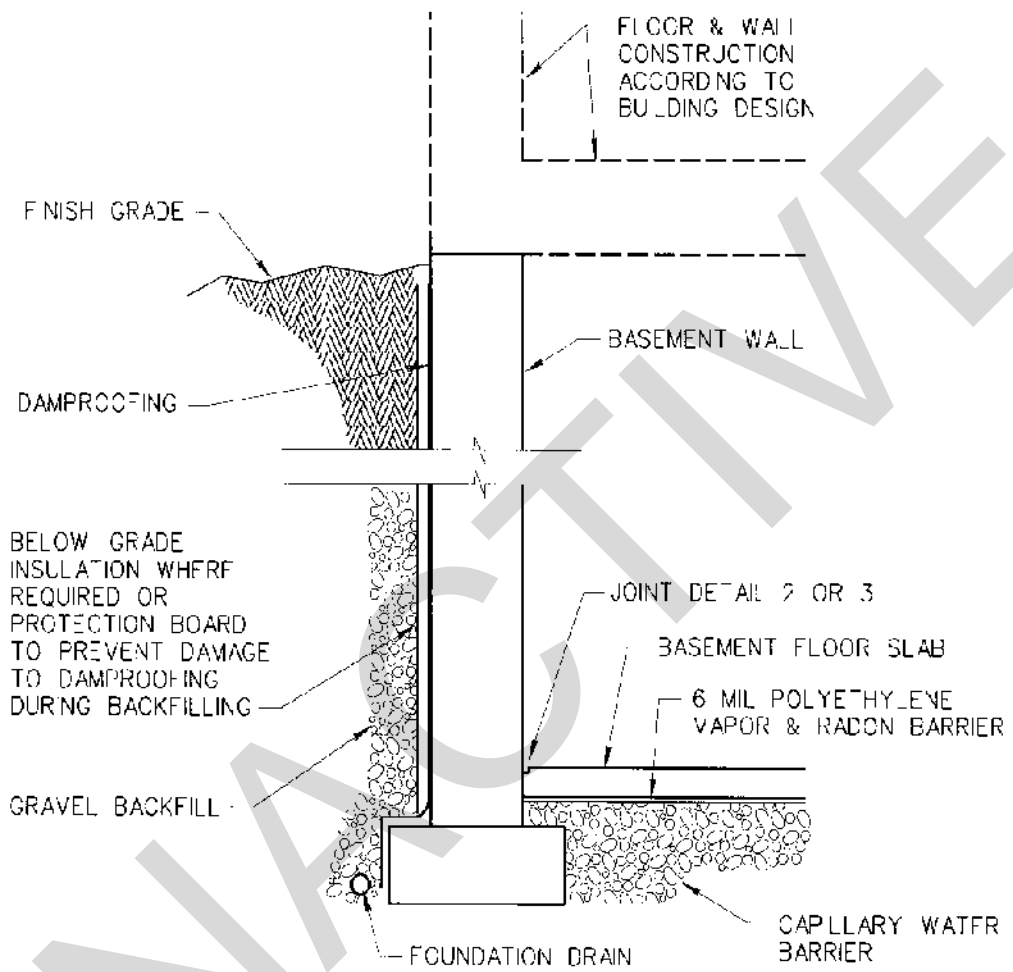
DETAIL 10
XIX
PIPE OR CONDUIT THROUGH
FLOOR OVER CRAWL SPACE
CODE A



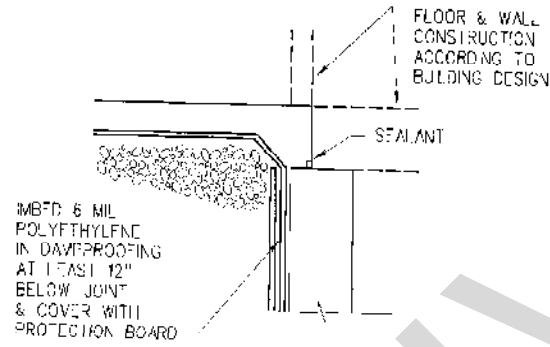
FOUNDATION & SLAB PLAN

NO SCALE

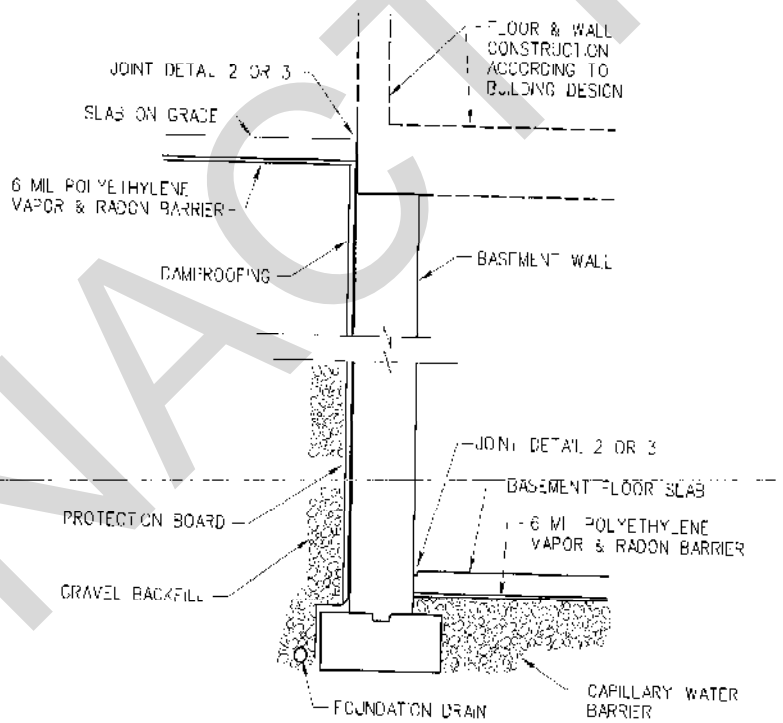
PLAN AND FLOOR ELEVATIONS ILLUSTRATE
TYPICAL LOCATIONS WHERE RADON
BARRIER DETAILS ARE REQUIRED.



