LONG-TERM RELIABILITY OF COLLATERAL MITIGATION

By
David Wilson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
William Brodhead, WPB Enterprises, Riegelsville, Pennsylvania, USA
and
Stanley Ng, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawaii, USA

ABSTRACT

During 1997 and 1998, members of the Oak Ridge National Laboratory (ORNL) Radon Team installed 47 single-suction-point active soil depressurization (ASD) systems in 47 multiplex housing units located in 24 buildings in Guam. Subslab vacuum measurements performed within adjacent housing units found sufficient field extension to provide potential radon reduction within 39 additional units. Follow-up radon testing confirmed that mitigation had occurred in these additional units. During the summer of 2000, retesting of the 39 units revealed that mitigation had failed in 12 (31%) of the units that underwent collateral mitigation. Detailed investigations identified degradation of fan performance, fan failure, and the property management's energy policy regarding vacant units as the main causes for mitigation failure.

COLLATERAL MITIGATION

Simply speaking, in active soil depressurization (ASD), the vacuum field extends concentrically from the suction point to a point where the soil gas is no longer being drawn toward the exhaust point (typically the 4-Pa contour line). This contour, called the lateral field extension (LFE), defines the boundary where effective mitigation can be anticipated (Figure 1). In certain cases, the LFE can be impeded by subslab footings (Figure 2) or in cases of nonhomogenous aggregate conditions, the LFE can be biased or doughnut shaped (Figures 3 and 4). However, if interior footings have good aggregate beneath them, the vacuum field could extend for a considerable distance (Figure 5). If the vacuum field extends under the interior footing of a multi-family building (e.g., duplexes and townhouses), installing an ASD mitigation system in one unit could reduce the radon level in one or more adjacent units. This type of mitigation is called collateral mitigation (CM).

BACKGROUND

Apartment complex "Q", located in Guam, consists of 130 two-story townhouse apartments. The complex, covering about two square miles, is located over a karsts limestone formation with soil depths ranging from 0 ft to 4 ft. All units in the complex are identical: 2312 ft^2 area, 4 bedrooms, 2½ bathrooms, slab-on-grade construction, with central air conditioning (AC). Exterior walls are solid block construction, and each building has a single-level poured concrete roof. The 130 townhouses are grouped together in 24 buildings, with either four or six units per building. A photograph and floor plan of a typical unit are illustrated in Picture 1 and Figure 6 respectively.

During 1995 to 1996, long-term radon measurements were made using alpha track detectors. Of the 130 units tested, 117 (89%) were identified as having elevated radon levels, ranging from 4.0 pCi/L to 370.7 pCi/L (Figure 7).

MITIGATION DIAGNOSTICS

In 1997, the Oak Ridge National Laboratory (ORNL) Radon Team was tasked to determine the best overall approach for mitigation in housing complex Q. Because so many units had elevated levels of radon (117 units), the customer directed our focus to the 40 units with radon levels > 20 pCi/L. Corrective actions within the remaining units > 4 pCi/L are expected to be performed in a later phase. Additional considerations for mitigation were as follows:

1. Because ASD is the most efficient means of reducing radon levels in the long term, preference was given to ASD wherever feasible. In addition, wherever possible, the systems should follow uniform specifications in pipe size (4 in. PVC, SCH 40), pipe fittings, clamps, and fans to significantly reduce the number of spare parts needed for future system repair and maintenance.

2. Because Guam has a tropical climate and the occasional typhoon, roof integrity is a significant concern. Therefore, wherever possible, the ASD should make a lateral egress route to the outside and then up the exterior wall to above the roofline.

3. Housing space is typically divided into two categories, livable and nonlivable. Livable space is simply the rooms where residents routinely spend most of their time (e.g., living room, kitchen, and bedroom). Conversely, nonlivable spaces are areas that are usually not intended to be occupied for any extended time (e.g., storage and clothes closets, pantries, bathrooms, and mechanical rooms). To minimize the potential impact on residents and for aesthetics reasons, the location of the suction points should be in the nonlivable areas of a unit.

4. Depending on the type of fan and the volume of air being withdrawn beneath the slab, ASD fans can produce a low but detectable level of noise. Therefore, every effort will be made to locate the fan away from bedrooms and family rooms.

5. Because 90% of the units are occupied, consideration must be given to working with the residents to schedule and perform the mitigation. Ideally, the mitigation should be completed within a half a day.

With these considerations in mind, ORNL researchers performed detailed subslab diagnostics within four units. Because of the floor plan, the most desirable location for the suction point was inside the mechanical room (Figure 6). In addition, the preexisting pipe chase allowed for unhindered pipe egress through the second floor and above the roofline. However, LFE tests performed at 5000 Pa showed about 3 ft of LFE (Figure 8). Further excavation of the 0.5-in. test hole found 36 in. of compacted coral on top of the karsts limestone and no appreciable soil under the aggregate base. The subslab diagnostics were then repeated about 15 ft away in the closet under the stairs (Figure 6). This time however the LFE was greatly improved. The LFE test performed at 500 Pa showed a doughnut-shaped pattern along the perimeter of the subslab with at least 150 Pa of vacuum (Figure 9). As in the first LFE test, no communication was observed in the mechanical room. Further refinement of the LFE identified a trapezoid-shaped area under the center of the unit that had no communication with the perimeter of the subslab. Additional testing performed in the kitchen storage room (Figure 6) and to the right side of the entry hallway found the identical compacted coral conditions that were observed in the mechanical room.

Because the LFE was so high along the perimeter, additional 3/8-in. test holes were placed in adjacent units to determine the full extent of the vacuum field. For fourplex buildings, the vacuum was found to extend about 60 ft, providing vacuum coverage for two additional units (Figure 10). For sixplex buildings, a grade beam between units 2 and 3 (Figure 11) prevented the vacuum from extending under the footings into the next unit (unit 3). However, if the field extension test was repeated in unit 6, the LFE was found to extend 60 ft, as in the fourplex, and to cover two additional units (units 4 and 5). As was observed in the initial test unit (Figure 9), all units had a trapezoid area along the center of the unit with no communication. Excavations in the other three test units found the identical compacted coral conditions. The placement of the suction point within interior units (e.g., units 2 or 3) (Figure 10) to enhance the vacuum field was also examined. However, the LFE extended only into the immediately adjacent units; no combination was found to extend the vacuum into all four units of the building.

