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INSTALLATION AND EVALUATION TECHNIQUES USED TO MEASURE PRESSURE FIELD EXTENSION FROM SUB-SLAB DEPRESSURIZATION SYSTEMS INSTALLED IN NEW FLORIDA HOMES

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ABSTRACT

The Florida Solar Energy Center (FSEC) has installed a number of sub-slab depressurization systems in new Florida homes in the past year, and in the interest of testing these systems after construction has used a novel approach designed to lessen damage to the slab and simplify testing procedures.

A series of small diameter plastic tubing is laid down in measured locations around the slab at the same time as the ventilation mat, and is ganged together at two or three locations on the exterior of the slab form after passing under the footer or through the stem wall. This allows for easy testing of the pressure field extension without disruption of the construction process. Pressure measurements are made at remote sub-slab locations from the end of each plastic tube by hand-held micromanometer.

The pressure field extension is then graphically produced by computer using a program developed at FSEC from measurements taken along the ventilation mat and those taken at the perimeter of the slab footprint. This method yields a good measurement of the pressure field extension without damaging the slab or taking an inordinate amount of time.

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INTRODUCTION

The Florida Solar Energy Center (FSEC) has been contracted by the Florida Department of Community Affairs (DCA) to demonstrate radon resistant construction techniques in new Florida homes as part of the Florida Radon Research Program (FRRP). The project is designed to collect data on radon resistant construction techniques to determine their effectiveness in preventing radon intrusion into the home. As part of this project, FSEC is installing and testing sub-slab depressurization systems.

Pressure differential measurements between the house interior and the sub-slab region have been made for other projects, but always entailed drilling into an existing slab at some remote location, and repairing the hole at the end of the test. This method naturally limits both the number and location of the measurements, and also affects the slab boundary by puncturing the vapor barrier.

As it was necessary for us to measure in many locations to determine the overall pressure field extension, and to keep the slab system as intact as possible, it was decided to use small diameter (3/16 inch) plastic tubing laid under the slab to take the measurements.

INSTALLATION PROCEDURES

PLASTIC TUBING

The tubing is run to each measurement spot, inserted into a small square of ventilation mat cut for the purpose, and anchored to the fill soil. This is done using an S hook from a garden supply store, commonly used to hang plants. These hooks are cut in half, leaving two strong pins with one end turned over, and are easily pushed through the backing of the ventilation mat. A good kick with the heel of the installer's shoe pins the end of the tubing and the square of ventilation matting in the desired location. This is done to insure the pressure reading is being taken where the investigator thinks it is, and to insure that high winds or careless workers do not alter the tube locations. The pins are also used to secure the ventilation mat in place. The installation procedure is illustrated in Figures 1 and 2 on the following page.

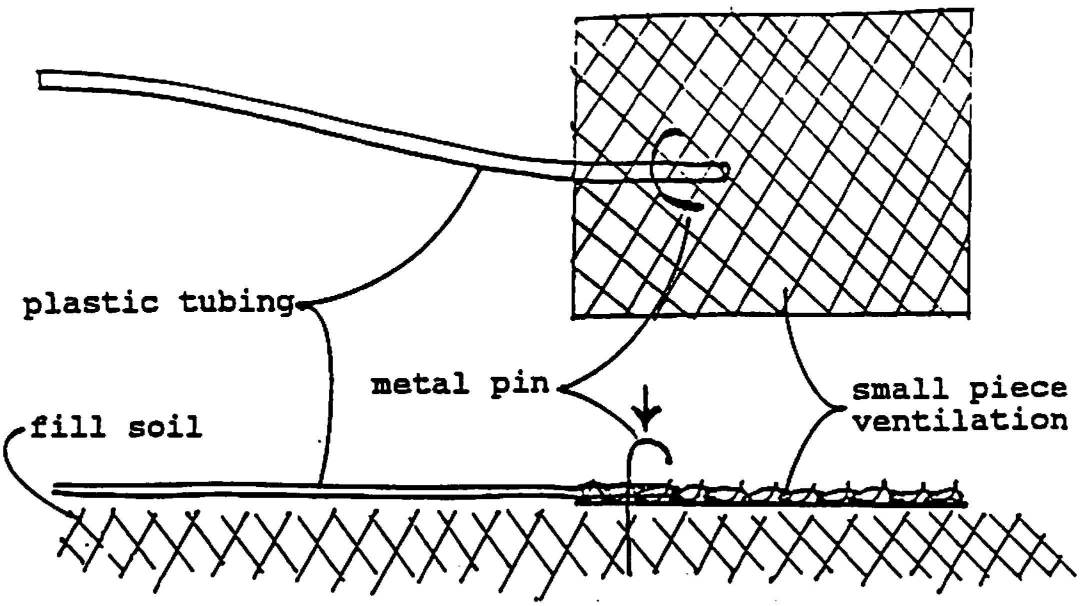

Figure 1. Top and side views of measurement point installation.

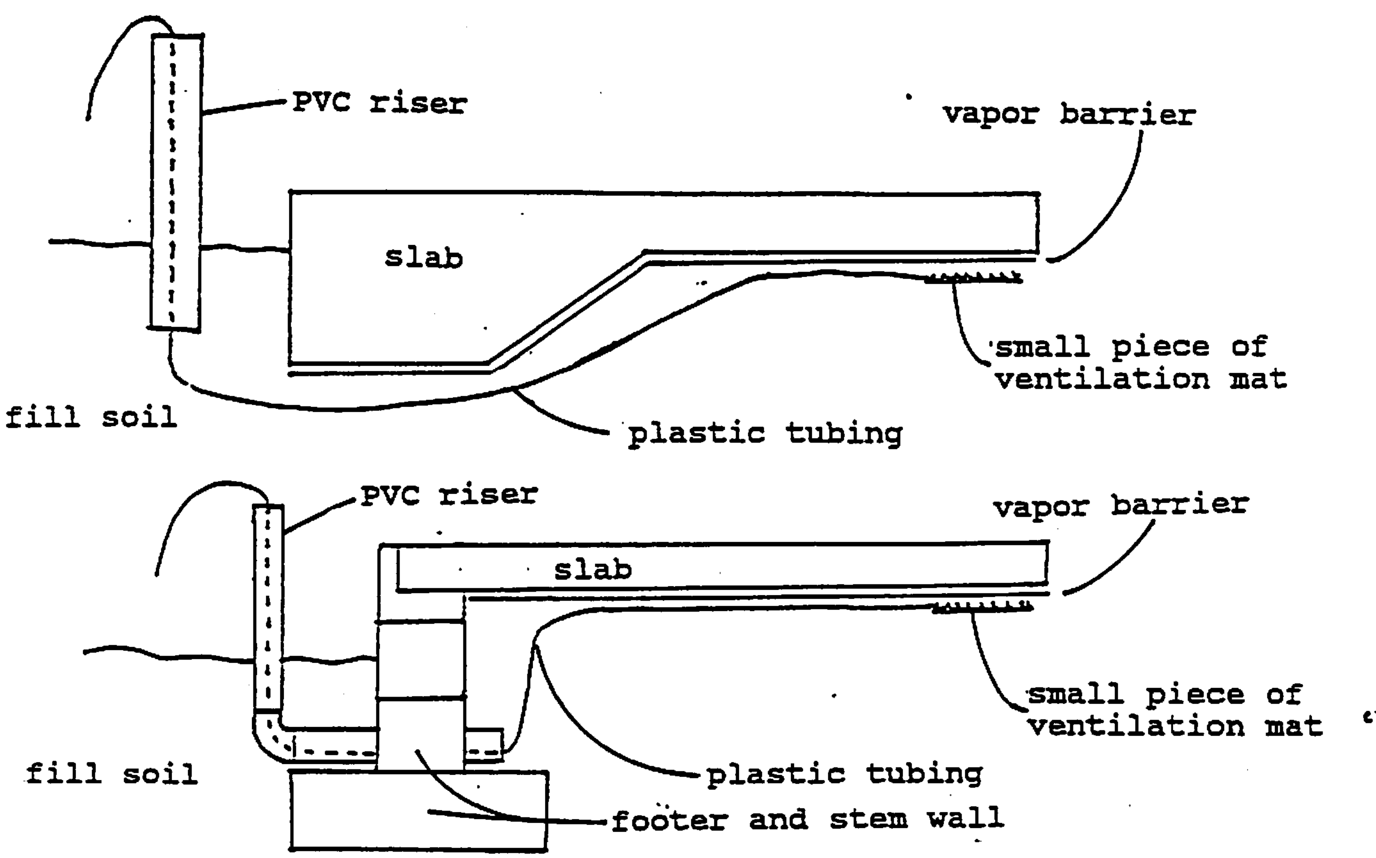

Figure 2. Variations of tube installation for monolithic and stem wall slabs.

