Building Research Establishment Report

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Construction of new buildings on gas-contaminated land

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SUMMARY
Incidents involving landfill gas in buildings have increased in recent years and these are of concern to developers and builders who are faced with the problem of developing sites where this gas is present. The principal components of landfill gas are methane (which is flammable) and carbon dioxide (which is toxic), but these two gases are also associated with coal strata, river silt, sewage and peat.

Approved Document C of the Building Regulations has been revised to take account of the problems that landfill gas poses to building development and this report is intended to supplement the information contained in that Approved Document. The report provides a brief background on the production of landfill gas, its properties and how it migrates off-site. It then goes on to discuss assessment of gas-contaminated sites and outlines the construction principles that need to be followed when ground where methane and carbon dioxide are present is built on.

The types of construction covered in this report are a concrete slab with a granular venting layer, and a ventilated subfloor void. It is recommended that private houses should be protected using only passive measures, and that active measures, which include gas monitoring, are only appropriate where there is a responsible body which can provide continuing maintenance for these measures. The report gives minimum recommended areas of ventilation and the standard for gas-proof membranes. It also recommends that service pipes and cables should be directed into buildings above the floor but that if this is unavoidable then all entry points should be properly sealed against gas ingress.

Guidance on the construction of buildings on landfills that are actively producing gas is not given in this report; in these instances further specific guidance should be sought.

INTRODUCTION

Incidents involving landfill gas in buildings have increased in recent years and these are of concern to developers and builders who are faced with the problem of developing sites where this gas is present. The principal components of landfill gas are methane (which is flammable) and carbon dioxide (which is toxic), and so if it enters a building it can pose a risk to both health and safety. These two gases are also associated with coal strata, river silt, sewage and peat.

Requirement C2 of Schedule 1 of the Building Regulations 1991[1] for England and Wales states that 'precautions shall be taken to avoid danger to health and safety caused by substances found on or in the ground to be covered by the building'. Approved Document C[2] to the Building Regulations includes methane and carbon dioxide as contaminants, and it refers to the present report for guidance on the construction of new buildings to control the ingress of these gases.

A full discussion of site investigation is given in another BRE report[3].

PRODUCTION OF LANDFILL GAS

Landfill gas is produced by the breakdown of organic material by micro-organisms under anaerobic (oxygen-free) conditions. The principal components of landfill gas are methane (typically 60% by volume) and carbon dioxide (typically 40% by volume), but other gases such as hydrogen, hydrogen sulphide and a wide range of trace organic vapours can also be present. The production of landfill gas goes through various phases during which the composition of the gas generated changes significantly. Further information on the production and nature of landfill gas can be found in DOE's Waste Management Paper 27[4].

PROPERTIES OF LANDFILL GAS

Methane is a flammable, asphyxiating gas, the flammable range being 5 to 15% by volume in air. If such a methane–air mixture is confined in some way and ignited then it will explode. The 5% by volume concentration is known as the lower explosive limit (LEL). Methane is a buoyant gas, having a density about two-thirds that of air.

Carbon dioxide is a non-flammable, toxic gas with a long-term exposure limit of 0.5% by volume, and a short-term exposure limit of 1.5% by volume. It is about one and a half times as heavy as air.

The properties of landfill gas are principally determined by the proportions of these two gases and any air that it is mixed with. Although landfill gas may be heavier or lighter than air depending on the relative quantities of methane and carbon dioxide, the gas will move from a high-pressure area to a low-pressure area independently of its density. The components of landfill gas remain mixed and do not separate, although the mixture can remain separate from surrounding air.

MIGRATION OF LANDFILL GAS

Landfill gas will migrate from a site as a result of diffusion (moving from a high concentration of gas to a lower concentration) and flow due to pressure differences. Pressure-driven flow is more dominant within the landfill itself and when the gas is pumped, whereas diffusion is more dominant for off-site migration. Flow rates of landfill gas will obviously be higher through high-permeability ground (eg sand and gravel) than through low-permeability ground (eg clay). However, cracks, cavities, pipelines, tunnels and so on provide ideal pathways for the gas[4]. Emissions of landfill gas can be increased by rapid falls in atmospheric pressure and by a rising water table. Rainfall and freezing conditions tend to seal the ground and so encourage migration of landfill gas.

