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Project Summary

Measurement of the Surface Permeability of Basement Concretes

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Wall/floor joints are often sealed to reduce the entry rate of radon-containing soil gas into buildings. This practice is generally ineffective because of one or more of the following:

(1) not all openings are sealed;
(2) the sealants do not block soil gas entry because of inadequate coverage or adhesion; and
(3) the permeability of the concrete is high enough (>10^{-15} m^2) to allow significant soil gas entry rates through the concrete itself.

The problems with unsealed openings or poor sealants can be overcome by better seal designs, improved training, and quality control; but if the construction materials have high permeability, then soil-gas-resistant foundations cannot be produced regardless of design or workmanship. The purpose of this study was to develop a method and apparatus to test the surface permeability of concrete sections *in-situ*; and to perform field measurements to determine whether surface permeability is generally so high that standard sealing techniques will be unsuccessful at curtailing the entry of radon-containing soil gas.

Modern sealant materials have very low air permeability when set; thus, seal performance is determined by the permeability of the surfaces bridged by the sealant. Concrete basement walls and floors are poured separately and are not interlocked; the joint between them presents the largest potential opening for soil gas and radon entry. Radon resistant foundations must seal this entry path. Horizontal floor surfaces are usually trowelled or floated smooth for appearance, which works cement paste to the surface and eliminates pores from the surface layer. In contrast, walls are poured into vertical forms, and their surface is untouched until the concrete sets. The surface consists of cement paste and the smallest aggregate fragments. During the setting process, water bleeds to the surface and tends to drain down between the form and the face, producing vertical channels in this surface layer. A wall/floor joint sealant contacts both surfaces, and may be rendered ineffective if the pores and channels in the vertical wall surface layer are large enough to act as a bypass for soil gas.

A portable surface permeameter, suitable for field use, was developed, tested, and used to measure surface permeability of concrete in new houses. The operating principle is based on measurement of airflow induced by a pressure difference across a temporary test seal applied to a surface. The feasibility of the equipment and the test procedure was demonstrated and developed by laboratory tests. The equipment can measure surface permeability as low as 10^{-16} m^2, the nominal bulk permeability of solid concrete.

Measurements were made on concrete basement walls and floors of houses under construction. Areas selected to be free of obvious surface defects such as air bubbles were found to have permeability in the range 10^{-14} to 10^{-16} m^2. High resistance seals can be produced between surfaces with this low permeability.

However, air bubbles and other surface defects were found to be very common on vertical concrete surfaces. These defects caused the permeability of areas chosen at random to be $>10^{-12}$ m^2, too high for standard sealing details to produce effective seals between vertical concrete sections.

As seal performance depends on surface permeability, sealing will be a practical passive radon exclusion measure only if there are low cost surface preparation methods, sealing details, and procedures to produce high-resistance seals even when there are surface defects.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Radium in the soil is a continual source of radon, which enters the air spaces between the soil grains and is carried into the house by air movement through the soil. The flow rate into the house is set by the pressure difference between the house and the soil, and the series airflow resistance of the soil and the house foundation.

The resistance of a concrete house foundation is set by the resistance of the floor and walls, and the resistance of the joints and openings between and in them. In normal basement construction there are so many open joints that foundation resistance is only a small fraction of the soil resistance. The report identifies a performance criterion for radon resistant housing, suggesting that a "radon-resistant" foundation should have an average soil gas entry rate below 40 L/h ($1x10^{-4}$ m^3s^{-1}). This standard of soil gas exclusion will ensure low house radon concentrations regardless of soil conditions.

The report identifies the air permeability of bulk concrete as 10^{-15} to 10^{-16} m^2, too low to allow significant soil gas flows through concrete. Most of the soil gas and radon enters the building through low-resistance joints and openings between the concrete sections, such as the wall/floor joint, shrinkage, or settlement cracks.

Radon Resistant Construction

The report identifies the characteristics of a radon resistant foundation as:

- Soil gas entry rate < $1x10^{-5}$ m^3s^{-1},
- Total basement flow resistance $>4x10^6$ $Pa.s.m^{-3}$,
- Concrete resistance $>4x10^8$ $Pa.s.m^{-3}$ per m^2.
- Joint resistance $>1.6x10^8$ $Pa.s.m^{-3}$ per m,
- Surface resistance in contact with sealant $>3.2x10^8$ $Pa.s.m^{-3}$ per m (implies surface permeability $<10^{-13}$ m^2), and
- Length of unsealed joints <100 mm.