The plastic tubes are brought together at two or three convenient locations at the slab perimeter, and either trenched under the footer or punched through the stem wall. A two to three foot section of PVC sewer pipe is used as an upright to keep the tubes off the ground and prevent damage from the construction process. The tubes are run up through the upright, with enough length to ensure easy measurement later. The upright is then capped off to prevent it from filling up with rainwater, and flagged to keep it from being run over by machinery. The ends of the tubes are filled with a bead of caulking to keep insects and rainwater out, and to ensure that no short-circuiting occurs through the tubing when the sub-slab depressurization fan is turned on. When measurements are taken, the end of each tube is snipped off for the measurement, and then recaulked immediately afterward. After the house is completed and all measurements are taken, the PVC uprights are simply lifted out of the ground, the tubes either bundled up or snipped off, buried and landscaped over.

The placement of the measurement tubes has changed over the course of the project. In the beginning, when we worried whether or not the pressure field was a straight-line gradient between the ventilation mat and the perimeter of the slab, we put several tubes in a straight line from the mat to the edge in several places. These measurements showed that there was a straight line gradient, so that subsequently we have limited the measurement locations to the mat and the perimeter of the slab. This pattern was only altered when there were unusual patterns or corners in the ventilation mat that needed investigating, or when interior footers in the slab called for measurements to be taken on both sides of the trench to quantify the amount of pressure extending under it.

VENTILATION MAT

The length of ventilation matting used on each house was kept under 100 feet to keep from having to install more than one suction point per house. As a general rule the matting was run down the center of the long axis of the house, and kept more than six feet from any edge to guard against short-circuiting to the outside. Priority was given to areas with multiple slab penetrations such as bathrooms and areas prone to negative indoor pressures as identified in studies by J. Cummings of FSEC, and J. Tooley and N. Moyer of Natural Florida Retrofit (Cummings et al 1990). These areas include the main body of the house (living, dining, family rooms), and utility rooms.

Special consideration was given to slabs with interior footers. Ventilation matting was run down into these trenches and up the other sides into areas that might not have felt the pressure field otherwise.

The suction point is created by taking a short piece of 3 inch schedule 40 PVC inserted into a toilet flange, and attaching it to the mat with wire at the desired location. This was usually a 6 inch wall or a cavity in the framing. The mat was secured with the pins mentioned earlier, and tubing was inserted at different points along its length to measure the pressure.

MEASUREMENT

Measurements can be made at any time after the slab has cured sufficiently for construction to continue. We use 4 or 6 inch in-line fans to depressurize the system attaching the fan to the rough stub of the suction riser or to the end of the stack on the roof if construction has progressed that far. Fans are only installed permanently on these systems if after final testing the indoor radon level is above 4 picoCuries per liter.

Measurements are taken with a hand-held electronic micromanometer at each tube end, first snipping off the caulked end, and then recaulking the end after the measurement is taken. There are typically 20 to 30 measurement tubes on a house, and this process can be completed in less than one hour. We then have a map of the house footprint with pressure measurements in the ventilation mat, at different points between the mat and the slab edge, and around the slab perimeter.

EVALUATION

The pressure contours are obtained using the program FSECPLT, written by Dr. Muthusamy Swami of FSEC. FSECPLT is an output processor for the program FSEC 2.1 (FSEC, 1989). FSEC 2.1 uses the principle of the Finite Element Method (FEM) to solve coupled partial differential equations. The basic idea of the finite element method is to divide the region of interest into a large number of finite elements. These elements contain nodes where the field variable is obtained after solution. In our case the elements are triangles and the nodes are the measurement points. The space and pressure distributions are defined through shape and parameter functions. In our case, the functions describing the geometry and distribution within an element are the same, known as isoparametric elements. In finite elements, nodes are placed at the corners of the element. The elements in FEM link the nodes it contains and this connectivity allows the specification of the influence of one node on the other. This is a distinct advantage of FEM that allows one to obtain contours using relatively fewer measurement points and also specify the influence of one measurement point on another.

Consider the triangular element shown in Figure 3. Continuity requires that the pressure be continuous between elements but not the pressure gradient. The point p is an arbitrary internal point not on a node. A normalized coordinate system in terms of areas may be defined as follows:

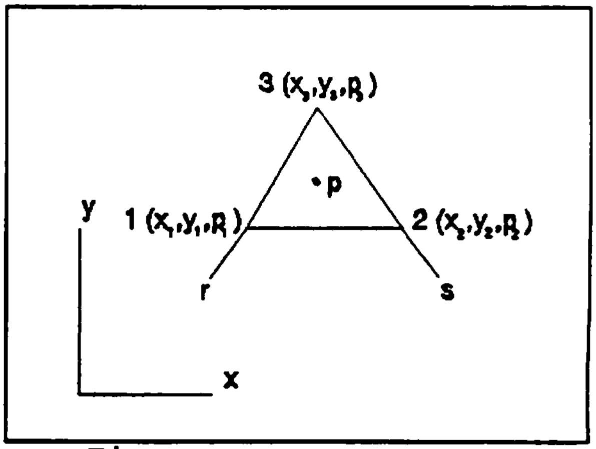

Figure 3. FEM Geometry

$$r = \frac{\text{area } p23}{\text{area } 123}$$
$$s = \frac{\text{area } p31}{\text{area } 123}$$
$$t = \frac{\text{area } p12}{\text{area } 123}$$
with the limits $0 \le (r,s,t) \le 1$ *and* $r+s+t = 1$

The shape functions may be thus defined as:

$$N_1 = r$$
$$N_2 = s$$
$$N_3 = t$$

It follows that for a given pressure p_c, the normalized coordinates can be determined knowing the nodal pressures by:

$$p_c = \sum_{i=1}^{3} N_i(r,s)\ p_i$$

Several pairs of (r,s) can be determined for a given pressure within the element. The global coordinate (x,y) for each normalized pair can then be determined by:

$$x = \sum_{i=1}^{3} N_i(r,s)\ x_i$$
$$y = \sum_{i=1}^{3} N_i(r,s) y_i$$

The global coordinate pairs of (x,y) for a given pressure, p_c, may then be connected to obtain a pressure contour.

These pressure contours are then handed to a computer graphics person for smoothing out of the field lines, as the program produces some sharp corners due to the relatively small number of data points. The result is placed on an outline of the house footprint, labels are attached, and a presentation-grade slide or publishable printout is obtained.

EXAMPLES

It is instructive to take this process from installation to evaluation to illustrate the steps along the way to a presentable result. Figure 4 shows house #4, with the ventilation mat and measurement points. The circle on the mat line is the suction point. The ventilation mat is placed to reach the main body of the house interior, and the majority of the slab penetrations. The measurement points are located on the ventilation mat, close to the corners of the slab, and along the long sides of the perimeter, and are given a grid location measured from the lower left hand corner of the footprint seen from the front of the house. This creates the X,Y coordinate system for the program to work with.