Landfill gas should not be allowed to migrate from landfills in an uncontrolled manner since it might enter buildings located nearby. Migration can be controlled before it reaches sites of building by means of granular vent trenches, low-permeability membranes, clay-filled and slurry trenches, and grout curtains[4] around the landfill.

LANDFILL GAS IN BUILDINGS

Landfill gas can enter buildings through gaps around service pipes, cracks in walls below ground and floor slabs, construction joints, and wall cavities. It can also accumulate in voids created by settlement beneath floor slabs, and in drains and soakaways, and in confined spaces within buildings such as cupboards and subfloor voids. The force driving landfill gas entry is principally the positive pressure arising from the conditions under which it is generated and the slight negative pressure relative to atmosphere that exists in buildings as a result of the stack effect (warm indoor air is less dense than cold outdoor air) and the wind.

DEVELOPMENT NEAR TO LANDFILL SITES

Waste Management Paper 27[4] recommends that the local waste disposal authority should be consulted about any proposed development less than 250 m from the boundary of a site which has received waste in the previous thirty years. This limit was incorporated into Planning Circular 17/89[5], and the General Development Order was also amended to include it.

This figure is not absolute; it does not mean that landfill gas will not be present outside this distance, or that landfill gas will always be present within it. Landfill gas migration is dependent on numerous factors, and so migration may extend further where the ground conditions are favourable, or there may be little or no migration where gas controls are present or where the ground permeability is low. A thorough site investigation should be carried out whenever a building is to be constructed within 250 m of a landfill or when the presence of any hazardous gases is suspected.

ASSESSING GAS-CONTAMINATED LAND

For land contaminated with solid substances such as heavy metals the concept of trigger concentrations is used[6]. There are difficulties in setting a single 'action level' for gas-contaminated land because:

(a) Concentrations of landfill gases in permeable strata can vary significantly with time.

(b) Methane presents an explosive risk which is extremely difficult to quantify, unlike other toxic substances which relate to health.

(c) The background concentrations of these gases in the ground are not zero and they can be found at high concentrations in apparently innocuous environments. Under normal soil conditions the methane concentration is extremely low, of the order of a few parts per million (1% by volume is equivalent to 10 000 parts per million), but higher concentrations of methane can originate from natural sources such as coal-bearing strata, river silts and peat. High concentrations of carbon dioxide can also be produced by these and other sources which include aerobically decaying vegetation (eg grass and leaves) and acidic groundwater reacting with carbonate rocks (limestone).

With many of these natural sources of methane and carbon dioxide, the rate of production of the gas is low and so is the quantity of gas. In some cases, the gas may be trapped by, for example, overlying material with a low permeability such as clay. So, when first tapped, the rate of emission may be high, but subsequent emissions will be very much lower because the reservoir of gas is not replenished. Site investigation methodologies are given in a BRE report[3].

Waste Management Paper 27[4] recommends that housing with private gardens should not be built near landfill sites where methane and carbon dioxide concentrations exceed 1% by volume and 1.5% by volume respectively. The reason for this is that, although the houses may be constructed to an acceptable standard, gas might accumulate in sheds, greenhouses and extensions. In addition, the heat from garden bonfires could cause burning or smouldering of the waste which could result in an underground fire. The paper also recommends that housing should not be built within 50 m of the boundary of a landfill still evolving gas, and that gardens should not extend to within 10 m of the wastes.

Approved Document C[2] contains some broad guidelines for methane and carbon dioxide concentrations in the ground (these two gases should be assessed separately):

(a) If methane concentrations in the ground are unlikely to exceed 1% by volume and a house or similar small building is constructed with a floor built in the manner described in the next section, then no further protection is required.

(b) If carbon dioxide concentrations in the ground are above 1.5% by volume then floor constructions such as those described in the next section should be considered to prevent gas ingress. For concentrations in the ground above 5% by volume, these floor constructions are required.

In other cases, further specific guidance should be sought. As explained earlier, these values should be used in conjunction with an assessment of the quantity of gas in the ground and its rate of emission: high concentrations of gas have less of an impact when the quantity of gas is low. It must be stressed that the concentration of gas found in the ground does not necessarily relate to the concentration of gas which would be found in a building.

CONSTRUCTION PRINCIPLES

Introduction

A gas protective scheme for a building should consist of a low-permeability ('impermeable') gas barrier and also a high-permeability layer from which gas can be extracted in a controlled manner. This section discusses this principle and illustrates it with examples of construction techniques. The solutions outlined apply for methane concentrations in the ground of less than 1% by volume. In other cases further specific guidance should be sought.

