ANALYSIS OF TWO TYPES OF PRESSURE EXTENSION TESTS*

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SUMMARY

The Building Research Establishment have been involved in two different types of pressure extension tests. In this paper the two groups of results have been brought together, and the effect of both on future designs of protective measures for new buildings considered.

In one study the pressure field due to a central sump has been measured at many points within the fill below the floor slab, using tubes laid before the concrete floor was poured. These tests give detailed results for a small number of sites. This work was carried out with Cornwall County Council.

In the other set pressure extension tests were carried out on the floors slabs of 78 newly built UK houses. The tests were carried out using holes drilled after the floor has been laid, so provide less data, but from more floors. The work was carried out by Wimpey Environmental Ltd, under contract to BRE.

From the results we have greatly increased our understanding of how the type of fill material affects soil gas flow. There is considerable variation between results from sites which are supposed to be using similar fill materials. However with care very good pressure extensions can be achieved over large floor areas.

In the UK there has been concern from builders about how to build on the recommended 'clean permeable fill'. These projects will help in the process of designing efficient, cost effective protective measures.

INTRODUCTION

In the Building Regulations for England and Wales there is a requirement to build in protective measures against radon ingress in areas which have been declared 'affected' [1]. The effectiveness of these measures is discussed elsewhere [2]. There is some concern however about the ease with which these measures can be built into houses, and the cost of doing so. One problem which has been raised is what exactly is meant by 'clean permeable fill', and how important it is. As well as possible extra costs in purchasing and transporting special fill materials, builders have expressed concern about the compaction of these fill materials, and possible problems of settlement and cracking of concrete floors. There are also problems of the installation of a design; will it be carried out in a way that will make it ineffective?

In order to investigate these it was felt important to look at the effectiveness of different fill materials in allowing air flow, to see whether it is possible or desirable to define a particular fill type to be used in radon protection. The experiments took the form of a series of pressure extension tests on floor slabs in England, using two different methods.

In one set of experiments a total of 78 pressure extension tests were carried out over a 15 month period, with a good spread of locations and fill types. The method used is described more fully below. The project was funded by the Department of The Environment through the Building Research Establishment. The experimental programme was undertaken by Wimpey Environmental Ltd, using, where practical, floor slabs constructed by Wimpey Homes Holdings Ltd. It has been partially reported on elsewhere [3].

In the second set of experiments Trevor Gregory and Roger Stephen, see also [4], have measured pressure fields within the floors of a 5 schools in Cornwall. They were able to collect data from a large number of points below each floor by laying pipes on the fill material before the concrete was poured on top. Each floor represented a devolopment on the previous one, in the sense that new measures were tried to improve the pressure extension. Not all of them were successful, as the results indicate.

PRINCIPALS AND TEST PROCEDURE FOR THE WIMPEY TESTS

A sump (or sub-slab depressurisation system as it is known in some countries) works principally by depressurising the fill below the concrete floor. This region is then at a lower pressure than the internal air of the dwelling, preventing significant flow of radon laden air between the fill and the dwelling.

The dominant entry point for radon in an unprotected floor is usually the shrinkage crack which occurs at the join between the floor slab and the walls. This occurs because, in standard UK construction, concrete is poured wet into the space between the walls and left to cure. As the concrete cures there is shrinkage away from the walls, and it is not practical to seal up all of the gap this leaves between the wall and floor. Although this is typically only a millimetre wide, other studies show it to be important in radon entry [4].

A sump will almost certainly be effective in minimising radon entry if it can achieve a negative pressure across the whole of the floor area. Hence measuring the pressure produced at the edge of a floor by extracting air from the centre is an indicator of the likely effectiveness of a sump. In these tests this was achieved by drilling a central suction hole, pulling air from it with a vacuum cleaner, and measuring the pressure at a series of smaller holes in the floor slab. The principle is described in the figure below, but more details of the experiment have been given elsewhere [6].