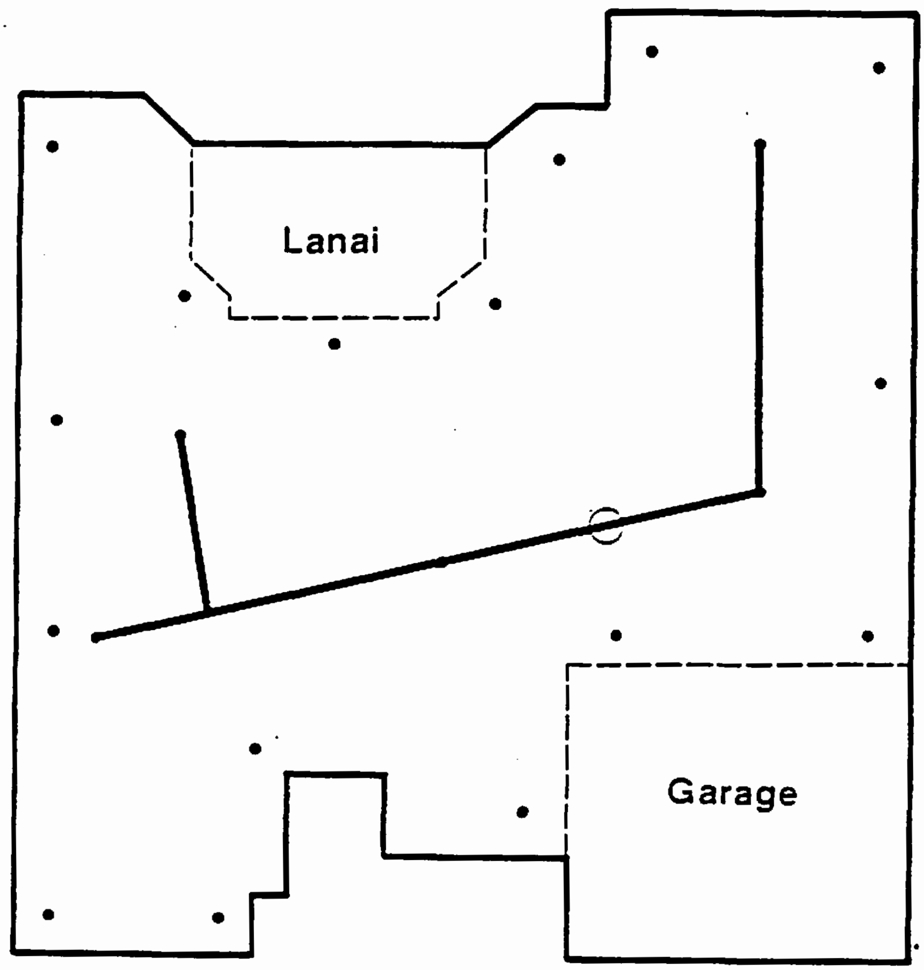

Figure 4 House #4 footprint, with mat layout and measurement point location.

The finite elements used by the program are obtained by connecting the measurement points together in threes, creating contiguous triangles covering the area of the house footprint inside the measurement points. Figure 5 shows the configuration of these triangles for house #4, called a "mesh" in the language of the program. This is a fairly simple mesh, with measurement points along the ventilation mat and the house perimeter only.

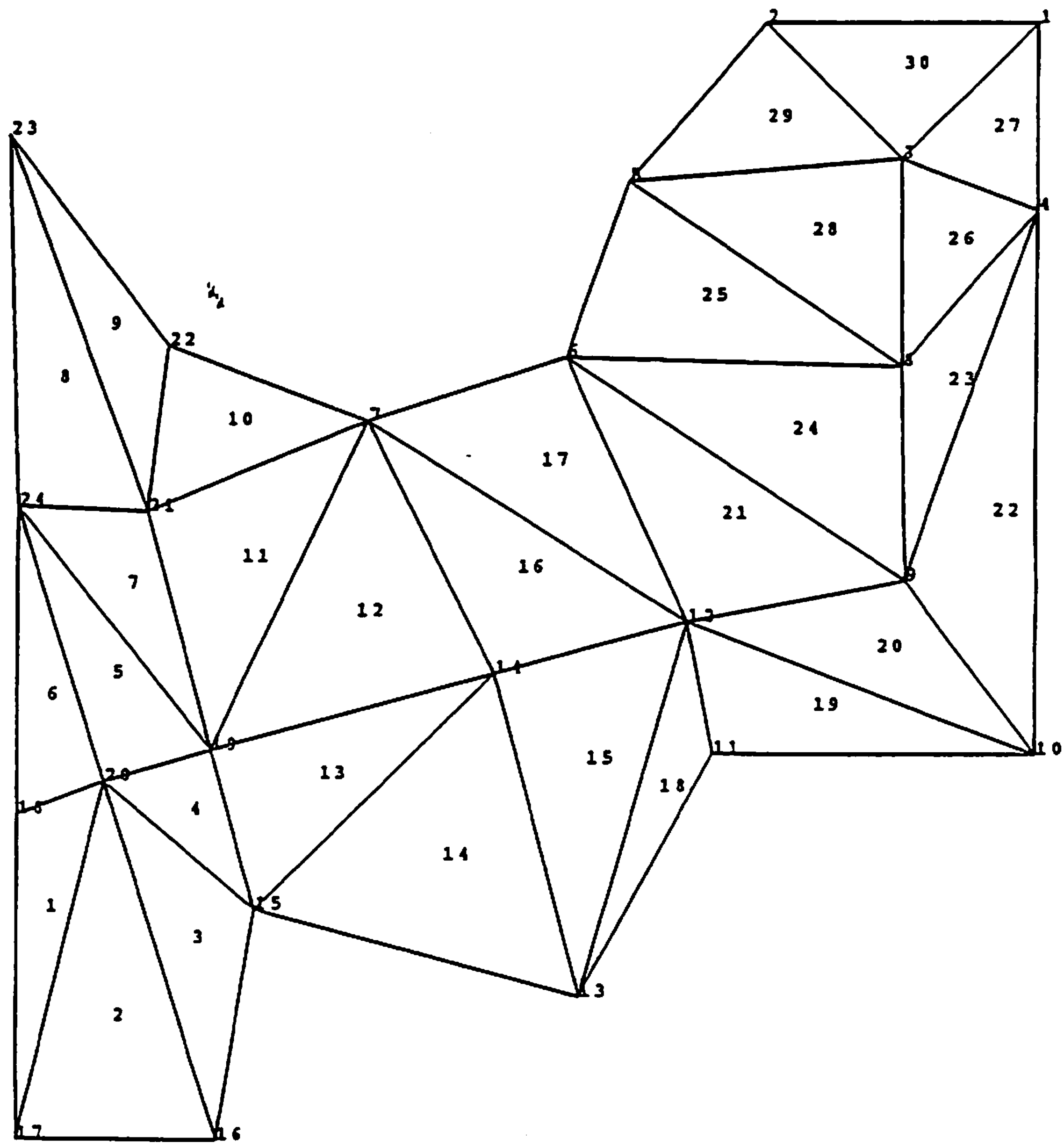

Figure 5 Mesh for house #4.

The numbers appearing in the center of the triangles are the element numbers. The measurement points make up the corners of each triangle, and are entered in the program as the element nodes. The outline of the mesh follows the lines drawn from the measurement points along the perimeter of the house, and so does not match the house footprint exactly. Lines are drawn radially outward from the measurement points on the ventilation mat, and along the mat, but do not cross the mat, as the program assumes a straight line gradient along the element lines from one node to another. Errors in grid locations of the measurement points, or in transcribing to the computer can be checked using the mesh. Comparison of the hand-drawn and computer versions will point out any discrepancies between the two. Figure 6 shows the mesh for house #4 with the grid location of points 12 and 14 reversed in the data base. It is readily seen that something is wrong with the data, and the error can be traced easily. This same process can be used to trace errors in pressure measurements using the pressure field contour map.

