Building and Environment 59 (2013) 417–425

Contents lists available at SciVerse ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Simulating the effect of slab features on vapor intrusion of crack entry

Yijun Yao, Kelly G. Pennell [1], Eric M. Suuberg*

School of Engineering, Brown University, 182 Hope St., Providence, RI 02912, USA

ARTICLE INFO

Article history:
Received 19 June 2012
Received in revised form
12 September 2012
Accepted 13 September 2012

Keywords:
Vapor intrusion
Crack
Three-dimensional simulation
Slab features

ABSTRACT

In vapor intrusion screening models, a most widely employed assumption in simulating the entry of contaminant into a building is that of a crack in the building foundation slab. Some modelers employed a perimeter crack hypothesis while others chose not to identify the crack type. However, few studies have systematically investigated the influence on vapor intrusion predictions of slab crack features, such as the shape and distribution of slab cracks and related to this overall building foundation footprint size. In this paper, predictions from a three-dimensional model of vapor intrusion are used to compare the contaminant mass flow rates into buildings with different foundation slab crack features. The simulations show that the contaminant mass flow rate into the building does not change much for different assumed slab crack shapes and locations, and the foundation footprint size does not play a significant role in determining contaminant mass flow rate through a unit area of crack. Moreover, the simulation helped reveal the distribution of subslab contaminant soil vapor concentration beneath the foundation, and the results suggest that in most cases involving no biodegradation, the variation in subslab concentration should not exceed an order of magnitude, and is often significantly less than this.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

In any vapor intrusion study, one of the most important issues is how the contaminant soil vapor enters a building of interest. This issue cannot be avoided for research no matter with focus on soil vapor transport [1–7], indoor air concentration [8–11] or both [12–18]. Two general hypotheses have been used in the analysis of the process. One is to assume that contaminants enter through a permeable concrete slab [8,9,18], and the other involves assuming existence of a crack or cracks in the slab as the main entry pathway for soil vapor [1–7,12–14,19–21]. The use of the former is limited, largely due to the generally accepted low permeability of the typical concrete slab, while the latter was developed for radon intrusion studies, and later widely employed in chemical vapor intrusion studies [22–24]. One example of its use involves the application of Nazaroff's equation [25], to calculate soil gas flow rate into a perimeter crack of a building, e.g. in the Johnson–Ettinger (J–E) model [12].

Though the crack concept has also been used in many more detailed studies beyond the J–E model, e.g. Abreu and Johnson's three-dimension (3-D) CFD numerical model [1–3], the Brown 3-D CFD model [4–7,14] and some case studies [26], most of these studies in vapor intrusion focused on the influence of environmental factors such as soil characteristics and contaminant source separation and distribution, and only a few of them considered the details of crack features on predictions. In Abreu's thesis [2], the "center crack" scenario was simulated in a study of biodegradation effects, and it showed that the crack location can play a significant role in cases involving high biodegradation rate constants. Another important issue is the variation with position of subslab contaminant soil vapor concentration and how this might influence entry rates into a building. The question that this poses is whether taking monitoring data from one or two subslab sample points is sufficient to fully describe the necessary subslab near-crack concentration used in predicting contaminant entry rates?

Equation (1) shows the relationship between contaminant mass flow rate into a structure and indoor air concentration [12].

$$c_{\text{in}} \approx \frac{J_{\text{ck}}}{Q_b A_e} \tag{1}$$

Where c_{in}. the indoor air contaminant concentration $[M/L^3]$, J_{ck}. the contaminant mass flow rate into the building $[M/T]$, Q_b. the volume of the enclosed space $[L^3/T]$ and A_e. The air exchange rate $[1/T]$.

In this study, contaminant mass flow rate, rather than indoor air concentration, is used as the index of vapor intrusion risk, as suggested elsewhere [6,14]. In equation (1), both Q_b. and A_e are in

* Corresponding author. Tel.: +1 401 863 1420.
E-mail addresses: kpennell@umassd.edu (K.G. Pennell), Eric_Suuberg@Brown.EDU (E.M. Suuberg).
[1] Current address: Department of Civil & Environmental Engineering University of Massachusetts-Dartmouth, Dartmouth, MA 02747, USA.

0360-1323/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2012.09.007

practice often difficult to identify or measure, and will cause uncertainties in predicted c_{in}. As an alternative, J_{ck}. the contaminant mass entry rate, can be obtained directly from 3-D numerical models. This merely postpones the problem of establishing Q_b. and A_e. another point in the visual risk assessment based on c_{in}, but it more explicitly highlights the problem, and also allows comparing the potential for the vapor intrusion impacts in different structures without getting tied up in issues of idiosyncratic building operation.

2. The 3-D numerical model

The full 3-D model examined here is essentially that presented earlier by this group [4–7,14], and partly validated by previous study. The case of interest here is the steady-state "base case" discussed in the earlier studies, i.e., a single structure built atop an otherwise flat, open field, underlain by a homogeneous soil that stretches from the ground surface to a water table which serves as an infinite source of the contaminant vapor of interest.

Fig. 1 presents a diagram of the base case situation, while Fig. 2 shows different hypothetical crack shapes and distribution in the foundation slab. Table 1 shows the various parameters assumed in the modeling work. The model equations solved here are those shown in previous publications by our group [4–7,14].

Effective soil diffusivity is in reality correlated with soil permeability [27]. However, in this paper we chose to assume a constant soil diffusivity to keep the comparison clearer as the small possible variation in dry soil diffusivity does not make a large difference in the results, as also noted in our previous research [4–7,14]. Permeability can show significant variability with soil type and moisture content, but this is not a focus of this paper, which is concerned with the influence of the foundation crack characteristics.

