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COST EFFECTIVENESS OF RADON RESISTANT CONSTRUCTION USING A WOOD FOUNDATION WALL

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ABSTRACT

An All-Weather Wood Foundation (AWWF) contains a foundation stem wall assembled with pressure treated lumber and plywood. Advantages of the AWWF system, coupled with radon resistant construction, can produce a home with lower initial costs, smaller operating costs and reduced radon concentrations. Foundation vents are not needed with an active sub-membrane depressurization system. This allows for insulating the crawl space envelope and reducing energy consumption. The AWWF, insulated AWWF, block stem wall and slab-on-grade construction methods are detailed and construction costs calculated. Annual energy costs are estimated for the different foundation methods. The insulated AWWF system costs 11% less to build than the block stem wall system and uses 95% less energy. The insulated AWWF system costs 16% more than the slab-on-grade and uses 83% less energy.

INTRODUCTION

The American Plywood Association (APA) has developed a different approach to foundation stem wall construction. The All-Weather Wood Foundation (AWWF) has been approved for residential construction by the major building codes and lending institutions. It is being used successfully in many parts of the country.

The APA's incentive clearly is to increase the use of plywood, a major component of AWWF construction. However, this system can easily be combined with radon resistant construction to provide economic incentives for builders and homeowners. Homeowners will also enjoy reduced radon concentrations, increased indoor air quality and lower utility bills.

The AWWF differs from the more commonly used CMU stem wall and suspended floor joists in two ways. Continuous concrete footings are replaced with a gravel filled foundation trench and block stem walls are replaced with pressure treated walls composed of dimensional lumber and plywood. The suspended floor system, plywood nailed and glued to floor joists, does not differ from common practice.

Installation of an impervious membrane prior to placing the stem wall will trap soil gases below the crawl space. These trapped gases (moisture, radon, soil poisoning, musty odors, etc.) can then be removed with a ventilation fan. The crawl space membrane, in addition to other techniques suggested by the Environmental Protection Agency, will provide resistance to elevated indoor radon concentrations.

The AWWF system is compared with two alternate construction methods; suspended floor on a block stem wall and slab-on-grade with a block stem wall. Initial construction costs and annual energy costs are compared for each of the construction methods.

MATERIALS AND CONSTRUCTION METHODS

A building footprint 28 feet (8.5m) by 60 feet (18.3m) is used in estimating construction costs for the methods of interest. Marginal cost differences are not considered for land clearing or any construction above the subfloor. A uniform slope of three feet (0.9m) over the footprint is factored into the construction costs. Materials are estimated using local costs plus 7% sales tax. Labor is estimated using an average man hour cost of $15, this averages a working foreman, craftsman and laborer then adds payroll taxes and insurance. A 15% overhead and profit mark-up is added to labor costs based on production. Some labor estimates are based on local unit costs. The estimate can be adjusted for costs and construction variations fitting any region of interest. No effort has been made to equitably weigh variations within the Southeastern United States. Stem wall finish material, finished floor covering and regional plumbing differences are not considered. Soil poisoning differences are ignored.

Awwf Wood Stem Wall Design Option

Construction of this system, illustrated in Fig. 1, should be in accordance with the design specifications described in "Design/Construction Guide, All-Weather Wood Foundation" published by the American Plywood Association. This guide addresses stem wall construction for suspended floor systems using concrete or gravel foundations, crawl space or basement designs, exposed or backfilled walls.

A representative design has been chosen consisting of the following details:

a. Gravel foundation trench 6 inches (15cm) deep by 12 inches (30cm) wide.
b. 2x6 (50x150mm) Southern Yellow Pine No. 2 studs 16 inches (40cm) on center.
c. 2x6 (50x150mm) Southern Yellow Pine No. 2 top and bottom plates.
d. One half inch (13mm) thick CDX plywood.
e. Chromated Copper Arsenate preservative salt is impregnated in all wood foundation products with a retention rate of 0.60 pounds per cubic foot (0.01gm/cc) of wood.

A trench is excavated to the size specified, gravel placed and tamped. Debris is removed from the ground contact area, a perforated drain pipe laid, and a six mil (0.15mm) membrane installed prior to setting the foundation walls. A four inch (100mm) diameter PVC vent is attached to the drain pipe for future extension to a fan placed in the attic for radon removal. Foundation vents are not needed for ventilation because moisture will be removed with the radon removal system.