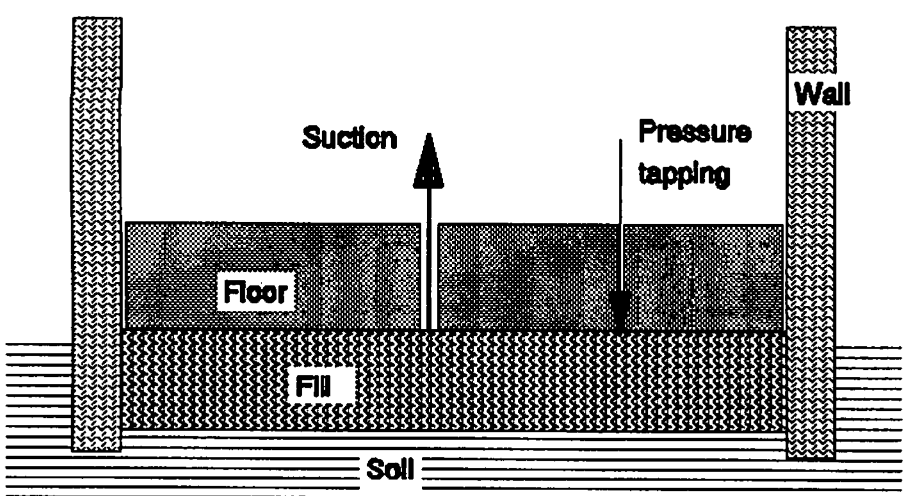

Figure 1: Diagram of pressure extension test

As well as measuring pressures the flow rate through the system was measured, to allow analysis of the overall resistance of the floor to gas flow. A sample of the fill material from each site was collected, and tested to give the grading curve of each material, using British Standard sieve tests [7]. The grading curves are not discussed in this paper.

METHOD FOR CORNWALL TESTS

In all five case studies the same basic method of measuring the sub-slab pressure field extension has been used. After the hardcore fill has been laid and compacted 6 mm diameter crush resistant nylon pressure tubing is laid out, weighted down, and the ends protected from blockage by short lengths of 12 mm rigid plastic pipe. Blinding, membrane(s) and concrete floor slab are then laid in the normal way.

The other ends of the tubes are led to a convenient position above the floor brought out through holes in corresponding positions on a plastic encapsulated drawing of the floor plan. This plan is attached to a plywood backing board and housed in a plastic box.

When pressure field extension measurements are made the radon sump is activated either by using a permanently fitted fan, or by temporarily fitting a fan to the capped-off end of the extract pipe provided.

Using an electronic micromanometer, pressure differences are measured between the pressure tubes buried under the floor slab and the interior of the building. The pressure field extension data are normalised by dividing by the pressure measured in the sump itself. In windy weather measurements are difficult to make, but in more favourable conditions a maximum variation of ± 2 Pascal is more typical.

The use of permanent pressure tubes is relatively expensive but for research purposes has some advantages over the more common method of drilling test holes through the floor slab: there is no need to puncture any membranes; the measurements can be repeated easily at any time; there is no risk of damaging services buried in the floor; there is no need for sealing of test holes in the floor. However, it has been found necessary to clear the pressure tubes of condensation before measurements are taken by blowing air through each tube in turn using an ordinary automotive foot-pump.

RESULTS FROM THE WIMPEY TESTS

Pressure extension

One way to assess the results is to compare the pressure extensions, expressed as the pressure at the edge of the floor slab. Since a typical maximum indoor depressurisation due to wind and stack effects is about 5 Pa, a sump system which achieves more than 5 Pa at the edge of the floor is likely to be successful.

The problem in comparing test data with the reality of a sump is that the conditions are not exactly the same. In particular the size of the extraction region is much less in these experiments than would be the case for a sump. This would reduce the pressure extension for a given fan power, which does at least mean that these tests give a worst case result.

Looking at all of the results without any adjustments for the central suction pressure, just over half fail to achieve 5 Pa at the edge of the slab. This implies that many would not be certain to give good radon reductions with a sump.

It is interesting to look at these results divided up into the different types of fill material used. Samples from six sites were consistent in that all slabs gave the same result. Of these two used a cheap material with a wide spread of particle sizes called MOT Type 1, and both failed to reach 5 Pa on any of ten slabs. However the other four sites give a more curious result. Two of these used 3" clean stone, two used 2" clean stone, but one of each size gave good pressure extensions, and the other poor. Hence there is a potential problem with a specification based on fill descriptions, since these are not tightly enough defined for this requirement.

