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Building on Landfill: A World Perspective

A J Barry, BSc(Eng) MSc DIC CEng CGeol MICE FIHT FGS
G B Card, PhD BSc CEng MICE EurIng FGS
J S Younger, BSc MS PhD CEng FICE FIHT FHKIE FGS

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FRANK
GRAHAM

Head office
Shinfield House
School Green
Shinfield
Reading
Berkshire RG2 9EW
Telephone 0734 882222
Fax 0734 885274
Telex 848830 Grampa G

UK regional offices

Exeter
22 Waterbeer Street
Guildhall Centre
Exeter
Devon EX4 3EH
Telephone 0392 432748
Fax 0392 412846

Hertford
Graham House
Yeoman's Court
Ware Road
Hertford SG13 7NJ
Telephone 0992 587848
Fax 0992 551872

Maidstone
65 College Road
Maidstone
Kent ME15 6SX
Telephone 0622 692442
Fax 0622 692443

Reading
Shinfield House
School Green
Shinfield
Reading
Berkshire RG2 9EW
Telephone 0734 882222
Fax 0734 885274
Telex 848830 Grampa G

Wakefield
6 South Park Way
Wakefield 41 Business Park
Wakefield
West Yorkshire WF2 0XJ
Telephone 0924 290484
Fax 0924 368468

Worcester
Elgar House
Shrub Hill
Worcester WR4 9EN
Telephone 0905 613910
Fax 0905 613907

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A J Barry O'Sullivan & Graham Limited
G B Card O'Sullivan & Graham Limited
J S Younger O'Sullivan & Graham Limited

Abstract

The development of urban landfill sites offers particular challenges and rewards. The paper describes some of the problems, and commonly adopted solutions. Two case studies are described illustrating development on landfill sites. The need to take account of climatic and social differences in different countries is highlighted.

Throughout the world the increasing value of land in large cities makes it attractive to consider developing land which previously would have been dismissed as unusable, or put aside as uneconomic. Furthermore there is an increasing awareness of the benefits of taking advantage of development to clean up land which has been environmentally damaged.

There are numerous sources of environmental pollution (Barry, 1991), but one of the types which has been found to cause some of the greatest difficulties is the waste disposal, or landfill, site. These have problems from two causes:

☐ the fill material is highly compressible and unsuitable for founding any but the very lightest buildings

☐ many waste fills, particularly municipal landfills, contain significant quantities of organic matter, which produce methane and other gases from the organic matter decay; these gases can then reach explosive levels.

Foundations

The problems with foundations can be overcome in a broadly similar manner to development on soft clays and peats: by piled foundations, surcharging, ground treatment by vibroreplacement etc. However where there is decaying organic matter it has to be borne in mind that settlement will continue solely as a result of the decay, and thus surcharging is only of limited benefit.

The amount of settlement of landfills will vary firstly on the constituents of the waste, which vary widely as shown on Table 1. Then the amount of settlement will depend on how the waste was deposited; traditional loose tipping of material will result in much higher settlements than modern highly compacted or baled waste landfills.

	United Kingdom	United States	Middle East City	Asian City
	% by volume			
Vegetable	31	20	50	75
Paper	31	43	16	2
Metals	5	7	5	0.1
Glass	4	9	2	0.2
Textiles	4	3	3	3
Plastics	5	5	1	1
Other	20	13	23	13
kg/person/day	0.85	1.95	1.1	0.42

Table I Constituents of Waste Around the World (Robinson, 199 1)

The settlements are difficult to quantify with any accuracy; Parkinson (199 1) estimates that total settlements of 10 to 40% of the thickness occur, including compression under the self weight during placement. Yen and Scanlon (1975) provide a relationship between settlement and time based on a rate of biodegradation; and Oweis & Khera (1985) divide settlement into three phases, and provide typical parameters for each phase, based on actual landfill settlements.

From case histories the typical magnitude of estimated total settlement can be of the order of 200mm to 500mm occurring during the design life of the development. Such large settlements preclude the use of conventional shallow foundations for structures. Piled foundations with ground beams are the most likely technical solution. Drainage and underground services may be constructed using flexible construction techniques. Provision for settlement in drainage pipes may be accommodated using flexible couplings and gradients over and above those required for hydraulic design taking into account the estimated long term settlement characteristics of the waste. Where flexible construction techniques cannot be used to accommodate large settlements, piled structures are likely to be the only acceptable solution.