The suspended floor joists consisting of 2x10 (50x250mm) S4S Southern Yellow Pine No. 2 (SYP#2) are spaced 16" (400mm) center to center. One end is supported by the stem wall, the other by a similar wall running the length of the foundation. Nailed and glued to the floor joists are sheets of 3/4 inch (19mm) thick tongue and grove underlayment grade plywood subflooring . During utility installation all floor penetrations are sealed as detailed in EPA publications.

Alternate Awwf Wood Stem Wall Design Option

This option, also shown in Fig. 1, is identical to the one above with the exception of wall insulation. Fiberglass batt insulation (R-19) is installed between the studs of the foundation walls.

Block Stem Wall Design Option

A continuous concrete perimeter footing, pictured in Fig. 2, is installed eight inch (200mm) deep by sixteen inch (400mm) wide with two #4 (13mm) reinforcing steel rods. Eight isolated footings, two feet (0.6m) square, are placed down the center of the structure, seven feet (2.1m) apart. Standard 8x8x16 (200x200x400mm) CMU's are placed around the perimeter in a running bond. Block piers are built on the isolated footings. The joists are set on pressure treated 2x8 (50x200mm) S4S SYP#2 plates attached to the block with anchor bolts. Foundation vents are installed around the stem wall to ventilate the crawl space.

A double 2x10 (50x250mm) S4S SYP#2 foundation beam is built on top of the piers. Construction of a suspended floor system is completed similar to the AWWF option above. A perforated drain pipe is installed, a six mil (0.15mm) membrane is spread on top of the ground contact area then sealed to the block foundation walls and piers with urethane sealant. A four inch (100mm) diameter PVC vent is attached to the drain pipe for future extension to a fan placed in the attic for radon removal similar to the above option.

Slab-On-Grade Design Option

A continuous concrete footing, as detailed in Fig. 3, is constructed identically to the design option above. A CMU stem wall is placed around the perimeter as above, however, there are several differences. The wall will be two courses lower because the head room required in a crawl space is not needed. The slab edge is formed with a header block on the top course. No foundation vents are needed. Structural fill is placed and compacted, the under slab plumbing is installed, and a four inch (100mm) thick gravel bed applied with a pit area for soil gas collection. A four inch (100mm) diameter PVC vent is secured for future extension to a fan placed in the attic for radon removal similar to the options above. A six mil (0.15mm) membrane is placed, Welded Wire Mesh installed and 2,500 psi (17MPa) concrete poured and finished.

ENERGY CALCULATION METHODS

Approximate heat loss can be calculated using the basic equation:

$$Q = U * Area * (Ti - To)$$

where Q = Heat loss in BTU/hr
U = Overall heat transfer coefficient (BTU/hr/deg F/SF)
Area = area exposed to the exterior (SF)
Ti = inside temperature (deg F)
To = outside temperature (extreme) (deg F)

An estimate of the annual energy usage can be made with the calculated heat loss method:

$$F = Q * 5088 * (Ti - Ta)/(Ti - To)$$

where F = Energy used for heating in BTU's/year
Q = Heat loss in BTU/hr
5088 = number of heating hours in a year
Ti = inside temperature
Ta = average winter temperature
To = outside temperature (extreme)

The following temperature assumptions are made:
Inside temperature is 68 deg F (20 deg C).
Extreme outside temperature for Auburn, Al is 18 deg F (- 8 deg C).
Average outside temperature for Auburn, Al is 55 deg F (13 deg C).

Use of these equations with adjustments for each of the construction methods described above will provide a general idea of each system's annual energy consumption. Relative energy costs can then be compared to determine any economic advantages.

Builders and homeowners involved with new construction in the Southeast will normally select a heat pump system unless natural gas is available. Electric energy costs for Alabama average $22.52 for each million BTU's. Air-to-air heat pumps do not turn electric energy directly into heat, they transfer heat from outside air to the inside. They are able to do this with an efficiency greater than one, in some newer heat pumps the efficiency (coefficient of performance or COP) can reach four. These units are not, however, normally installed in the typical home. Contractors and new homeowners seldom spend the extra money required for the more efficient units, they will purchase a unit with a COP of 2.5 or 3. A heat pump with a COP of 2.5 is able to transfer heat energy into a house for $9.00/million BTU's ($22.52/2.5). This cost is used in the calculations below to find relative annual energy costs.

