# SUB-SLAB PRESSURE FIELD EXTENSION IN SCHOOLS AND OTHER LARGE BUILDINGS

by

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ABSTRACT The most direct method of projecting or measuring the performance of an active soil depressurization (ASD) system is to measure the strength and extent of the pressure field established under the slab. The pressure field extension (PFE) can be determined during diagnostics to help design an ASD system and following installation to ascertain system performance. In schools and other large buildings, these data are invaluable to provide a system which will mitigate the building without undue cost escalation. This paper presents EPA's experiences using PFE to design ASD systems for old and new schools, including instances where the data collected resulted in the installation of smaller systems than expected and selection of high vacuum fans instead of "normal" mitigation fans. A central collection system for use under very large slabs is presented, and PFE data for a hospital under construction are presented.

This paper has been reviewed in accordance withe the U. S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

## BACKGROUND

As the concern about radon contamination shifts from the house to school and the work place, the mitigation techniques used for radon control have moved with it. Active soil depressurization (ASD) has been applied to the great majority of houses mitigated across the United States. Extending ASD applications to these larger buildings means that more detailed information about the construction of the building is needed than for house mitigation. Techniques have been developed to gather such data for houses, but the data have not been routinely gathered as mitigation experience and cost competition have grown. These techniques have been transferred to large buildings as part of the research program conducted by EPA's Radon Mitigation Branch.

## APPLICATION TO EXISTING BUILDINGS

The first step during any diagnostic testing is to examine the blueprints of the building for sub-slab features. The aggregate or lack thereof plays a large part in determining how far the pressure field can be extended. The more uniform and narrowly sized crushed stone allows further reach than crusher run or ungraded river run gravels. Sometimes the existence of gravel can be indicated in section detail prints. Usually no indication or specification of stone size is given. Sub-slab barriers have the greatest effect on the performance of ASD systems and determine the approach that PFE diagnostic procedures must follow. If few or no barriers are present, a single test to determine the extent of the pressure field extension will establish the linear distance and circular area that a single suction point would mitigate. A number of these areas could be drawn to scale on a print to indicate the number of points needed for this building, subject to adjustment to ease installation or satisfy aesthetics. The presence of sub-slab barriers such as walls going to footings, grade beams, plumbing lines, electrical lines, or utility tunnels often limits the development of PFE. Tne limitation is usually from high flow resistance, but it can also be due to very low flow resistance which short circuits the flow and drops the fan suction, thereby reducing the PFE driving force. These short circuits are usually caused by roof drains or waste line vents. The information from the prints is only an indication of the potential performance of an ASD system; the only sure way to determine the data needed to design a system is to perform the PFE test.

Once the possible barriers have been located, the suction points for the PFE can be picked. Effort is made to position them in closets or room corners so that the ASD suction pipe can be located there if needed with minimum interference with room use. The data from the PFE test at this location give a good indication of the performance of a potential ASD system.

The PFE test was developed at Lawrence Berkeley Laboratory (1) and Oak Ridge National Laboratories, and modified by Princeton University and EPA's Radon Mitigation Branch (2). The PFE test uses a high vacuum shop vacuum cleaner to apply a suction through a 1-1/4 to 1-1/2 in.* hole at a point selected as a possible mitigation suction point. Several remote points at varying distances and directions from the suction hole are selected and 1/2 in. holes are drilled through the slab. One of these remote holes is drilled 12-18 in. from the center of the suction hole as a reference point. This point is used to estimate the performance of normally used ASD fans using a pit dug below the suction point 12-18 in. in diameter. Current practice by EPA uses this point to set the vacuum for each test. Before the PFE test is run, sub-slab radon levels are measured using a Pylon AB-5 continuous radon monitor. The suction induced at each point and the velocity of air moving into or out of the hole are measured for each level of suction applied at the reference hole. The magnitude and extent of suction induced through these remote holes indicate the potential success possible with an ASD installation (Figure 1).

The remote sensing holes are located to measure the impact on the PFE of the sub-slab barriers indicated on the prints or determine the extent of the pressure field developed. Typically, one hole is drilled in the center of each room and another near the edge of the unrestricted sub-slab area indicated on the prints. The center hole gives a point probably away from possible problems and a good radon source strength indicator. Across the barrier, it can provide a good indication of the ability of an ASD system to pull past that barrier. If the barrier is a block wall to a footing under each room wall, the ability of the ASD to pull a negative pressure in the middle of the adjacent room would mean only every other room at a minimum would need a suction point. If the barrier is a grade beam, it is possible that the suction could be measured several rooms away from the suction point which would indicate that the aggregate goes under the beam and provides a continuous medium for the pressure field. A pressure field extending to several rooms would indicate that one suction point could control a large area and a smaller system could be installed.

Craig et al. (3) and Leovic (4) reported the results of two schools in which PFE testing was applied to situations described above to assist in the design of radon mitigation systems. One was a large middle school with grade beams supporting the walls along the corridor and nothing under the cross walls separating the rooms. The suction points were selected assuming that two points would be needed in each classroom wing. The PFE data are shown on Figure 2. Measurable suction was seen in all rooms in the original

(*) Readers more familiar with the metric system may use the factors listed at the end of this paper to convert to that system.

section of each wing. The last four rooms in the north wing were an addition, but depressurization was found in the hall and one room. The reach into this area was probably due to removal of the old wall in the hall when the old outside door was removed and continuation of the gravel from the old section to the new. (Note: This test was run before the reference hole technique was in use. The above data are for pipe suctions of 6 in. W.C.) From these data, the surprising conclusion was that a single suction point could mitigate each wing. A temporary ASD system was installed to verify this large control area. The results of the PFE with this system operating were far better than the original test (Figure 3). It has been EPA's experience that the shop vacuum test is very conservative, but the use of the reference hole brings it closer to the installed ASD system performance.

The second school was an elementary school with all walls built on footings. Four suction points were used to generate the PFE data shown in Figure 4. The sub-slab aggregate was tight, as indicated by the relatively low communication measured at the hole in the suction room; yet, some measurable suction could be found in some adjacent rooms. An ASD system placing a suction point in every other room was installed and PFE measured as shown in Figure 5. Reasonable values were obtained for all but two rooms, and summer measurements showed all rooms below 4 pCi/L. Subsequent winter tests showed those rooms with marginal suction to be above this level. The system was modified to put a suction point in each room and two suction points in each of two rooms (Figure 6). This system has successfully lowered the radon levels.