Pressure fields

In each test around 6 pressure measurements were made along a line for each floor slab. Analysing these data allow estimates of the key parameters of the fill to be made. The main one of these is the permeability of the fill, but the resistance to flow of the edge crack, and a non-linear flow resistance term arising in the Darcy-Forcheimer Law may also be significant. The theory of this, and some analysis, was presented in a previous paper [3].

A typical result set is given as figure 2. It shows the pressure falling away from the central suction point, towards the edge of the slab. Two possible models, using the Darcy law and the Darcy-Forcheimer law, both in cylindrical polar co-ordinates, are shown as well. In this case the Darcy-Forcheimer law gives a better fit than the Darcy law.

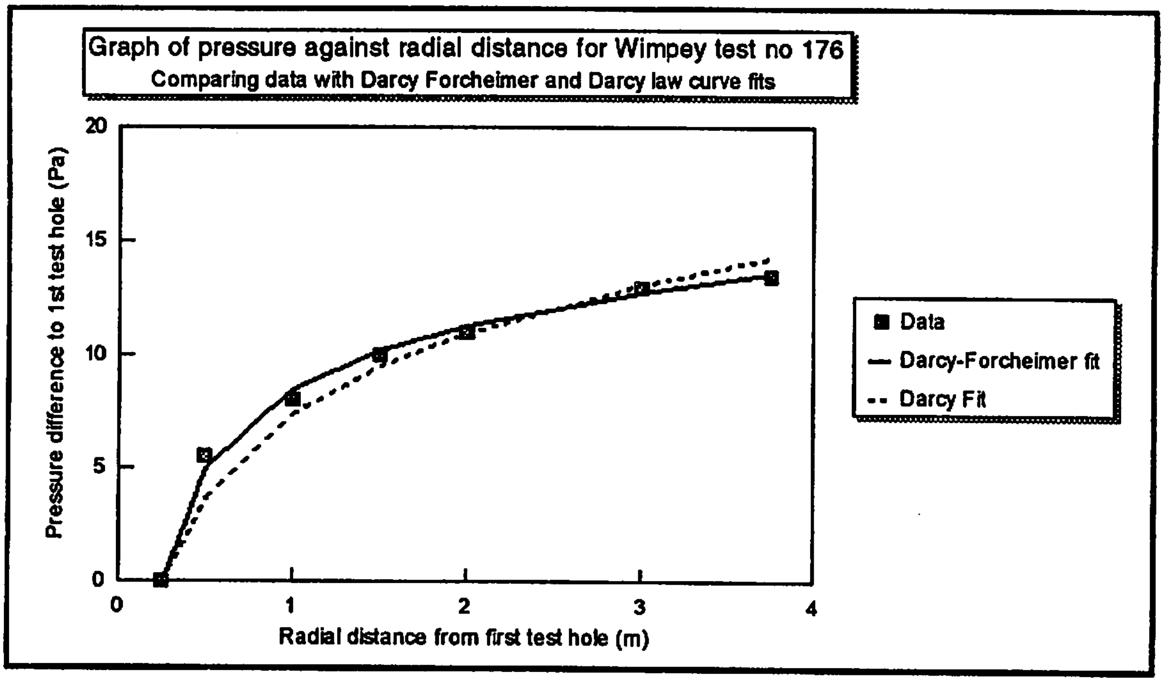

Figure 2: Typical pressure field result from Wimpey tests

Within those results a considerable variation in permeability was found between sites. The permeability could be obtained from each set of results, to reasonable accuracy. However the other parameters needed to describe the soil were often impossible to determine, because of the small number of data points available.

RESULTS FROM THE CORNWALL TESTS

Case studies

The case studies are reported fully in [4, 8]. A brief description of them is included here to give the background and to allow comparisons between the pressure field extension results obtained.