RESULTS

Estimated construction costs for the three options are calculated using current labor and material prices for Auburn, Al. Labor productivity and quantity estimates are approximate and may not be identical to those experienced in other regions of the country. There is enough detail to make local adjustments if desired.

Construction Cost For AWWF Stem Wall Option

Footing	
materials:	
gravel: (0.5' * 1' * (176'+60')/27cf/cy) * ($20/cy) * (1.07)	$ 87.41
labor:	
(236') * ($1/lf)	236.00
AWWF stem wall (0.60 lbs/cu ft CCA retention)	
materials:	
236 BF of x SYP#2 top plate	
236 BF of x SYP#2 bottom plate	
564 BF of x SYP#2 studs (3' long)	
(1.036 MBF * $500/MBF) * 1.07	554.26
18 sheets 1/2" CDX plywood	
(18 sheets * $15.74/sheet) * 1.07	303.15
nails	20.00
drain pipe	30.00
labor:	
1.036 MBF * 20MH/MBF * $15/MH * 1.15	357.42
0.576 MSF * 13MH/MSF * $15/MH * 1.15	129.17
Suspended floor system	
materials:	
2393 BF of 2x10 SYP#2 joist	
(2.393 MBF * $523/MBF) * 1 .07	1,339.15
83 BF of 1x4 SYP#2 bridging	
(0.083 MBF * $422/MBF) * 1.07	37.48
60 sheets 3/4" plywood subfloor	
(60 sheets * $16.06/sheet) * 1.07	1,031.05
plywood flooring glue	
(60 tubes * $1.57/tube) * 1.07	100.79
nails	42.80
labor:	
2.393 MBF * 15 MH/MBF * $15/MH * 1.15	619.89
8 MH * $15/MH * 1.15	138.00
1.92 MSF * 10 MH/MSF * $15/MH * 1.15	331.20
TOTAL	**$ 5,357.77**

Construction Cost For AWWF Stem Wall Option Insulation Alternate

R-19 fiberglass batt insulation can be purchased from a subcontractor for $0.25/SF.

(176' * 3') * ($0.25/SF)	**$ 132.00**

Construction Cost For Block Stem Wall Option

Footing	
materials:	
(7 cu yd concrete) * ($47/cy) * 1.07	$ 352.03
(23 pcs #4 rebar) * ($2.94/ea) * 1.07	72.35
misc.(rod chairs, grade stakes, steps)	35.00
labor:	
(208 lf) * ($1.25/lf)	260.00
Block stem wall	
materials:	
700 regular block * ($0.73/ea) * 1.07	546.77
7 bags mortar * ($4.10/ea) * 1.07	30.71
2 cu yd sand * ($16/cy) * 1.07	34.24

10 foundation vents * ($4.70/ea) * 1.07	50.29
44 anchor bolts * ($0.31/ea) * 1.07	14.59
192 BF of x PT SYP#2 sill	
(0.192 MBF * $500/MBF)*1.07	102.72
labor:	
700 block * $1.25/block	875.00
0.192 MBF * 15MH/MBF * $15/MH * 1.15	49.68

Suspended floor system

materials:	
2553 BF of 2x10 SYP#2 joist	
(2.553 MBF * $523/MBF) * 1.07	1,428.68
83 BF of 1x4 SYP#2 bridging	
(0.083 MBF * $422/MBF) * 1.07	37.48
60 sheets 3/4" plywood subfloor	
(60 sheets * $16.06/sheet) * 1.07	1,031.05
plywood flooring glue	
(60 tubes * $1.57/tube) * 1.07	100.79
nails	42.80
labor:	
2.553 MBF * 15 MH/MBF * $15/MH * 1.15	660.59
8 MH * $15/MH * 1.15	138.00
1.92 MSF * 10 MH/MSF * $15/MH * 1.15	331.20
TOTAL	**$ 6,177.39**