Briefly, the 3-D modeling approach used here solves Darcy's Law to obtain soil gas advection profiles, and then solves the contaminant gas diffusion-advection equation subject to the soil gas advection velocity profiles obtained from solving Darcy's law. Again, details of the modeling procedure have been presented elsewhere [4–7,14].

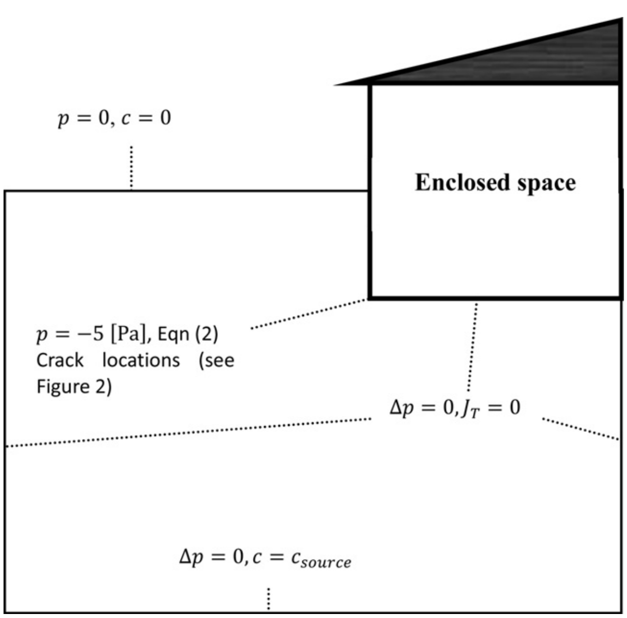

Fig. 1. Cross sectional view and boundary conditions of the model domain and house with a foundation crack.

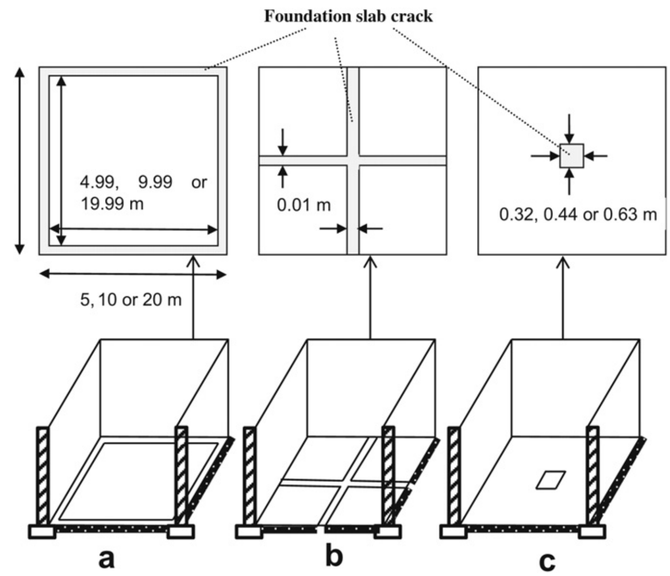

Fig. 2. Plan view of the location of the crack in the foundation of slab: (a) perimeter crack; (b) center crack; (c) center hole (The crack area in three cases is the same.).

The governing equation of non-compressible soil gas flow in steady state is [14]:

$$q = -\frac{k}{\mu_g}\nabla p \tag{2}$$

Where q is the Soil gas velocity (L/T), k is the soil permeability (L^2), μ_g is the viscosity of soil gas ($M/L/T$) and p the pressure of soil gas ($M/L/T^2$).

And the general governing equation for convection and diffusion of non-biodegradable contaminant in soil is [14]

$$J_T = qc - D_{\text{eff}}\nabla c \tag{3}$$

Where J_T. Bulk mass flux of contaminant ($M/L^2/T$), c the concentration of contaminant chemical in soil gas (M/L^3) and D_{eff} the effective soil diffusivity (L^2/T).

The entry rate of contaminant into the house is given by [12]

Table 1
Input parameters used in the 3-D simulations (unless otherwise noted in the figures and table).

Building/foundation parameters	**Contaminant vapor source properties**
Domain cross section size: 24 m × 24 m or 50 m × 50 m (for the foundation footprint size 20 m × 20 m). Foundation foot print: 5 m × 5 m, 10 m × 10 m, or 20 m × 20 m. Depth of foundation (d_f). : 0.1 m or 2 m. Crack/foundation slab thickness(d_{ck}). : 152 m Crack width(w_{ck}). : 005 m Depth to groundwater/source (d_s). 35, 8, 11, 14, or 18 m bgs	Contaminant: TCE Diffusivity of TCE in crack (D^{ck}). 7.4×10^{-6} m^2/s Effective diffusivity of TCE in soil (D_{eff}). 1.04×10^{-6} m^2/s
3-D finite element analysis parameters	**Soil gas flow properties**
Size of the grid elements: 0.001 m^{-1} m Number of elements: 200 k–1,000 k	Viscosity of air/soil gas (μ_g). 1.8648×10^{-5} kg/m/s Density of air/soil gas (ρ_g). 1.1614 kg/m^3 Soil permeability (k). 10^{-10}, 10^{-11}, 10^{-12}, 10^{-13} or 10^{-14} m^2 Total soil porosity (ϕ_t). 0.35 Soil porosity filled with gas (ϕ_g). 0.296

Download English Version:

https://daneshyari.com/en/article/6701314

Download Persian Version:

https://daneshyari.com/article/6701314

Daneshyari.com