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Project Summary

Laboratory Assessment of the Permeability and Diffusion Characteristics of Florida Concretes: Phase II. Field Samples and Analyses

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The report gives results of a study to establish the capability to measure concrete's permeability and diffusivity; to measure these parameters in a small sampling of the typical types of Florida concrete; and, if possible, to correlate the physical parameters of the concrete (mix design, porosity, etc.) to the measured diffusion and permeability coefficients.

Sample permeability was measured and analyzed with a device developed for the project. The diffusion coefficient was determined using a system also developed for the project.

The statistical analysis consisted of 1) a stepwise search using an Efromyson-type search methodology, 2) a standard linear-modeling, least-squares approach to evaluate individual variables and sets (up to sets of three), and 3) robust or least-median-square methods to further evaluate possible correlations and examine the dataset for outliers.

For both permeability and diffusivity, the amount of water added to the mix at the site was directly and positively related and identified as a possible major factor. The data indicated that the total amount of sand and stone in the mix was possibly correlated to the permeability. A third possible correlation involved the amount of fly ash or the cement to fly ash ratio.

This Project Summary was developed by EPA's National Risk Management 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).

Overview

Much of Florida's natural soil, as well as the disturbed overburden and the sand tailings from the phosphate mining/ beneficiation process, contains significant quantities of radium. Buildings constructed on these high-radium soils contain elevated radon gas levels. Elevated indoor radon gas levels can cause lung cancer in humans.

To decrease elevated radon gas levels, Florida's legislature instructed its Department of Community Affairs to develop new construction standards for radon-resistant buildings, primarily slab-on-grade construction.

It is well-known that the concrete slab is the primary barrier to radon entry. However, the extent of its ability to permit air flow under pressure (permeability) and to permit the passage of radon gas without any pressure difference (diffusivity) has not been well-determined. To establish a standard concrete mix and its maximum radon-resistant placement, these parameters needed to be quantified and their relationship to concrete's physical properties evaluated.

Primary research objectives were to establish the capability to measure concrete's permeability and diffusivity; to measure these parameters in a small sampling of the typical types of Florida concrete; and, if possible, to correlate the physical parameters of the concrete (mix design, porosity, surface finish, etc.) to the measured diffusion and permeability coefficients.

Sample permeability was measured with a device developed for this project. The sample holder's open end was sealed airtight into the permeability test fixture using Mortite, a non-hardening, clay-type sealant. A top plate kept the sample holder sealed to the fixture. Compressed air at 25 psi (172 kPa) (nominal) pressurized the space enclosed by the test fixture and the bottom side of the concrete. The pressurizing valve was shut, and a pressure-sending unit measured the pressure in the sealed volume. As the air escaped through the concrete, the pressure decreased.

The diffusion coefficient was determined with a system developed by and purchased from Rogers and Associates Engineering Corporation. The method uses uranium mill tailings as a strong emitter of radon gas. The tailings are in a 30-gal (114 L) drum the lid of which has a fitting into which the sample holder is mounted, and the detector assembly is mounted on top of the holder. After the background count rate is measured, the valve between the drum of radon gas and the bottom surface of the concrete sample is opened. The scalar/ratemeter counts and produces a paper record of the number of counts per interval. When the count rate stops increasing, the radon gas in the drum and in the space above the concrete has reached equilibrium. The valve is shut, and the sample holder and detector apparatus are disassembled.

The permeability time-versus-pressure data were analyzed by software written for this permeability determination method. The software also provided the automatic data collection system. Usually, data were collected from the pressure sender every 10 s. Then, six of the data points were averaged to produce a raw data point every 1 min. This could be varied; for some of the high permeability concrete samples, raw data points were saved each second with no averaging. The sampling technique allowed more data to be collected and improved the standard deviation.

The physical parameters of the test (air temperature, sample thickness, sample diameter, and volume under pressure) were used to calculate the permeability coefficient. The software requested the data as measured, then converted it to the appropriate units. The errors in each parameter were used to determine an estimated standard deviation for the calculated permeability coefficient. The results were written to a data file in a format suitable for printing.

Rogers software was used to determine the diffusion coefficient. The software uses 10 pairs of data points from the breakthrough region of the alpha activity data. For this work, 10% offsets from the baseline and the equilibrium level were used to determine the breakthrough region.