Case study 1 - St Levan School

In this school of a total floor area of 145 m^2, an area of floor 87 m^2 was replaced with concrete on builders rubble as hardcore fill. Because of a history of high radon levels, sub-slab depressurisation was provided by incorporating two BRE/CCC "standard sumps" below the floor linked by 110 mm rigid PVCu pipework to a single extract fan. The pressures measured in the sumps were very different, 125 Pa for the sump with the shortest pipe run and only 56 Pa for the other sump which has a pipe run twice as long and with an extra bend.

A year later the pressures in the sumps were found to have risen considerably to 138 and 71 Pa. The pressures under the floor had also risen, though to varying degrees. A third visit was made to school another two years later. The sump pressures were found to have fallen again to 116 and 61 Pa but the normalised pressure field was almost identical to that found on the second visit.

The normalised results for the first and third visits are presented in Figure 3 and show that there is considerable scatter, particularly for the third visit. This may be partly due to interaction between the two sumps and partly due to variations in permeability.

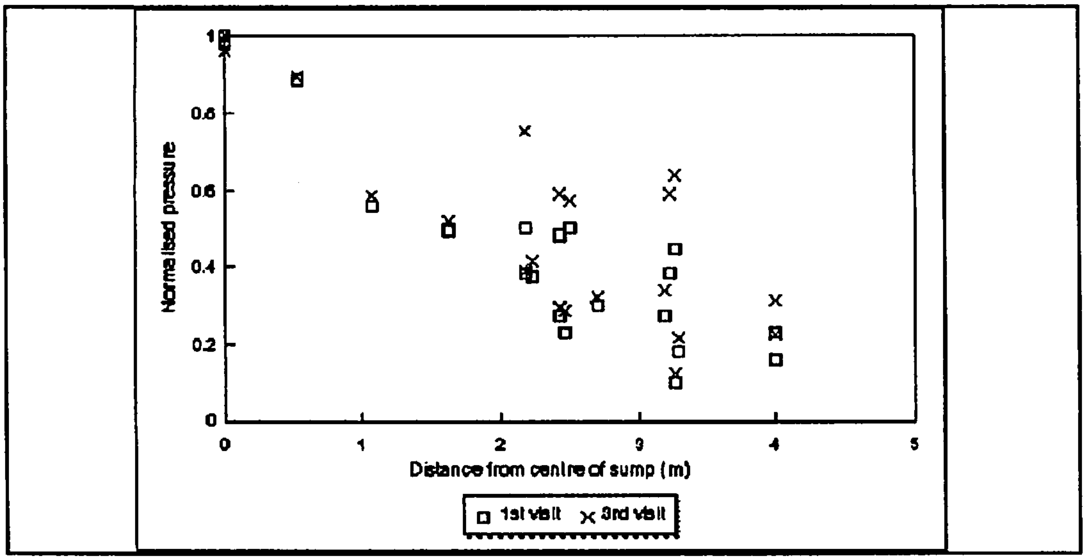

Figure 3: Pressure field at St Levan

These data also suggest that the pressure field extension has actually improved slightly over the first year of operation rather than deteriorated. Possible reasons for this improvement include a change in moisture content of hardcore/soil and (partial) blockage of air flow paths around the edges of the floor.

<u>Case study 2 - Trannack Primary School</u>

Much encouraged by the work at St Levan School, and by work on permeable hardcore fill by the EPA in America [9, 10] a similar exercise was carried out at another small primary school at Trannack. In both size and construction it is very similar to St Levan. A floor replacement exercise was carried out together with the fitting of a single central sump and 51 small bore pressure tubes. The significant difference between this floor and St Levan is that the hardcore fill was covered by a 150 mm thick high permeability layer of 25 mm granite chippings. Unfortunately the chippings delivered to site contained considerable fine material and so the fill was less permeable than had been intended. The total floor area replaced was 71 m^2. A fan was fitted to the sump and a full set of sub-floor pressure measurements taken, presented as a contour plot in figure 4.

The contour plot shows a computer estimated fit between points at which the same pressure would be measured, equivalent to the height lines on a geographical map. An interesting feature of this plot is the way in which there is a direction for which the pressure falls away much less than in the other directions. This implies some variation in the fill in this direction, and it makes the results much harder to interpret. One possible reason for this effect is a drain pipe laid in pea shingle located near this region. It is important to remember that this could occur with any floor slab, so all results where the data were collected in one direction only must be treated with care.