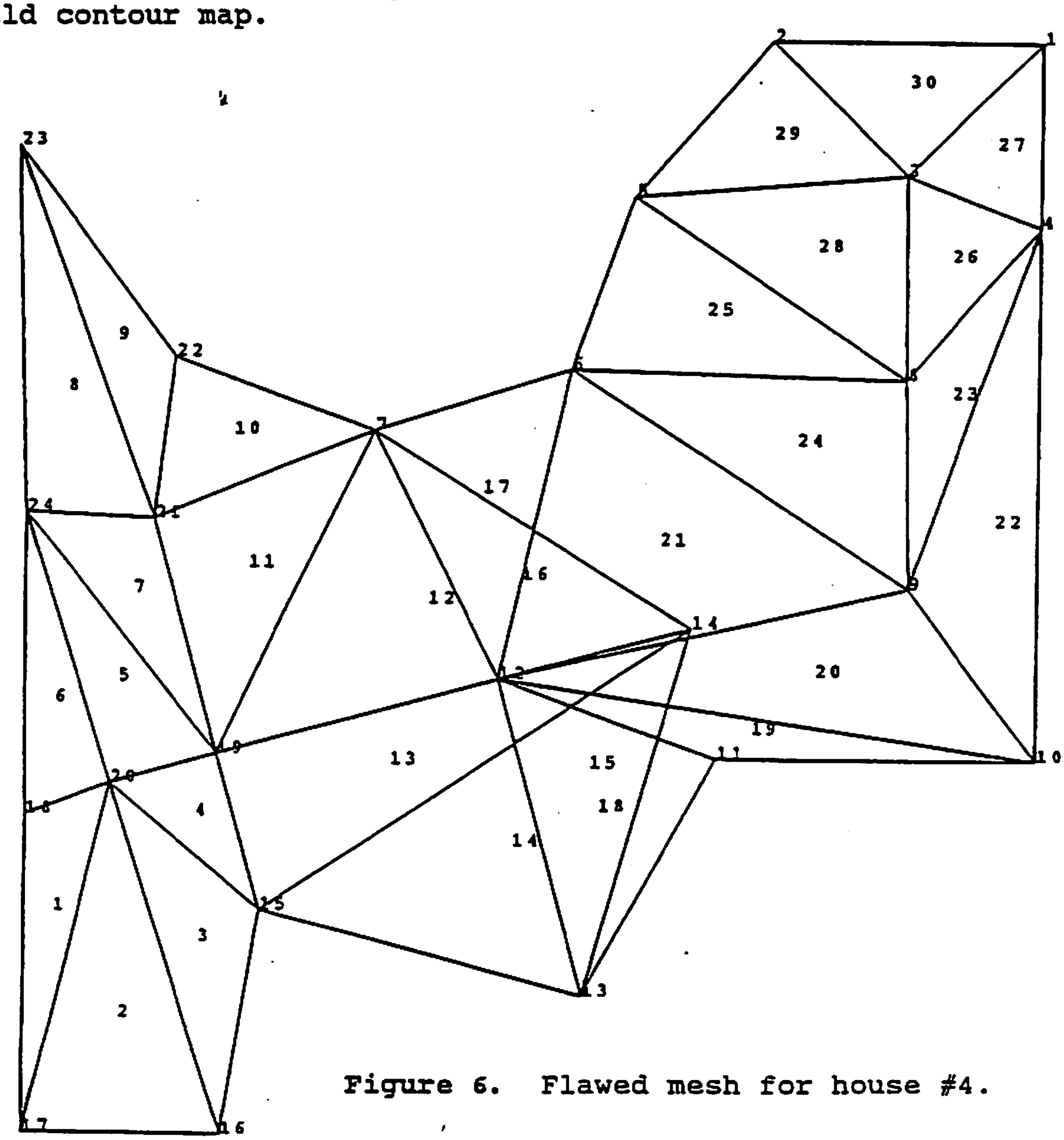

Figure 6. Flawed mesh for house #4.

Being satisfied with the mesh, we now can produce the pressure field contour map. Figure 7 shows the map for house #4, with the placement of the mat readily apparent.

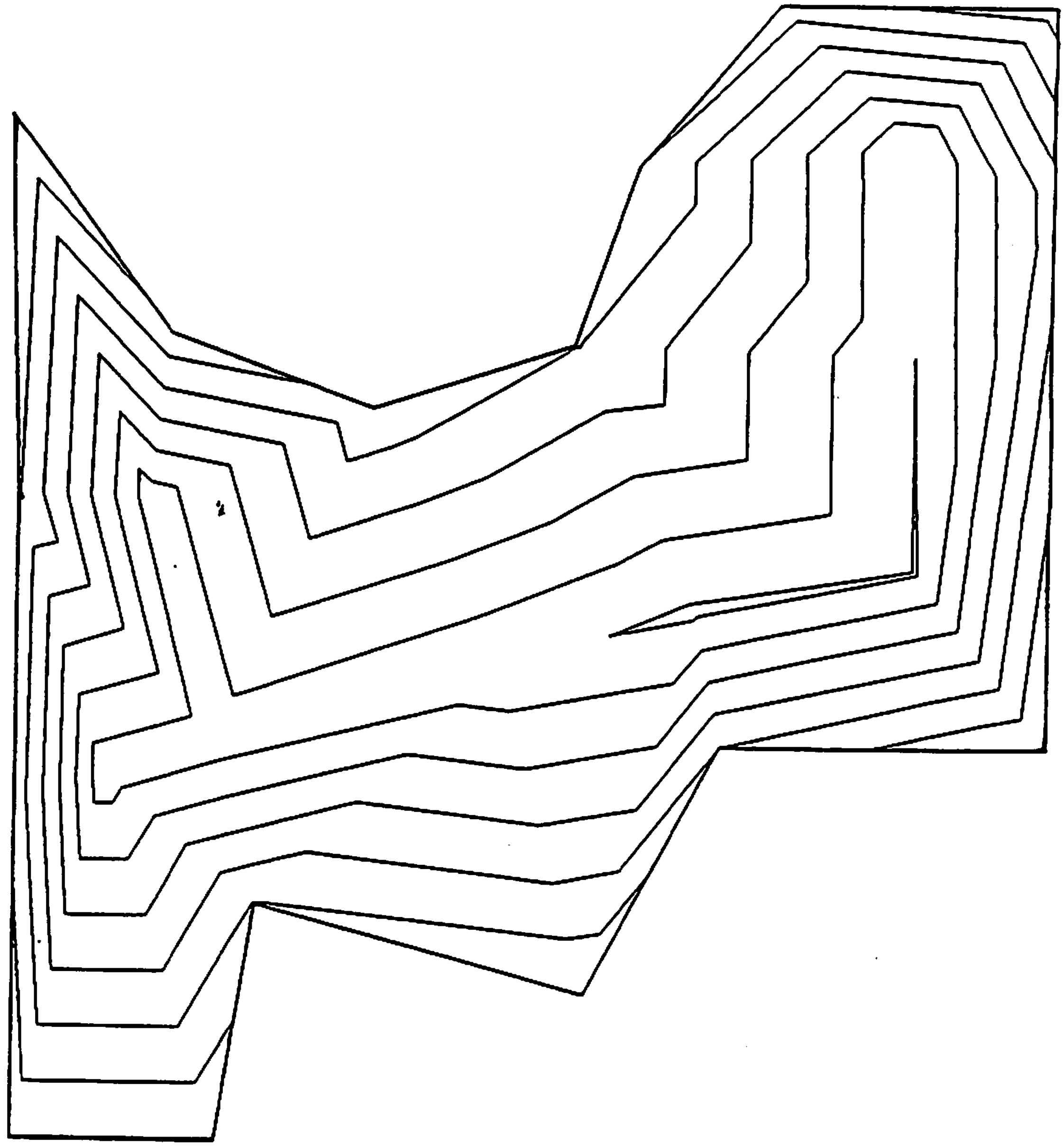

Figure 7. Pressure field for house #4.