Gas Generation

The problem of gas from landfills was first brought to public attention at Loscoe in England in 1984 (Williams & Aitkenhead, 1991), when the migration of landfill gas into an adjacent area resulted in an explosion which destroyed a house; the problems of landfill gas had however been known previously (PSA, 1977).

Other countries have also reported incidents from landfill gas explosions:

In Canada the incidence of landfill gas is well understood and studied, but the incidence of reported explosions is very limited; one case is of an explosion in a house, but the extent of damage is not reported (Fugler, 1992).

In Algeria an explosion in a hotel basement resulting from landfill gas entry is reported to have killed one person.

In Hong Kong a worker in a trench caused an explosion from landfill gas migrating from a nearby site, without serious injury.

In the United States the Environmental Protection Agency have carried out much research, but there are no reported cases of loss of life from landfill gas explosions. In Europe the problem has been less studied, and again reported cases are rare or absent

It is thus clear that concern about landfill gas results from its potential for harm, rather than any serious history of damage or loss of life. Nevertheless, some countries have introduced controls over building on or near gassing sites. In the United Kingdom it is considered unacceptable to site most new developments within 250m of a former or active landfill site. However this approach should not be adopted without considering all the issues involved.

Firstly there are numerous developments adjacent to old landfills, and some actually built on top of landfills; the number of deaths and injuries resulting from this is not known, but in comparison to other risks is small. In the United Kingdom the risks from a number of causes are shown on Table 2

Cause	Deaths per year
Fires in the home	625
Lung cancer caused by radon	2000
Accidents in the home	4000
Road accidents	*5000*

Table 2 Some Causes of Death in United Kingdom

To these risks might be added, in less developed countries, those from lack of piped water, and lack of medical attention, both of which might well be lessened by provision of low-cost housing, perhaps on a landfill site.

Secondly the technology exists to engineer safe development, so long as the long-term control of the site can be assured.

Thirdly past and present gas levels vary widely on landfill sites, and the risk associated with development also varies over a wide range.

The Engineering Approach

The most economic solution to developing on or adjacent to a gassing landfill site is generally achieved by capping the site to control the rate of emission of the gas to an acceptable level.

Specific measures for controlling gas fall into two broad categories:

3 controls for preventing or regulating gas emissions and migration from the landfill source, both from surface and subsurface boundaries.

❐ controls for preventing migration of gas into confined spaces within building structures.

Within the gas generating area it is normal to provide controlled venting and removal of gas by passive ventilation measures (trenches, wells etc) and active abstraction systems (pumped extraction and flaring). Where generated gas levels are high the gas has been used to provide energy; however it is unlikely that such an actively gassing site could be developed safely.

General guidance on construction aspects of passive venting trenches and wells have been published (HMIP, 1989). However research is currently being undertaken by the second author on behalf of the Construction Industry Research and Information Association (CIRIA) to provide comprehensive guidance, and the results of this research are due to be published later in 1992 (Card, 1992).

A recent technique developed for stabilising landfill sites for highways and parking areas is the use of lime (calcium hydroxide) flyash pressure injection (Blacklock, 1987). Since methane producing bacteria function best in a pH range between 6.4 and 7.4, by raising the pH to above 8 by injecting lime the generation of methane can be reduced, or possibly even eliminated. Thus this technique both stabilises the fill structurally and controls the generation of gas from the biodegradation process.

Long term Consequences

Control measures relying on capping and ventilation require long-term maintenance. Thus they may not be suitable for development involving ultimate fragmentation of final ownership, or where in the long-term the commitment of the owner to maintenance cannot be assured.

Thus landfill sites lend themselves to development for

- municipal buildings
- shopping centres
- hotels

where long-term building service management is undertaken as routine, and maintenance of the gas control system can form part of this. Social housing may be a suitable development if there is adequate control of unauthorised development, or the risks from the gas are low.

Case Histories

The following two case histories identify firstly how a low risk gassing site with some additional problems of contamination could be developed for offices. In the second case a substantial level of gassing was controlled sufficient to allow use for a retail development.

Case 1

The uncontrolled tipping of domestic waste over a number of periods between 1930 and 1950 provided engineering problems for the development of a site in south east England for a prestigious new office development, for the headquarters of the Frank Graham Group, the parent organisation of O'Sullivan and Graham.