With respect to mitigation design, it was determined that a single suction point located in the stairwell closet (Figure 6) addressed all of the key customer concerns (e.g. aesthetics, loss of functional space, uniformity, etc.) about mitigation (Figure 12). An interior penetration was selected because diagnostics had found that the monolithic slab was about 36–40 in. thick at the point of side coring into the aggregate bed. With respect to fan selection, the diagnostics determined that to mitigate a single unit, the projected vacuum at the suction point would need to be around 250 Pa. However, in anticipation of CM, a larger fan capable of at least 500 Pa was selected and installed.

MITIGATION

Although the diagnostic data indicated a strong potential for CM, the number one priority was to take corrective action within the 40 units found to be ≥ 20 pCi/L. Within the first 3 days of mitigation, six ASD systems were installed within units > 70 pCi/L in five different buildings. Checks of the vacuum field in the adjoining eight units confirmed the presence of vacuum as predicted by the diagnostics. Postmitigation testing (short-term electret) confirmed that mitigation via CM had indeed been accomplished.

Because of these positive initial results, the diagnostic data, individual radon results, and in particular the type of building were evaluated more closely. Seventeen of the 24 units were within a sixplex building, and each would require three ASD systems. In addition, each of the seven fourplex units would require two ASD systems. Therefore, empirically speaking, a minimum of 65 ASD systems would be needed to collaterally mitigate 52 units. Because of schedule and funding restraints, a maximum of 41 ASD systems could be installed during this study. We therefore strategically placed the remaining 41 ASD systems where they would provide the maximum benefit, while still ensuring that the remaining 34 units with radon > 20 pCi/L would be mitigated. With these parameters in mind, it was estimated that an additional 35 units (maximum) would be collaterally mitigated.

Overall, the postmitigation results (short-term electrets) were excellent. All units with ASD were reduced to < 2 pCi/L. Of the 43 units in which CM was theoretically possible, 39 were reduced to < 4 pCi/L. In the four units in that were not collaterally mitigated, all were reduced to between 4 pCi/L and 8 pCi/L. Field extension measurements conducted in these units showed that the extension within the three buildings was significantly less than that observed during the diagnostics. Hole excavation in one of these units revealed that the aggregate base was only 2-3 in. thick (compared with 18 in. in the other buildings) and was imbedded with clay. Because CM was unsuccessful in these units, ASD systems were installed, all were reduced to < 4 pCi/L.

FOLLOW-UP TESTING

The EPA publication *Radon Mitigation Standards*, October 1994 (EPA 402-R-93-078), recommends that a home with a radon mitigation system be retested every 2 years. During the summer of 2000, ORNL researchers returned to Guam to retest the 86 units (47 units with ASD and 39 units with CM) and to inspect the 47 ASD systems. Upon arrival in Guam, it was learned that the occupancy of Complex "Q" had fallen from 90% to around 15% over the previous two years. As a result, about two months before our arrival the managers of the property had shut off power to 65 units to save money. Unfortunately, the power interruption included 21 units with ASD systems that also collaterally mitigated 10 of the remaining occupied units. After electrical power was restored to the 21 units and three weeks had elapsed for the units to stabilize, ORNL retested the 86 units (short-term electrets) and inspected the 47 ASD systems. The findings were as follows:

1. In units with ASD systems, 12 of the 47 fans were found to be inoperative because of mechanical failure of the fans.

2. Using current and 1998 LFE data, 12 CM failures were linked to reduced fan performance in the eight adjoining ASD units. Air velocity measurements collected in theses ASD systems found a 35% reduction in airflow on average.

Investigation of the 12 fans that had failed identified the following problems:

1. Two fans had been hit by something that had destroyed the fan housing, such as during a typhoon.

2. Six of the fans had suffered catastrophic capacitor failure (Picture 2).

3. Upon disassembly, four fans were found to contain bearings that showed excessive wear, resulting in fan lock-up.

After the blown capacitors were replaced and the fans reactivated, a noticeable vibration was observed. Flow measurements in the pipe found that the flow was 20–25% lower than when initially installed. Examination of the bearings found excessive wear when compared with a fan that had been procured at the same time but not installed. All eight fans with reduced capacity were observed to have increased vibration relative to the other nonsuspected fans. Three of these fans were selected at random and disassembled; again; excessive wearing of the bearings was identified as the cause. Using manufacturing dates found inside the 18 fans failed and suspected fans, it was determined that all were manufactured within a three-month period. Examination of the manufacturing date for the remaining 29 fans that were operating properly found that they were manufactured before or after this period. To remedy the situation, ORNL replaced all 18 fans with equivalent fans from a different manufacturer and retested the 24 units. All were found to again be < 4 pCi/L. In addition, LFE measurements performed in four of the CM units were similar to the 1998 measurements. As an added precautionary measure, LFE was also remeasured within eight units that were **not** noted as having fan problems. All of the LFE measurements were within ± 1% of the post-installation value. One year later (summer 2001), the LFE was also rechecked within these eight units and four of the units whose fans had been replaced. Again, all of the LFE measurements were within ± 1% of the post-installation value. A retest (short-term electret) of radon levels in these 12 CM units during 2001 found all still below 4 pCi/L.

CONCLUSION

In a single family home, if the ASD system fails, only one family is affected. However, as seem in this study, the impact of ASD system failure by either mechanical failure or electrical disconnect resulted in mitigation failure in the adjoining units mitigated by collateral means. In addition, the degradation of fan performance in some of the ASD systems resulted in additional CM failure as well. On the surface, the obvious solution to avoid this problem would be to install an ASD system in each unit. However, this approach significantly increases both the initial installation and long-term maintenance costs. In this case, better maintenance practices would have found and corrected the ASD fan failure problem. Better planning would have avoided the problem caused by disconnecting the power in the units with the ASD systems. The data collected in collaterally mitigated units in which fan failure or performance issues were not a problem, shows that CM mitigation can be a viable long-term solution. Therefore CM if properly managed, can provide multifamily housing property owners a long-term cost effective mitigation solution.