Inputs for the field include the minimum and maximum pressures to be delineated, and the number of lines desired in between. In this instance, the minimum which is the last line toward the edge of the figure, is 10 Pascals, the maximum 230 Pascals, and the number of lines 6. These measurements were taken with a 4 inch in-line fan attached to the suction point, creating a pressure slightly higher than 230 Pascals at the suction point, and extending to the house perimeter in all directions.

Figure 8 shows the same pressure field calculation with just two of the pressure measurements transposed. In this case it is not readily apparent where the error lies, only that it exists. A careful check of the paperwork and data files is needed.

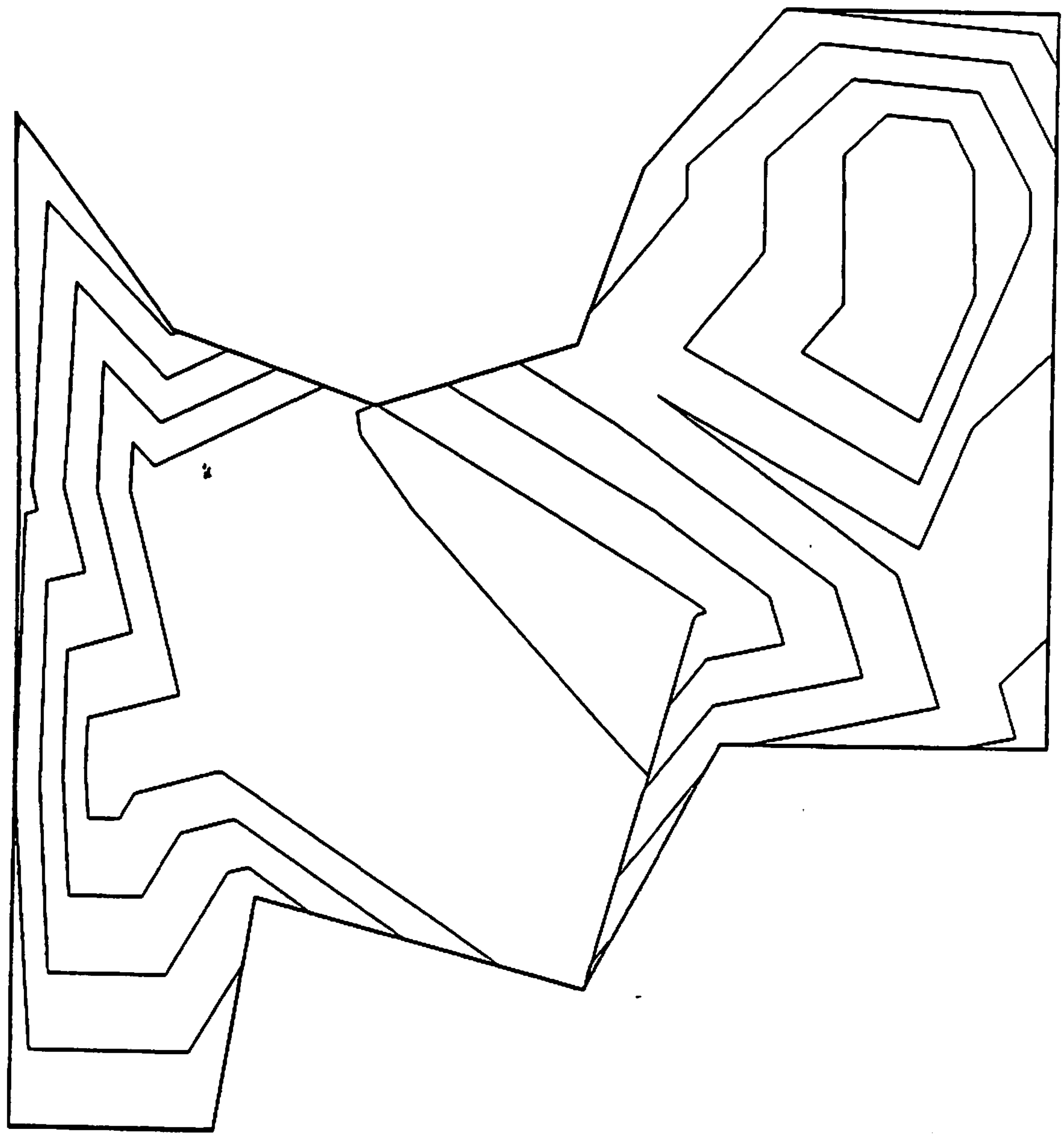

Figure 8. Flawed pressure field for house #4.

Having chased down all errors and satisfied oneself as to the correctness of the data, the raw pressure contours can be delivered to be massaged into the final state. Figure 9 is a paper printout of the slide developed from the pressure field contours of house #4.

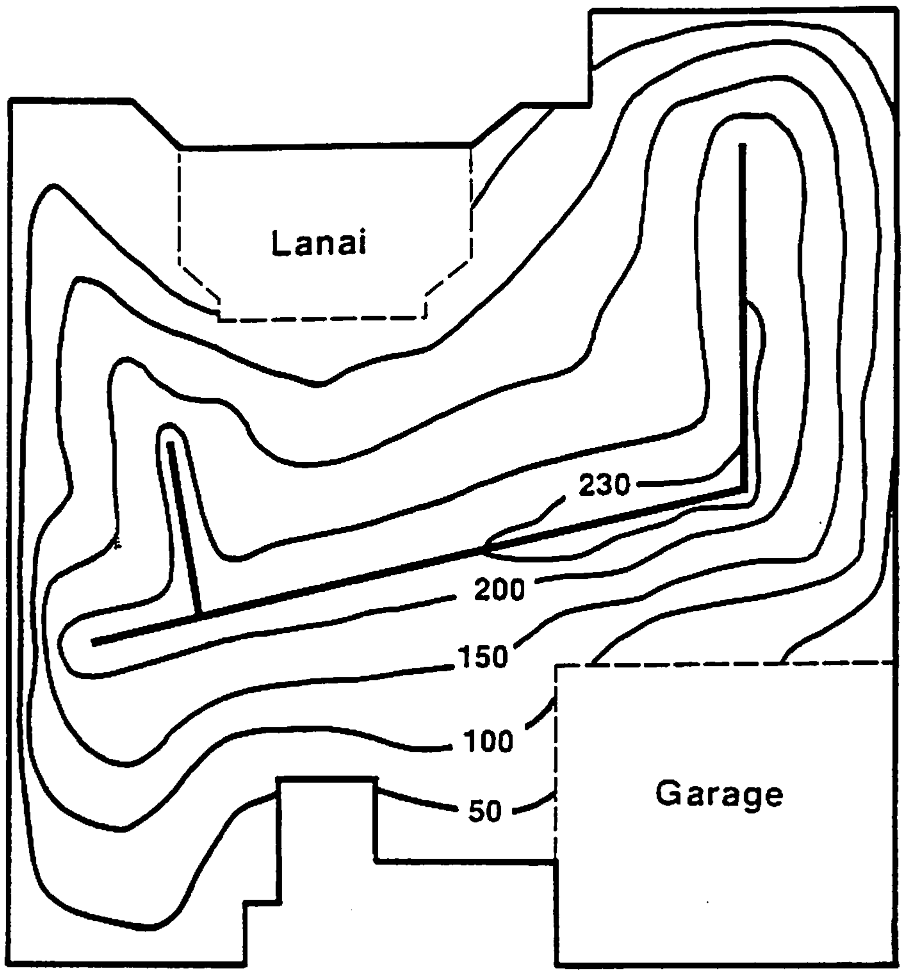

Figure 9. Presentation slide of house #4 pressure field extension.

Houses with interior footers or other obstructions to the pressure field extension present unique problems for measurement. More measurement points are needed to determine if the field has extended beyond the obstruction. Figure 10 shows the footprint for house #3, with the mat placement indicated in bold lines, and the interior footers in light lines. The ventilation mat was run down into the trenches and up the other side where it is shown the lines cross in the figure. The measurement points are situated to find out whether the field extends unimpeded beyond the obstructions.