Construction Cost For The Slab-On-Grade Option

Footing

materials:	
(6 cu yd concrete) * ($47/cy) * 1.07	$ 301.74
(20 pcs #4 rebar) * ($2.94/ea) * 1.07	62.92
misc.(rod chairs, grade stakes, steps)	35.00
labor:	
(176 lf) * ($1.25/lf)	220.00

Block stem wall

materials:	
220 block * ($0.73/ea) * 1.07	171.84
145 header block * ($0.88/ea) * 1.07	136.53
4 bags mortar * ($4.10/ea) * 1.07	17.55
2 cu yd sand * ($16/cy) * 1.07	34.24
labor:	
366 block * $1.25/block	457.50

Concrete slab

materials:	
72 cy structural fill * ($9/cy) * 1.07	693.36
21 cy gravel * ($20/cy) * 1.07	449.40
21 cy 2500 psi concrete * ($47/cy) * 1.07	1,056.09
1680 SF 6 mil membrane * ($0.02/SF) * 1.07	35.95
2 1/2 rolls WWM * ($40/roll)*1.07	107.00
44 anchor bolts *($0.31/ea)*1.07	14.59
labor:	
1680 SF *($0.85/SF)	1,428.00
TOTAL	**$ 4,602.05**

ENERGY COST ESTIMATES

Estimated energy costs for the four options are calculated using the heat loss and energy consumption equations identified in the methods section above. Electric energy prices are based on an average for Alabama. Energy usage and electricity costs are approximate and may not be the same as those experienced in other areas. There is enough detail to make adjustments to other locations if desired.

AWWF Stem Wall Option

Q = U * (Perimeter * Average wall height) * (Tcs - To)

where U = 1/R
R = air films + plywood walls
R = 1.2 + 0.62 = 1.82
U = (1/1.82) = 0.55
Perimeter = 176 feet
Average wall height = (1.5'+4.5')/2 = 3 feet
Tcs = crawl space temperature
= (Ti + Te)/2
Ti = inside temperature = 68 deg F
Te = earth temperature = 64 deg F
= (68 + 64)/2 = 66 deg F
To = outside temperature = 18 deg F

Q = (0.55) * (176) * (3) * (66 - 18)

Q = 13,939 BTU/hr

Alternate AWWF Stem Wall Option

Same as above except : R = air film + plywood + insulation
= 1.2 + 0.62 + 19 = 20.82
U = (1/20.82) = 0.048

Q = (0.048) * (176) * (3) * (66 - 18)

Q = 1,217 BTU/hr

Block Stem Wall Option

Q = U * Floor Area * (Ti - Tcs)

where U = 1/R
R = air films + plywood floor
= 1.2 + 0.93 = 2.13
U = 1/2.13 = 0.47
Floor area = 1680 SF
Ti = 68 deg F
Tcs = (Ti + To)/2 = (68 + 18)/2 = 43 deg F

Q = (0.47) * (1680) * (68 - 43)

Q = 19,740 BTU/hr

Slab-On-Grade Option

Investigation into heat loss through the edge of a slab has provided the following empirical heat loss equation.

Q = 0.81 * perimeter * (Ti - To)

where perimeter = 176 feet
Ti = 68 deg F
To = 18 deg F

Q = .81 * 176 * (68 - 18)

Q = 7,128 BTU/hr

Approximate annual energy usage for the four construction options, estimated from the calculated heat loss method, would be as follows:

F = Q * 5088 * (Ti - Ta)/(Ti - To)

where Ti = 68 deg F
Ta = 55 deg F
To = 18 deg F

AWWF Stem Wall Option

Q = 13,939 BTU/hr

F = 18.4 million BTU/yr
Energy Cost = F * $9/million BTU

Energy Cost = $166/yr

Alternate AWWF Stem Wall Option (Insulated)

Q = 1,217 BTU/hr

F = 1.6 million BTU/yr

Energy Cost = $14/yr

Block Stem Wall Option

Q = 19,740 BTU/hr

F = 26.1 million BTU/yr

Energy Cost = $235/yr

Slab-On-Grade Option

Q = 7,128 BTU/hr

F = 9.4 million BTU/yr

Energy Cost = $85/yr

CONCLUSION

Slab-on-grade construction provides an economic advantage over suspended floor systems. Initial construction costs ($4,600) are lower than the AWWF ($5,400) or the CMU foundation ($6,200). This advantage is lost as more structural fill is required to accommodate a more sloping building site. Annual heating costs for the uninsulated slab ($85/yr) are less than the uninsulated AWWF ($166/yr) and the CMU stem wall ($235/yr). The AWWF insulated option, however, has a greatly reduced ($14/yr) annual heating expense.