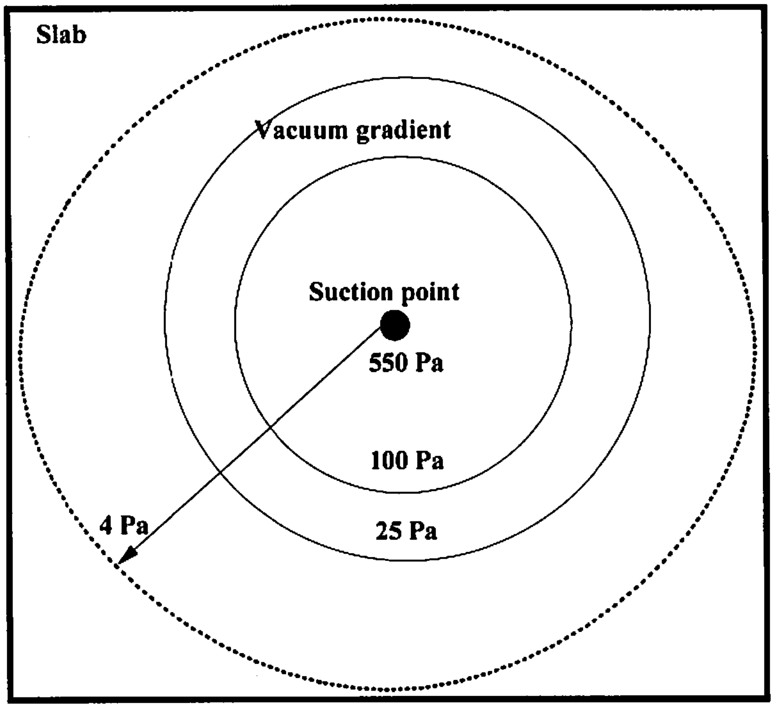


Figure 1. Ideal vacuum field

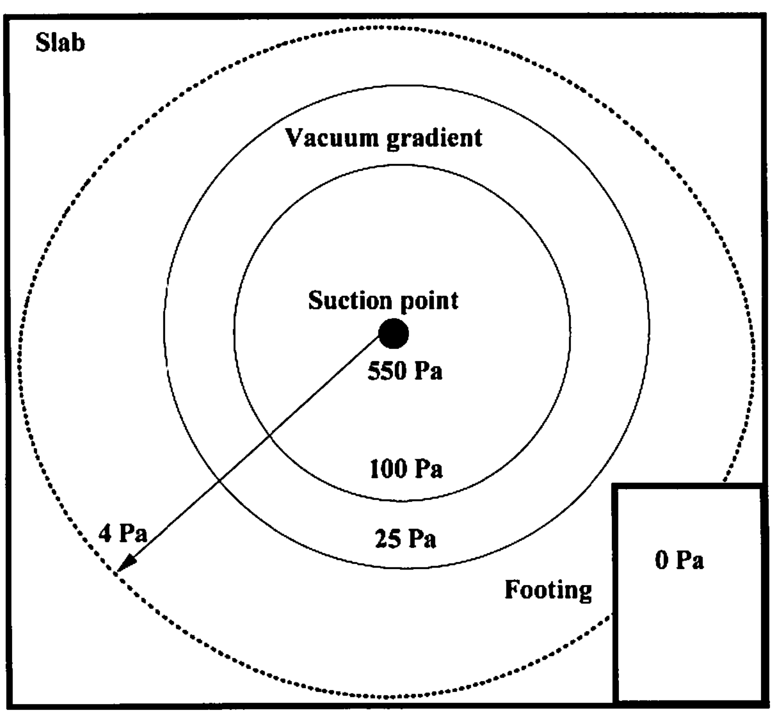


Figure 2. Footing blockage of vacuum field

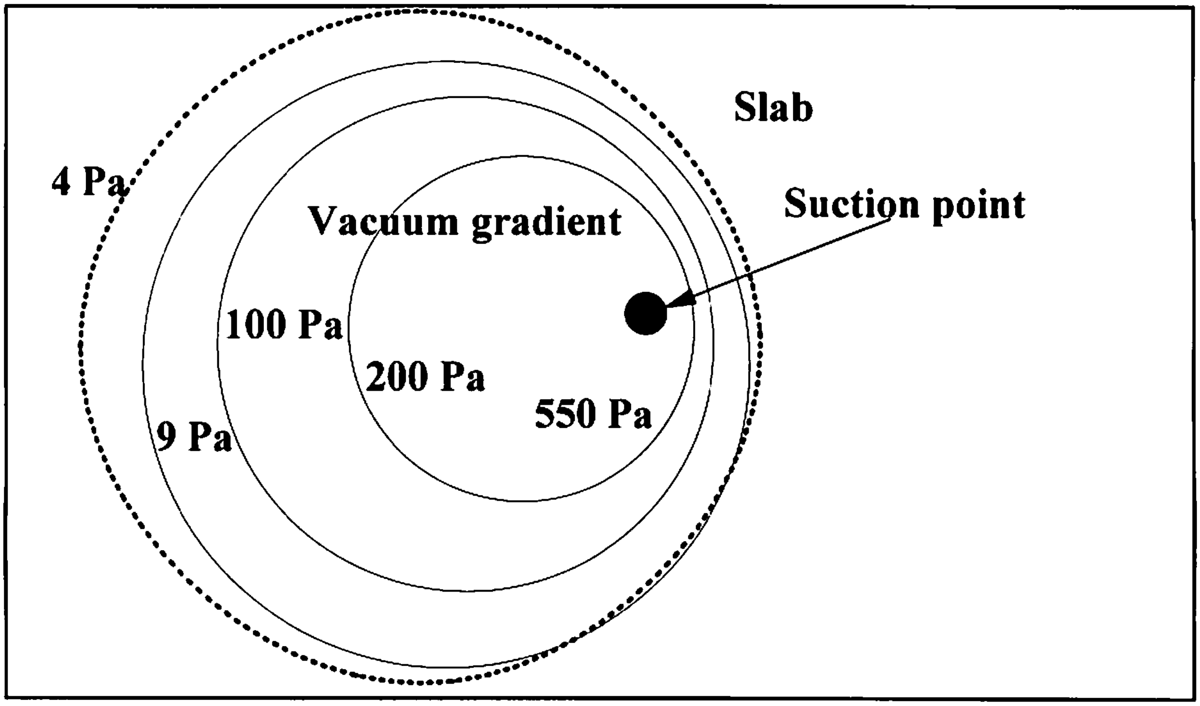