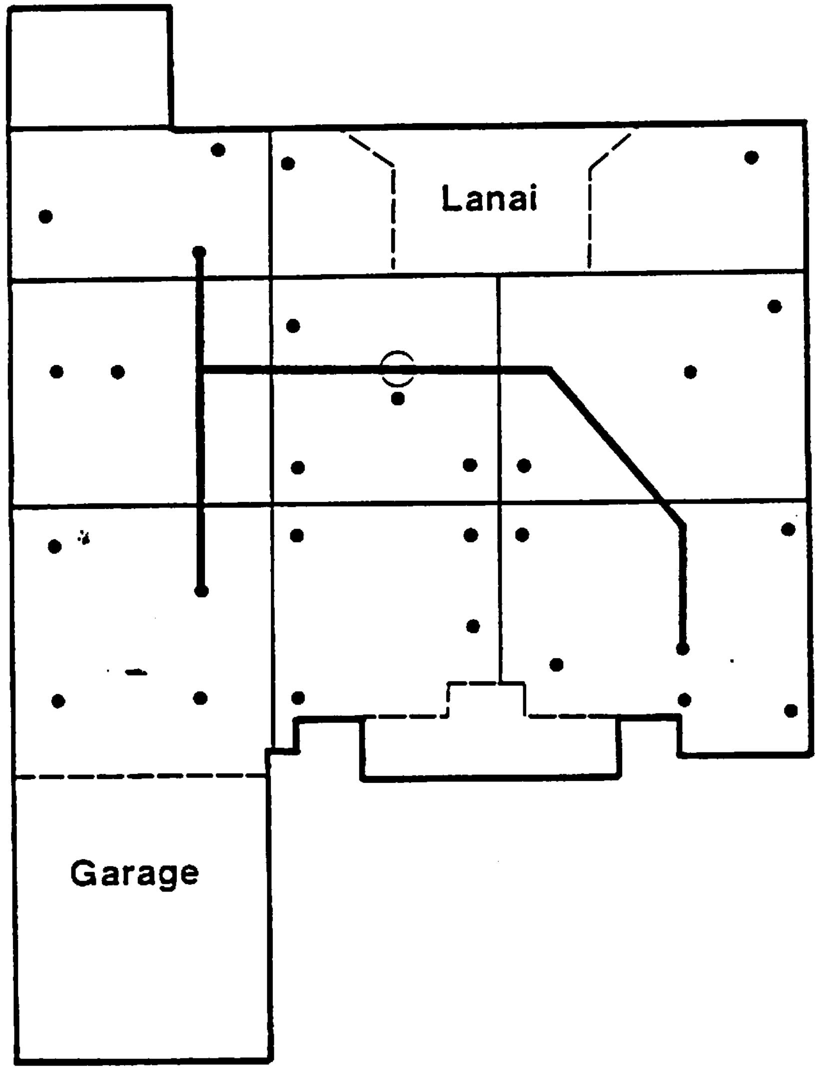

Figure 10. House #3 footprint, with mat layout, interior footer and measurement point location.

The mesh for house #3 will of course be more complicated, and is shown in Figure 11.

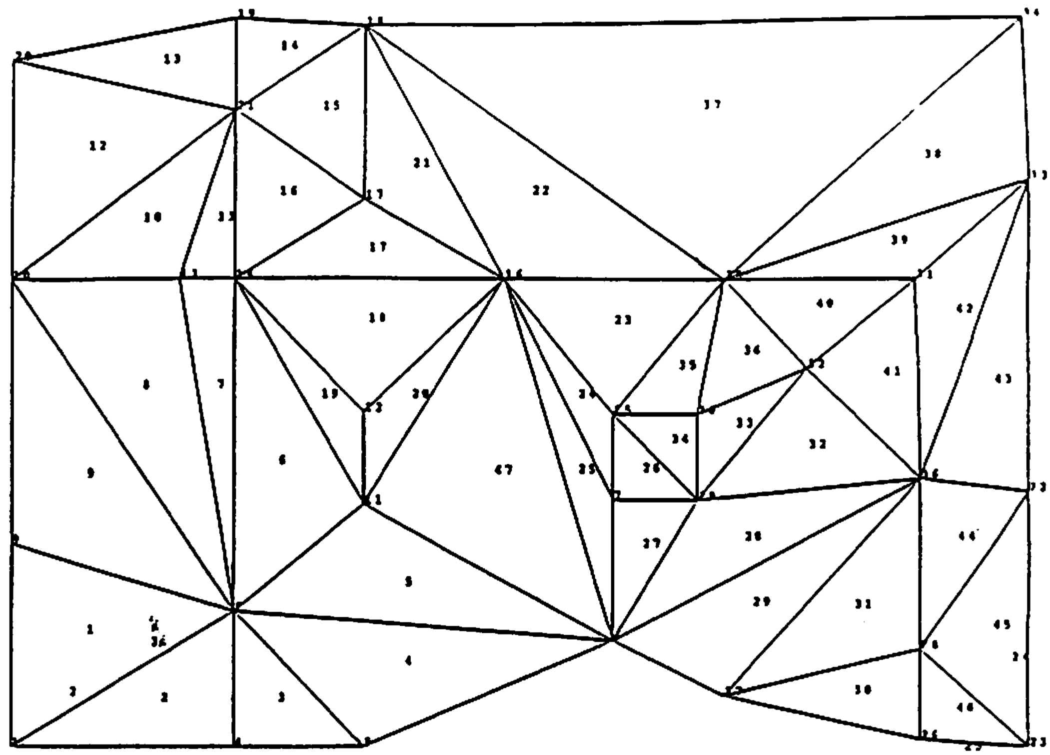

Figure 11. Mesh for house #3.

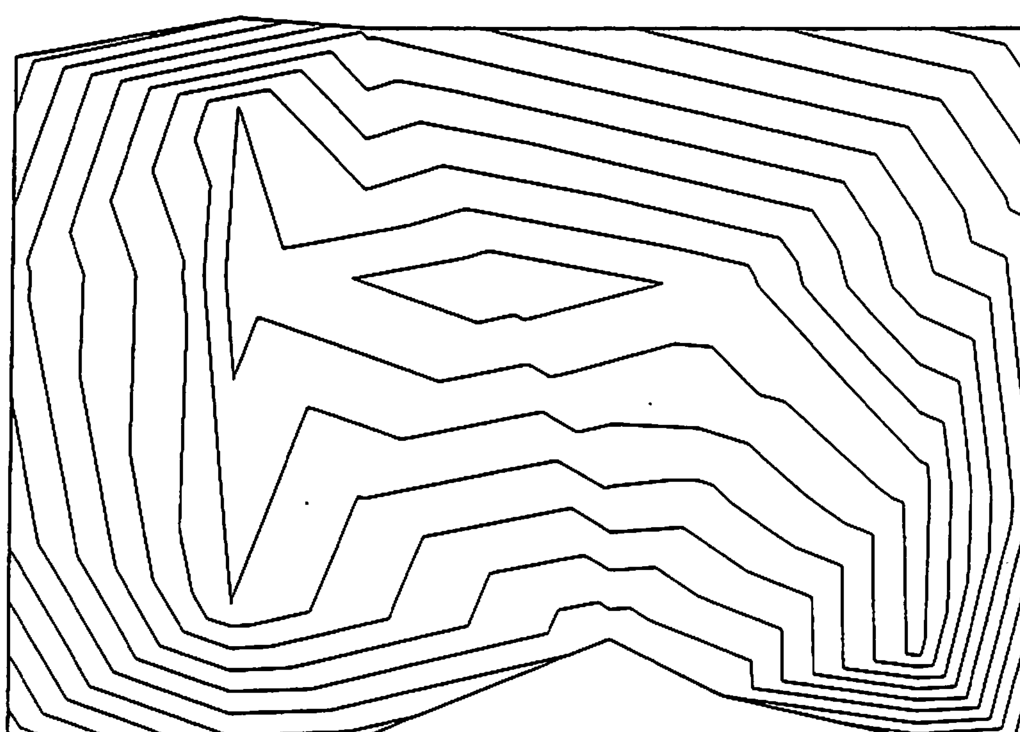

Figure 12. House #3 pressure field contours.