DETAIL 11
xix
EXTERIOR BASEMENT WALL
CODE A



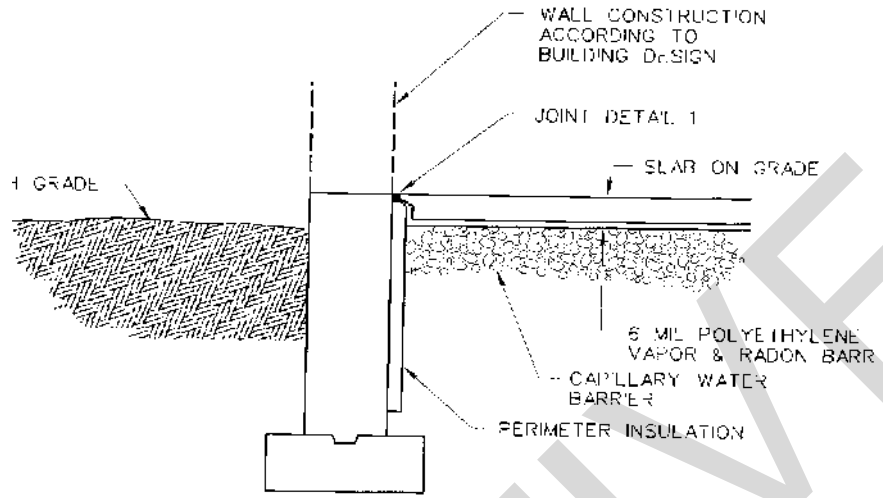
ALTERNATE FIRST FLOOR DETAIL



DETAIL
EXTERIOR BASEMENT WALL
CODE A

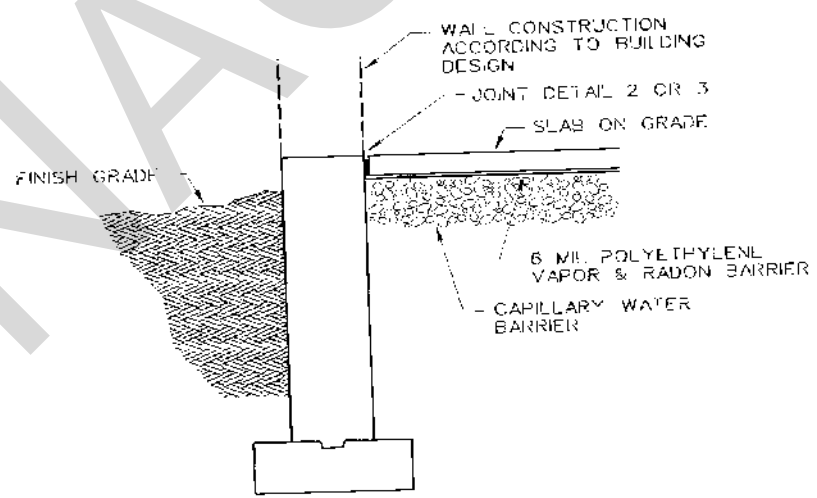
12
XIX

INACTIVE



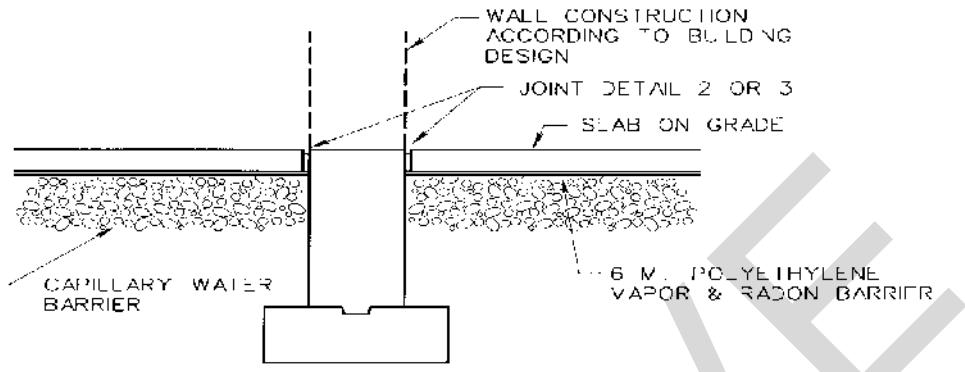
DETAIL 13
xix
EXTERIOR WALL WITH
PERIMETER INSULATION

CODE A

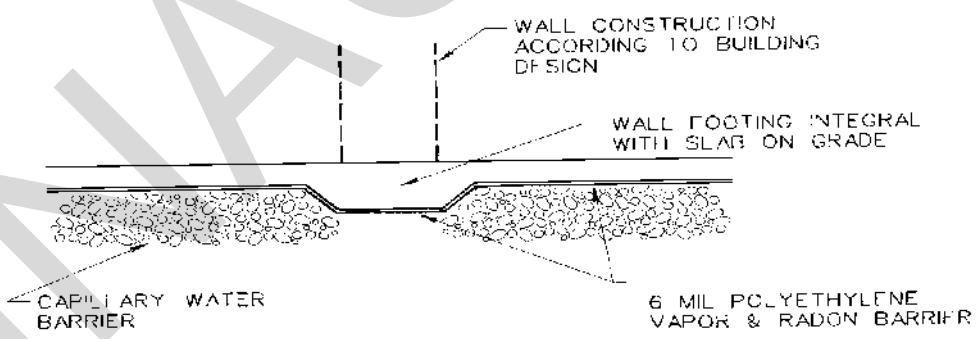


DETAIL 14
xix
EXTERIOR WALL
UNINSULATED

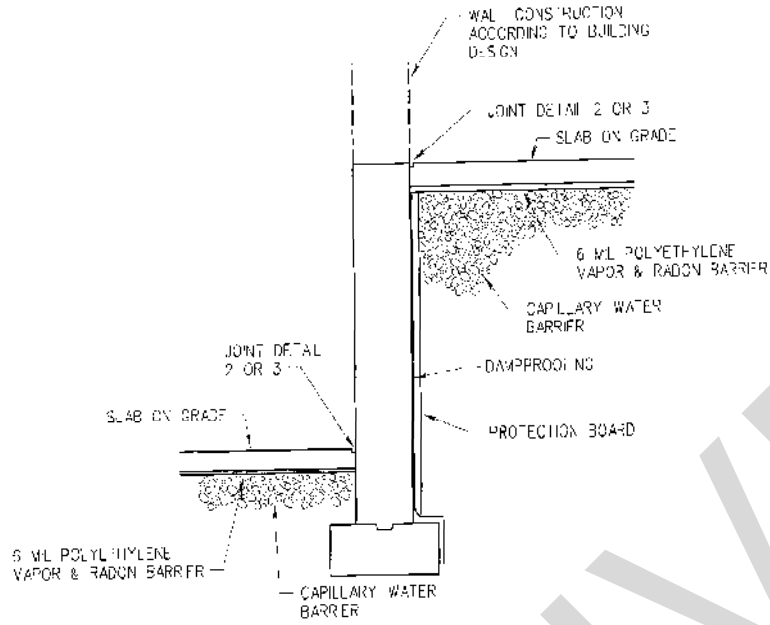
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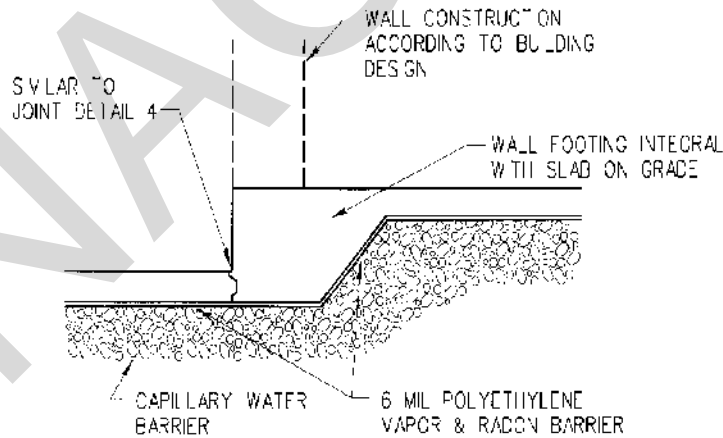
DETAIL 15
INTERIOR WALL XIX
CODE A



