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RECOMMENDED STANDARDS AND PRACTICES FOR RADON RESISTANT PASSIVE CONSTRUCTION IN SLAB-ON-GRADE HOUSES

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ABSTRACT

The State of Florida has developed a draft radon standard for new residential construction. A study was conducted to evaluate the effectiveness of the standard's features in controlling radon entry in new houses built over relatively high radon potential soils. Special attention was given to foundation preparations and slab placements to insure that the draft standard requirements were being met and to identify areas or practices that would assist in achieving the desired results. The combination of using a high range water reducing admixture in the concrete mix, slab reinforcement at re-entrant corners and around large work spaces, and other prescribed activities such as vapor barrier and slab penetration sealing performed well in achieving the objective. Recommendations are made for more specific code language and guidance. Moreover, certain features of local practice will necessitate specific training or retraining in order for adequate implementation of the proposed standards.

INTRODUCTION

The Florida Radon Research Program (FRRP) was implemented to provide radon research related to the detection, control, and abatement of radon in new house construction and in existing buildings. The purpose for this research effort was the development of construction standards for radon resistant buildings and corresponding standards for mitigation of radon in existing buildings. From the fundamental studies in the first years of the program came a draft standard for radon-resistant building construction. The FRRP then shifted emphases to field evaluation or validation of specific areas of the proposed standards (Sanchez et al 1990). The overall purpose of this project was to evaluate the performance and effectiveness of the radon resistant features of the "passive" barrier floor system in 14 new houses built over relatively high radon potential (>1000 pCi/L) soils in South Central Florida. One of the objectives of this study was to evaluate the effect of following specified standard features in controlling radon entry into the houses. Special attention was given to foundation preparations and to slab placements to insure that the draft standard requirements were being met and to identify areas or practices that would assist in achieving the desired results. A review will be presented of the specific standard features that were implemented, with illustrations or examples given. Where there were areas of the standard language or guidance that could be strengthened or improved, these recommendations will be outlined. Certain features of local practice were found that will necessitate specific training or retraining in order for the standards to be better understood and adequately implemented.

As the house sites and builders that were screened for participation in this study were identified and selected, a package of information on the project, the standards, and the requirements for participation in the study was delivered to the builders or to prospective home owners, and their active involvement in the standard implementation and review was solicited. The construction of the selected houses was monitored with the aid of a construction check list developed for that purpose. All of the houses used in this research were of slab-on-grade construction, and efforts were made to have a balanced number of monolithic slab (MS) and slab-in-stem wall (SSW) houses.

An active sub-slab depressurization (ASD) system using ventilation matting was installed in each house selected and constructed as part of the study. Direct oversight of the pre-slab preparations and the concrete placement, curing, and cracking was accomplished, and documentation of these activities was recorded on the check lists and with photographs of the work in progress.

MATERIALS AND METHODS

At the beginning of the project the standard that was in place and being evaluated was the October 1991 draft (Florida DCA 1991). By the completion of the study, another draft was being reviewed (Florida DCA 1994). The construction check list and other guidance given to the builders were based on the 1991 draft, but to make the recommendations in this report more timely and meaningful, specific references will be made to the current (1994) draft. Before work was begun on this and the parallel new house evaluation project conducted in Alachua and Marion Counties (Hintenlang et al 1993), the Florida Department of Community Affairs (DCA), the sponsor of the program, outlined a technical approach modification listing the specific construction standards to be evaluated in the studies. These included the sub-slab and soil cover membranes, the concrete specifications, the slab design and construction practices, the sealing of joints, penetrations, and cracks, specifications concerning equipment rooms, enclosures, and air distribution systems, and the active radon mitigation systems to be installed. Therefore an investigator was present, overseeing the installation of the ventilation matting that was used in all 14 houses. The placement and sealing of the sub-slab membrane was also closely inspected, with recommendations and advice given as needed. Other pre-slab activities, such as the placement of reinforcement in re-entrant corners and the proper preparations of plumbing or other penetrations were visually inspected and, in many cases, documented with photographs. The concrete mix design and its proper placement was insured at all sites. After the slab had set, the penetrations were again inspected to be certain that adequate sealing activities had occurred. Slab curing and loading were also monitored in the days following its placement. Documentation of unplanned slab cracking and its sealing, if necessary, was also recorded. Features of the air handling system were monitored and their completion documented.