A third school in another section of the country was tested as a result of high radon levels found during testing conducted by the EPA School Evaluation Program and the state health department. This school was known to be constructed on native sand without gravel aggregate. The use of the PFE testing is an example of another way to use the data to design an ASD system. The suction point adapter shown in Figure 1 has provisions for the measurement of the volume of air being pulled from the sub-slab. The flow volume can be plotted for each reference point differential pressure as a "system curve" as is done in heating and air conditioning design. Using these data and the fan curve supplied by manufacturers, the operating point of a fan can be estimated. Applying this approach to this school indicated that the normal low pressure ASD fans probably would not extend the pressure field enough to cover all rooms unless each room contained a suction point. As a research alternative and because of limited access to some rooms, a higher vacuum fan, recently available for ASD installations, was tried. As installed the fan developed 4.5 in. W.C. in the pits and was able to reduce all rooms except the library (which is essentially three rooms). The subsequent addition of a second suction point in the library has reduced it below 4 pCi/L. A continuous monitoring program is underway in this school and additional data will be presented in a future paper.

## APPLICATION TO NEW BUILDINGS

Many additional school tests have led EPA to devise an ideal sub-slab configuration for the application of ASD. Craig et al. (5) discuss these in detail. Essentially, the native soil should be compacted to provide a relatively impermeable base; a graded, crushed aggregate (ASTM 5 or equal) should be spread at least 4 in. deep over the entire building footprint; and a large suction pit should be built. The concrete slab laid upon this aggregate should be sealed as well as possible so few openings exist through which soil gas can move. What EPA needed was a building owner willing to follow these suggestions and allow the results to be tested.

Late last year an opportunity presented itself to demonstrate ASD in a large building under optimum conditions, a hospital under construction in Johnson City, TN. The hospital building is one story in height, with a floor area of about 60,000 sq ft, and slab-on-grade construction with no foundation walls penetrating the slab. Mechanical piping, electrical conduit, and structural columns penetrate the slab. The columns sit on footings below the slab, and support steel beams overhead which in turn carry the bar joists for the roof. This type of construction is referred to architecturally as post and beam construction. It is used in most commercial and industrial buildings currently being built in the U.S. All internal walls are gypsum board on metal studs, and the exterior walls are metal stud supporting gypsum board and composition board. The 4 in. slab was poured over a 6 mil vapor barrier underlain with a 4 in. layer of crushed aggregate which was continuous under the entire slab. The slab, exterior walls, and footings were poured monolithically. The slab was divided into about 15 ft squares by a combination of pour joints (1,000 lineal ft) and control saw joints (5,000 lineal ft). No expansion joints were used.

EPA was requested to review the plans and specifications and to recommend a radon mitigation system since the region was known to have high radon potential. After this review, the following recommendations were made to the architect designing the building:

1. Good compaction of the clay soil below the aggregate to decrease permeability of the material under the aggregate.

2. A minimum of 4 in. of crushed aggregate meeting the specifications for #5 stone as defined in ASTM-33-86 "Standard Specifications for Concrete Aggregate" carefully placed so as to not include any soil.

3. Sealing of all pour and control saw joints and any slab penetrations with a polyurethane caulking.

4. Installation of one subslab suction pit of the design shown in Figure 7 in the center of the slab with a 6 in. stack leading

to the roof capped with a Kanalflakt 3B turbo fan capable of moving 510 cfm at no head.

5. Operation of the heating, ventilation, and air-conditioning (HVAC) fans continuously in order to pressurize the building in all areas except those where negative pressure was necessary to control odors, noxious chemicals, or infectious diseases (toilets, kitchen, pharmacy, soiled linens area, isolation wards, etc.).

All of the recommendations were accepted and incorporated into the building design. Upon completion of the shell of the building and the sealing of the slab, diagnostic measurements were made to determine the potential of having a radon problem and the effectiveness of the ASD system in depressurizing the entire slab. Test holes were drilled through the slab at varying distances from the suction pit including a series around the entire perimeter about 6 ft from the slab edge (Figure 8). Radon levels below the slab were measured by "sniffing" using a Pylon AB-5 continuous monitor. Levels from 200 to 1800 pCi/L were found under the slab. This is a significant but moderate level of radon which could result in indoor measurements in the 4 to 20 pCi/L range under some conditions of building operation.

The depressurization fan was then turned on and sub-slab pressure was measured using a Neotronics micromanometer. The fan removed about 200 cfm of soil gas at a vacuum of about 1.5 in. W.C. Negative pressure was 0.45 in. W.C. in the suction pit, 0.22 in. W.C. 50 ft from the pit, and 0.18 in. W.C. at the farthest point on the perimeter (a distance of 185 ft). Complete PFE data are shown in Figure 9. This is considered extremely good PFE. The PFE data, plotted in Figure 10, give essentially a straight line on semi-log paper. Extrapolation of these data indicates that the system could mitigate a much larger slab.

Upon completion of the building, radon levels were measured in half of the building with the HVAC and the ASD systems off using open faced charcoal canisters. Average radon levels were 1.5 pCi/L ranging from less than 0.5 to 4.5 pCi/L. The entire building was then measured with the HVAC on and the ASD system off. Several bathrooms were above 4 pCi/L with the highest at 16.5 pCi/L. Turning the ASD system on lowered these to below 0.5 pCi/L. No measurable radon levels were found in any remaining part of the building. This is not surprising in view of the relatively large negative pressure under the slab with the installed ASD system in operation, even though the HVAC system was depressurizing the building as much as 0.015 in. W.C.

This experience would normally lead EPA to conclude that a prescriptive approach to radon control in large buildings could be applied for very little cost. (The above installation cost $0.096/sq ft as a change order.) Other experience has led EPA to doubt that the extraordinary quality control applied on this job could be expected everywhere. Consequently, relying only on building technique without post-construction testing could miss some buildings with elevated radon levels. Short-term PFE tests using a temporarily installed mitigation fan (as done in the middle school) or a permanent fan as done in the hospital would quickly establish the level of success of the ASD, and radon testing should confirm it.

## CONCLUSIONS

The PFE test can be a useful tool in diagnosing the sub-slab condition of an existing building before designing an ASD system and an evaluation tool for an installed ASD system. As more large buildings are found with elevated radon levels or as new ones are built in radon prone areas, the application of PFE testing or construction techniques to maximize PFE should become more widely used.

## REFERENCES


1. Turk, B. H., J. Harrison, R. J. Prill, and R. G. Sextro, *Preliminary Diagnostic Procedures For Radon Control*, EPA-600/8-88-084 (NTIS PB88-225115) (Research Triangle Park, NC: U.S. EPA).

2. Harris, D. B., "Mitigating Radon in Two Four-Story Dormitories," *Proceedings of 84th Annual Meeting of the Air and Waste Management Association, Vancouver, BC,* Paper No. 91-63.7 (Pittsburgh, PA: Air and Waste Management Association).