The cost advantage may explain why concrete slab floors enjoy a large market share in the South. Virtually all new homes in Florida, Texas and Louisiana, relatively flat States, are constructed this way. Suspended floor systems, however, are still selected for 20% to 25% of the new homes in other parts of the region.

Factors other than cost can enter into design decisions on construction methods for floor systems. Some homeowners want the flexibility provided by a crawl space floor system because of future alterations or repairs. Others are more interested in the underfoot comfort inherent in wood vs concrete floors. Hardwood finish floor popularity is returning and they are more readily installed on suspended floor joists than a concrete slab. A slab-on-grade will cost more than a suspended floor to construct on a heavily sloping lot because of the increased fill cost. It is for these reasons, and others, that crawl space homes still account for a significant portion of new home construction in the South.

Homeowners building in a area with increased radon potential and wanting suspended floor construction might investigate the insulated AWWF option. The floor system should cost 10% less (wall insulation included) than the standard block stem wall option used in most cases. Costs for the annual energy losses through the floor system are considerably less with an insulated AWWF ($14/yr) than the block stem wall ($235/yr). These savings more than offset any radon readiness expenses and should be considered by all homeowners, regardless of the radon potential zone where they build. Side benefits would include; guaranteed less indoor radon concentrations, better indoor air quality because of reduced soil gas infiltration, reduced operating expenses and all the other advantages of a wood floor system.

REFERENCES

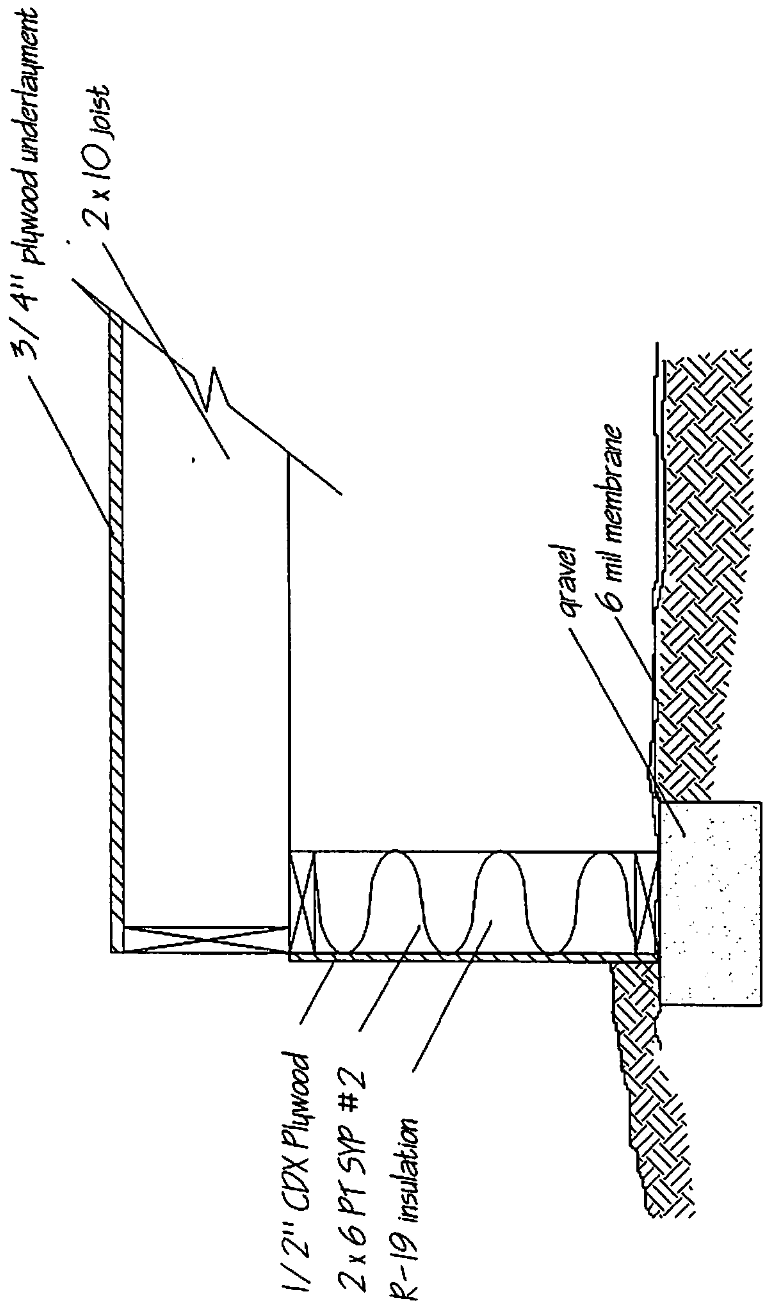
Adams, T. (1993). Alabama Department of Economic and Community Affairs; Science, Technology and Energy Division. Montgomery, AL