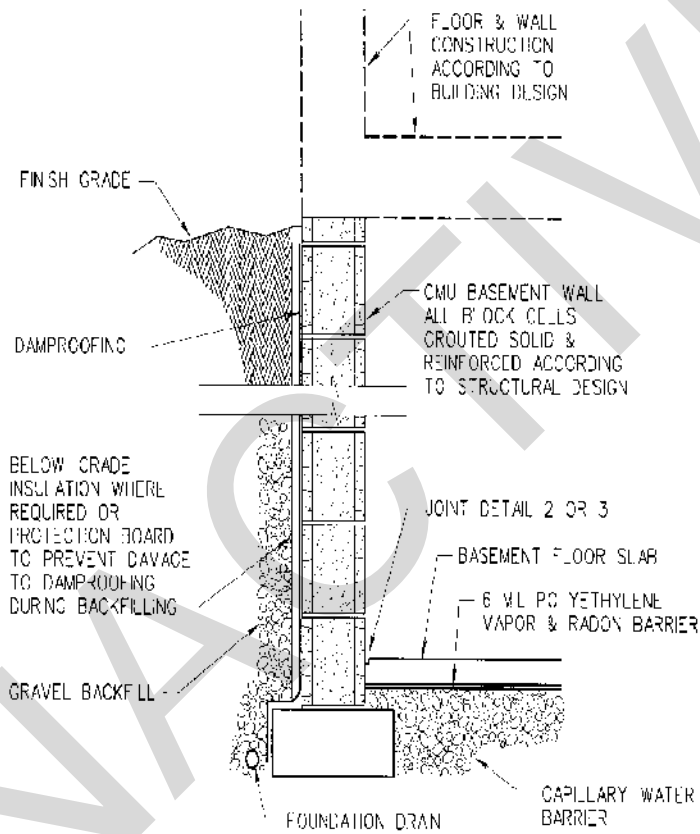
DETAIL 15
INTERIOR WALL XIX
CODE A



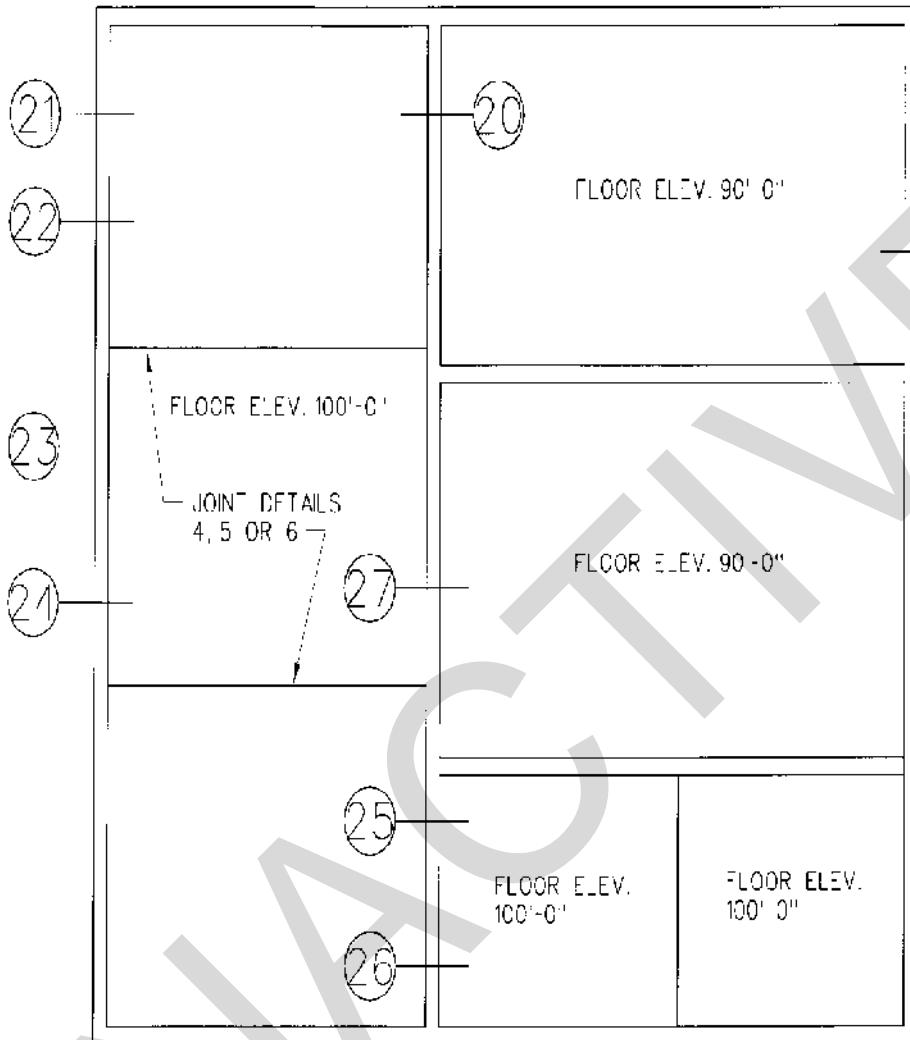
DETAIL 17 XIX
INTERIOR WALL WITH CHANGE IN FLOOR LEVEL
CODE A



DETAIL 18 XIX
CHANGE IN FLOOR LEVEL (EQUIPMENT PAD SIMILAR)
CODE A



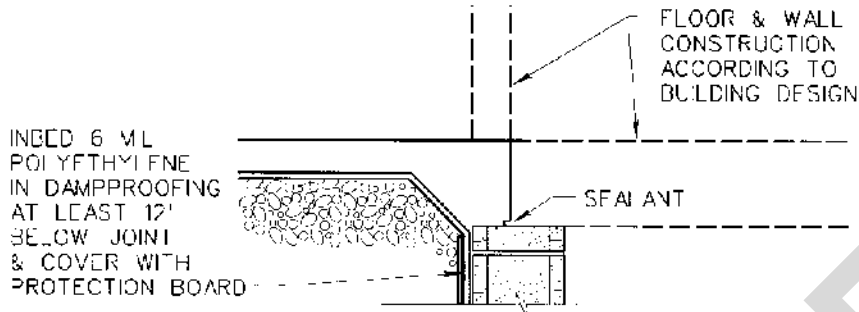
DETAIL 19
EXTERIOR BASEMENT WALL
CODE A
xix



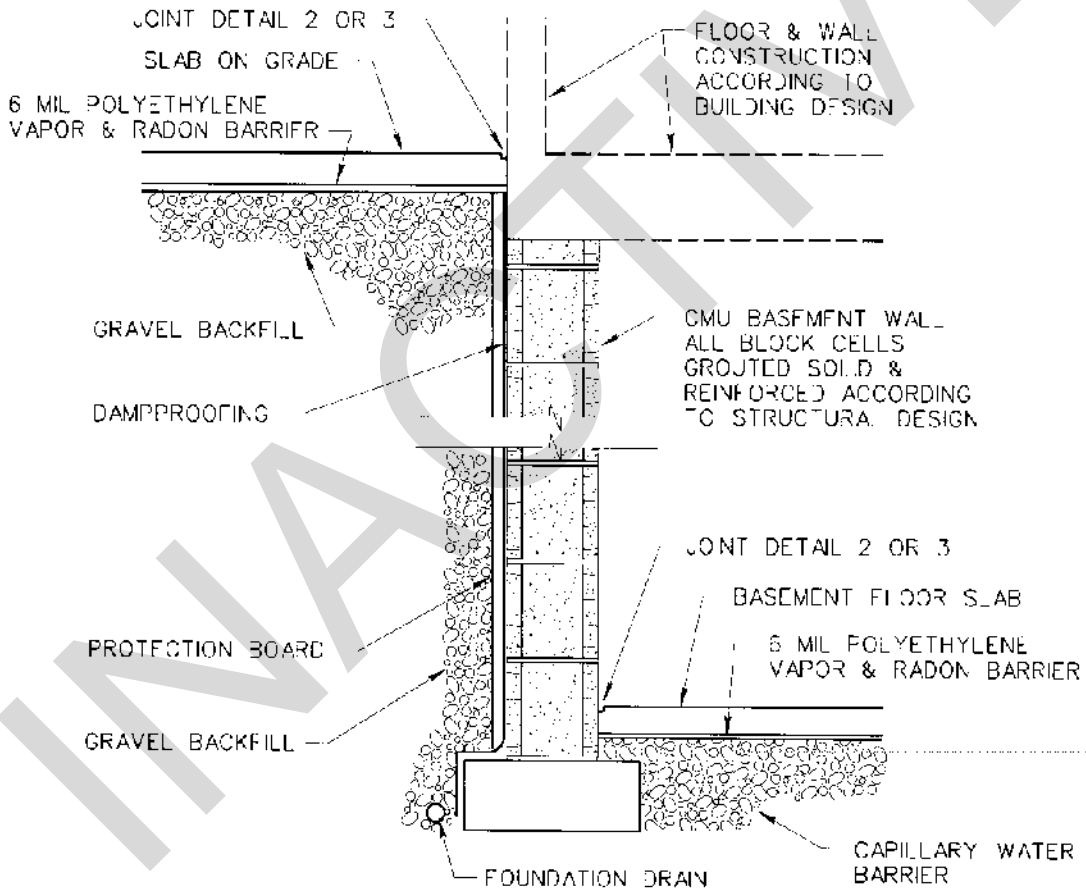
FOUNDATION & SLAB PLAN

NO SCALE

PLAN AND FLOOR ELEVATIONS ILLUSTRATE
TYPICAL LOCATIONS WHERE RADON
BARRIER DETAILS ARE REQUIRED.