One might expect the interior footers to have a large effect on the pressure field extension, but as can be seen in Figure 12, this is not the case in house #3. The pressure field lines appear as one would expect for this ventilation mat layout, without a discernable effect from the interior footers. The final slide for house #3 is presented in Figure 13.

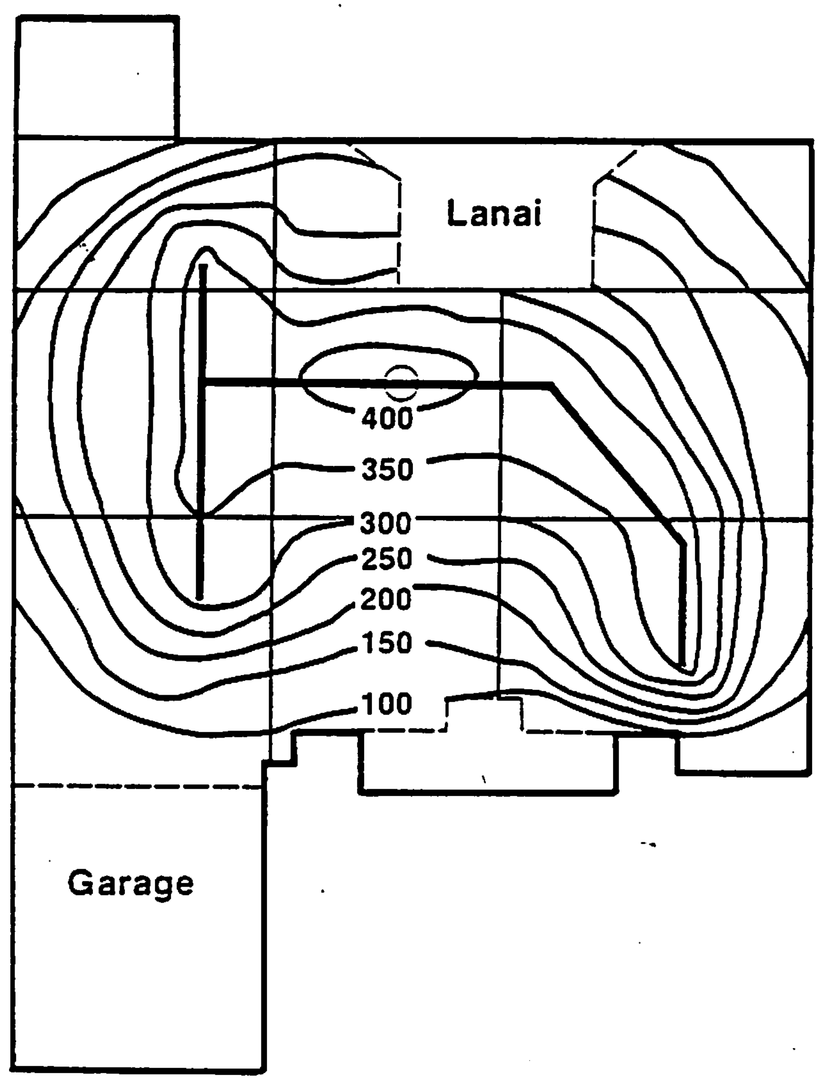

Figure 13. House #3 pressure field extension.

As an example of how the pressure field can be affected by interior footers, house #2 is presented. This footprint, as shown in Figure 14, shows some interior footers, represented by the lighter interior lines. The darker lines are the ventilation mat, which was placed to try and reach the sections cut off by the interior footers which were more prone to negative indoor pressures, hence the unusual shape for this layout.

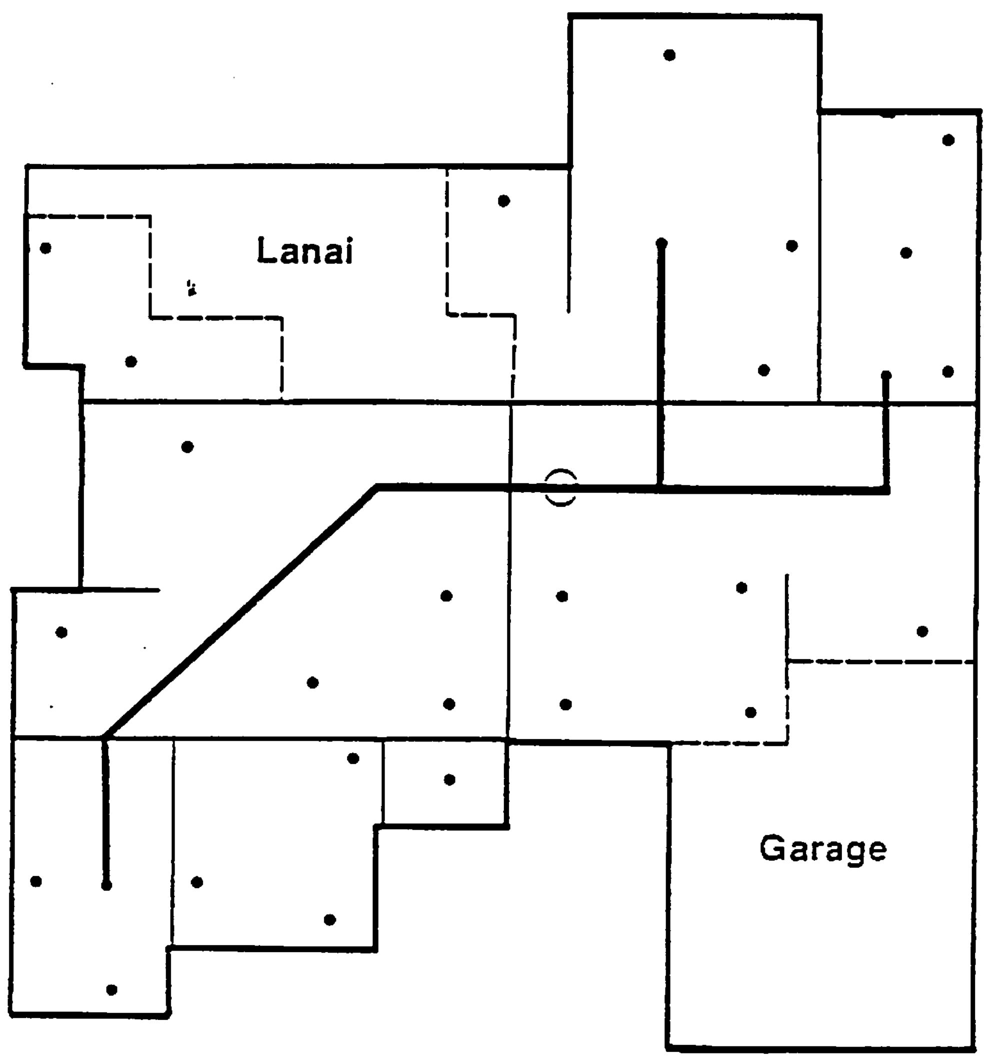

Figure 14. House #2 footprint, with mat layout, interior footer and measurement point location.

The mesh for house #2 underwent three different iterations, the changes designed to align the element boundaries with the interior footers, which were assumed to be causing the abrupt changes found in the pressure contours. Figures 15 and 16 represent the first and last of these mesh iterations, and illustrate the versatility of this evaluation method.

