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TECHNIQUES FOR MEASURING THE AIR LEAKAGE CHARACTERISTICS OF BELOW GRADE FOUNDATION COMPONENTS

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INTRODUCTION

In recent years, a great deal of attention has been devoted to tightening above grade building envelope components (1). In residential construction, substantial reductions in overall building envelope leakage rates have been achieved through improved construction techniques and site monitoring (2,3). Although the initiative for this activity may have resulted from a need to reduce air infiltration/exfiltration to save space heating energy and reduce moisture migration into exterior building components, another benefit has been the reduced transfer of outdoor pollutants across the building envelope.

It is becoming more widely recognized that a number of pollutants can enter buildings through the below grade building components: volatile organic compounds, hydrocarbons, water and water soluble gases and liquids and microbiological contaminants, to name a few. Radon gas is one contaminant that has been specifically identified as a potential health hazard in residences. Yet, while over 238 papers (4) have been written on building and building component air leakage, none of them have focused on the below grade building components.

The primary pathways for outdoor pollutant entry are diffusion through the building envelope materials and air flow through discontinuities in the building envelope. As with above grade envelope components, air flow may be the dominant mechanism for pollutant entry through the below grade building envelope. Unlike above grade air leakage, even small below grade air leaks can represent potential problems since the concentration of pollutants in soil gases can be very high. Thus, while many of the concepts of fan depressurization air leakage testing that were developed for whole house measurement can be applied, more sensitive measurement capabilities are required.

Major factors governing pollutant entry rates include the size and type of air leakage sites, differential air pressure between the soil gas and the building, concentration of the pollutant in the soil gas and the permeability of the soil. From a construction perspective, the soil gas is usually a non-controllable factor. Thus construction techniques and materials must be available to ensure that the soil gas entry rate is controlled. For high concentrations of pollutants in the soil, high levels of air tightness will be required to control pollutant entry rates.

New building designers and contractors doing remedial work require basic information on where soil gases can enter foundations and what the magnitudes of the entry rates are. With this information, control strategies can be developed and evaluated.

This paper describes a simple, portable measurement system and procedure being developed to measure the air leakage characteristics of below grade building envelope components. The system is designed to measure the "in situ" air leakage characteristics of various components, identify primary air leakage sites and evaluate control measures. Preliminary system design requirements and components are discussed.

FUNDAMENTAL PRINCIPLES

The basic mechanism of soil gas entry into foundations is one of a gas generated in a permeable medium flowing through a complex network of resistors into a ventilated cavity (Figure 1). The gas flow is driven by a pressure gradient, $P_{sg} - P_i$. In many ways, trying to analyze this situation is analogous to attempting to predict the flow from a specific supply air diffuser in a multiple path ductwork system when none of the flow characteristics of the ducting, fittings or fan are known.

In the case of soil gases, since the gas generation rate, permeability of the medium, and pressure gradient are all known to vary with time, the entry rate will also vary. Attempting to predict the entry rates for a specific building is error prone and requires great effort. The number of possible foundation geometries further complicates the problem.

For most applications, it is not necessary to predict the flow of soil gas. The primary requirement is that the soil gas entry be minimized using practical methods. One approach (and essential first step in any control strategy) is to place a very large resistance (the below grade building envelope) between the soil gas and the building interior. If the foundation air flow resistance (R_f) can be made much larger than the other resistors such as the soil air flow resistance (R_s), variations in the other resistors will not substantially affect the soil gas flow rate. Increasing R_f will always reduce the total soil gas inflow to the building. If a subsequent technique such as sub-slab depressurization (5) is required, a tight foundation will minimize the amount of indoor air that is removed.

MEASUREMENT SITES

Figure 2 shows a typical foundation and potential air leakage sites. Air leakage can occur through homogeneous building components or at joints of component assemblies. Components of interest will include:

a) wall/floor intersection - straight section
- corner

b) wall section - no visible cracks
- visible crack

c) floor section - no visible cracks
- visible crack

d) service penetrations

e) telepost through floor slab

f) floor drain/drainage tile

SYSTEM DESCRIPTION AND TEST PROCEDURE

A schematic of the air leakage measurement system is shown in Figure 3.