3. Craig, A. B., K. W. Leovic, D. B. Harris, and B. E. Pyle, "Radon Diagnostics and Mitigation in Two Public Schools in Nashville, Tennessee." In: Proceedings: The 1990 International Symposium on Radon and Radon Reduction Technology, Volume 2, EPA-600/9-91-026b, July 1991.

4. Leovic, K. W., *Summary of EPA's Radon Reduction Research in Schools During 1989-90*, EPA-600/8-90-072 (NTIS PB91-102038) (Research Triangle Park, NC: U.S. EPA).

5. Craig, A. B., K. W. Leovic, and D. B. Harris, "Design of Radon Resistant and Easy-to-Mitigate New School Buildings." Presented at The 1991 International Symposium on Radon and Radon Reduction Technology, Philadelphia, PA, April 2-5, 1991.

METRIC EQUIVALENTS

Readers more familiar with metric units may use the following to convert to that system:

| Non-metric | Times | Yields Metric |
|---|---|---|
| cfm | 0.028 | $m^3/s$ |
| in. | 0.025 | m |
| in. W.C. | 249 | Pa |
| ft | 0.3 | m |
| mil | 0.000025 | m |
| sq ft | 0.093 | $m^2$ |

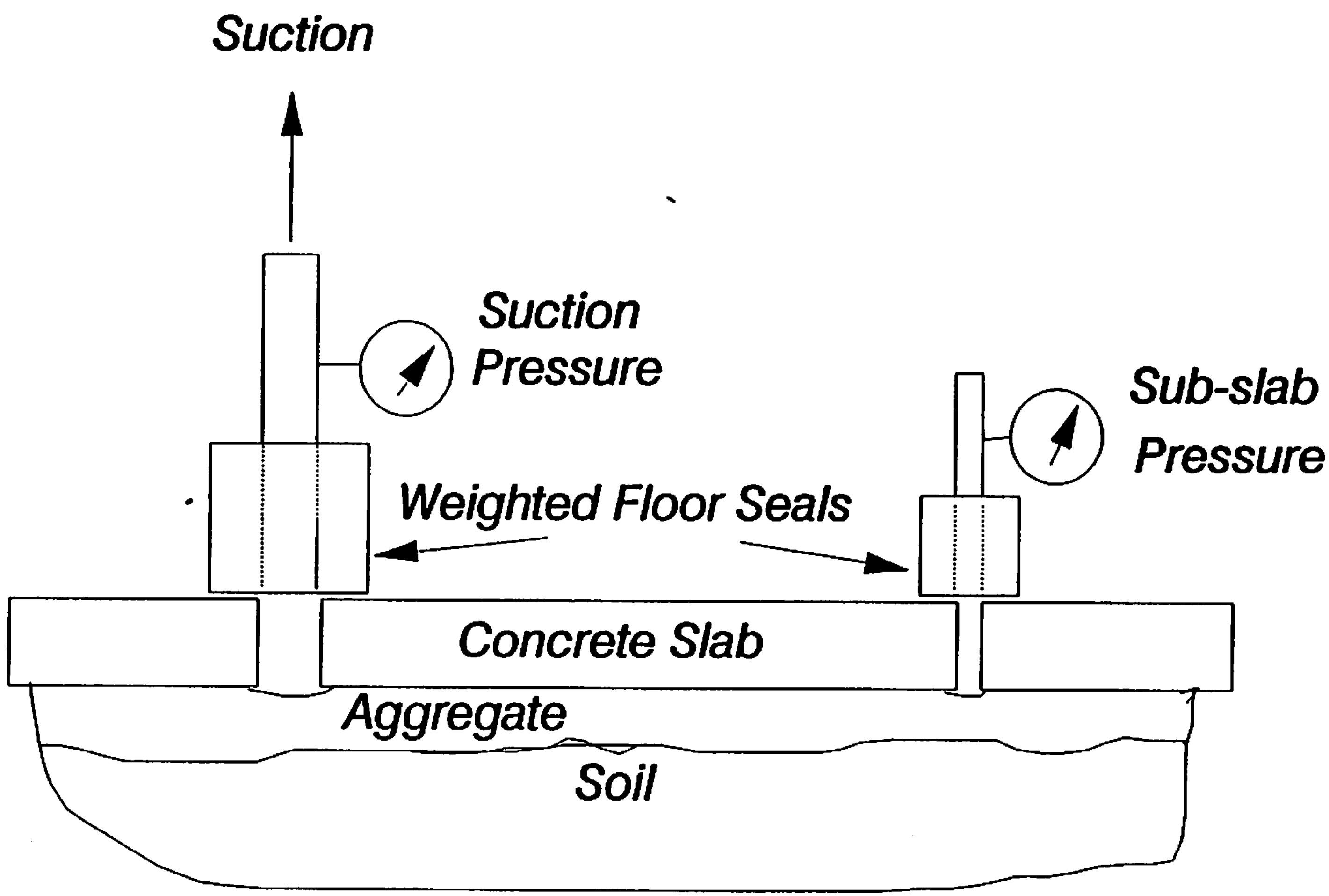



Figure 1. Pressure field extension measurement

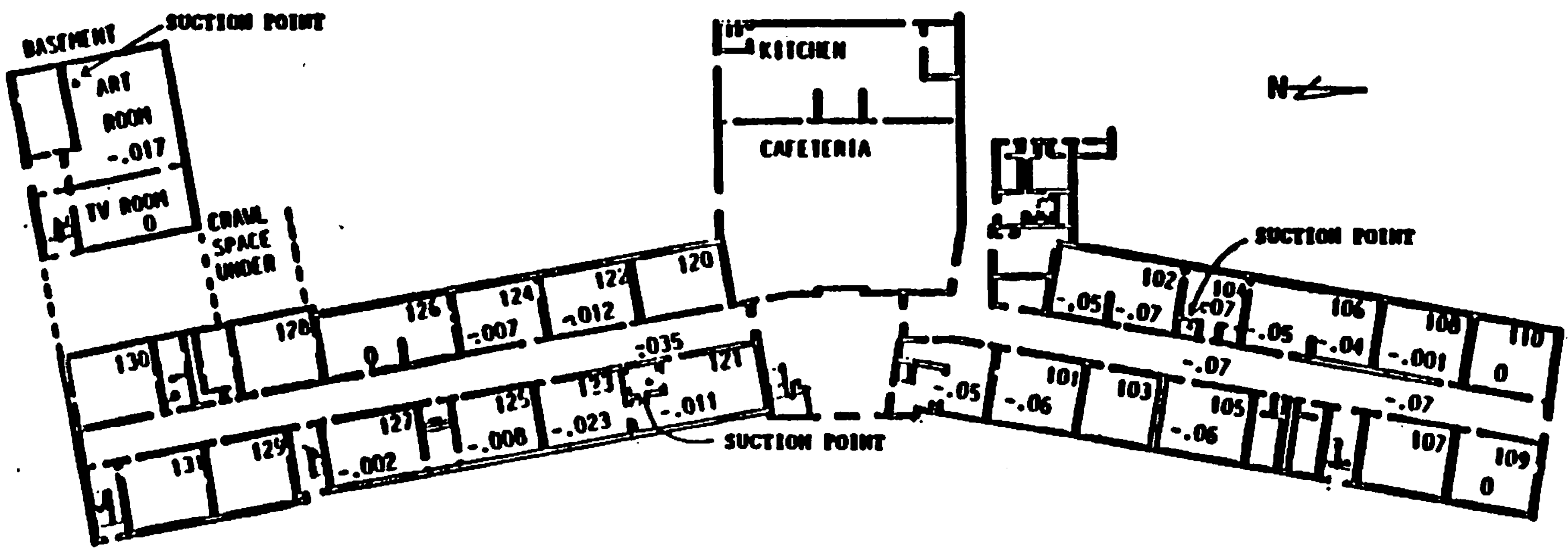



Figure 2. Pre-mitigation pressure field extension, in. W.C. (all readings taken in center of rooms)

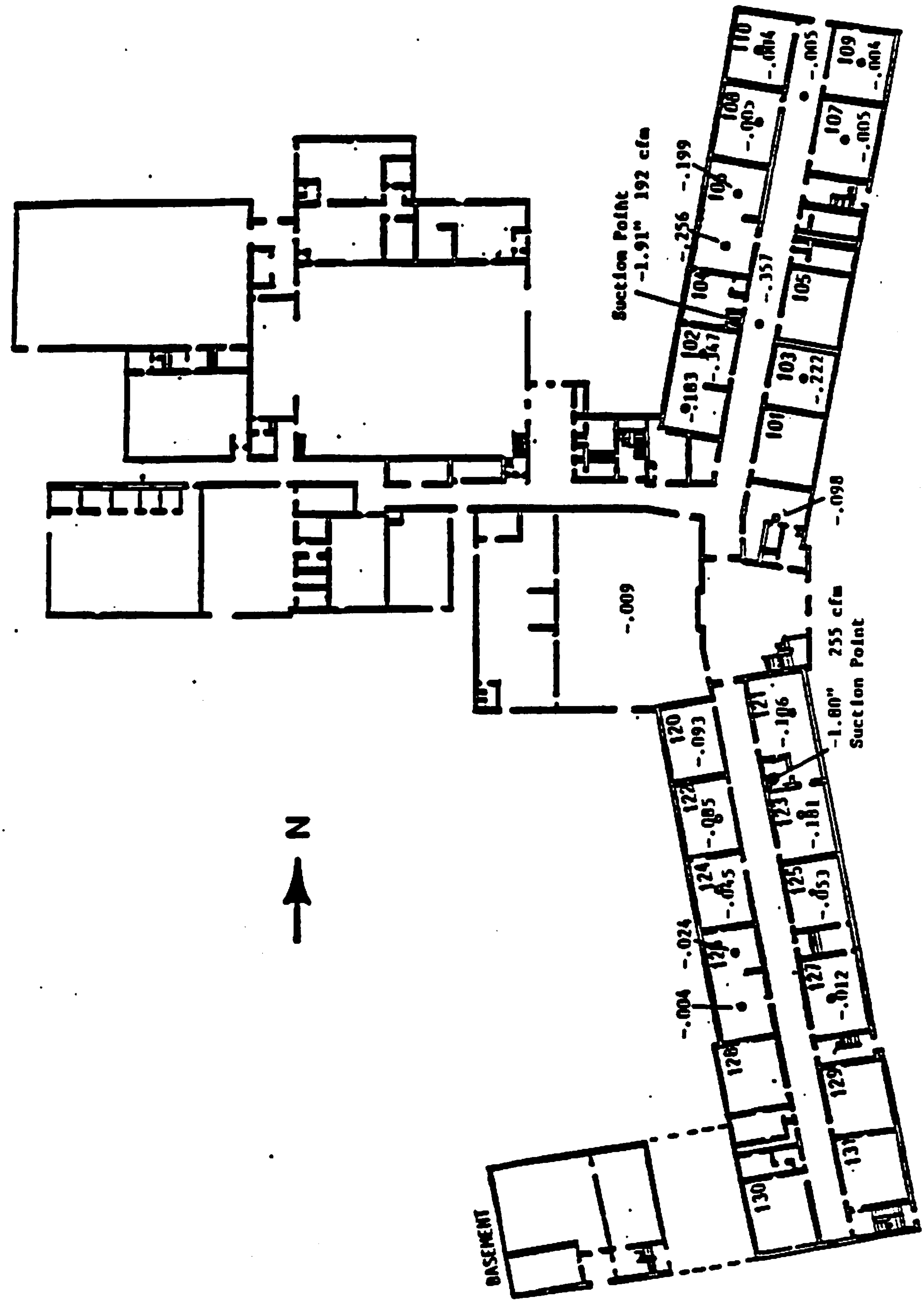



Figure 3. Temporary ASD pressure field extension, in. W.C.