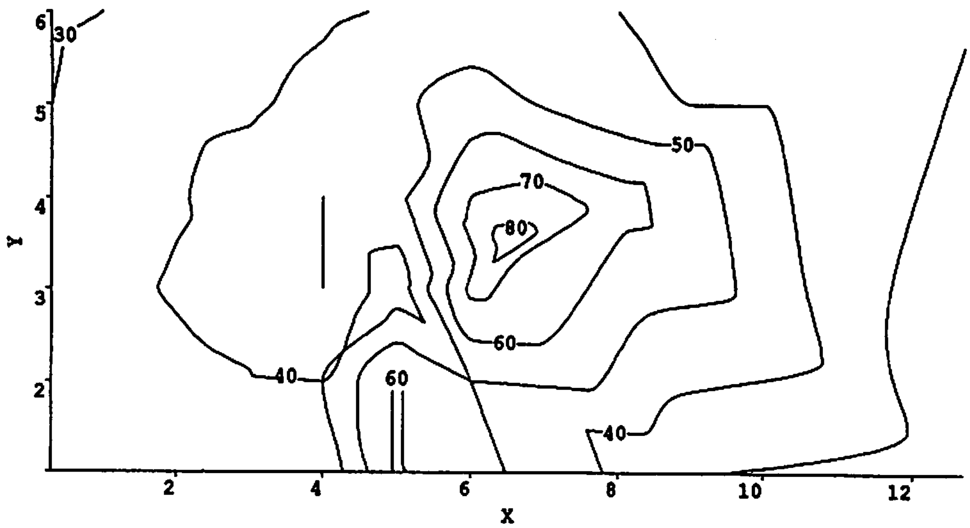

Figure 4: Contour plot for the pressure extension at Trannack

Case study 3 - Pool School

The original floor of one of the classrooms of Pool School was replaced during 1993. Again, a sump with capped off pipework and small bore test tubing was fitted when the floor was replaced. The new floor was similar to that used at Trannack but this time the permeable fill layer had little fine material in it and was covered with a 2000 gauge (0.3 mm) polyethylene sheet before blinding with dry lean-mix concrete (coarse sand and cement) instead of sand. Thus the blinding was prevented from entering the permeable layer by the extra membrane. The floor area replaced was 35 m^2.

A fan fitted to the sump, gave a pressure of 58 Pa, and a full set of sub-floor pressure measurements were taken. The results are presented in Figure 5. The pressure field extension was very good, certainly better than at St Levan or Trannack, although the floor at Pool is significantly smaller than the other two. There was also little scatter in the data.