The basis of the method developed by the authors involves isolating a building envelope component and using mechanically induced pressure gradients to force a range of airflows through the component. This is a new application of a common technique for characterizing building air leakage. Using the pressure/flow data, the orifice characteristics of the leakage site can be calculated and the effect of modifications evaluated.

To properly characterize the foundation resistance without the confounding effects of the soil, the pressure drop across the foundation component alone must be measured. As with above grade components, using the average measured pressure distribution over the exterior envelope surface will affect the accuracy of localized measurements. Below grade pressure distributions are even more difficult to estimate since accessibility to the building envelope surface is restricted by the backfilled soil.

Soil pressure probes are used to measure the local pressure at different below grade locations adjacent to the foundation components. A number of probes (above and below grade) should be installed and used as exterior reference pressures until more experience is obtained on selecting the location that most accurately represents the true pressure difference across the component.

Rigid, airtight boxes are used to isolate the various building components. The dimensions of the boxes are selected to allow testing of one meter of component crack length and/or one half square meter of surface area. The size and shape of the boxes is not critical; however, the volume should be kept small to avoid long transient times associated with changing the pressure and corresponding airflow from the envelope component. The edges of the boxes are sealed to the envelope surfaces using a combination of closed cell foam gasket and rubberized caulk materials. The boxes are held in place by a variety of reaction devices including weights and levers.

A technique that can be used to measure the air leakage of the teleposts involves using an inflatable bladder to seal off the interior of the telepost just above the lowest row of support pin holes and exhausting air through the holes using the fan depressurization apparatus.

The basic procedure to be used to evaluate the air leakage characteristics of the below grade building components is as follows:

1) Install the box to isolate the component and use a fan to induce a negative pressure on the inside surface of the component.

2) Measure the exhaust air flow rate and differential pressure between the component and the exterior reference. In addition to the soil pressure probes, an ambient air pressure averaging station (one location on each of four sides of the house) should be used to reference the tests to outdoors (6).

Measurement of the component air leakage should be done using the balanced fan depressurization technique (7). A fan depressurization apparatus (blower door) should be installed in an exterior door (or basement door) of the house (6) and used to balance the pressure between the house and the box. Although time consuming, the balanced technique will ensure that the measured air leakage will be from the exterior only since the house pressure will be equal to the box pressure.

After the box is installed and the edges are sealed, a test can be done. The box can then be removed, the component (crack, opening, surface) sealed or otherwise modified and a subsequent test done.

A minimum of six air flows should be recorded at differential pressures (interior of box referenced to the outdoor pressure tap) ranging from approximately 20 to 200 pascals (Pa). Care must be used to ensure that the house envelope is not damaged by excessive depressurization.

The air leakage associated with the component or modification can be calculated from the difference in the pre/post sealing test results.

Several areas of each building component should be tested to examine the spatial variations.

EQUIPMENT

In the prototype system, Sierra Top-Trak Model 821S mass flow meters with direct reading digital outputs were selected for measurement of the air flow rates. Unlike orifice plates or rotameters, the calibrations of mass flow meters are not affected by air density changes due to moderate temperature and pressure variations. The measurement range is 0-100 standard litres per minute (SLM) with an accuracy of 2% full scale.

Modus Model T10 differential pressure (0 - 250 Pa) transducers with ±2% full scale accuracy were used to measure the pressure difference between the boxes and the pressure taps. A common power supply was used for all transducers to minimize inter-instrument errors caused by supply voltage variations. The transducer ranges were selected to bracket the measurement ranges.

Soil pressure probes were constructed with 38 mm diameter galvanized steel pipe driven down pre-augered holes. For the initial testing, multiple probe locations were used. Tests may be done with one probe if a suitable, representative location can be identified. The criterion for locating the probe is that it will represent the pressure at the soil/foundation interface so the true pressure drop across the building envelope can be determined. Experience with applying the technique will assist in determining when this criteria is met.