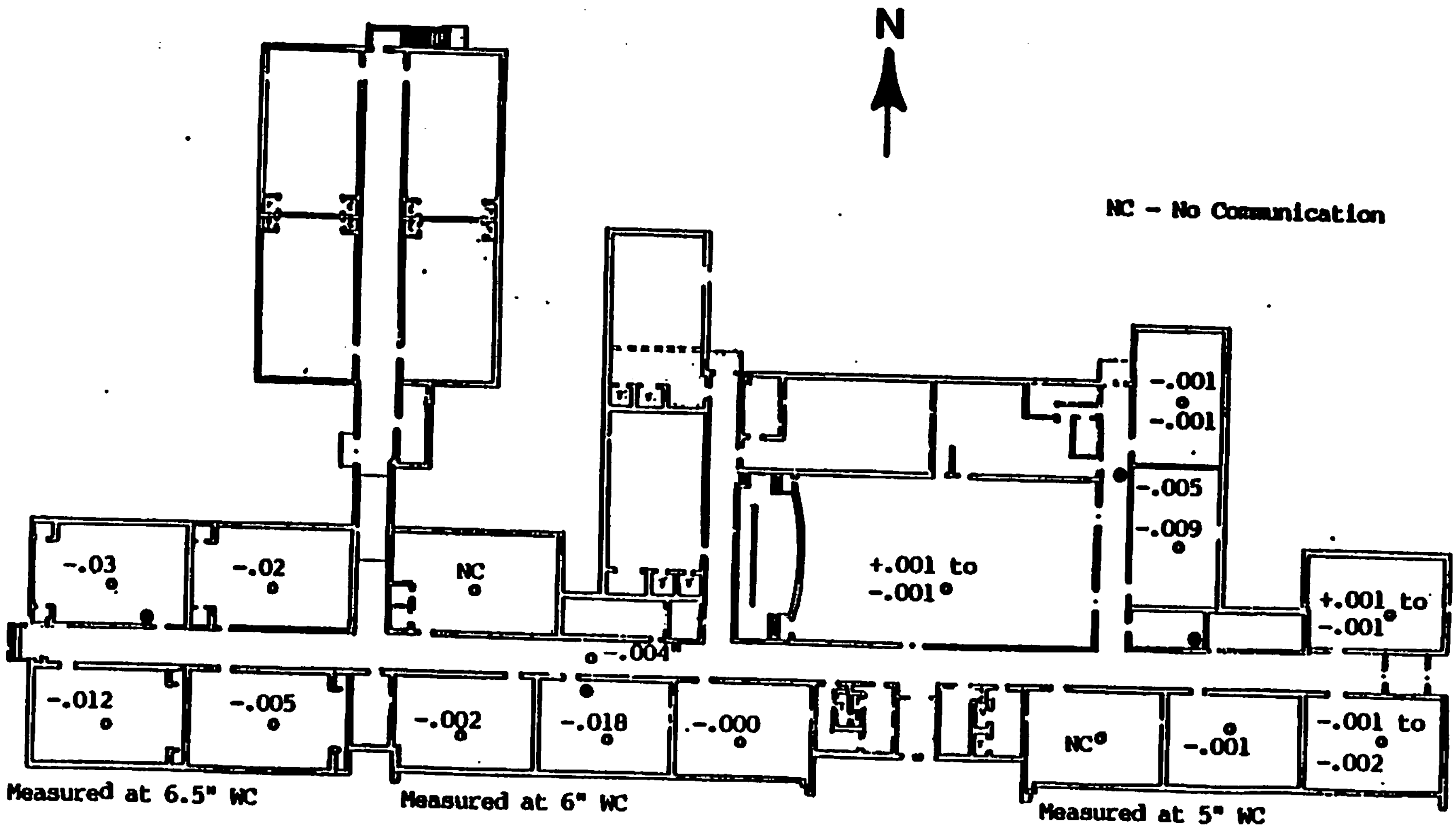



Figure 4. Pre-mitigation pressure field extension, in. W.C.

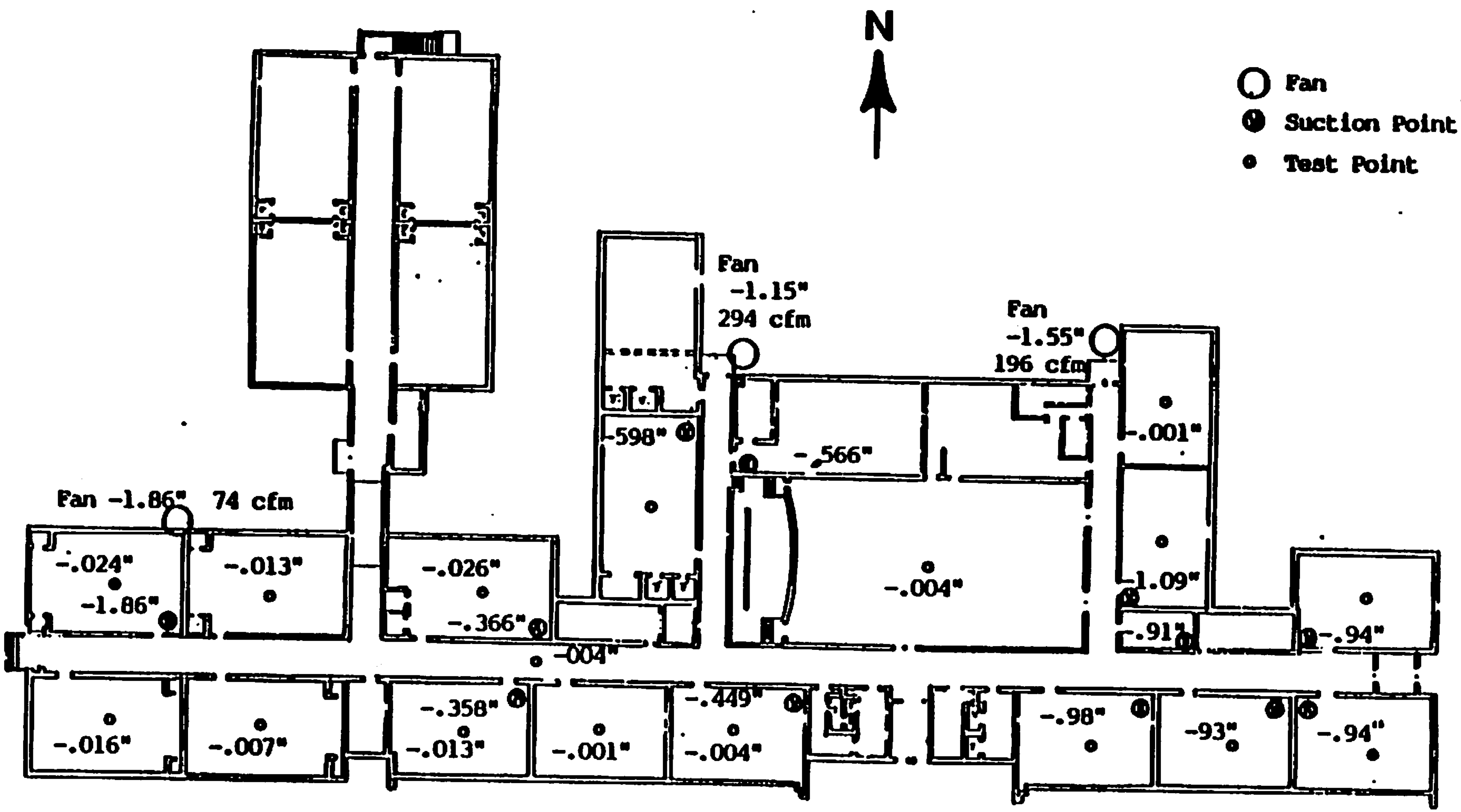



Figure 5. Post-mitigation pressure field extension, in. W. C.