ALTERNATE FIRST FLOOR DETAIL

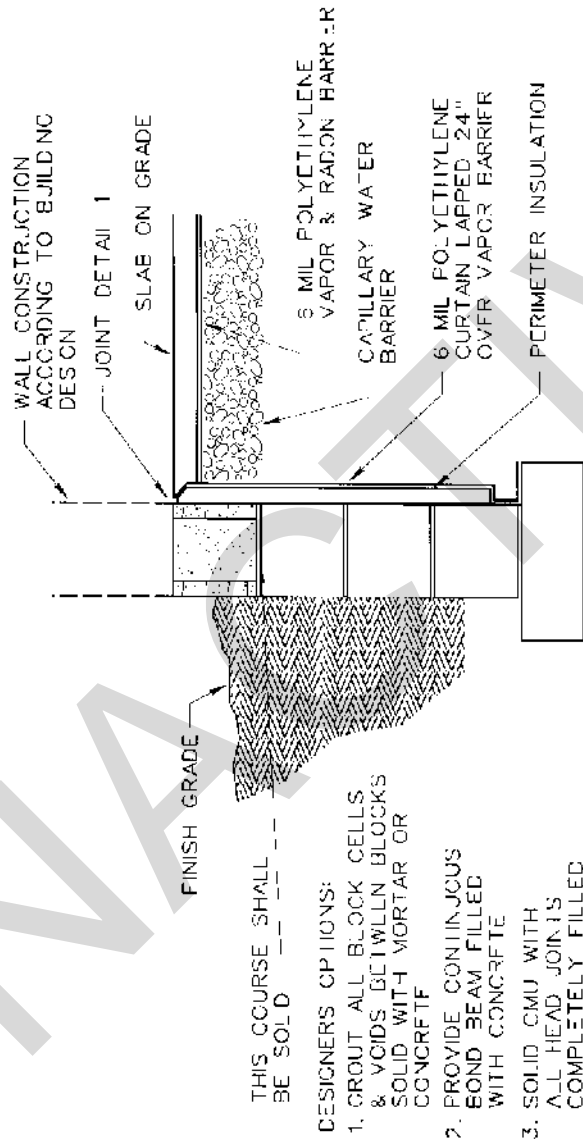


DETAIL

INTERIOR BASEMENT WALL JOINING SLAB ON GRADE

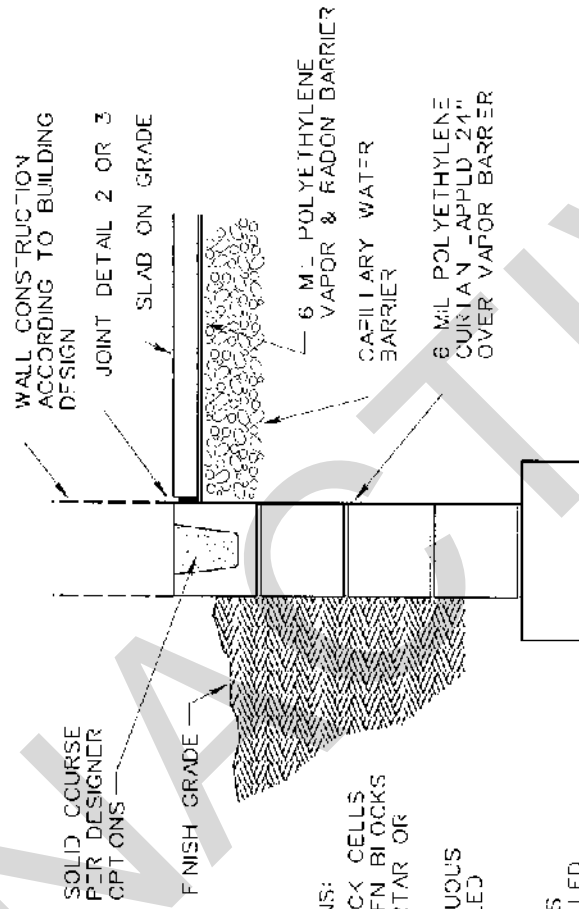
20
xix

CODE A



DETAIL 21
EXTERIOR WALL WITH PERIMETER INSULATION XIX

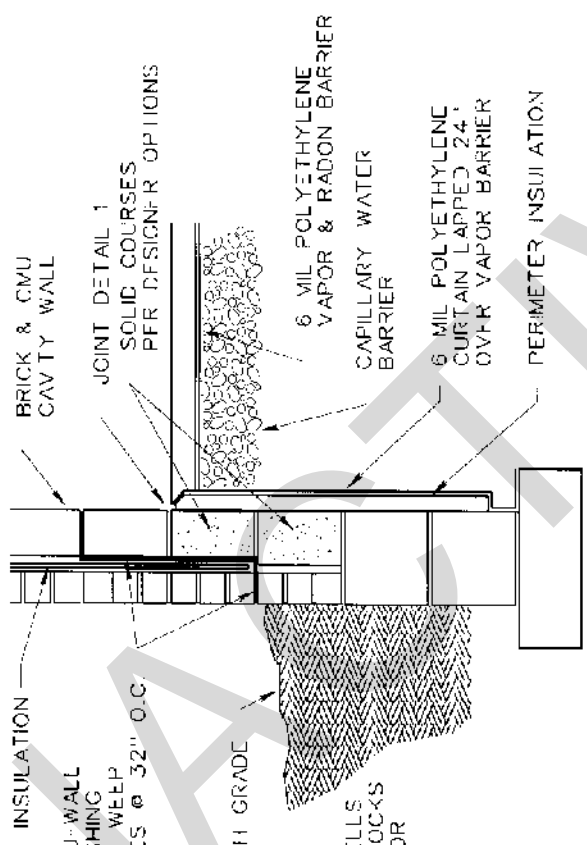
CODE A



- DESIGNER'S OPTIONS:
1. GROUT ALL BLOCK CELLS & JOINTS BETWEEN BLOCKS SOLID WITH MORTAR OR CONCRETE
 2. PROVIDE CONTINUOUS BOND BEAM FILLED WITH CONCRETE
 3. SOLID CMU WITH ALL HEAD JOINTS COMPLETELY FILLED

DETAIL
EXTERIOR WALL
UNINSULATED

22
XIX
CODE A



INSULATION THROUGH WALL FLASHING WITH WEEP HOLES @ 32" O.C.

FINISH GRADE

DESIGNERS' OPTIONS:

1. GROUT ALL BLOCK CELLS & VOIDS BETWEEN BLOCKS SOLID WITH MORTAR OR CONCRETE
2. PROVIDE CONTINUOUS BOND BEAM FILL (F) WITH CONCRETE
3. SOLID CMU WITH ALL HEAD JOINTS COMPLETELY FILLED