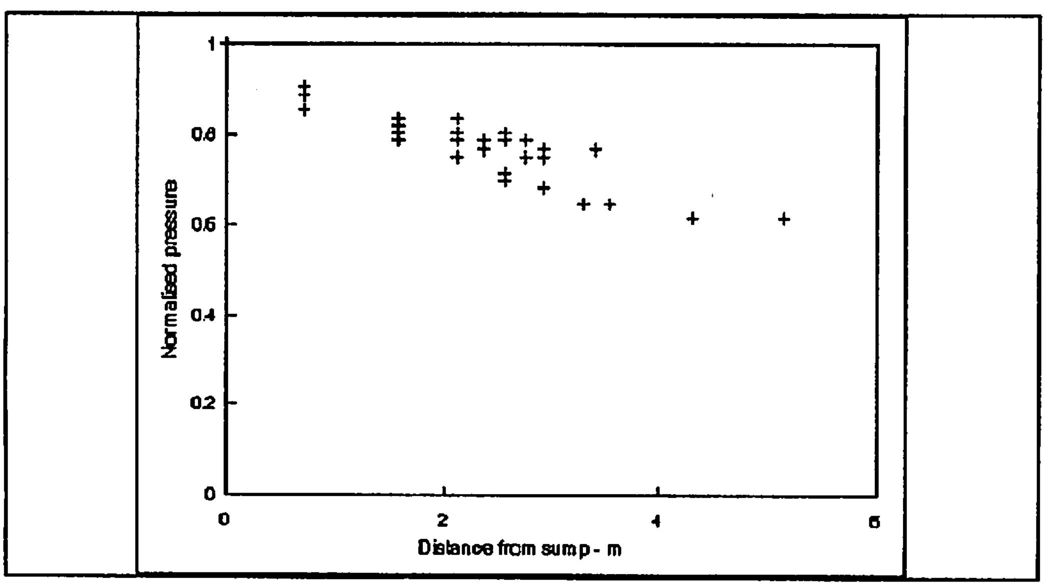

Figure 5: Pressure field extension for Pool School

The pressure measured in the sump at Pool was much lower than that measured at both St Levan and Trannack and with similar pipework attached to the fan outlet. It was concluded that the good pressure field extension combined with a relatively high air flow rate was due to both good fill permeability and the small floor area. It was hoped that the next case study, having a much greater floor area, might provide more useful information.

Case study 4 - Launceston College

At Launceston College gymnasium the original 254 m² wooden sprung floor needed to be replaced. The small bore test tubing and a single central radon sump were fitted across the 16 metre square floor area.

The replacement floor comprised: builders rubble hardcore fill up to top of sleeper walls, 300 mm thick layer of high permeability hardcore of clean 25 mm granite chippings, 2000 gauge (0.3 mm) polyethylene membrane, blinding layer of dry lean mix concrete, glass fibre reinforced heavy duty polyethylene damp proof membrane with lapped and taped joints followed by the 125 mm thick concrete slab.

A significant difference between Launceston College and the previous case studies was the presence of a concrete oversite below the rubble hardcore fill layer. This would be expected to greatly limit, though not eliminate, air flow from the soil below the permeable hardcore, which might be expected to help to maintain the pressure field to the edges of the floor.

The results for Launceston College (Figure 6) show that the pressure field extension achieved was similar to that at Trannack and considerably worse than that achieved at Pool and in an American study [10]. This result was particularly disappointing because the floor construction was known to have been exactly to specification and should have provided the optimum conditions for excellent pressure field extension.