On-site personnel worked closely with the builders, site supervisors, workers, plumbers, concrete batch plant operators and drivers, slab finishers, inspectors, air conditioning sub-contractors, and others involved with the construction of the houses in an effort to insure that the spirit, the letter, and the rationale of the standard was communicated to all concerned. In return, many helpful suggestions, comments, insights, and practical applications were offered and evaluated. In the sections that follow, the appropriate portions of the standard that address the above-mentioned features will be extracted and a description of the implementations will be given. Problems that may have surfaced will be listed, and recommended solutions that have either been tested or just hypothesized will be given. Areas for improvement or clarification will also be noted. Finally, specific features that hold little hope of being adequately implemented without direct oversight and rigid inspection will be identified with suggestions for training or retraining, if necessary.

RESULTS

In this section, only those sections of the July 1994 draft standard (Florida DCA 1994) for which specific recommendation for changes or other comments are being made will be addressed. Chapter and section titles will be listed so that the context of the document may be better understood. The current wording of the paragraph will be given, followed by the comments or recommendations.

103.3 Foundation Fill Materials

Foundation fill materials shall satisfy one of the following requirements.

(1) The borrow pit from which the material originates shall be located in a green area of the radon protection map.

(2) The borrow pit from which the material originates shall be demonstrated to have a green radon potential category using the site-specific methodology given in Chapter 6.

(3) The average radium concentration of the fill material shall be less than 1 pCi per gram dry weight. At least one radium measurement shall be made for every 10 cubic yards of fill material.

(Comments and recommendations) This section was not in the 1991 draft of the standard used for the houses in this study. Only one of the 14 houses would have met this requirement if it had been. The general area of the investigation was in a red area of the map and was not very close to a predominantly green area. Therefore, it is anticipated that there will be considerable resistance to the requirements of this section. It would be perceived that this requirement would make the fill considerably more expensive because of the increased cost of transporting it a much greater distance. One argument would be that if the site were in a red area, using fill from a green area would still require the passive and active radon controls to be installed. If active controls were used, then there would be little, if any, benefit derived from the use of the more expensive fill soil. A more acceptable wording would be that foundation fill materials could not come from a map area that has a higher radon potential than the site.

<u>(Chapter 4. Construction Requirements for Passive Radon Control</u>
<u>402 Sub-Slab and Soil Cover Membranes)</u>
<u>402.7 Penetrations</u>

At all points where pipes, conduits, stakes, reinforcing bars or other objects pass through the membrane, the membrane shall be fitted to within 1/2 inch of the penetration. When penetrations occur within 24 inches of a soil-depressurization-system mat or pit, the gap between the penetrating object and the membrane shall be sealed with tape. Other penetrations may be sealed with either mastic or tape. When necessary to meet this requirement, a second layer of the membrane, cut so as to provide a minimum 12 inches lap on all sides, shall be placed over the object and shall be sealed to the membrane with a continuous band of tape.

(Comment and recommendation) While the 1/2 inch specification may be a target that certainly would fulfill the intent of the requirement, its practical application is probably almost never reasonably attained. When placing the membrane in the field, wind or trapped air will make marking and fitting the membrane to within 1/2 inch almost impossible. While the wording may remain as written, the most practical approach in terms of efficient management of labor and resources is to emphasize the technique allowed in the last sentence. All of the training documentation targeted both for the construction industry and for the inspectors, should illustrate and recommend this approach.

<u>(403 Floor Slab-on-Grade Buildings)</u>
<u>403.2 Slab Edge Detail</u>

(2) Slab Poured Into Stem Wall - Where concrete blocks are used as slab forms, the sub-slab membrane shall extend horizontally at least 1 inch into the stem wall, but shall not extend upward along any vertical faces of the stem wall. The concrete slab shall be poured into the stem wall to completely fill its open volume to form a continuous and solid stem wall cap of minimum 8 inch thickness. Framed exterior walls shall be sealed or gasketed to the slab.