Figure 3. Biased vacuum field

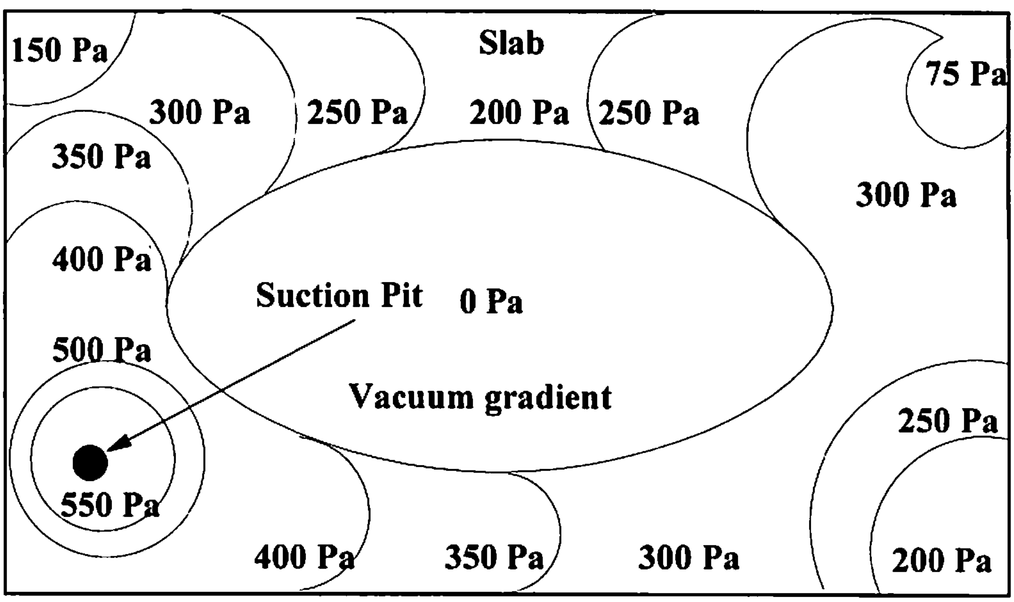


Figure 4. Doughnut vacuum field

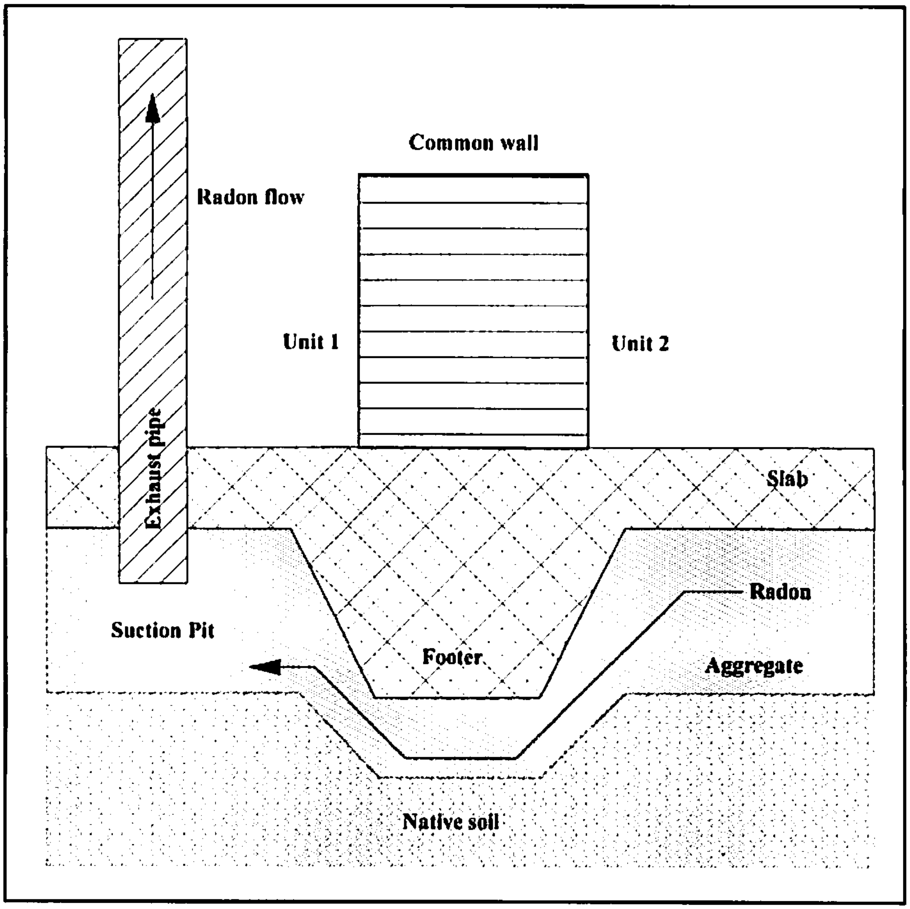


Figure 5. Vacuum extension under a footing