ANALYSIS

A least squares regression can be used to fit the fan depressurization data from the airtight boxes (air flow and corresponding pressure difference) to an equation of the form:

$$Q = C\,\Delta P^{n} \qquad (1)$$

where:
Q = air flow rate (m^3/s)
C = constant ($m^3/s\cdot Pa^n$)
ΔP = pressure difference (Pa)
n = exponent (0.5 to 1.0)

The pressure difference used in equation 1 should be the pressure difference between the box and the soil probe that most closely represents the exterior surface pressure of the component.

Equation 1 can be used to describe pressure driven flow through a variety of openings. If the airflow is laminar, the flow exponent will be 1; if the airflow is turbulent, n=0.5. In most cases, the airflow will be a combination of the two and the exponent will be between 0.5 and 1.0.

All of the field data should be corrected for soil temperature and pressure using the method outlined in the CGSB standard for air leakage testing (6).

Subsequent tests on a building component following tightening modifications will yield a series of curves as illustrated in Figure 4 (assuming n=1). By subtraction, the relative effectiveness of the modifications can be determined.

The specification of air leakage for building components varies depending on the component and the testing protocol. Whole building air leakage is usually described in air changes per hour at a 50 Pa differential pressure (8) or as an equivalent leakage area (6). Window and door air leakage is usually reported per unit of crack length of opening perimeter (L/s·m), and wall section air leakage may be expressed per unit total surface area ($L/s \cdot m^2$), both at a reference pressure of 75 Pa (9). One method (10) defines the air flow resistance, r, (Pa·s/m) assuming the air flow is laminar. It is difficult to compare values calculated at different reference pressures when the flow exponent is not unity.

To avoid problems with interpretation of data and provide the most universal set of data, equation 1 should be used to calculate values for C and n for each of the air leakage tests. These values can be used with equation 1 to generate a complete data set. Subsequent calculations can be made to convert the data into other forms as required. The overall calculated values of C may then be normalized, C_n, for the most important parameter (length for cracks, surface area for plane surfaces). Telepost and floor drain tests will not be normalized.

RESULTS

Although the purpose of this paper is to describe the method, sample results are shown in Figure 5 to illustrate the application. The difference between the data obtained in the unbalanced and balanced tests highlights the need for interior pressure balancing. This data was taken at the floor/wall interface of a concrete block wall and cast-in-place floor slab. The lightweight blocks with unfilled cores allow a large amount of room air to be drawn through the blocks in the unbalanced test. For other less porous materials, the effect of cross leakage may be much less pronounced. As expected for air flow through long, narrow cracks exhibiting laminar flow, the flow exponent is approximately one.

APPLICATIONS OF THE TECHNIQUE

This technique can be used by contractors to identify the major sources of air leakage prior to developing a soil gas control strategy for an existing building. As control measures are implemented, their effects can be evaluated. In this application, a single reference pressure (to outdoors) may be adequate to evaluate the before/after changes. If site conditions change between measurements, the real effect of the modification may be masked and incorrect conclusions derived.

For new house construction, the technique can be used as a quality assurance method. The actual effectiveness of the soil gas control "system" used in the building envelope can be evaluated. Summation of the air leakage from all of the individual components (Σ typical component air leakage value * amount of component) will allow estimates of the total foundation air leakage rate.

The construction industry is seeking information on methods and materials for building "tight" foundations. A large field study to examine the air leakage characteristics of some typical new foundations is being planned. This study will show what works and how well and will provide a benchmark of information for evaluating other foundation systems as they are developed. Ideally, the study will include laboratory testing of building envelope components in addition to "in situ" testing before and after the foundations are backfilled. The effect of the foundation/soil interface pressure measurements could then be investigated.