(Comment and recommendation) In the earlier SSW houses of the study, a major problem was encountered in maintaining the 8 inch thickness of the concrete poured into the header block. The reason was that after the stem wall was laid, the fill was added to bring the slab base to the 4 inch cut in the header block. Inevitably fill soil spilled into the core of the header block. All subsequent activity within the fill base, placing and covering the plumbing, traffic back and forth across the stem wall, and so on, only worsened the problem. Finally, the termite treatment that was required in the State of Florida to be placed just before the membrane was laid was usually applied with a high pressure sprayer. Again this application resulted in fill soil being blown into the core holes. At this point, there was very little time to get the soil out, and the effort was extremely time-consuming and would never be adequately done without forced supervision. One of the builders offered a relatively simple, low effort solution with readily available supplies. There are cups made that fit into the core holes that are typically used in other applications to keep soil out of the cores. These should be required to be used in all SSW construction as soon as the stem wall is completed and removed after the membrane has been placed and just before the slab concrete is poured. They are reusable and take very little space to keep and store. If it is determined that this level of detail need not be placed in the standard, then this (or equivalent) technique should certainly be emphasized in the training of the construction trades and the inspectors.

403.3.4.1 Stake Penetrations

Any stake that extends through more than 1/4 the thickness of the slab shall be of a non-porous material resistant to decay, corrosion and rust, and shall be cast tightly against the slab, or sealed to the slab in accordance with Section 403.6. All stakes shall either be solid, or shall have the upper end tightly sealed by installation of an end cap designed to provide a gas-tight seal.

(Comment and recommendation) The use of wooden grade stakes that penetrated the sub-slab membrane was a well-entrenched local practice that violated the termite code as well as this standard. In order to overcome the inertia of the local practice, an acceptable (inexpensive, available, simple) alternative will have to be presented convincingly to the local construction trades, and the inspectors will have to be trained to enforce the ban strictly. Personal interactions with the University of Florida researchers who conducted the parallel study (Hintenlang et al 1993) indicated that one or more of their builders was using an alternate technique that seemed to be well received. The retraining could possibly use their experiences.

403.3.4.3 Pipe Penetrations

Plastic pipes shall be in contact with the slab along the slab's depth by casting the concrete tightly against the pipe. Where pipes are jacketed by sleeves they shall be sealed by one of the following methods:

(1) Formation of a slot in the slab around the pipe and casting with asphalt or an approved sealant from the slab to a point above the sleeve, or
(2) Seal the space between the sleeve and the pipe with an appropriate joint sealant.
(3) Pipes and wiring penetrating the slab through chases or conduit shall be sealed by placing an approved sealant between the pipe or wiring and chase or conduit. Plastic sheath, foam or insulation material shall not be used alone around pipes or conduit for sealing purposes.
(4) Where multiple pipes are ganged, block out a work space around the multiple pipes and seal as in Section 403.3.4.2 (Work Spaces).

(Comments and recommendations) It was the general impression that the builders did not understand fully how to accomplish method (1) above. One contractor developed an easy, efficient way to accomplish its intent. He placed a foam jacket at least 1/2 inch thick around each pipe (and sleeve, if used) so that the bottom of the foam jacket was about 1/2 inch below the top surface of the concrete when it was placed. This left the slot in the slab around the pipe about 1/2 inch deep and 1/2 inch wide. After the slab had sufficiently hardened, the foam jackets were removed, and the plastic sleeve (if present) was cut away to the level of the recessed concrete. Then an approved elastomeric sealant was used to fill any gaps between the pipe and sleeve and between the sleeve and concrete. The 1/2 inch cavity was filled with the sealant to the level of the rest of the slab. Concrete does not always cast tightly around the plastic pipes, either. The foam sleeve technique works well with plastic pipes as well. This technique accomplishes the intent of both (1) and (2) above. While it may not be necessary to rewrite the above portion of the standard to illustrate this technique, the training to follow should emphasize this or equivalent approaches. The foam jackets are fairly standard items; they are easy to install and remove; they are reusable (so the cost is small); and the whole process is time-efficient.

(403.4 Concrete for Slabs)

403.4.3 Workability

For improved workability of concrete used in the construction of slab-on-grade floors, additional water and/or water-reducing admixtures may be used within the following constraints:

(1) If no water-reducing admixtures are used, the slump of concrete, as measured on site at the point of discharge from the delivery vehicle, shall not exceed 4 inches with a tolerance of plus or minus 1 inch.