BRICK & CMU CAVITY WALL

JOINT DETAIL 1

SOLID COURSES PFR DESIGNER OPTIONS

6 MIL POLYETHYLENE VAPOR & RADON BARRIER

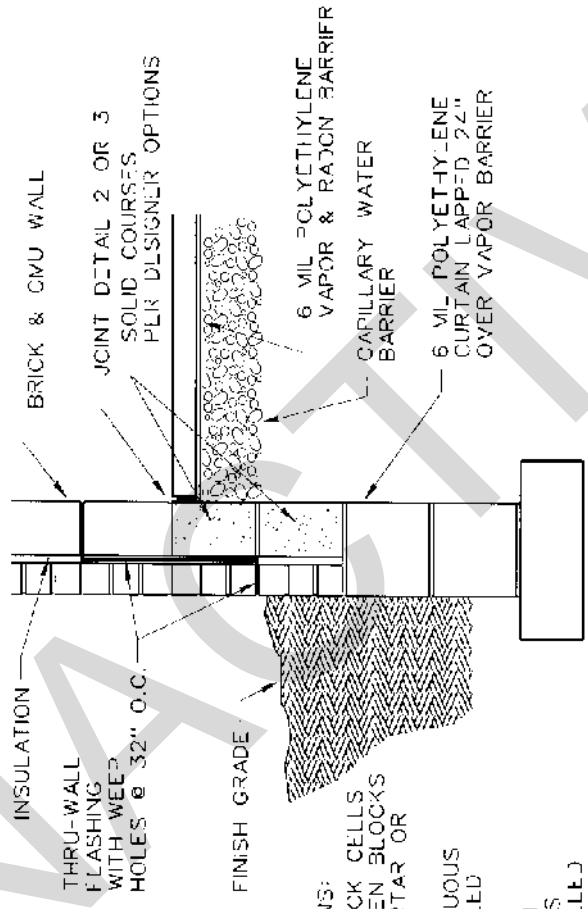
CAPILLARY WATER BARRIER

6 MIL POLYETHYLENE CURTAIN LAPPED 24" OVER VAPOR BARRIER

PERIMETER INSULATION

23
XIX

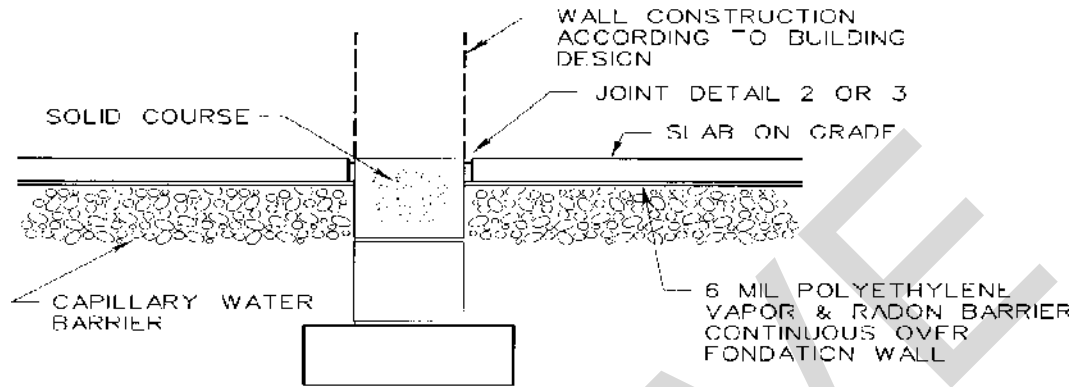
DETAIL
EXTERIOR MASONRY
CAVITY WALL INSULATED
CODE A



- DESIGNERS OPTIONS:
1. GROUT ALL BLOCK CELLS & VOIDS BETWEEN BLOCKS SOLID WITH MORTAR OR CONCRETE
 2. PROVIDE CONTINUOUS BOND BEAM FILLED WITH CONCRETE
 3. SOLID CMU WITH ALL HEAD JOINTS COMPLETELY FILLED

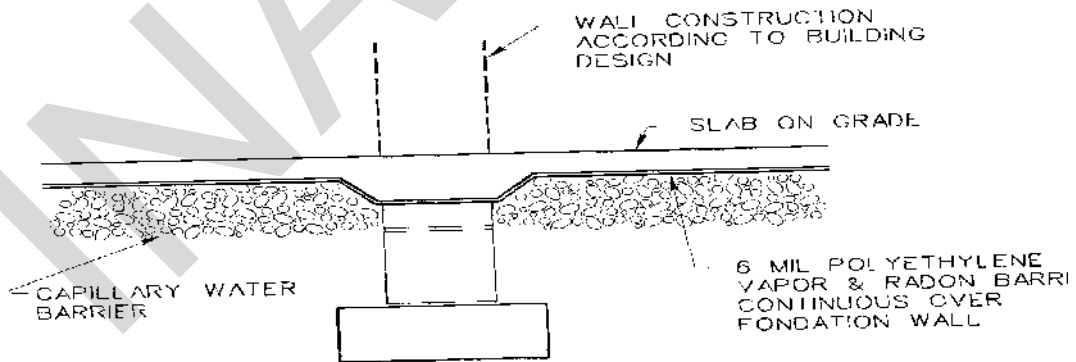
24
XIX

DETAIL
EXTERIOR MASONRY
CAVITY WALL UNINSULATED
CODE A



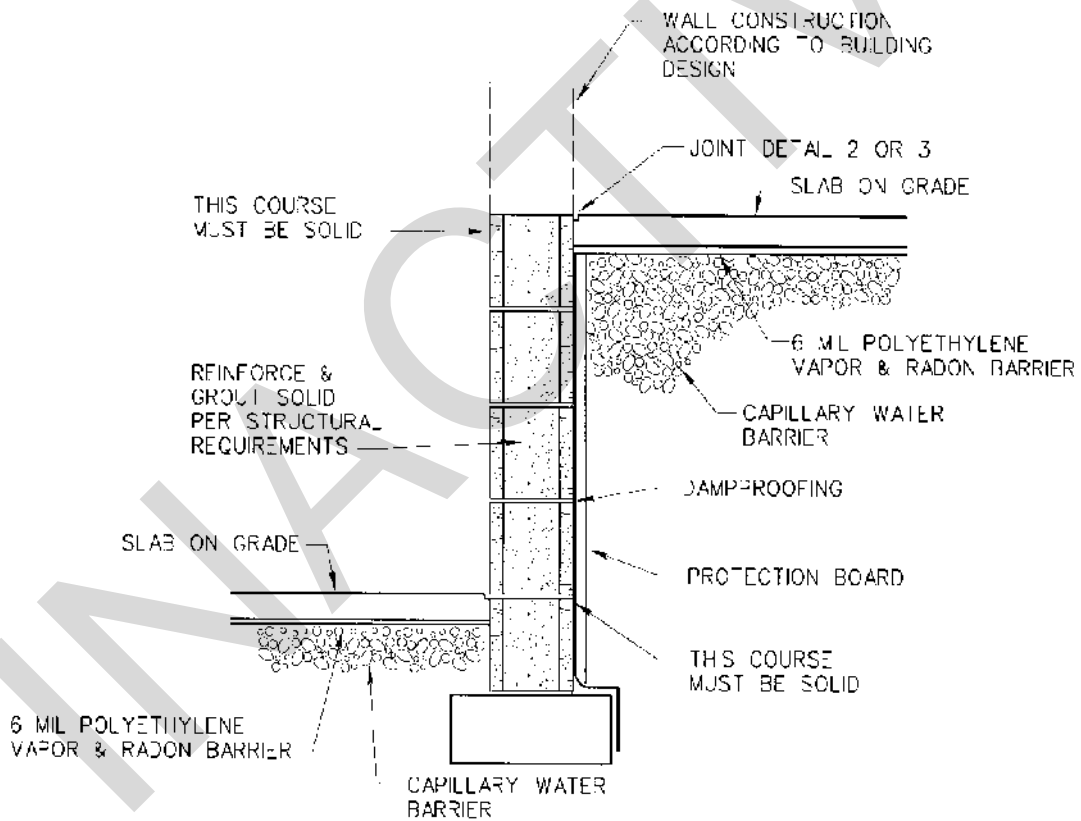
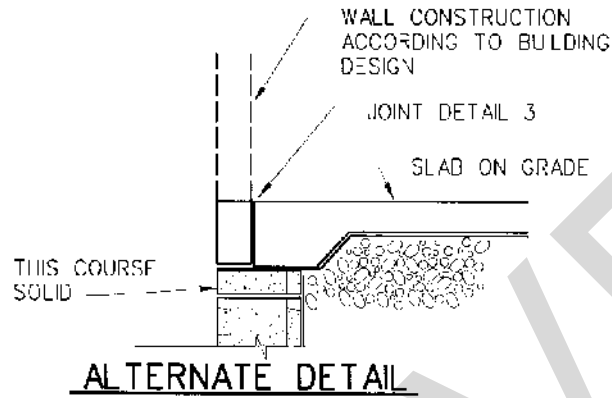
DETAIL 25
xix
INTERIOR WALL WITH
FOUNDATION WALL THROUGH SLAB