Picture 1. Typical unit

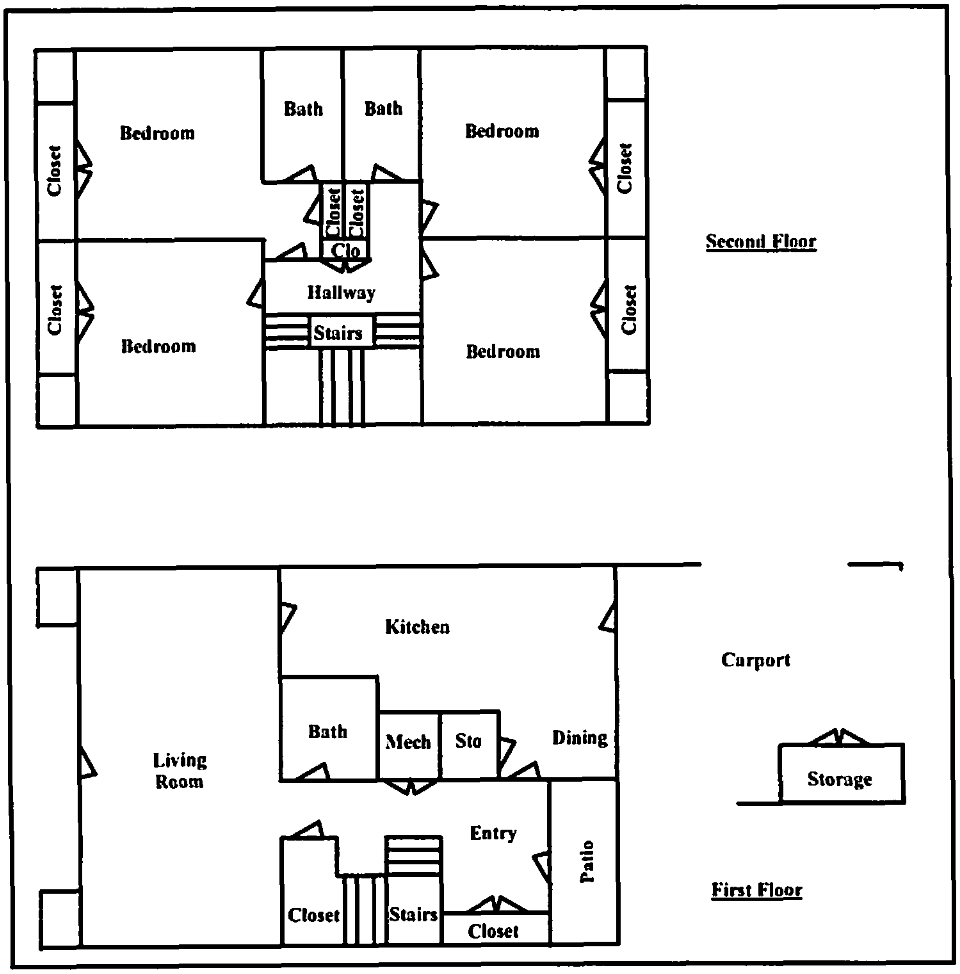


Figure 6. Unit floor plan

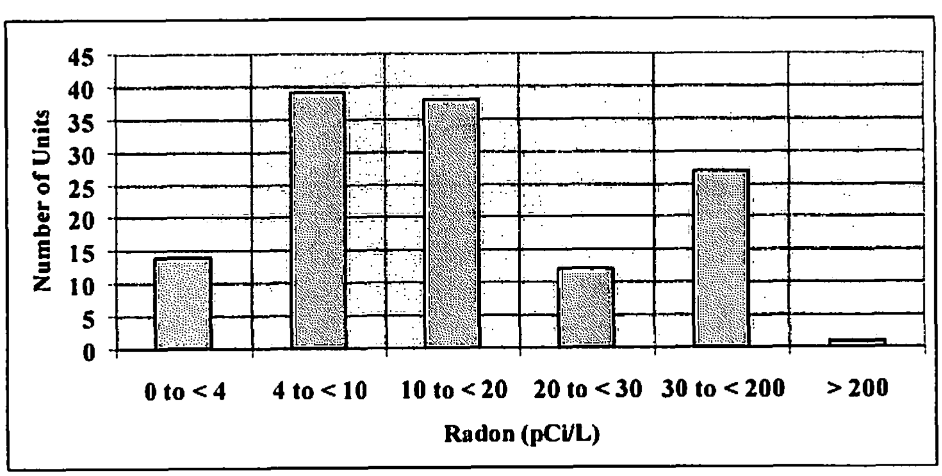


Figure 7. Complex Q radon distribution.