A computer model to predict the indoor concentration and distribution of radon and radon progeny is being developed (11). Critical inputs to the model are field data on the location and magnitude of radon entry sites. When coupled with information on ventilation rates and the internal pressure distribution, the model will be validated under field conditions and used in a parametric study to examine the effect of building parameters on indoor radon concentrations.

DISCUSSION

Use of this technique will provide a rational, quantifiable basis for comparison of air leakage through below grade building envelope components. The effectiveness of foundation sealing can be evaluated directly. Existing methods that rely on comparing the change in indoor pollutant concentrations to evaluate the effectiveness of sealing can include significant errors caused by changes in building parameters including the ventilation rate and strength of the pollutant source. Ongoing field studies will help to identify system parameters suitable for the wide range of site conditions that may be encountered and will assist in refining the test protocol.

Because of the small air flow rates involved, unintentional leakage through system components can introduce large errors in the estimated air leakage of the building components. A rigorous quality assurance test of the complete system will be required to ensure that all components are airtight. Methods that will be investigated include; sealing the boxes to an impermeable substrate, pressurizing and testing for no loss of pressure over time and the use of tracer gases as an independent measure of air flow rate.

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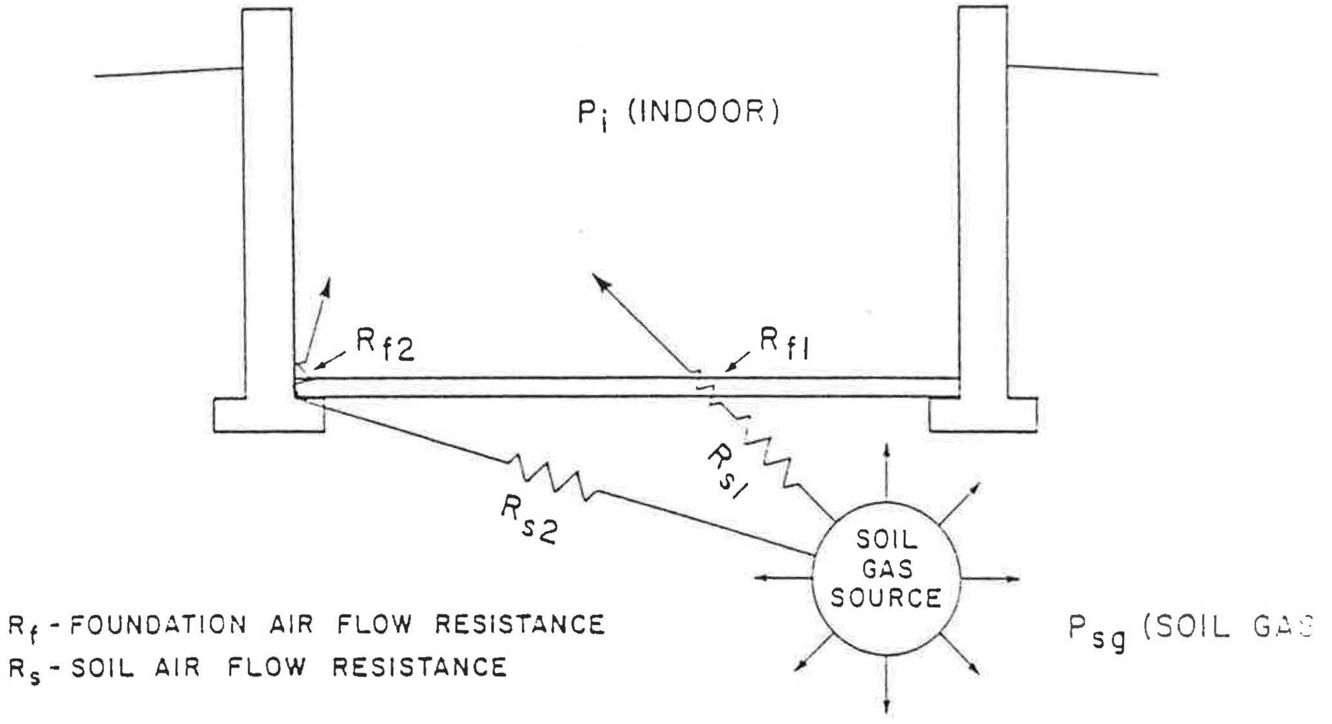
P$_i$ (INDOOR)
R$_{f2}$
R$_{f1}$
R$_{s1}$
R$_{s2}$
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P$_{sg}$ (SOIL GA
R$_f$ - FOUNDATION AIR FLOW RESISTANCE
R$_s$ - SOIL AIR FLOW RESISTANCE