CODE A

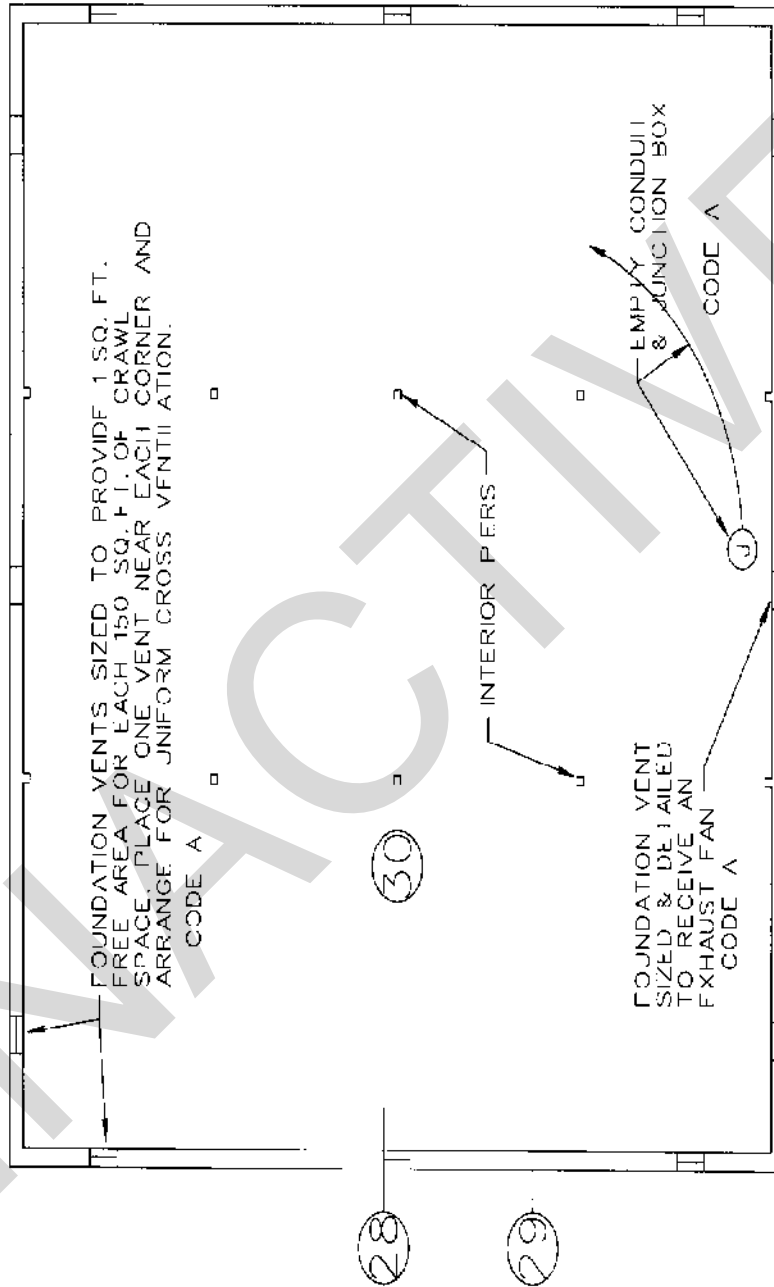


DETAIL 26
xix
INTERIOR WALL WITH SLAB
THROUGH FOUNDATION WALL

CODE A

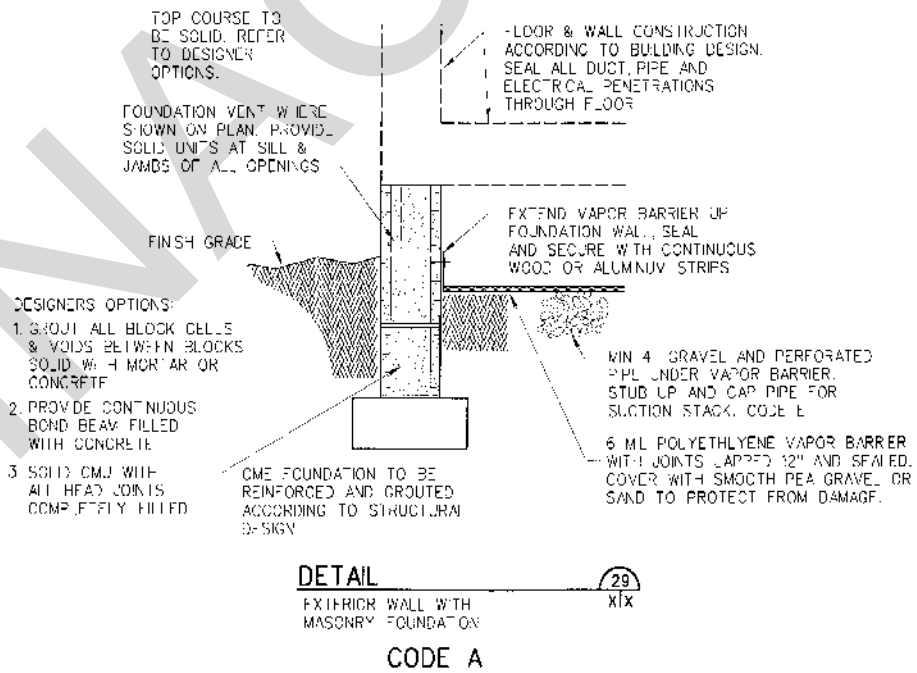
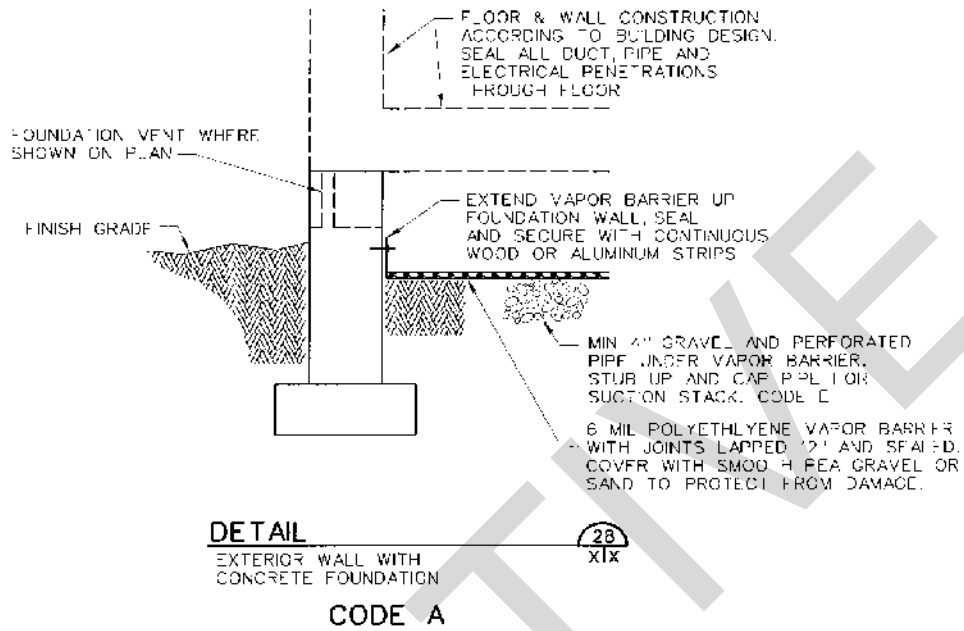