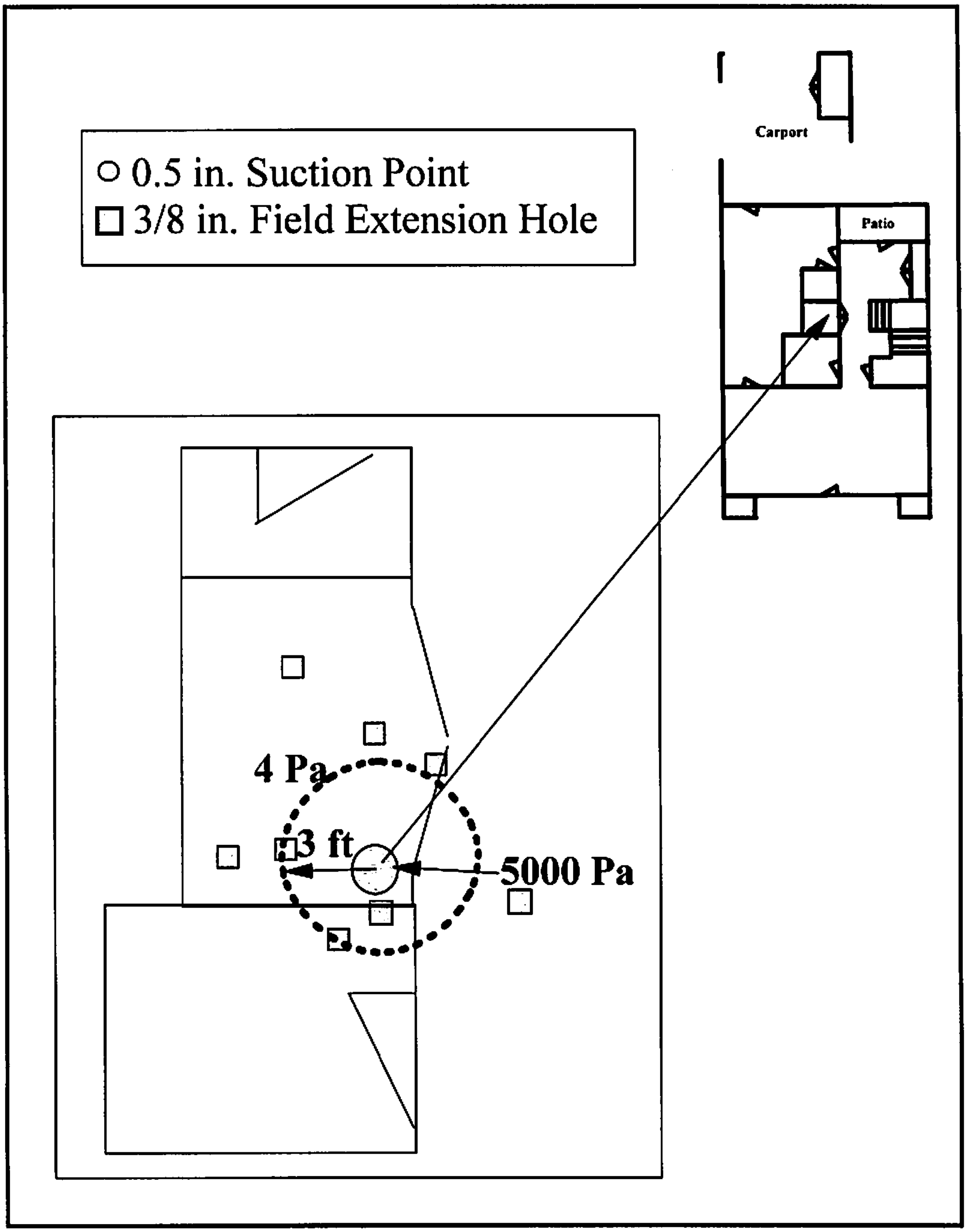


Figure 8. LFE inside the mechanical closet

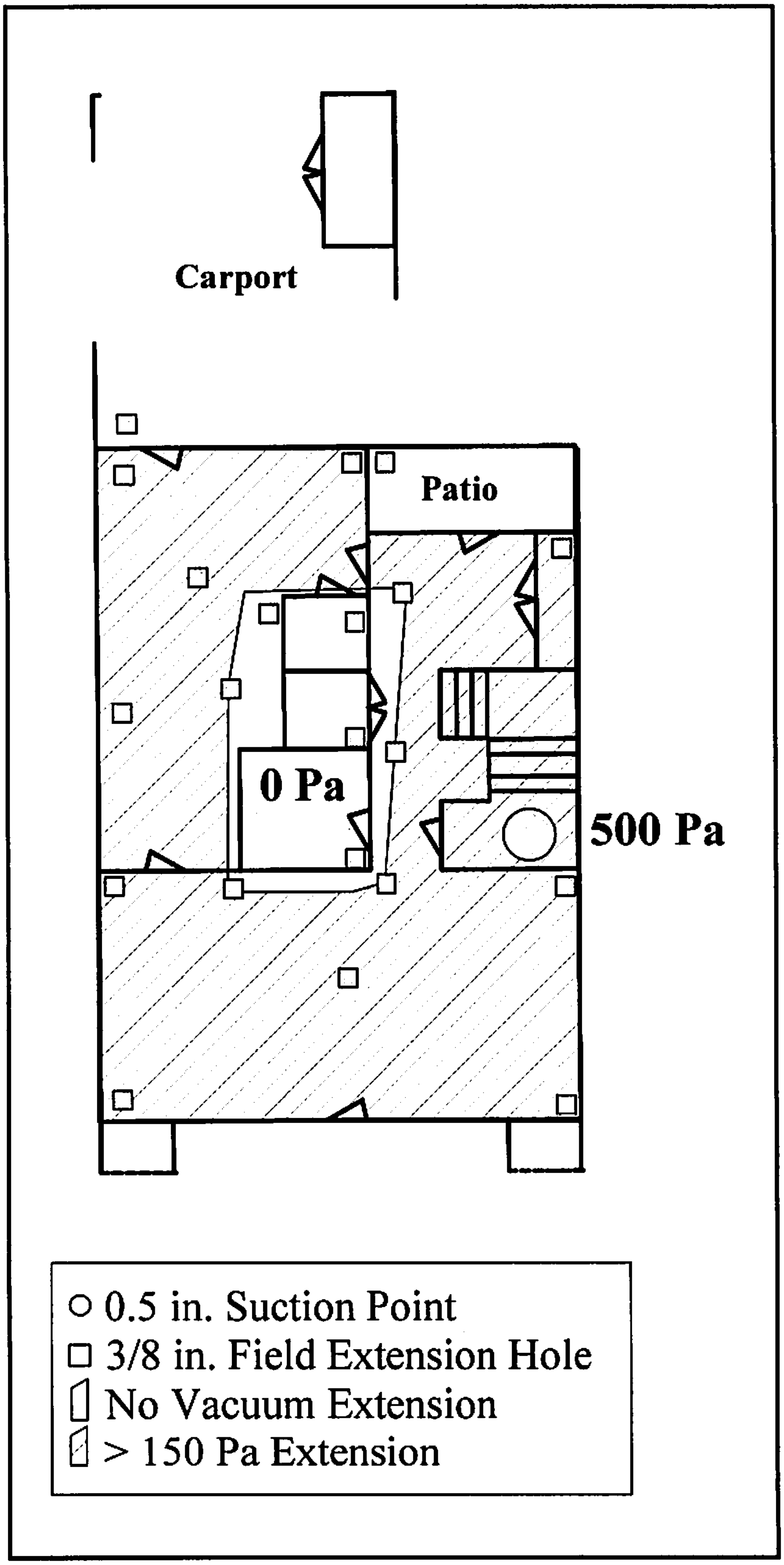


Figure 9. LFE from stairwell closet