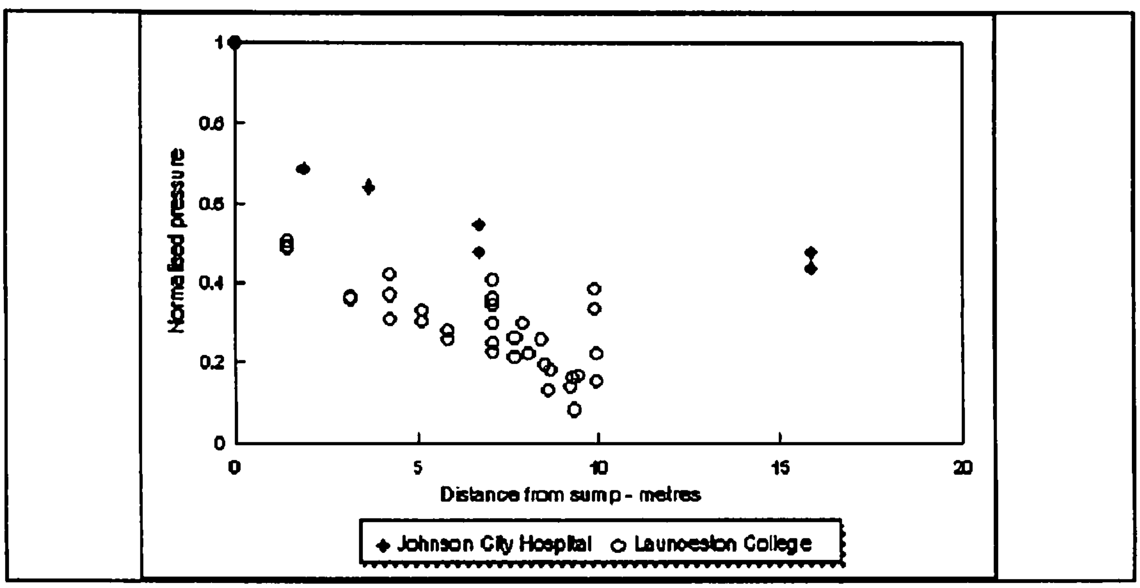

Figure 6: Pressure field from Launceston College

The sump pressure measured at Launceston was only 42 pascals, even without the resistance of a fan outlet pipe and rain cap as was used at Trannack and Pool. This suggests that the air flow rate was indeed higher at Launceston (we estimate an air flow rate of approximately 257 m³/h). It would appear that the concrete oversite, bounding wall and floor slab surrounding the permeable hardcore layer were not particularly airtight. Most of the pressure drop appears to occur through the permeable hardcore material.

Case study 5 - Stoke Climsland

Stoke Climsland school was under construction when measurements were taken. Changes were made to the original floor specification as follows: top 150 mm of sub slab fill changed to clean 25 mm granite chippings; use of dry lean-mix concrete as a blinding instead of sand; provision of short lengths of 32 mm diameter plastic pipe at approximately 1800 mm centres to encourage communication through the numerous internal foundation walls below the floor slab. The remaining floor construction remained unaltered. The existence of these internal walls within the foundation region was the main difference from the previous cases, and presents an extra challenge in ensuring good pressure extension.

Results for all three sumps were taken the actual sump pressures measured being 101, 121 and 151 Pascals and estimated air flow rates 270, 260 and 230 m^3/h in sumps 1, 2 and 3 respectively. The pressure results for sump 2 are given in Figure 7 below.

The pressure field extension at Stoke Climsland, presented in Figure 7, was similar to that obtained at Launceston, in spite of the numerous internal foundation walls and absence of a membrane under the blinding, but again was not as good as had been hoped for based on American experience [10], and see discussion below.

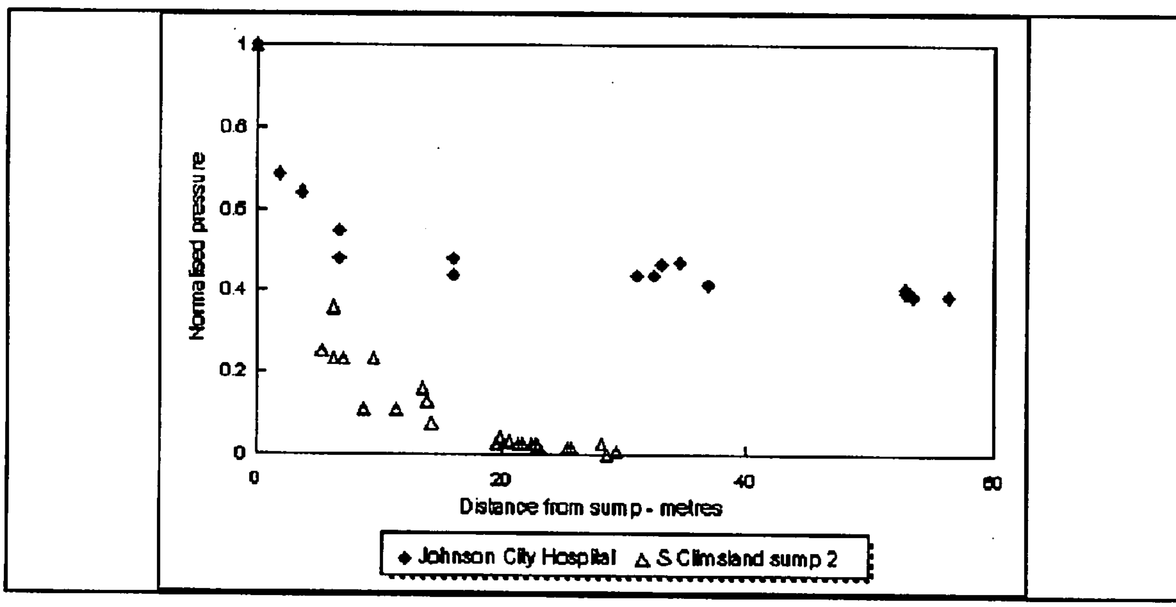

Figure 7: Pressure field at Stoke Climsland, compared to USA result

Although these results show pressure extending a considerable distance from the sump, the results are much less dramatic than those from the USA. It is not clear why this should occur, since a lot of care was taken in the design and installation of this floor. A feature not apparent from the sump 2 data was a definite drop in pressure at the sub floor walls, which the USA study appears to have avoided.