Obstacles to passive radon resistance include:

- not all openings through the basement walls and floor were sealed during construction,
- the effective resistance of the joints and openings was less than $4x10^6$ $Pa.s.m^{-3}$, despite the application of sealants, and
- the bulk permeability of the concrete used in the foundation was much higher than 10^{-15} m^2.

If the surface cement layer contains a channel 5 mm long, and 1 mm in diameter, the resistance of this tube is $4x10^6$ $Pa.s.m^{-3}$. Only four such tubes bypassing the sealant are required to reduce the resistance of a "perfect" radon resistant basement to 10^6 $Pa.s.m^{-3}$, too low to be fully radon resistant. Thus the connected porosity of the concrete surface layer is of major importance in determining sealant performance for soil-gas exclusion.

Permeameter Design

A surface permeameter was developed, tested in the laboratory, and then used to measure the surface permeability of basement walls and floors in newly constructed houses. The operation principle is that a temporary seal is placed on a concrete surface, a pressure differential produced across the seal, and the resulting airflow measured. A permeameter chamber is sealed to the surface on one side of the seal, and a second chamber is sealed to the surface on the other side of the seal. There is no connection between the chambers except that both touch the same concrete surface. One chamber is depressurized. Air drawn through the concrete beneath the temporary seal draws air out of the second chamber, and the volume removed is measured by the displacement of an oil slug in a capillary tube attached to the chamber.

Each chamber is semicircular in cross section, 0.35 m long, 80 mm wide, and 40 mm high. The length of concrete surface under test is 0.3 m. At a seal linear resistance of $1x10^{10}$ $Pa.s.m^{-4}$ (100 times higher than the required value for an effective radon resistant seal), an underpressure of 1000 Pa in the first chamber will give a flow of $3x10^{-8}$ m^3s^{-1} (3 cm^3/min) out of the second chamber. This is equivalent to a 0.2 m/min displacement rate in a 3 mm tube, which is readily detectable. A detailed description of the apparatus and its use are included in the report.

Conclusions

The maximum surface permeability acceptable for "radon-resistant" seals is ~10^{-13} m^2, which is larger than most measurements on smooth defect-free concrete. Good seals can be produced between selected or prepared concrete surfaces. However, when wall areas are chosen at random, and hence include subsurface defects, the effective permeability measured is $>5x10^{-12}$ m^2. This shows that high resistance seals cannot be guaranteed for unprepared concrete surfaces, due to the connected air bubble pores providing low resistance subsurface paths through the near-surface concrete layer. These by-passes limit sealant performance, no matter how good a bond the sealant makes with the surface.

Inspections of 10 houses found that the vertical concrete walls had a cement surface skin of 1 to 5 mm thickness, containing many small air bubbles and large pits, depressions, and wormtracks caused by air bubbles trapped between the concrete and the form. The surface finish depended on form preparation, not concrete mix, for different surface textures were found on adjacent vertical form sections of the same wall. Some forms even removed the surface skin when they were stripped from the concrete, leaving uneven and rough patches with many small surface pits caused by air bubbles entrained in the mix.

The surface cement paste layer on concrete sections has a permeability much lower than the 10^{-13} m^2 needed to produce good seals. There are no fundamental reasons to prevent high resistance seals for joints and openings in concrete foundations. However, seals have to be applied to unfinished vertical surfaces that are rough, uneven, pitted, covered with loosely adherent material, contain connected subsurface channels, and are difficult to reach. These defects either prevent the sealant from contacting solid concrete or provide subsurface by-pass paths around the seal, increasing the effective permeability to $>5x10^{-12}$ m^2. Good seals between vertical concrete sections cannot be guaranteed unless these surface defects and by-passes are removed. This requires removal of the surface cement layer. Application of a caulk bead in the vicinity of an unprepared wall/floor joint will not achieve a good seal.

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The complete report, entitled "Measurement of the Surface Permeability of Basement Concretes," (Order No. PB93-232114; Cost: $17.50; subject to change) will be available only from:
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