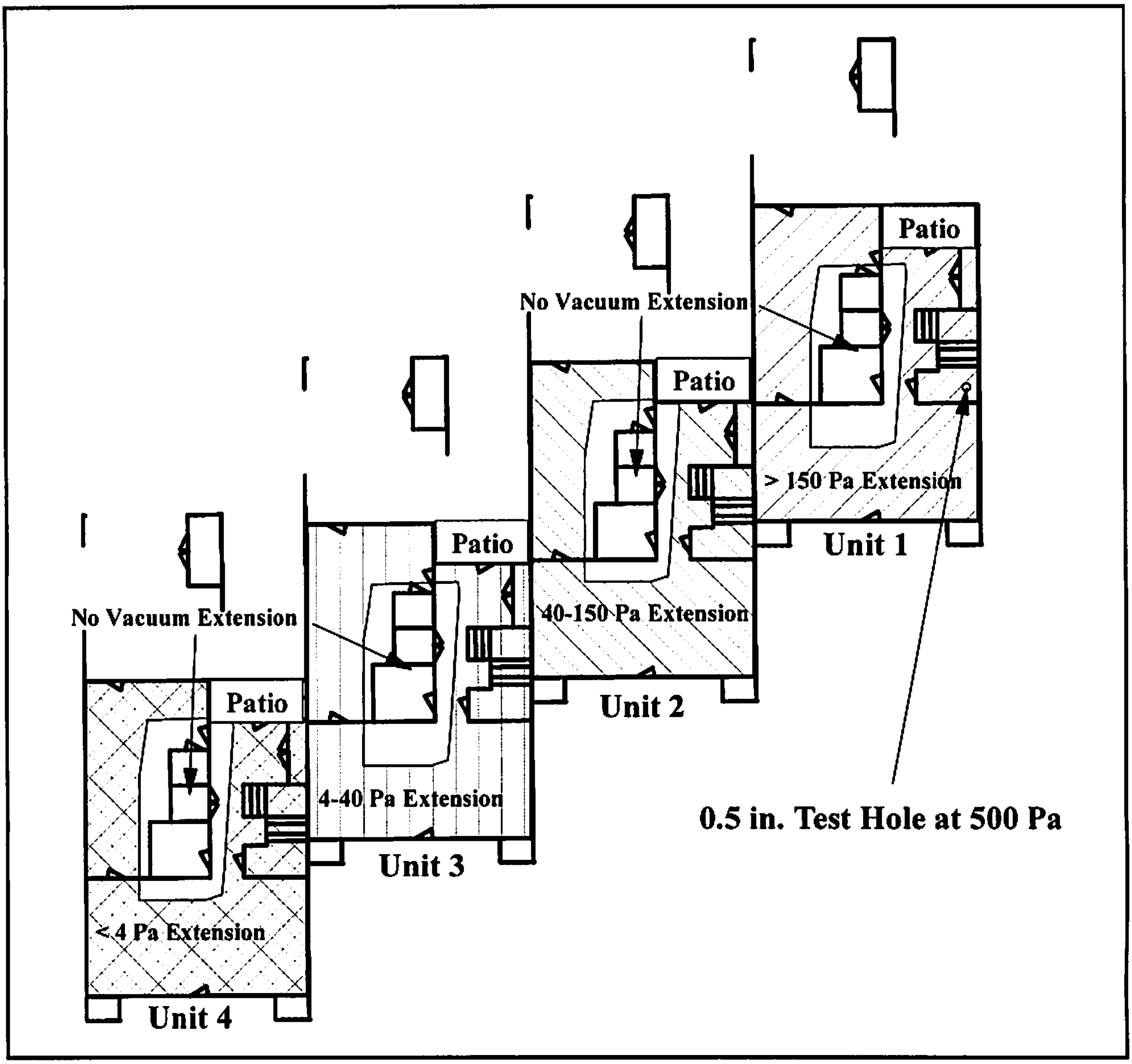


Figure 10. LFE extension in fourplex buildings

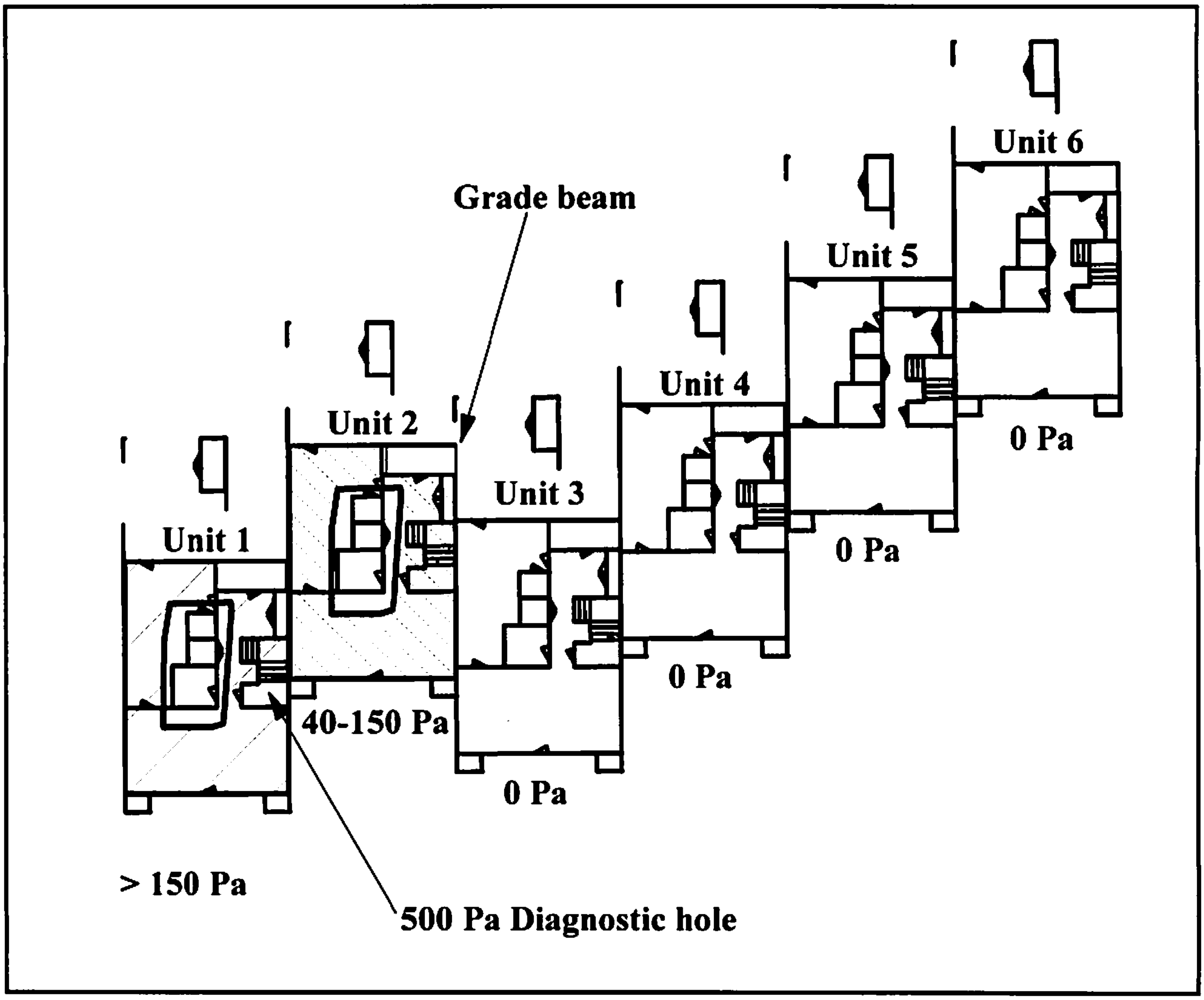


Figure 11. LFE in sixplex units