Any on-site addition of water shall comply with ASTM C94, and in no case shall exceed the amount required to achieve the maximum 4 inch plus or minus 1 inch slump and the limitations of Section 403.4.2 of this standard.

(2) If mid-range or high-range water reducing admixtures are utilized to achieve slumps in excess of 4 ± 1 inches, water shall not be used in excess of the limitations of Section 403.4.2 of this standard. Slumps of concrete containing mid-range water reducing admixtures shall not exceed 8 inches.

(Comments and recommendations) The field experience of the present study revealed that the concrete batch mixing plants were not at all familiar with these admixtures. It was necessary to bring in a quality assurance executive from the home office of one of the companies in order to instruct the operators how to determine the correct mixes. Even then, he was required to return after his instructions were misunderstood. Difficulties were still encountered over time as there were different operators for different shifts and plants. The training that is being planned for building contractors and inspectors may need to be expanded to include some of the building trades, such as the concrete batch mixing plant operators. Another alternative would be to work with the industry's association to encourage continuing education of their operators.

403.4.4 Curing

Concrete slabs shall be cured continuously after pouring according to one of the following procedures:

(1) Moist curing by means of ponding, fog spray or wet burlap for at least 7 days.
(2) Moist curing using impermeable cover sheet materials conforming with ASTM C171 for at least 7 days.
(3) Curing with liquid membrane forming compound according to manufacturer's specifications and conforming with ASTM C309.

Curing compounds shall be compatible with materials specified in Section 403.6.

(Comments and recommendations) The general impression was that slab curing of residential slabs for 7 days was not normally done, even though it is probably in the current code. One reason it is not is that this requirement is not enforced and may not be enforceable. Its enforcement would require an extra trip or trips to the site by the building inspector. Another reason the curing for 7 days is not done is the perceived loss of time and money by the builder. However, they seemed to be unaware of the existence of the compounds mentioned in (3) above. In general, this was their preferred method of curing once it was introduced to them, since they were being required to subscribe to the standard in order to participate in the project. The only problem that arose from using such a compound was on one slab where the compound puddled after a rain in an area of the slab that was to have tile laid. The collected compound in those puddles interfered with the adhesives used on the tiles. The training program must emphasize the need for this requirement to the construction trades affected, the importance of enforcement to the building inspectors, and the availability of suitable products and procedures (and their limitations).

403.4.5 Loading

Loading or use of the slab shall be delayed for a minimum of 48 hours after pouring. When the slab is used for material storage after the minimum 48 hour period, caution should be used to prevent impact loading.

(Comments and recommendations) The definition of "loading or use" needs to be explained. Like the curing situation, it was felt that such a restriction as this would not have been observed by most builders if it had not been a requirement for participation in the study and an investigator was not checking on its implementation daily. The rationale for its observance will need to be strongly communicated both to the trades and to the inspectors, but even then it is uncertain if the restriction will be honored if the standard is not backed by strict enforcement. Most building inspectors are not going to require that a slab not cured or loaded according to these guidelines be taken up and replaced by one that has.

403.4.6 Slab Reinforcement

Floor slabs shall be reinforced by steel reinforcing bars at re-entrant corners such as inside corners of an L-shaped slab. Re-entrant corners shall have two pieces of #4 reinforcing bar 36 inches long placed diagonally to the corner, 12 inches apart, with the first bar placed 2 inches from the corner. All reinforcement shall be appropriately positioned in the upper third of the slab.

(Comments and recommendation) It did not seem to be a local practice to place reinforcing steel bars at re-entrant corners among the eight builders used in the study. At practically every house, the re-entrant corners had to be identified and the procedures laid out for how to meet the standard requirements. It seemed that the trades had difficulty understanding and implementing the language of this paragraph. The training effort is going to have to stress the importance of this activity for the local practice to change. Therefore, the training of the inspectors will have to make this a point of careful inspection and required compliance before the slab preparation inspection can be signed. The requirement that all reinforcement be appropriately positioned in the upper third of the slab is another area where the local practice falls outside of the recommendations. In most situations the wire mesh reinforcement is just laid on the membrane with no effort to lift it into the upper third of the slab. The rationale for doing so did not seem to be understood at all. There were no easily adaptable techniques for keeping the mesh elevated that would withstand the force of the fluid concrete coming from the truck's chute. The only circumstance in which efforts were made to keep the mesh lifted involved using a hook to lift the mesh into the concrete after it had been placed but while it was still soft. Such an action with a hook had great potential and probability of puncturing the membrane which had been placed with all punctures, cuts, and tears repaired. If the local practice cannot be changed so that the wire mesh is consistently kept in the upper third of the slab, then one alternative would be to require the use of fiber reinforcement.