American Plywood Association (1982). APA Design/Construction Guide, All-Weather Wood Foundation. Atlanta, GA: American Plywood Association.

ICF Incorporated, Camroden Associates Incorporated (1992). DRAFT "Analysis of Options for EPA's Model Standards for Controlling Radon In New Homes". Prepared for Environmental Protection Agency, Washington, DC

Sarviel, E. (1981). Construction Estimating Reference Data. Carlsbad, CA: Craftsman Book Company.

Shuttleworth, R. (1983). Mechanical and Electrical Systems for Construction. New York, NY: McGraw-Hill Book Company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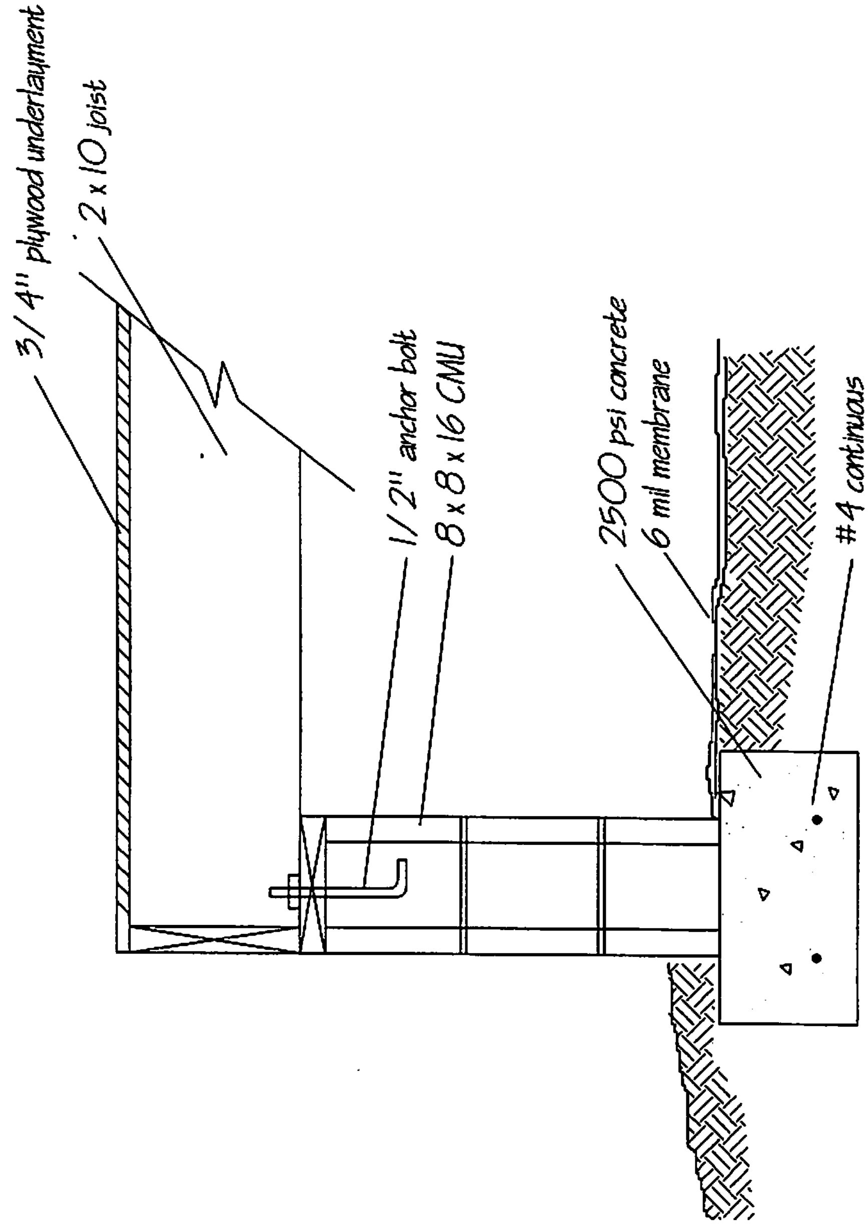
2 x 10 joist
gravel
6 mil membrane
1/2" CDX Plywood
2 x 6 PT SYP #2
R-19 insulation