It should be stressed that these are not the only solutions and others may be suitable, for example a pile groundbeam construction or a raft foundation.

Houses and other similar small buildings

Concrete slab and granular layer

A simple way of protecting a house from gas in the ground is to have a gas-proof membrane in conjunction with a reinforced concrete floor slab above a granular venting layer. This layer should have a minimum thickness of 200 mm. The membrane can either be sandwiched between the floor slab and the granular layer which would then need to be blinded, or it can be positioned above the floor slab and protected with a floor screed. (A blinded layer is one finished with a fine material, eg weak-mix concrete.) The granular material should be highly permeable (no fines) and not heavily compacted. This gives the two elements of the gas control measure: the concrete slab and membrane act as a barrier, and the granular material acts as a layer from which to extract the gas.

The gas can then be vented to the atmosphere by means of a granular trench around the perimeter of the house. Regularly spaced pipes (every metre or so) can provide a pathway through foundation walls into the trench (Figure 1).

If gas pressures are significantly greater than atmospheric pressure, it may be necessary to cover over the trench and insert vertical risers to vent the gas at roof level, above the eaves, using a suitable outlet device, eg a rotating cowl, to encourage flow (Figure 2). Another benefit of this method is that it can overcome problems caused by the trench becoming clogged or a householder paving it over, either of which will prevent gas from escaping freely.

An alternative scheme is to insert a perforated or slotted gas collection pipe (minimum diameter 100 mm) within the granular layer just below the floor slab. A suitable material for the pipe is high-density polyethylene (HDPE) or polypropylene. This pipe can be connected to the vertical riser (Figure 3).

Another way in which to extract gas from the granular layer is to use airbricks around the layer (Figure 4). In this case, the seal between the airbrick and the inner leaf should be gas-tight to prevent gas entering the cavity, and, if telescopic airbricks are used, the two halves of the telescopic section should be taped together. Cavities are discussed further in the section on membranes.

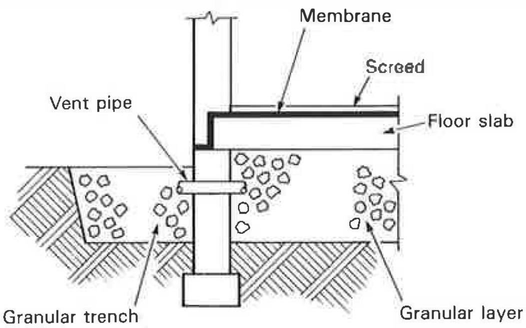

Figure 1 Granular layer beneath the floor slab venting to atmosphere through trench

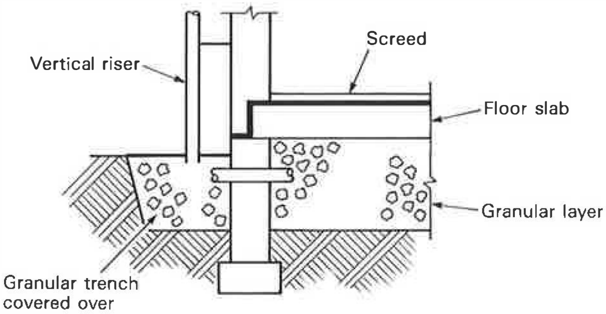

Figure 2 Granular layer beneath the floor slab venting to atmosphere through trench with vertical riser

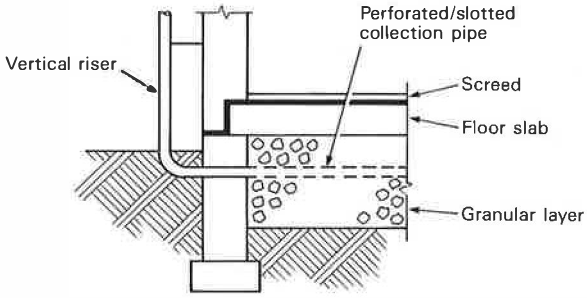

Figure 3 Granular layer beneath the floor slab venting to atmosphere through perforated or slotted pipe and vertical riser