(Chapter 5. Systems for Active Radon Control
502 Sub-Slab Depressurization Systems
502.6 Depressurization Systems in Permeable Soils: Ventilation Mat(s) Design)
502.6.1 Arrangement

Suction points and mat strips shall be distributed as follows:

(1) The suction point shall be centrally located along the length of each unconnected strip of mat; and
(2) Mat strips shall be oriented along the central axis of the longest dimension of the slab or diagonally to maximize the mat length; and
(3) A minimum of one strip shall be used for slabs having widths up to 50 feet (Additional strips shall be added for each additional slab width increment of up to 50 feet, and may be located in either parallel or crossed diagonal configurations.); and
(4) The mat strip shall extend toward the most distant perimeters of the building, but shall not lie any closer than 6 feet from any perimeter; and
(5) A separate suction point and fan shall be installed for each 100 feet linear length of ventilation mat.

(Comments and recommendations) This section discusses the placement of the suction point, but makes no mention of its relation to the exhaust riser, either in regards to choices of placement locations or means of connecting. At least two factors must be considered in the choice of the placement of the exhaust riser. One is identifying a suitable chase or interior wall to contain the riser. This is usually the first choice of an owner or builder. However, a corner of a closet or some other similar location may be chosen. In many current house plans the center of the house is an open (great room) area that has few convenient locations suitable for an exhaust riser to run. The standard as written does not discuss how to connect a centrally located suction point to an exhaust riser remote from that suction point. A second factor to consider in the placement of the riser is where the suction fan will be placed. Usually owners or neighborhood covenants do not allow for plumbing stacks to be visible from the front of the house. Also, there must be attic access to the fan location for maintenance purposes. Cathedral or other vaulted ceilings may restrict the potential placement locations of fans and even the piping leading to the fans, as well as access for repairs.

The means of connecting the mat to the riser at the suction point is another area not addressed in the current draft of the standard. If the riser is directly above the mat, then one method that has been used successfully is to attach a toilet flange to the mat at the exact location of the riser, and attach the riser piping to the flange. However, if the mat is even with the top of the prepared fill soil, then the flange and associated hardware will be protruding into the lower part of the slab thickness. This protrusion in effect makes the slab thinner at the point of the suction point, which has the potential of preferential crack formation because the slab will be weaker there. Therefore, it is recommended that the mat be recessed into the fill soil enough so that the top of the flange and other associated hardware is no higher than the grade of the rest of the fill. If the riser location is not directly above the mat, then the preferred means to connect the two is not discussed. One relatively simple solution would be to run a strip of mat from the main strip to the riser location. This technique was used as necessary in this study. A length of pipe could be placed in the fill soil between the mat and the riser location, but some guidance would be helpful to describe acceptable ways of connecting the pipe to the mat.

If the essence of the above comments is too detailed to be included in the actual standard wording, then the training program should emphasize suggested or recommended techniques for accomplishing the desired results. It must be kept in mind that depressurization systems are new concepts and applications of technology that at this time are not within the experience and expertise of most of the building community. Any places that either the standard or the training is not clearly addressing will be subject to misunderstanding or misinterpretation when applied in the field.