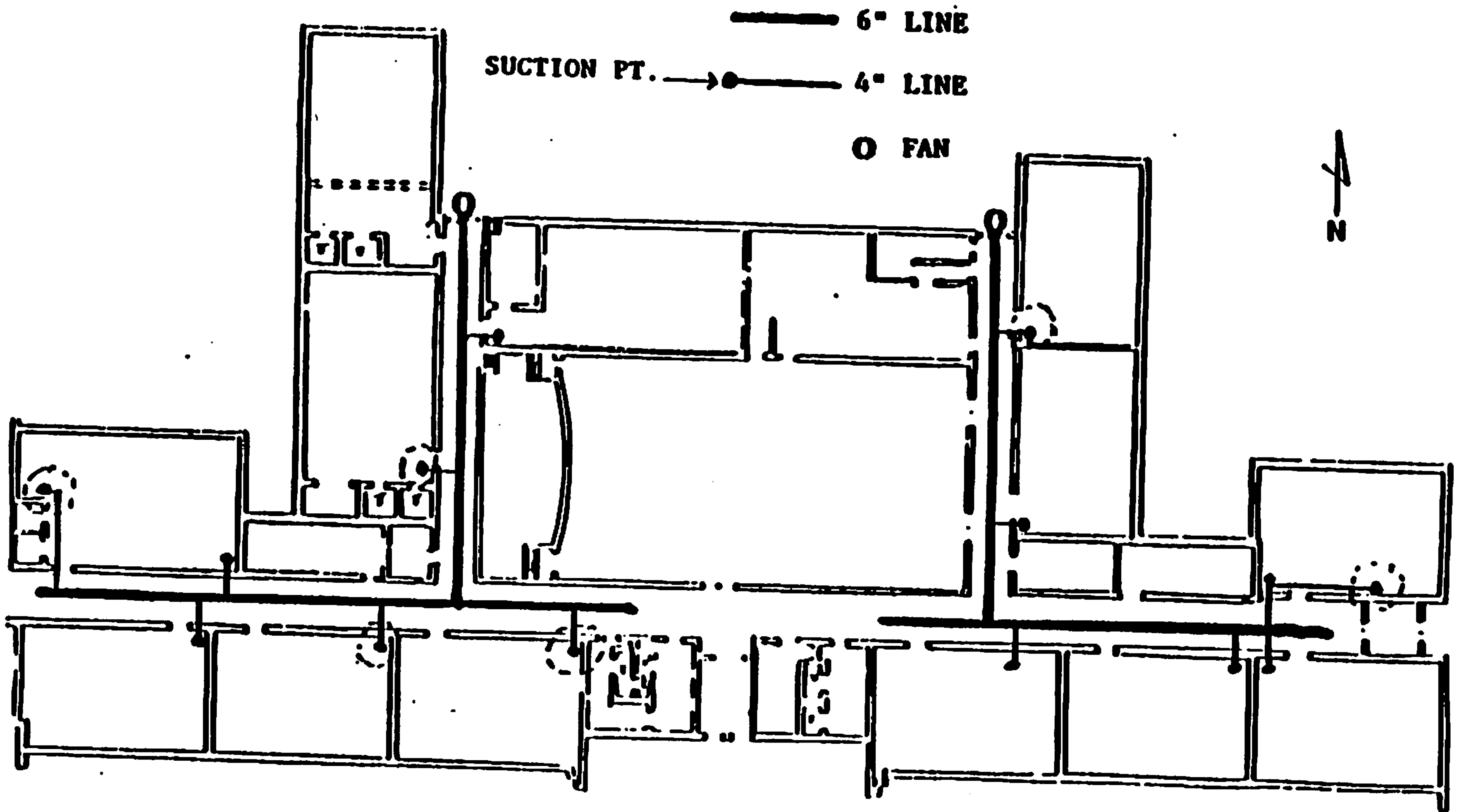
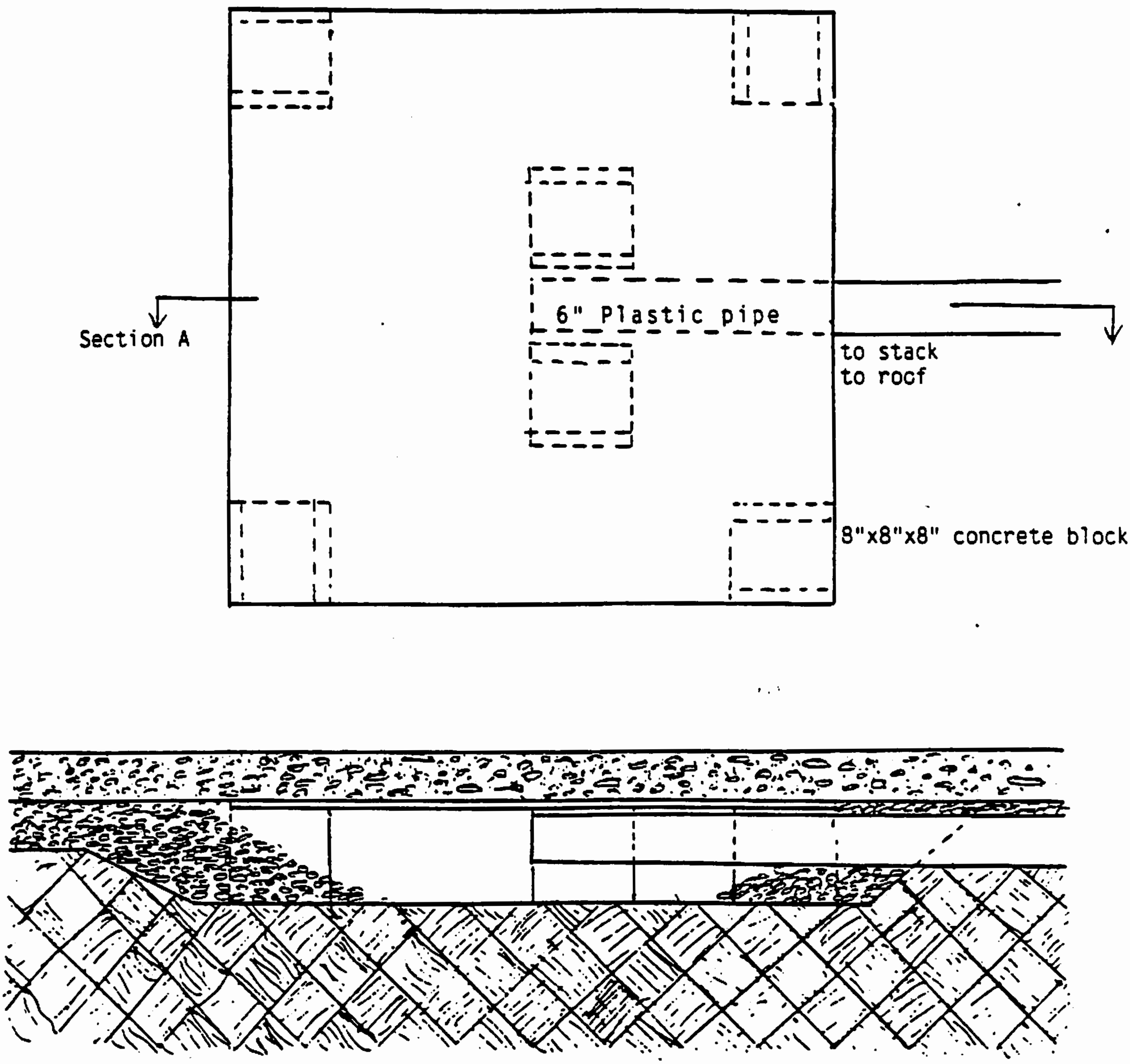