Within this region, 10 data points spaced evenly in log time were selected. The next highest adjacent data point was used as the second data point of the pair. The first data point of the pair was used to calculate the diffusion coefficient. The second data point was used to estimate the standard deviation of the diffusion coefficient.

Proper function of the diffusion test system was verified by testing four materials with different diffusion coefficients: air, 4 mm glass beads, coarse sand, and fine sand. Because the permeability test was a new method, there were no available data on the permeability of concrete, and there was no test standard for calibration purposes. It is not possible to calculate the percent difference between the actual and measured permeability values. The data collected in these tests compare favorably (order of magnitude) with the expected permeability coefficients. The limiting factor in the permeability test is the system leak rate. This leak rate imposes a minimum detectable limit of 10^{-20} m^2 which is a factor of 10,000 lower than the concrete samples measured.

A statistical analysis of the data was performed using the S-Plus statistical analysis package for desktop computers. A three-step process was used to evaluate possible correlations of the mix design and other factors to the permeability and diffusion coefficients. The first step used a stepwise search of the possible explanatory variables using an Efromyson-type search methodology. The second step used a standard linear-modeling, least-squares approach to evaluate individual explanatory variables and sets of explanatory variables (up to sets of three). The third step was to use robust or least-median-square methods to further evaluate possible correlations and examine the dataset for outliers. The correlation analysis has provided some indications of the components of mix design and placement which may have the greatest effect on the permeability and diffusivity of the concrete. The primary correlation to the diffusion coefficient was a direct relationship to the amount of water added to the mix at the site before the concrete was placed. Other possible correlations were the cement to fly ash ratio and the total amount of fly ash in the mix. The permeability coefficient was most correlated to the total amount of aggregates (sand and stone) in the mix. Other possible correlations to the permeability coefficient were the amount of water added at the site, the ratio of the total amount of aggregates to the total amount of cementitious materials, and the amount of fly ash in the mix.

The objectives of Phase II of this project have been met. Concrete samples from typical residential slabs from throughout Florida have been tested. The mix design and placement data have been examined for correlations to the permeability and diffusion coefficients.

For both permeability and diffusivity, the amount of water added to the mix at the site was directly and positively related and identified as a possible major factor. The data indicated that the total amount of sand and stone in the mix was possibly correlated to the permeability. A third possible correlation involved the amount of fly ash or the cement to fly ash ratio. Fly ash is commonly used as a cementitious material in addition to cement powder. It has good properties as a binding agent but is more porous than cement powder. This porosity may be negated somewhat by the small size of the fly ash particles and the ability of the cement powder to seal these small porosities and reduce their effect. The data for the admixtures were not included in the correlations since they tended to be unavailable or unreliable.

It is also interesting to note that samples c002a, c002b, and c018, which had defects, all have high permeability and average diffusivity. This indicates that small defects with high tortuosity have small effects on the diffusivity but are very good channels for air flow.

First and foremost, great care should be taken to ensure that the concrete slab remains a fully intact barrier. The effects of a very tight concrete mix are nullified by cracking and unsealed penetrations. Proper grading/compaction will help to eliminate settlement cracking. Drying shrinkage cracks can be reduced by ensuring that the slab wet cures for an extended time to allow the concrete to gain strength before stresses due to drying are placed on the slab. Reducing the amount of water in the mix may also reduce the amount of drying shrinkage cracks. Increasing the amount of cement in the mix will reduce radon transport and produce a better quality of concrete but will also increase the cost.

Additional barrier measures should also be considered. A plastic sheet or layer of asphaltic cement will reduce both transport and the impact of defects in the concrete. Coating the top of the slab (e.g., painting) could also be used to seal imperfections and small cracks in the slab. It is important that cracks are sealed to depth to prevent the soil gas from bypassing a thin surface seal. Resealing could be done when the floor coverings are replaced.

All of these options support the primary goal: to provide an intact primary barrier with reduced transport properties.

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The complete report, entitled "Laboratory Assessment of the Permeability and Diffusion Characteristics of Florida Concretes: Phase II. Field Samples and Analyses," (Order No. PB95-243168 Cost: $19.50, subject to change) will be available only from

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