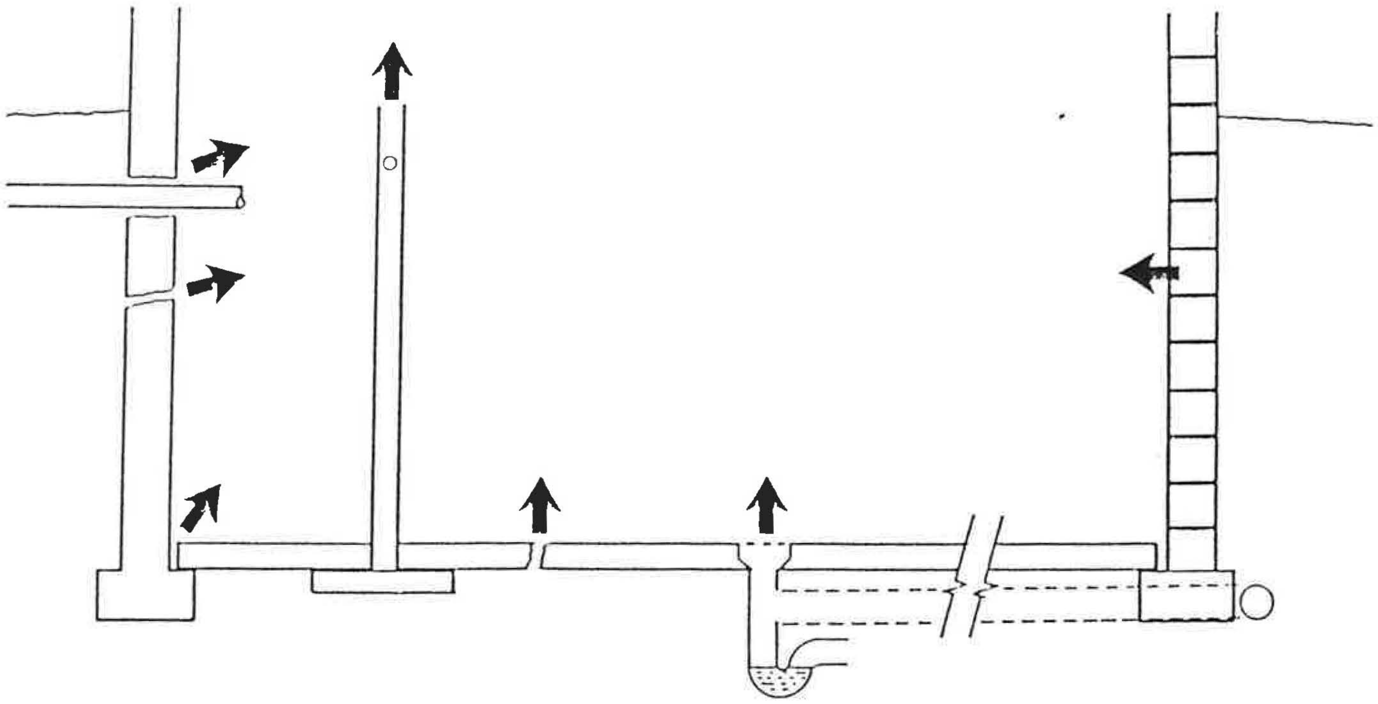

Figure 2. Potential Soil Gas Entry Sites

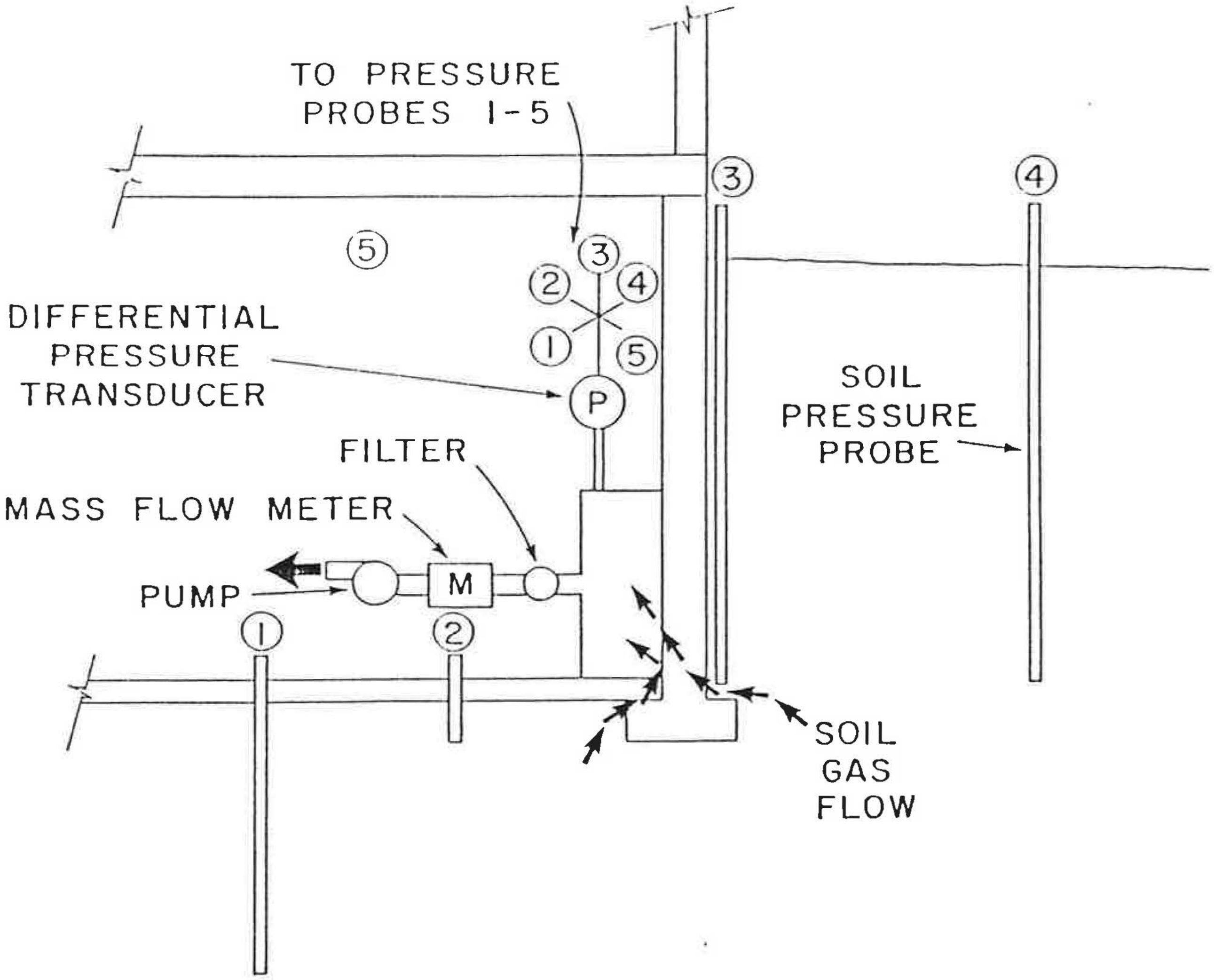