Figure 6. Final mitigation system




SECTION A

Figure 7. Sub-slab suction pit

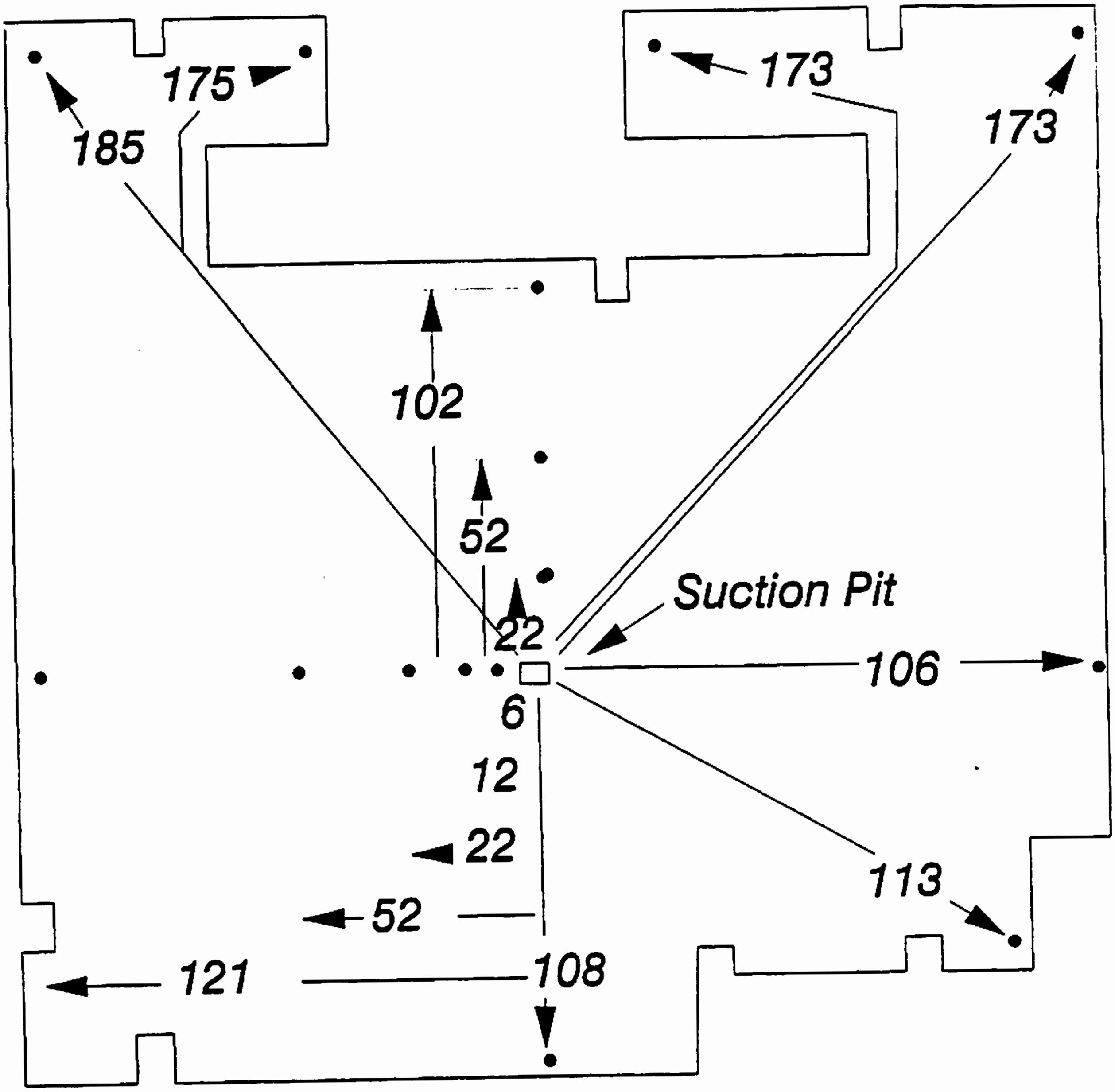



Figure 8. Diagnostic holes, ft