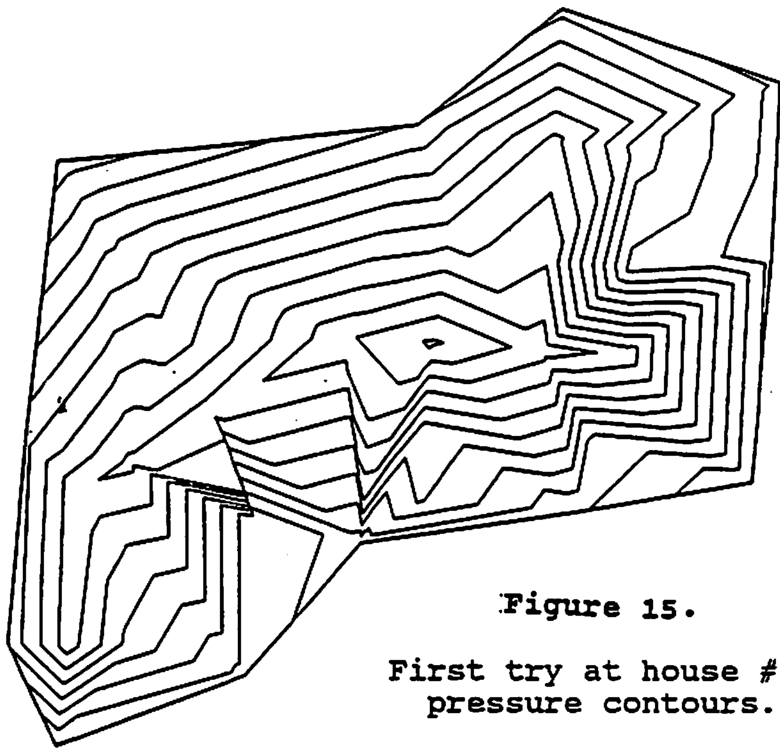

Figure 15.

First try at house #2 pressure contours.

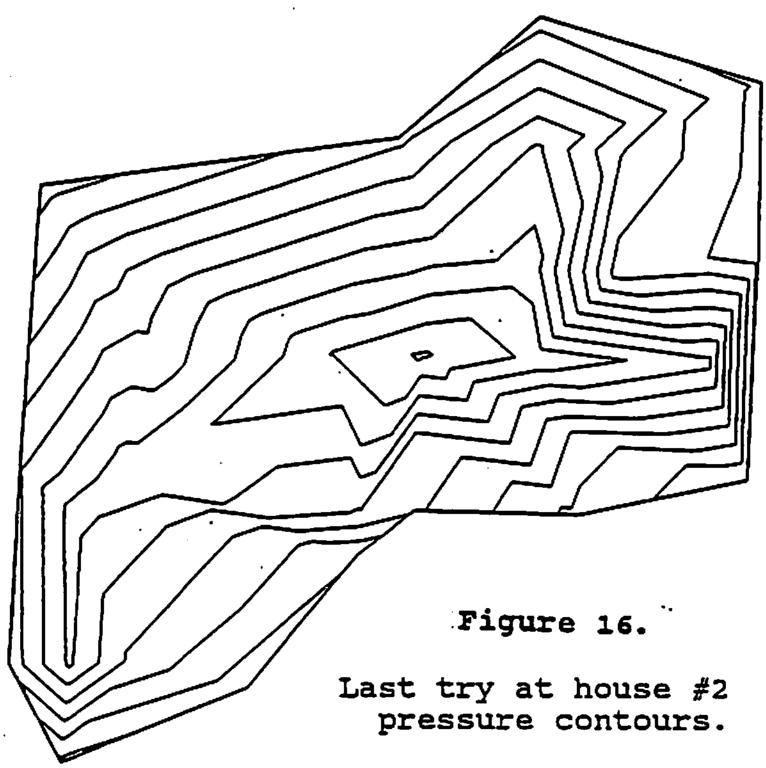

Figure 16.

Last try at house #2 pressure contours.

The pressure contours are finally presented in Figure 17, showing the effect the interior footers have had on the extension of the pressure field. The top right hand corner of the slab contains a short-circuit of the field along one footer, which happened to be one of the areas where our measurement tubes were put under the footer. The footer in the center of the slab extending to the front of the house seems to have extended the field along its length, but the footer perpendicular to it running along the front of the house has blocked the field extension somewhat along its path.

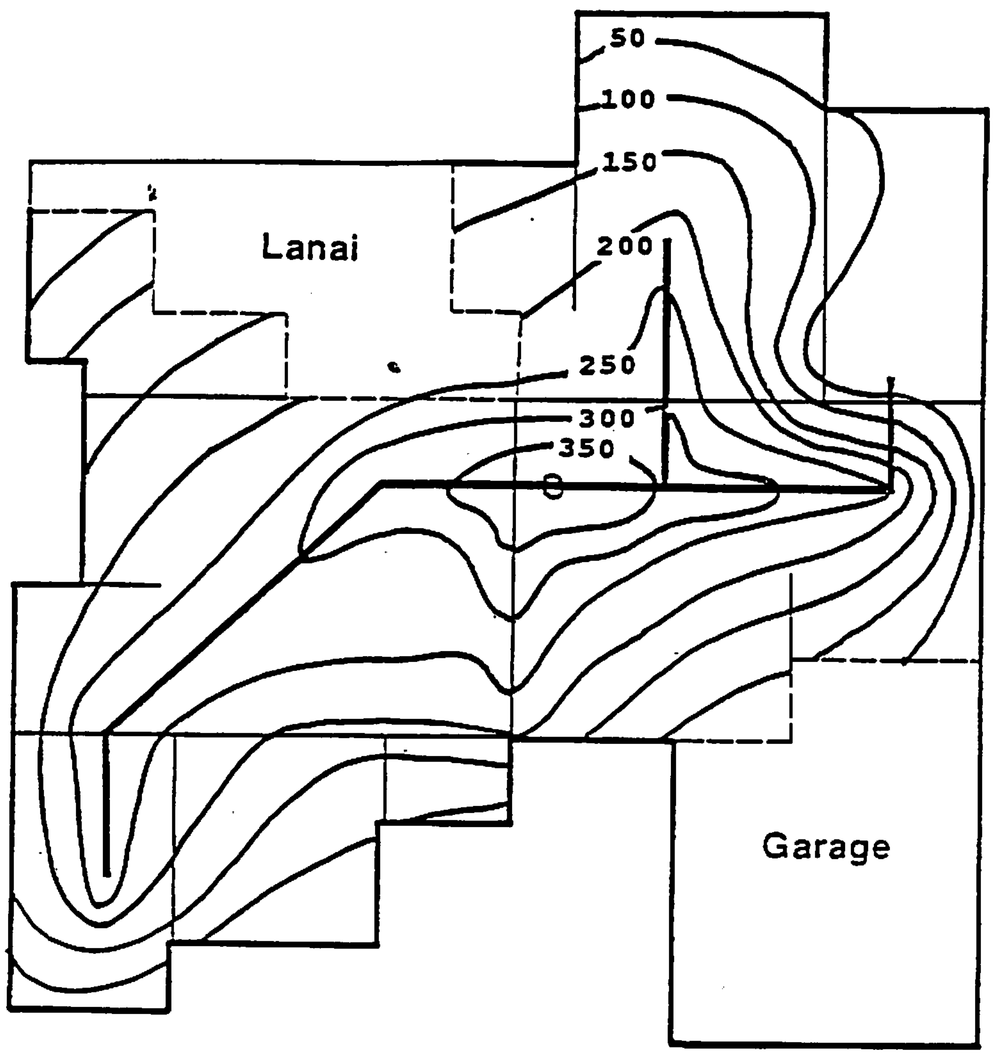

Figure 17. House #2 pressure field extension.

CONCLUSIONS

This method of installation and analysis has worked well on this project, due to the need for extensive knowledge on the pressure field extension. Of course, the more measurement points available, the more detailed the analysis can be, but it can also become too cumbersome to work with as the mesh becomes more complicated. A compromise between number of measurement points and analysis time should be struck on a house specific basis. This will depend on how large the slab is, and what obstructions to the field will exist under the slab.

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