Figure 3. Air Leakage Measurement System Schematic

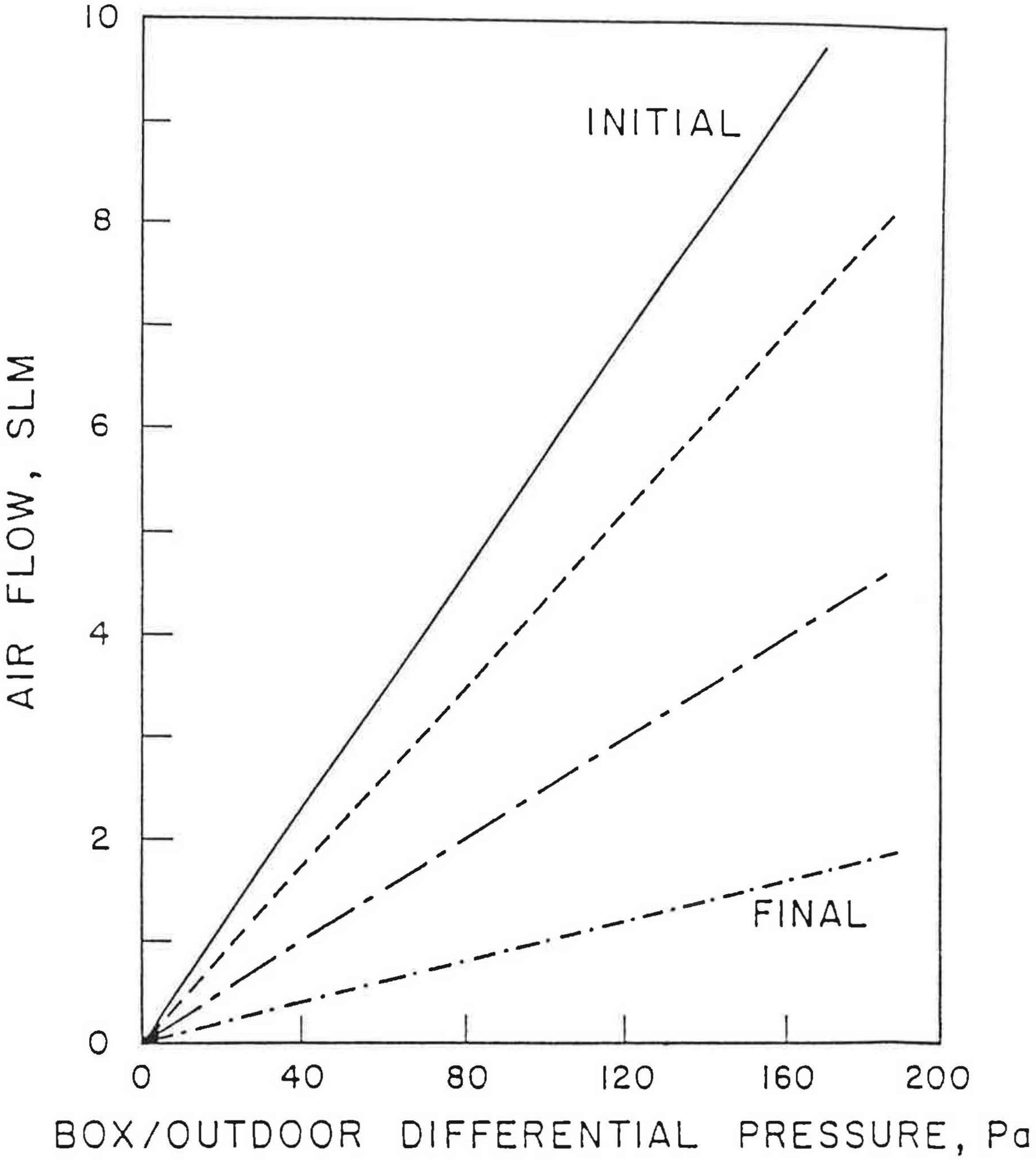

Figure 4. Air Leakage Characteristics for Typical Component with Sequential Tightening Techniques