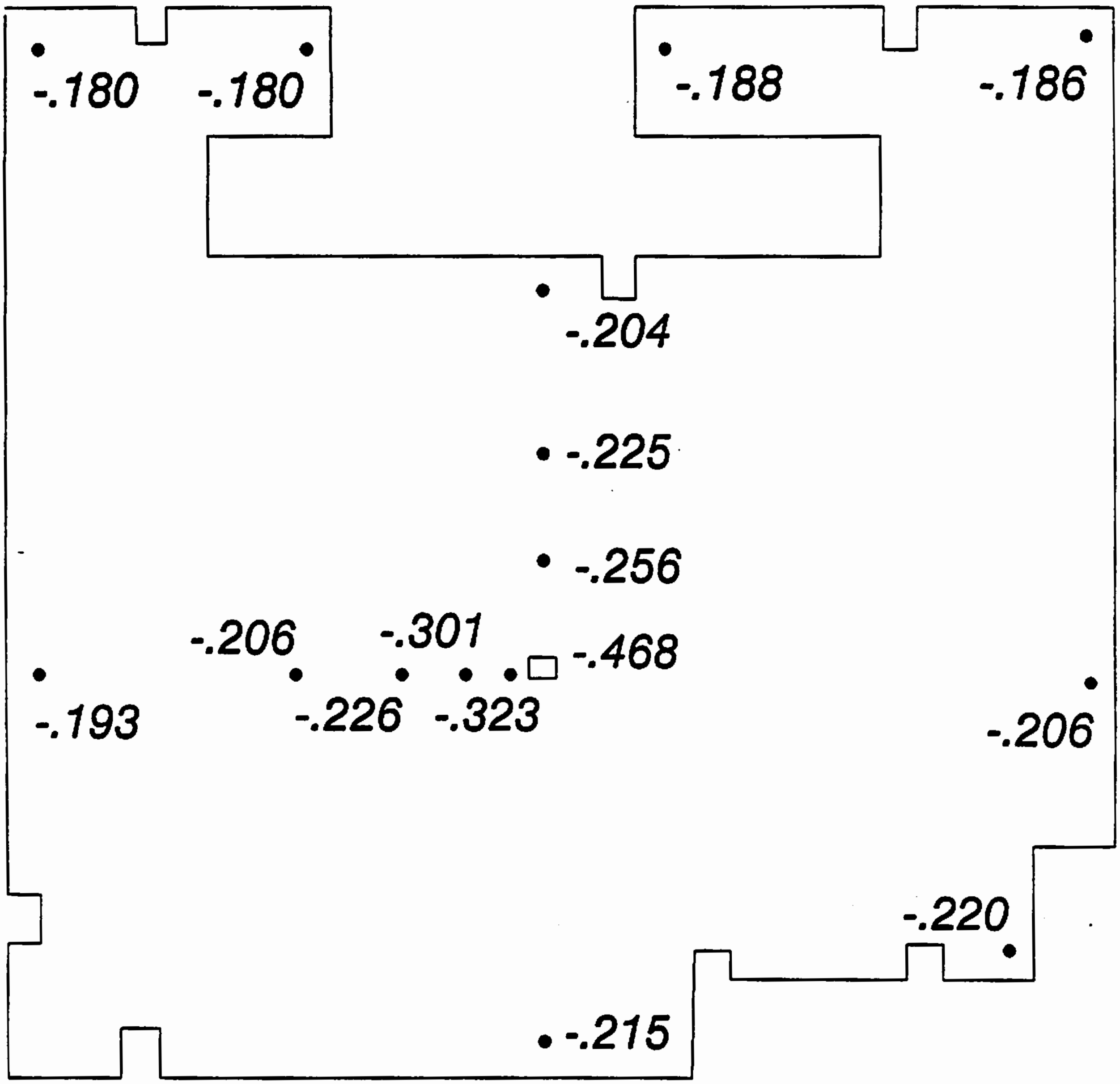



*Figure 9. Subslab pressures, ASD on (in. W.C.)*

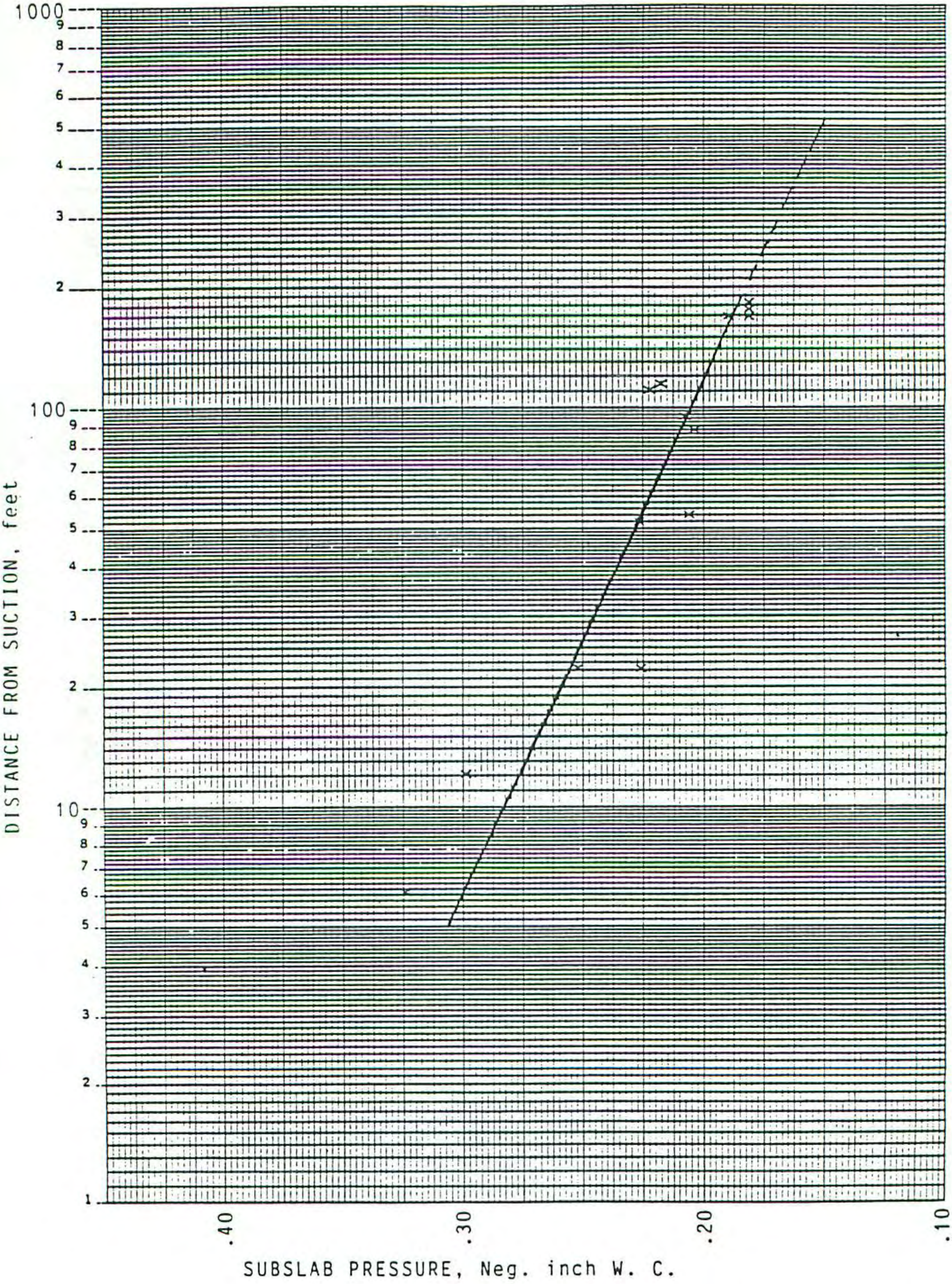



Figure 10. Pressure field extension for complete slab