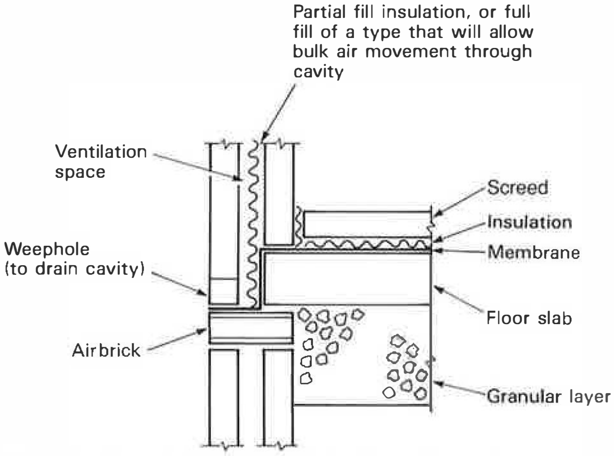

Figure 4 Granular layer beneath the floor slab venting to atmosphere through airbricks, and cavities ventilated

Ventilated subfloor void

Instead of a granular venting layer a passively vented subfloor void can be used to protect houses (Figure 5). Precast concrete flooring with a gas-proof membrane and protective floor screed would be suitable. The recommended minimum area of ventilation for a subfloor void is 1500 mm^2 per metre run of wall or 500 mm^2 per square metre of floor area, whichever gives the greater area of opening. The void should be well cross-ventilated (airbricks located on opposite walls) and there should be plenty of air gaps in sleeper walls to ensure that there will be no pockets of still air where gas could accumulate. Air should be allowed to flow freely through the airbricks and they should not be blocked by debris (leaves, etc) or covered up by further construction around the building.

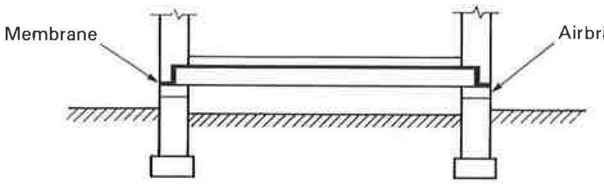

Figure 5 Gas-proof membrane in suspended concrete floor with subfloor void ventilated through airbricks

The performance of passively ventilated voids can be improved using knowledge of local weather conditions, ie wind speeds, directions and frequencies. A high degree of local shelter will impair the performance of such voids. It is desirable to maximise rates of ventilation in such voids to prevent significant concentrations of methane accumulating within them, and so adequate thermal insulation of the floor is important[7].

There may be circumstances in which the two methods of gas protection outlined (granular layer and ventilated void) could be combined, but for a house this is not usually necessary.

Gas protective schemes for new houses should be passive, ie they should not involve mechanical ventilation or monitoring, and therefore houses should only be constructed on sites where the level of gas will remain relatively low. A sharp increase in indoor methane concentration as a result of a mechanical ventilation failure cannot be tolerated at any time because a source of ignition will nearly always be present. A gas monitoring device cannot be used to detect a mechanical failure because it too would require maintenance to ensure that it is working correctly. It should be noted that a mechanical ventilation system can be used to reduce indoor radon concentrations[8] because, if the system should fail, a short-term increase in indoor radon concentration is not a significant risk.

Industrial, commercial and other large buildings

Introduction

The construction principles used to build floors for houses can be used for larger buildings too. An important consideration with these building types is the extent of post-construction control, ie whether there is a responsible body who will be able to maintain the gas control scheme for the building after it has been constructed. If there is such a body then a gas control scheme can include monitoring equipment and gas pumping systems/mechanical ventilation if needed.

Gas protective schemes which include mechanical ventilation/extraction and gas detection are by their nature more complex and involved than passive systems, and therefore further specific guidance should be sought for their design.

Concrete slab and granular layer

A concrete slab with a gas-proof membrane and a granular layer can be used in much the same way as for houses. It may be necessary, however, to have a more efficient method of gas collection beneath the floor, and this can be achieved by means of numerous perforated or slotted gas collection pipes within the granular fill which can be connected to vertical risers, as for houses, if needed. The spacing of these pipes will be determined by the quantity of gas in the ground, its pressure and the method of extraction, but spacings of between 6 and 12 m have been used. Again, the system can be passive but mechanical extraction could be used, with the pipework connected together as a network with a single extraction point (Figure 6). It may be desirable to allow replacement air to be drawn into the pipework by connecting the ends of the pipes to suitable air inlets (Figure 7). This can help to dilute the reservoir of gas beneath the floor.