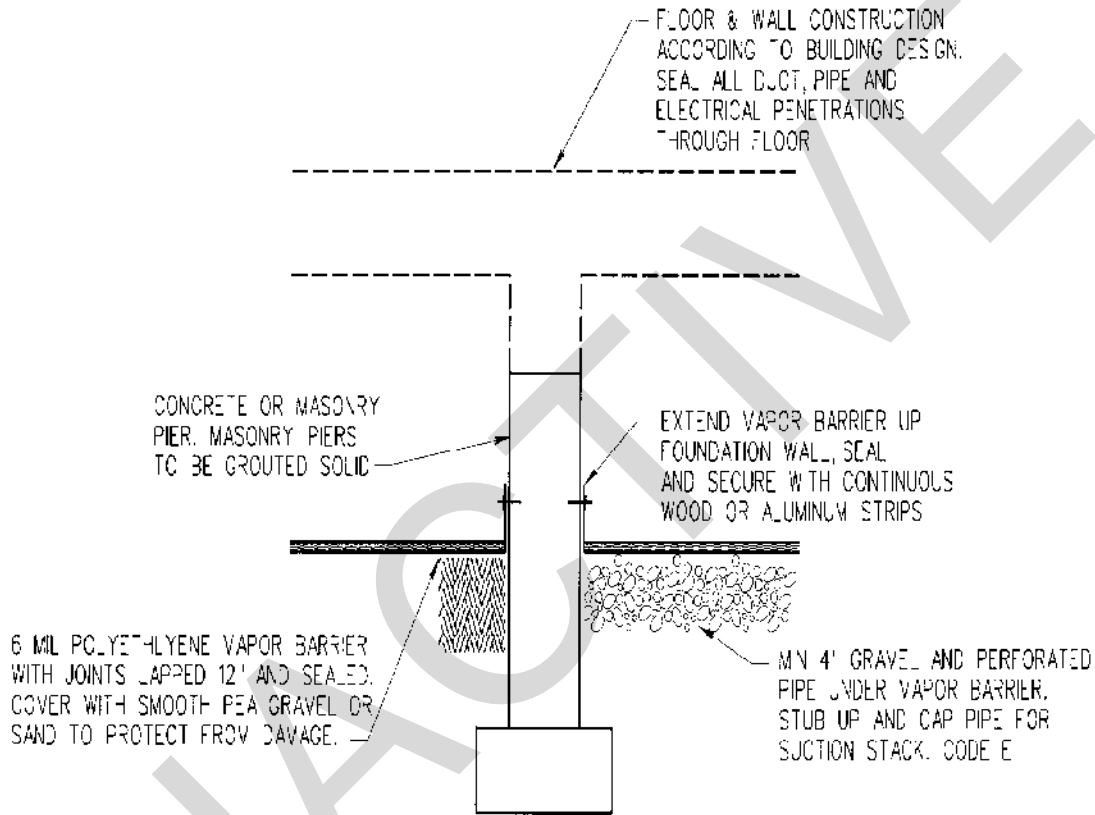
DETAIL 27
INTERIOR WALL WITH CHANGE IN FLOOR LEVEL XIX
CODE A



CRAWL SPACE FOUNDATION PLAN

NO SCAFF



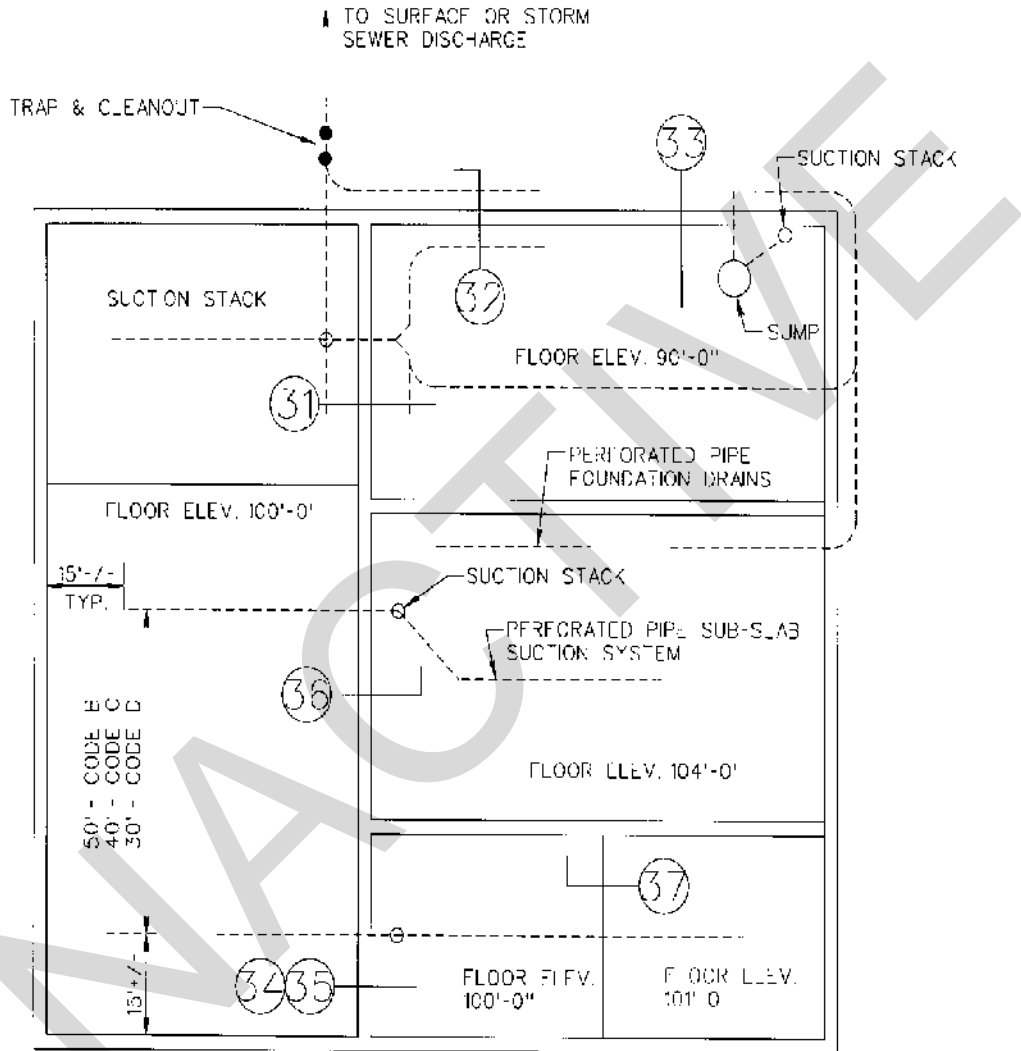


DETAIL

INTERIOR PIER FOUNDATION

30
x1x

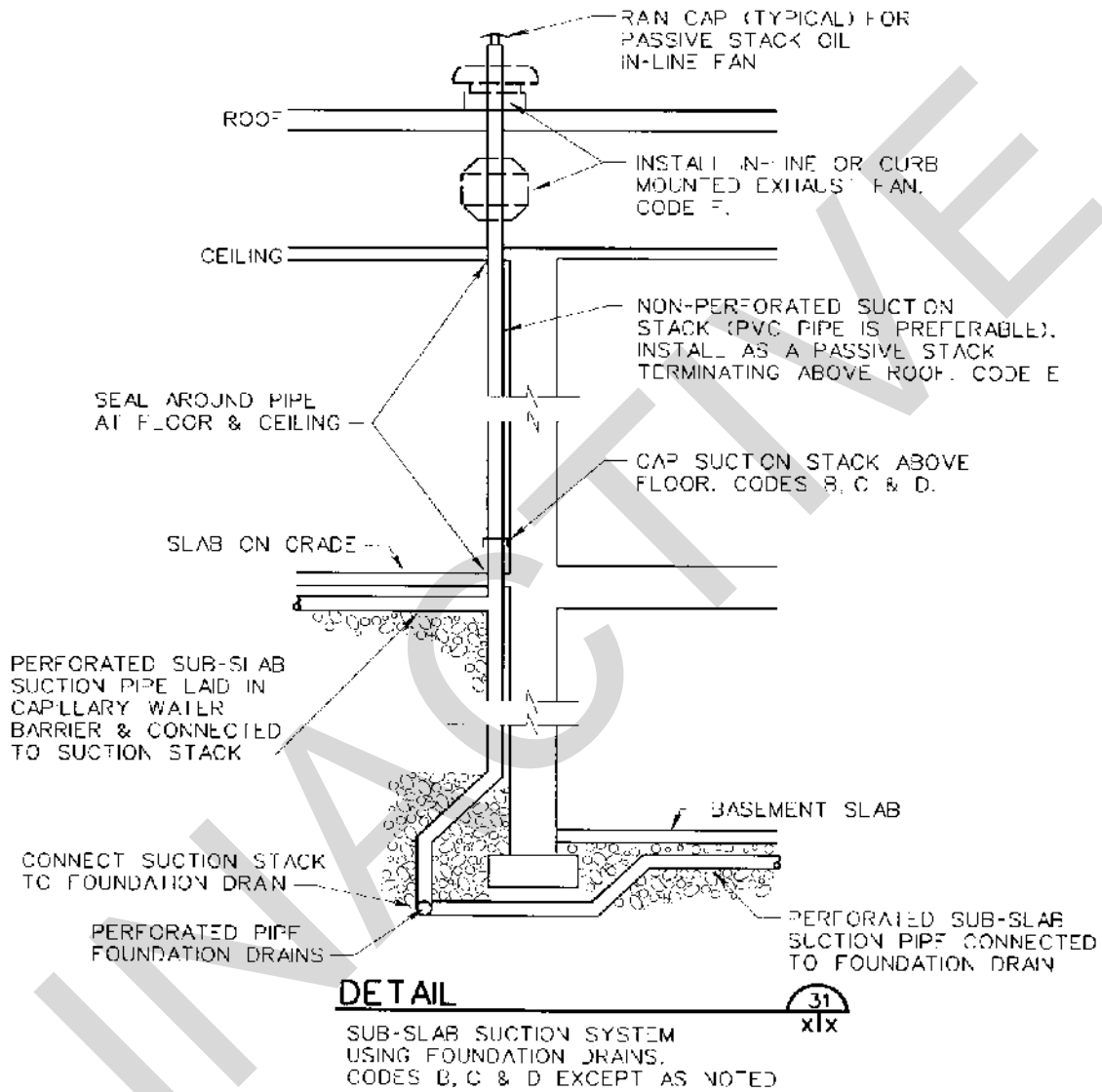
CODE A

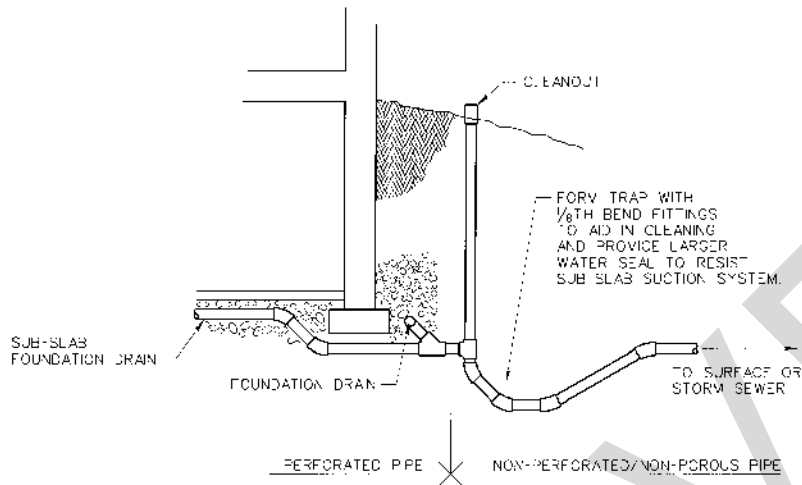


FOUNDATION & SLAB PLAN

NO SCALE

PLAN AND FLOOR ELEVATIONS ARE SHOWN
FOR ILLUSTRATIVE PURPOSES ONLY
CODES AS NOTED

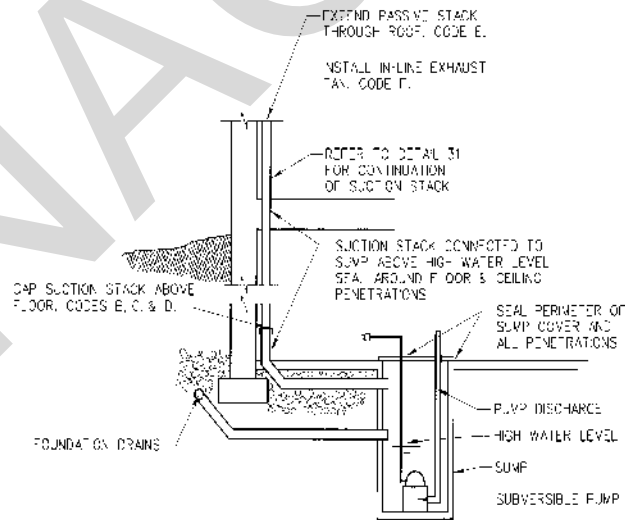




DETAIL

32
XIX

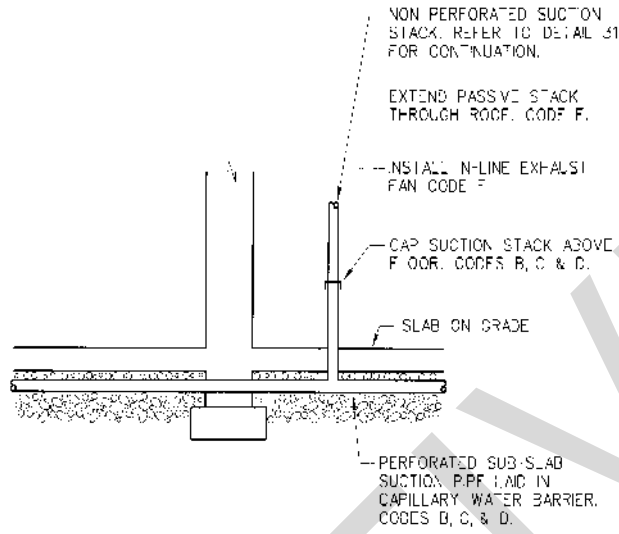
FOUNDATION DRAIN WITH GRAVELLY