Low but variable levels of landfill gas were monitored during investigations, and gas control measures were therefore recommended. A passive venting system was adopted to ensure no build up of gas beneath the development, and the ground floor slab was designed as a suspended slab with underfloor void. Air vents through the external walls were carefully designed to disperse any gas, with ample safety margin to allow for any subsequent increase in methane generation.

Monitoring of gas concentrations both during and subsequent to the development showed persistent but low levels of gas. No gas has been detected in the ventilated underfloor void space.

Case 2

In eastern England an infilled old chalk quarry was included within a site for coach and car parking facilities, with associated management buildings, for an 'out of town' retail development, Landfill gas was detected in monitoring wells on the site and a distinct pattern emerged. High levels of methane up to some 13% by volume in air and carbon dioxide up to some 6.6% volume in air were recorded in the backfilled chalk quarry. Beyond the zone of the quarry much lower levels of methane were detected although levels of carbon dioxide indicated migration over greater distances through natural ground.

The development programme did not give time to undertake detailed monitoring to establish gas generation patterns . 'Worst credible' gas parameters were therefore adopted to take account of time and of climatic variations on possible fluctuations in the landfill gas regime. These parameters were based on an evaluation of the total organic content of the infill which could be potentially converted into landfill gas and allowed to migrate through the site surface.

The gas control measures for the site were designed to form an integral system. Over the infilled chalk quarry a passive venting system was constructed comprising trenches and/or deep wells. The trenches were constructed to the full depth of the infill and into natural ground typically up to 3m in depth and backfilled with free draining granular material. Where the depth of the infill was greater than the reach of the excavator, gas wells were constructed to the Ml depth of the fill. The wells were interconnected by a series of trenches. Typical details are illustrated in Figure 1.

The arrangement of gas trenches and wells was designed to suit the layout of the car and coach park. The trenches and wells were generally on a grid layout across the infill and on the perimeter to intercept and cut-off gas. This was required to prohibit migration beyond the boundary of the site towards adjoining development land intendedfor residential housing.

In addition to the gas trenches and wells the site surface was encapsulated beneath a low permeability clay capping. All hardstanding and pavement construction was of gas permeable material, to allow venting to open areas.

All buildings on the site were supported on piled foundations and incorporated an integrated gas control system. The main components of this system were:

❒ a 0.5m thick clay capping

❒ ventilated void space beneath the ground slab

❒ gas resistant membrane across plan area of ground slab and cavity walls

3 installation of gas monitoring/detection equipment to allow performance of the control system to be checked.

A typical cross section is indicated in Figure 2. The clay capping layer was placed and compacted over the 'footprint' of the building. Its purpose is to regulate gas emission. In order to counter the adverse effects of excessive moisture loss and cracking of the clay through drying and shrinkage a polyethylene membrane was placed over the clay and in turn protected by a sand blinding. A gas resistant membrane was laid over the entire slab area of the building structures. The membrane comprised flexible high density laid across the ground floor and cavity wall void as indicated in Figure 3. The membrane was placed over the ground slab and underneath the concrete screed floor finish to ensure an integral seal. Care was exercised to ensure with the manufacturer that the membrane was capable of being laid beneath load bearing walls without excessive deformation and potential rupture.

The geometry of the ventilated void was based on conventional design procedures for natural ventilation systems for buildings as given in BS5925 (1991) and the CIBSE (1986). These documents give guidance on design wind speeds, friction losses, required ventilation rates and margins of safety. From this information it was possible to calculate the required dimensions of the void together with size and spacing of vents in order to maintain the level of any landfill gas to a design concentration of 0.25% by volume in air. In addition, the ventilated void was designed such that this design gas concentration could not be exceeded in any 72 hour period.

A gas alarm system was incorporated into the void space and incorporated two stages of activation:

- ❐ Low Level Alarm; set at 0.25% methane in air to provide warning that gas levels have increased and a requirement for immediate investigation, ventilation and, if necessary, further remedial action.

- ❐ High Level Alarm: set at 1% methane in air to indicate elevated gas levels in excess of the design levels and a requirement for immediate evacuation of all personnel, ventilation of the building, investigation of the cause and attendance of emergency services.

The implementation of these measures has allowed construction to take place on land otherwise blighted for development, and produced a general ‘clean up’ of the environment. The measures have also curtailed the previous levels of offsite migration below ground into adjoining land where planned residential development could also have been blighted.

The World Context

Designs to allow developments on gassing sites have been developed in some countries, notably Great Britain, and also in North America. Such experience can be drawn upon by other countries, who must however adapt it to their own circumstances.