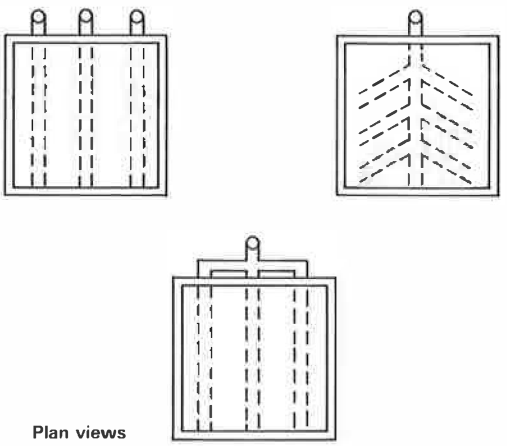

Figure 6 Examples of layout of gas extraction systems beneath buildings

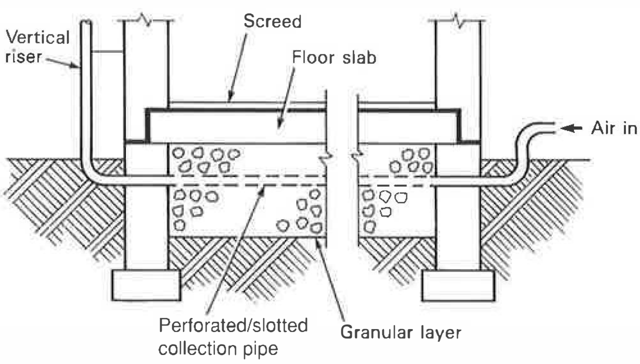

Figure 7 Gas extraction system for building with air inlet

Ventilated subfloor voids

Ventilated voids can be used for these types of buildings as well as for houses, but there can be practical difficulties in constructing them. For example, to achieve a floor free from cracks using suspended precast concrete slabs requires the use of flexible sealants. In the case of a slab cast *in situ*, permanent formwork could restrict air movement within the void. Downstand beams need to have regularly spaced openings to assist air movement. Constant mechanical ventilation of the void is an option with non-domestic buildings, and ventilation rates of 1 to 2 air changes per hour have been used, but the exact ventilation rate will depend on the results of the site investigation, ie the measured gas concentrations and emission rates. Any mechanical or electrical equipment, including fans, located in an area where there may be high concentrations of flammable gas must be capable of operating in a potentially explosive atmosphere.

Gas detection

Gas detection equipment can be used in commercial and industrial buildings. Monitoring can be either periodic, carried out using portable equipment, or continuous, using permanently installed gas detectors. The type of monitoring will depend on the nature and use of the building, and the concentration of gas. The frequency of monitoring can be reduced after a period of time if it has shown that the gas control system is successful in excluding gas from the building.

Permanent gas detectors should be located near to likely points of gas ingress, such as service entries, and in confined areas where gas may accumulate such as subfloor voids and cavities[3]. If gas concentrations exceed preset limits extra mechanical ventilation can be triggered or, if gas concentrations become unacceptably high, audible and visual alarms can be activated and the building evacuated. (Waste Management Paper 27[4] recommends that buildings be evacuated if the indoor methane and carbon dioxide concentrations exceed 1% by volume and 1.5% by volume respectively.) Evacuation procedures need to be established, and the local fire and police services as well as the environmental health inspectorate need to be made aware of these provisions.

Membranes

The minimum recommended standard of membrane is 300 micrometre (1200 gauge) polyethylene sheet. Other suitable materials with comparable and higher gas resistance are available, such as flexible sheet roofing materials, prefabricated welded barriers and self-adhesive bituminous-coated sheet products. The principal consideration with a gas-proof membrane is not with permeability (no membrane is 100% impermeable) but whether it can withstand the construction process because, once torn or damaged, the membrane ceases to operate as an effective barrier. Adequate quality control during the laying of the membrane is extremely important; the membrane should be protected either through the use of temporary boarding over its whole area, or by the immediate laying of a floor screed. Manufacturers of these membranes provide instructions on how to lay them but the main matters to be considered are:

(a) Protection for both sides of the membrane should be provided, eg through the use of floor screeds and blinding.