Fig. 1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2 x 10 joist
1/2" anchor bolt
8 x 8 x 16 CMU
2500 psi concrete
6 mil membrane
#4 continuous

Fig. 2

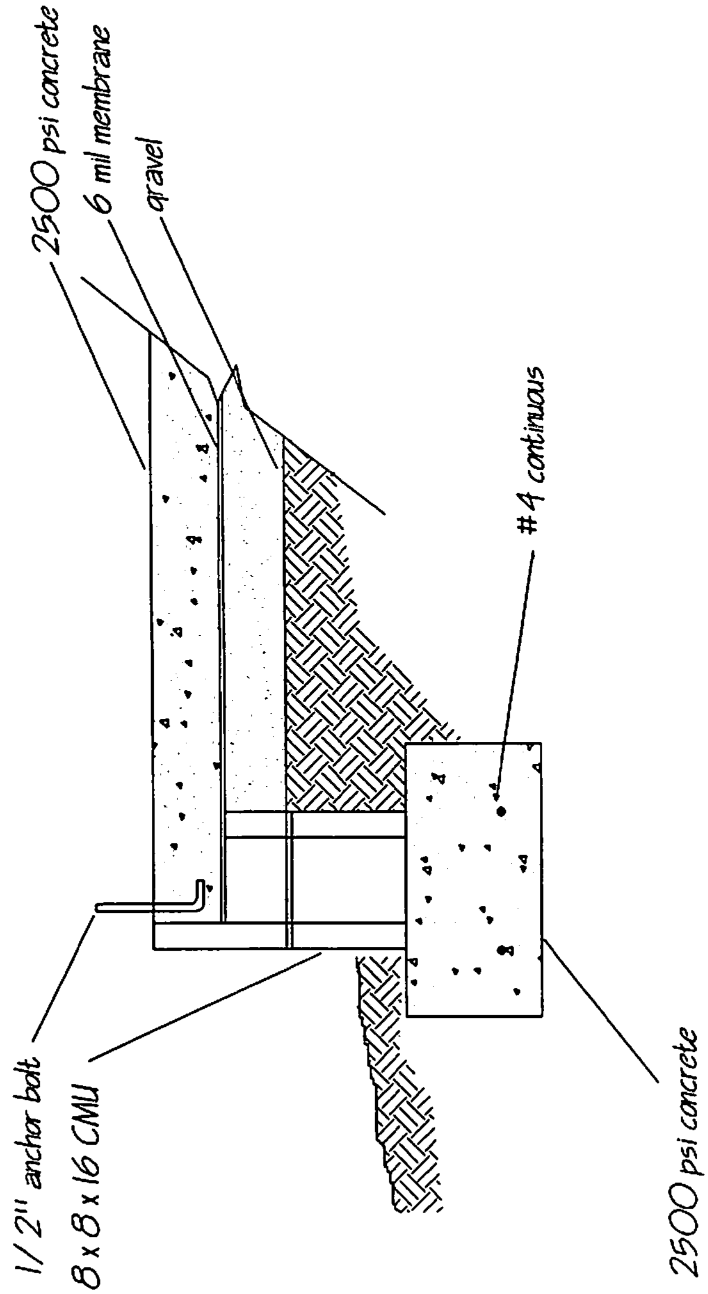
2500 psi concrete
6 mil membrane
gravel
#4 continuous
1/2" anchor bolt
8 x 8 x 16 CMU
2500 psi concrete

Fig. 3