DISCUSSION

The principal problem in building radon protection into floors is to balance the need for air flow through the fill material with the structural role of the fill in supporting the floor slab and the practicalities of constructing the floor. If the builders are not happy building with a particular fill they are unlikely to do so, and will build in a different way. In England this has been seen with the move in Devon and Cornwall to building precast suspended concrete floors. This is due in part to problems with the fill, and also to the requirement to lay the slab on top of the inner leaf of the cavity wall. To reduce the costs to a minimum these may need to be looked at again.

This work suggests that some of the materials routinely used on English building sites may not be adequate for ensuring sufficient air flow. The current mention of using 'clean permeable fill' is not adequate, and it may be necessary to describe the type of material more carefully in future.

One problem which it was not possible to address in the Wimpey work is how the layer of sand 'blinding', generally laid on top of the fill before the floor slab is poured, affects the air flow performance. The use of a membrane over the fill material seems to have been effective in the Cornwall test, together with lean mix concrete in place of a blinding layer. Whether this could be a routine method will need further discussion.

Other possible solutions to the problem could lie in using mixed layers of fill or a ventilation layer of another material. In the former case two layers of fill would be used, the lower one ideal for compaction, like MOT Sub Base Type 1, and a more permeable upper layer to allow air flow. An alternative is to replace the upper layer with a geotextile and drainage matting. BRE are currently looking at the performance of these in the laboratory, and hope to investigate their use beneath buildings in the future.

An interesting result found in both sets of tests is the significant difference between floors of similar specification. For example at Pool the specification for the floor was accurately followed and the result was excellent pressure field extension but this success was not repeated on the much larger floor at Launceston using an identical floor construction

Another area of concern is why the UK results do not match those found in the USA tests [9, 10]. This is in spite of the great care taken in some of the tests to achieve good pressure extensions. This deserves further study.

Comparing the test methods

The two different methods of obtaining pressure extension results give different but complementary information on the behaviour of floor slabs. The method used in the Cornwall tests gives a lot more information on each site, but could only be used for selected cases. There would be no benefit in using it in a wider number of cases, and this would be very expensive.

The vacuum cleaner type of test could be used for post-construction testing, in order to help in the sizing of a fan for a particular floor, and if the floor has been laid correctly. However it is unlikely that this will be worthwhile in the UK where the cost of remedial measures has to be kept to a minimum. It also punctures the damp/radon proof membrane in a way which is difficult to repair. The technique does give useful information on how different fill materials perform, and this information can be used to help to inform future choices.

CONCLUSIONS

A total of 78 tests of the air flow through fill materials have been carried out, using a post construction technique with a vacuum cleaner. In addition five detailed tests have been carried out by installing plastic tubing below the floor before it is laid. Overall these show that there is a wide variation in the behaviour of the fill materials to the air flow caused by sucking from the centre of a floor slab. However careful choice of hardcore specification and avoidance of excessive blinding can significantly improve under-floor permeability compared with normal UK floor construction practice, even when not carried out perfectly.

The extent of the pressure extension varies considerably, with more than half of the large group of floor slabs having less than 5 Pa at the edges. In the detailed cases the performance achieved in tests by the EPA in the USA was not reproduced. It is not clear why this occurred.

The Cornwall work indicates that blinding materials should be kept out of the permeable material. A polyethylene membrane would achieve this and may allow the usual sand blinding to be used. Alternative systems involving lean mix concrete blinding layers or preformed gas collection layers deserve consideration.

The increased pressure field extension obtained by improved design could result in new-build properties requiring fewer under-floor suction points and/or a reduction in fan power consumption with a greater degree of confidence of success than at present. However, this must be balanced against the extra floor construction costs, practical difficulties and current inconsistency in results. The results of these two studies will be used to feed into the process of improving the design of protective measures for new buildings in the UK.

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