(b) Separate sheets should be overlapped, rolled or taped to ensure continuity. (Alternatively, sheets can be welded together, although care should be taken to avoid damaging the membrane during this process.)

(c) Special sections for edges and corners can be used to continue the gas-proof barrier over these awkward areas.

(d) The gas-proof barrier should be continued across cavity walls to prevent gas accumulating in them and within roof voids (roof voids should also be properly ventilated). This can be achieved with a cavity tray ensuring that, as far as possible, all joints are gas-tight. The cavity should also be ventilated (Figure 4).

(e) Damage or tears in the membrane should be repaired.

(f) To avoid problems of differential settlement of the subsoil beneath the slab, the membrane can be attached to the underside of the concrete slab (Figure 8).

(g) The minor components of landfill gas and leachate can be corrosive. Therefore, if these chemicals are likely to be present, the membrane should be suitably resistant, eg high-density polyethylene or a bituminous membrane.

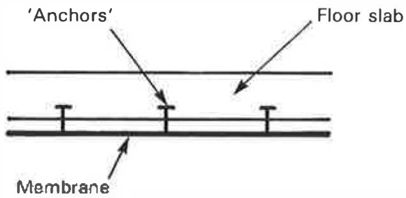

Figure 8 Gas-proof membrane attached to underside of concrete floor slab

With careful design and selection of material a single barrier will satisfy both the requirements of damp-proofing and gas protection.

Services

Service penetrations through the membrane should be kept to a minimum and to this end services can be directed into the building above the floor slab with all entry points sealed against gas ingress (Figure 9). Meters can be enclosed in naturally ventilated chambers. If services have to come through the floor slab and membrane (this may be unavoidable in the case of water and soil pipes) then they should be surrounded in dense concrete and puddle-flanged (Figure 10), or sealed using a suitable flexible sealant (Figure 11), and the membrane should be completely sealed around the service. This can be achieved, for example, by the use of a 'top hat' section welded onto the membrane (Figures 10 and 11).

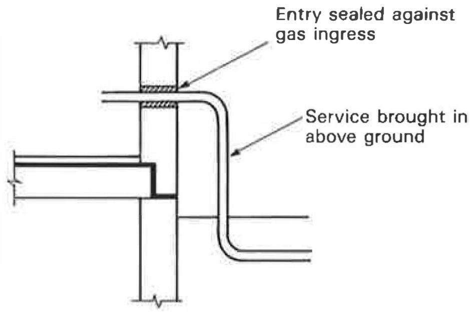

Figure 9 Sealed service entry above floor slab

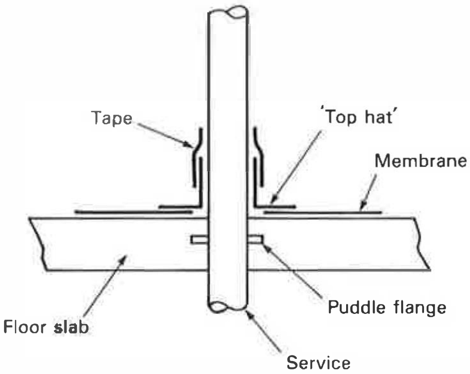

Figure 10 Service entry with puddle flange in floor slab

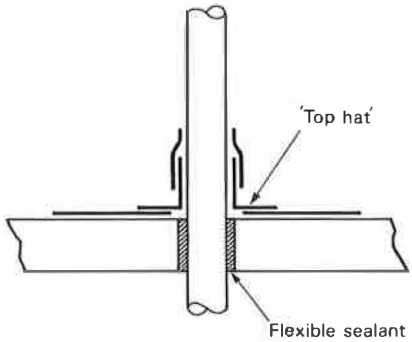

Figure 11 Sealed service entry through floor slab

BUILDING ON LANDFILLS PRODUCING GAS

Building directly on landfills still evolving gas entails dealing not only with large volumes of gas at high concentration but also with unstable ground conditions. There may be toxic materials in the waste as well. These sites should be left to stabilise and are therefore best returned to agricultural use or turned into a public open space.

If, however, building is considered, it should only be undertaken with expert advice. Traditional housing should not be built on these sites. The only suitable forms of 'hard' development are large-scale commercial developments such as offices, supermarkets, etc[9]. Schemes to protect buildings in these situations need to provide multiple levels of protection, eg extraction wells, sealing techniques, ventilated voids and extensive monitoring.

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