OUTFALL USED FOR SUB-SLAB SUCTION
CODES B, C, & D



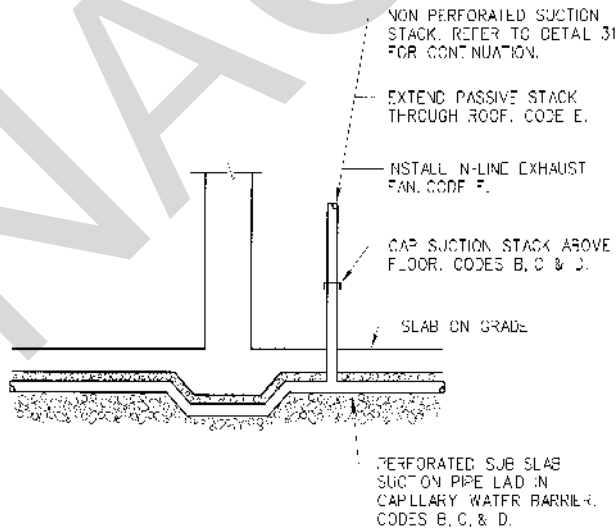
DETAIL

33
XIX

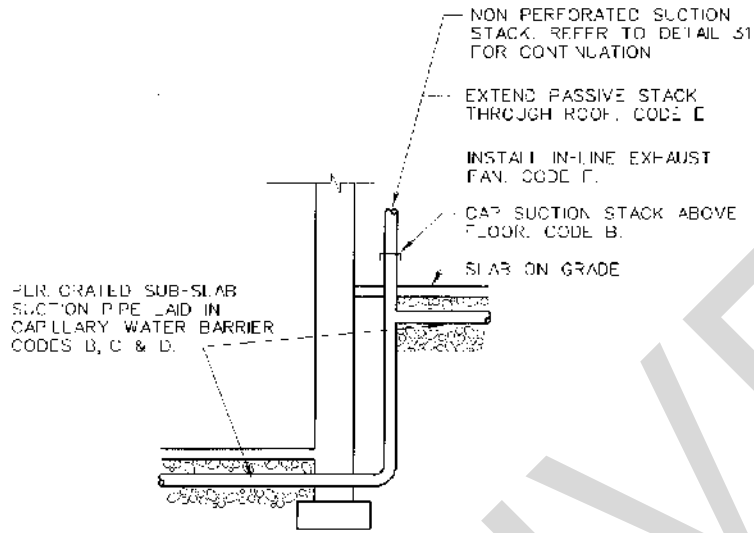
FOUNDATION DRAIN WITH DISCHARGE
TO SUMP USED FOR SUB-SLAB S.C. ON
CODES B, C, & D EXCEPT AS NOTED.



DETAIL 34
SUB-SLAB SUCTION WITHOUT FOUNDATION DRAINS. CODES AS NOTED. XIX

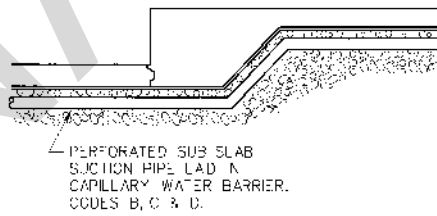


DETAIL 35
SUB-SLAB SUCTION WITHOUT FOUNDATION DRAINS. CODES AS NOTED. XIX



DETAIL 36
xix

SUB-SLAB SUCTION SYSTEM AT CHANGE IN FLOOR LEVEL. CODES AS NOTED.



DETAIL 37
xix