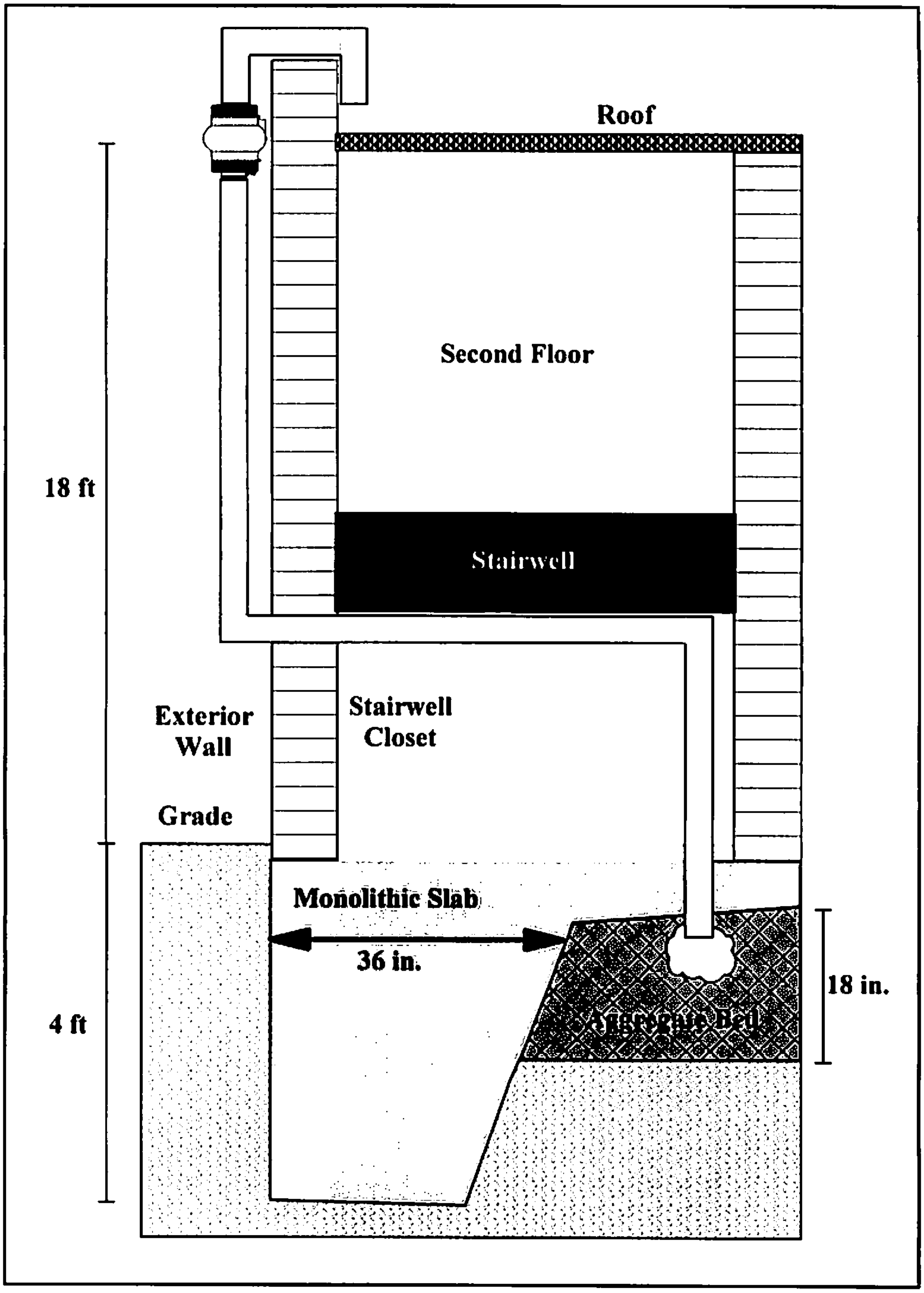
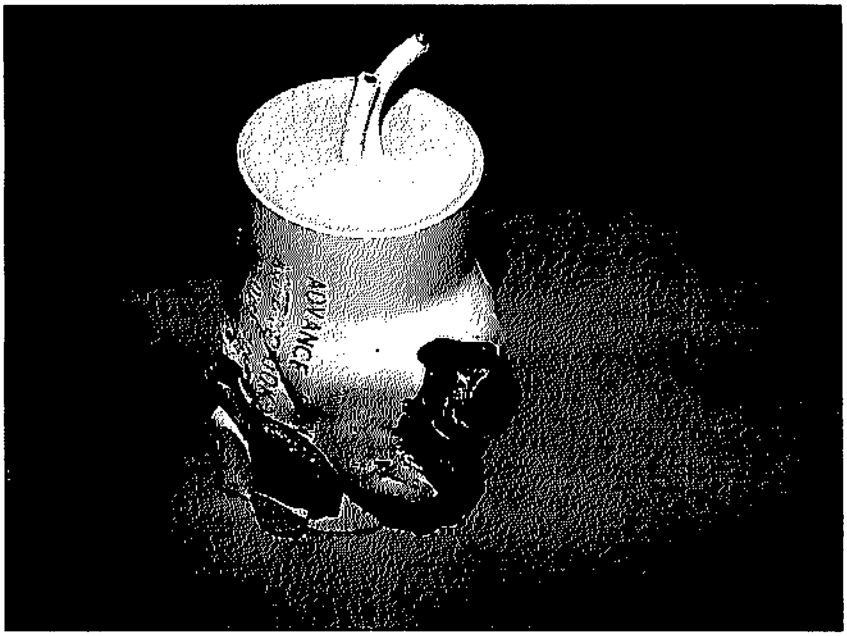


Figure 12. Mitigation design



Picture 2. Typical blown capacitor