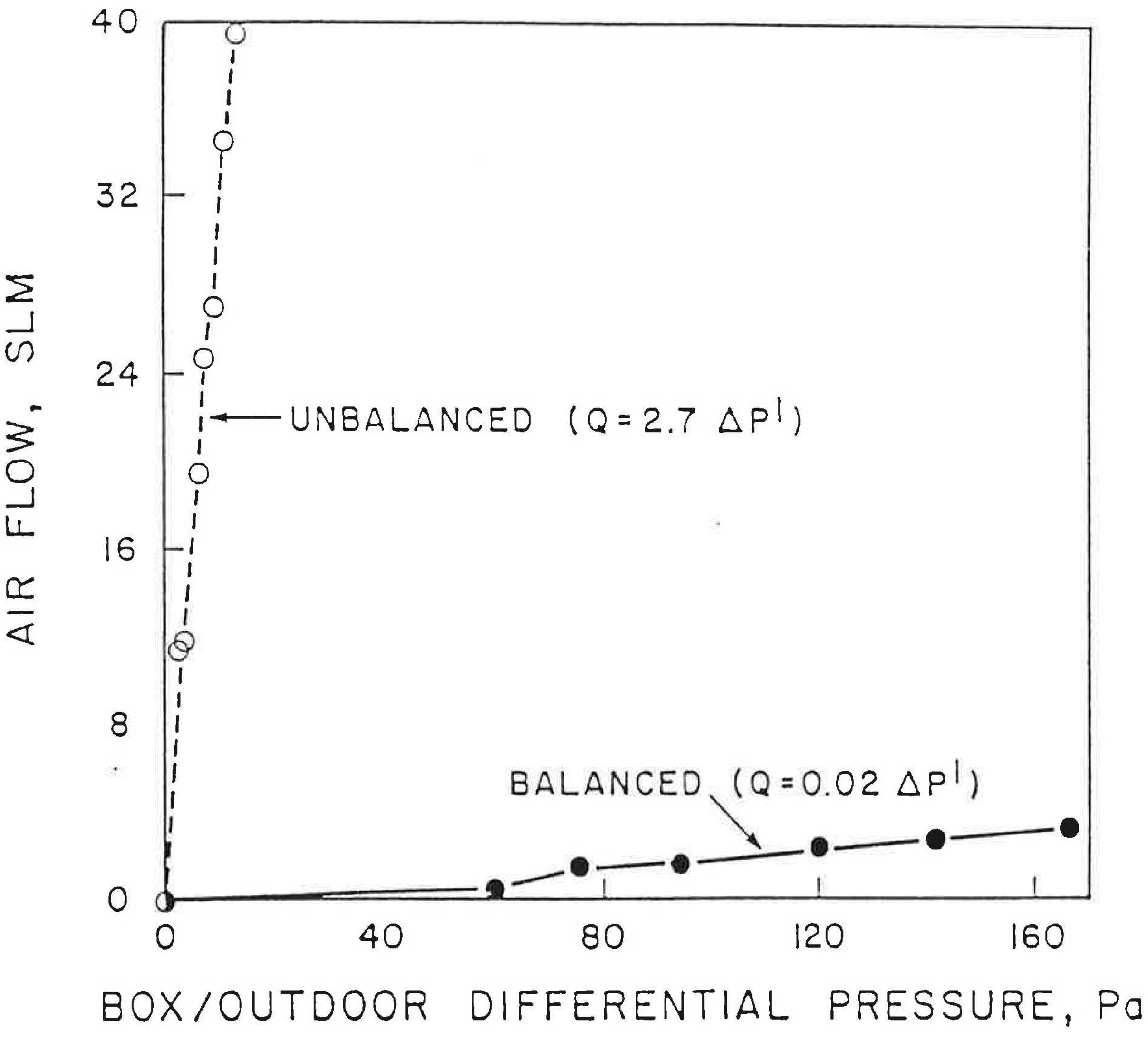

Figure 5. Measured Air Leakage Characteristics of Concrete Block Wall/Poured Floor Slab Component With and Without Indoor Pressure Balancing