DISCUSSION

Over the course of this study of 14 new slab-on-grade houses built on relatively high radon potential soil (1000-12,000 pCi/L soil gas radon concentration), the application of the 1991 draft radon standard requirements concerning the placement and sealing of the passive barrier (including the compacted base, the vapor barrier, and the slab) proved to be quite effective in limiting indoor radon concentrations to well below 4 pCi/L in 11 of the houses. The remaining three are still undergoing investigative measurements to confirm their indoor radon concentration levels. The standard features were installed with close oversight and frequent help of an environmental engineer in the field. Eight different builders were used in this study, who used concrete from three different batch mixing plants. Some of the builders had more than one crew, and certain of the specific tasks were performed by other sub-contracted groups (for example, concrete finishers). Usually it was only the building contractor who would have tried to read and interpret the standard requirements. Most of the other supervisors and workers operated from training received on the job. This type of environment supports the attitude of doing the job like it has always been done. Many of the standard features, even some that are currently in a building code but not being implemented, are new or different from the accustomed way of operating. To place the new requirements on paper is a necessary first step, but before any positive or beneficial effects will come from the new standard, the individuals doing the work will have to be instructed in the importance and necessity of implementing them correctly. The training will have to be clear and convincing and conducted in terms that are easily understood by the supervisors and workers. The current draft of the standard does a good job of stating the basics, but either it or accompanying training materials will need to be more detailed and descriptive in their approach. At the same time, some allowance for innovation should be left open; for the workers have the best sense of the most effective field techniques.

The second group who will need a complete understanding of both the basics and the specifics of the standard is the building inspection community. Without their requiring the builders to conform rigorously to the salient features identified as necessary for effective radon barrier construction, the industry will have little incentive to make the extra effort to train or retrain the workers or to improve upon the current locally accepted construction practices, which may be far short of what can be accomplished. The building inspectors will be more used to reading and correctly interpreting standards language, but they will still need to be given clear and sound guidance in the intent and scope of the proposed changes. If they are not, then they may require procedures that are not intended in the standard or allow practices that are either ineffective or even detrimental to the goal of achieving radon resistance. An intensive training program that emphasizes the basic rationale for the features of the standard and that demonstrates acceptable techniques for achieving the desired results will give the inspectors the theoretical and practical basis for correctly enforcing the proposed standard in the building community.

CONCLUSIONS

Applying the proposed standard was effective in reducing radon entry in new houses built over high radon potential soils. But in order to accomplish these promising results, the assistance of detailed explanations of the requirements of the standard, interpretation of the wording and intent of the language, vigilance in the oversight of the application of the standard features, and on-site instruction and training of supervisors and workers was necessary. In order for similar results of the proposed standards to be realized in the field, an equivalent effort of selling the importance of changing old habits and adopting new procedures will be required. The effort will have to address specific audiences in the building community. For example, general contractors and site supervisors will need to have the big picture of what the purpose of the standard is and the importance in adequately implementing it, as well as detailed indoctrination in specific procedures for successful application of the important features. Perhaps a strong emphasis on the negative health effects of increased exposure to ionizing radiation will be one motivational tool. However, realistically, the possible chance of litigation liability may be a stronger impetus for compliance. Workers in the specific trades that most closely affect radon resistance will also need detailed training. Plumbers or others who will be responsible for laying the mats or piping, concrete workers who prepare the foundations and finish the slabs, the batch plant operators, and others will need to be trained. More than likely, it will be supervisors who will perform this training on the job site. It will be necessary to get into their hands clear and illustrative materials that communicate acceptable and effective techniques to achieve the desired results. Finally without strong enforcement of the standards by knowledgeable inspectors, it is unlikely that the recommended features of the standard will become common practice.

REFERENCES

Florida Department of Community Affairs. Florida standard for radon-resistant building construction. Tallahassee: State of Florida: 1-28: 1991.

Florida Department of Community Affairs. Florida standard for radon-resistant residential building construction. Tallahassee: State of Florida: 1-23: 1994.

Hintenlang, D.E.: Shanker, A.: Najafi, F.T.: Roessler, C.E. Evaluation of building design, construction and performance for the control of radon in Florida houses: evaluation of radon resistant construction techniques in eight new houses. Gainesville: University of Florida: Contract 93RD-66-13-00-22-008 Final Report: 1-70: 1993.

Sanchez, D.C.: Dixon, R.W.: Williamson, A.D. The Florida radon research program: systematic development of a basis for statewide standards. In: The 1990 international symposium on radon and radon reduction technology: Volume 1. Cincinnati: U.S. Environmental Protection Agency: EPA-600/9-90/005a: 1990: Poster A-1-3.