In particular, climatic variations, and consequent different building needs, require widely different design solutions. To give one example: in the United Kingdom passive gas venting of buildings is provided-by vents from the under-floor void, placed near ground level. In Canada ventilation is by central chimneys, since ground level ventilation would be inoperative for much of the year when blocked by snow.

In tropical climates wind speeds can vary considerably seasonally, and over some periods passive ventilation relying on wind flushing of ventilators may be inadequate. However thermal gradients can be high, and be the dominant means of providing air and gas movement for ventilation.

Conclusions

The development of former landfill sites is a viable proposition, if the type of development is chosen to suit the circumstances of the site, and the whole of the development is designed to take account of the particular difficulties. By this means a liability can be turned into an asset.

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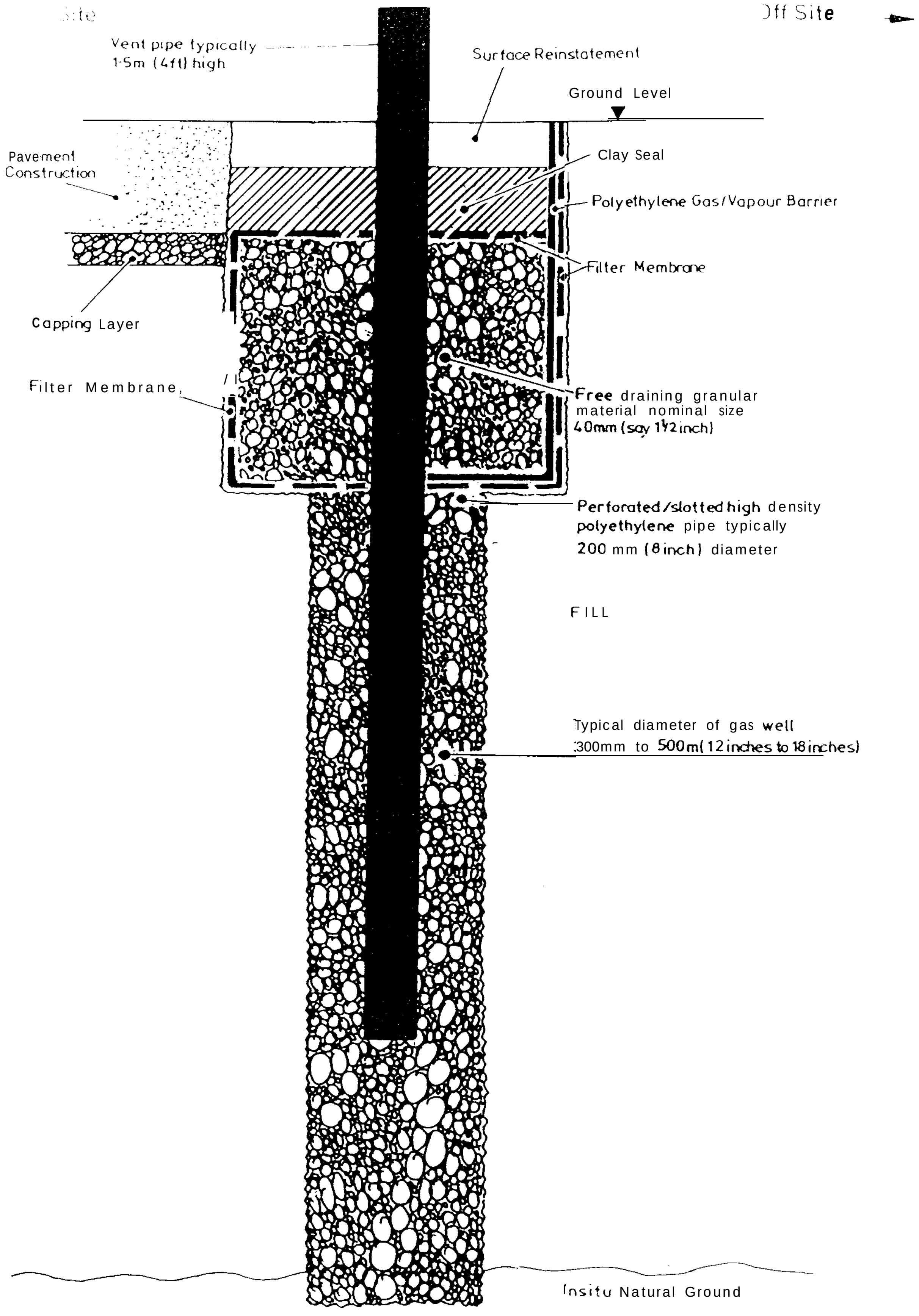
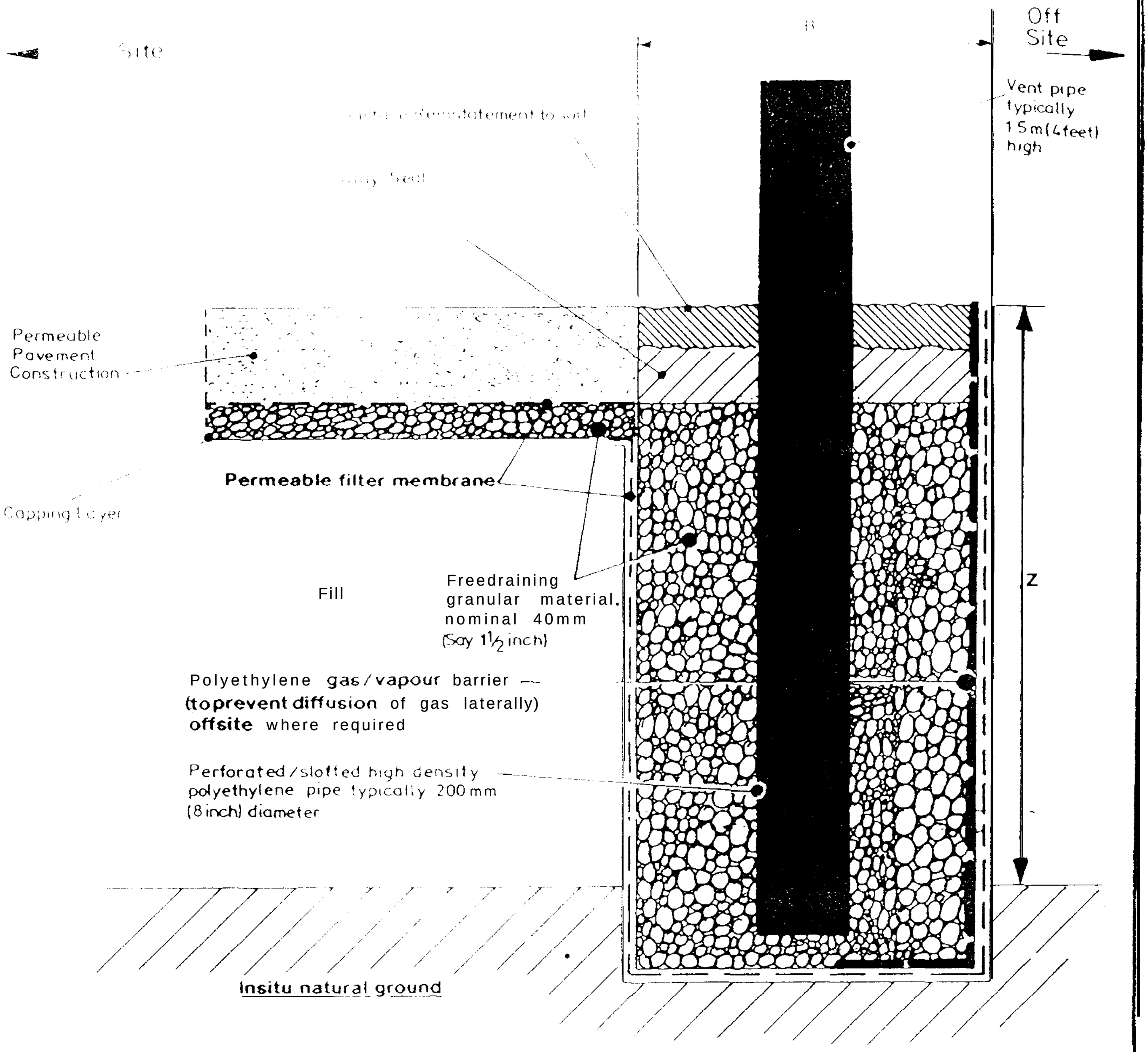


NOT TO SCALE

TYPICAL DETAILS Of GAS WELLS WITH CONNECTING SURFACE TRENCH.

Fig I



Notes

Dimensions

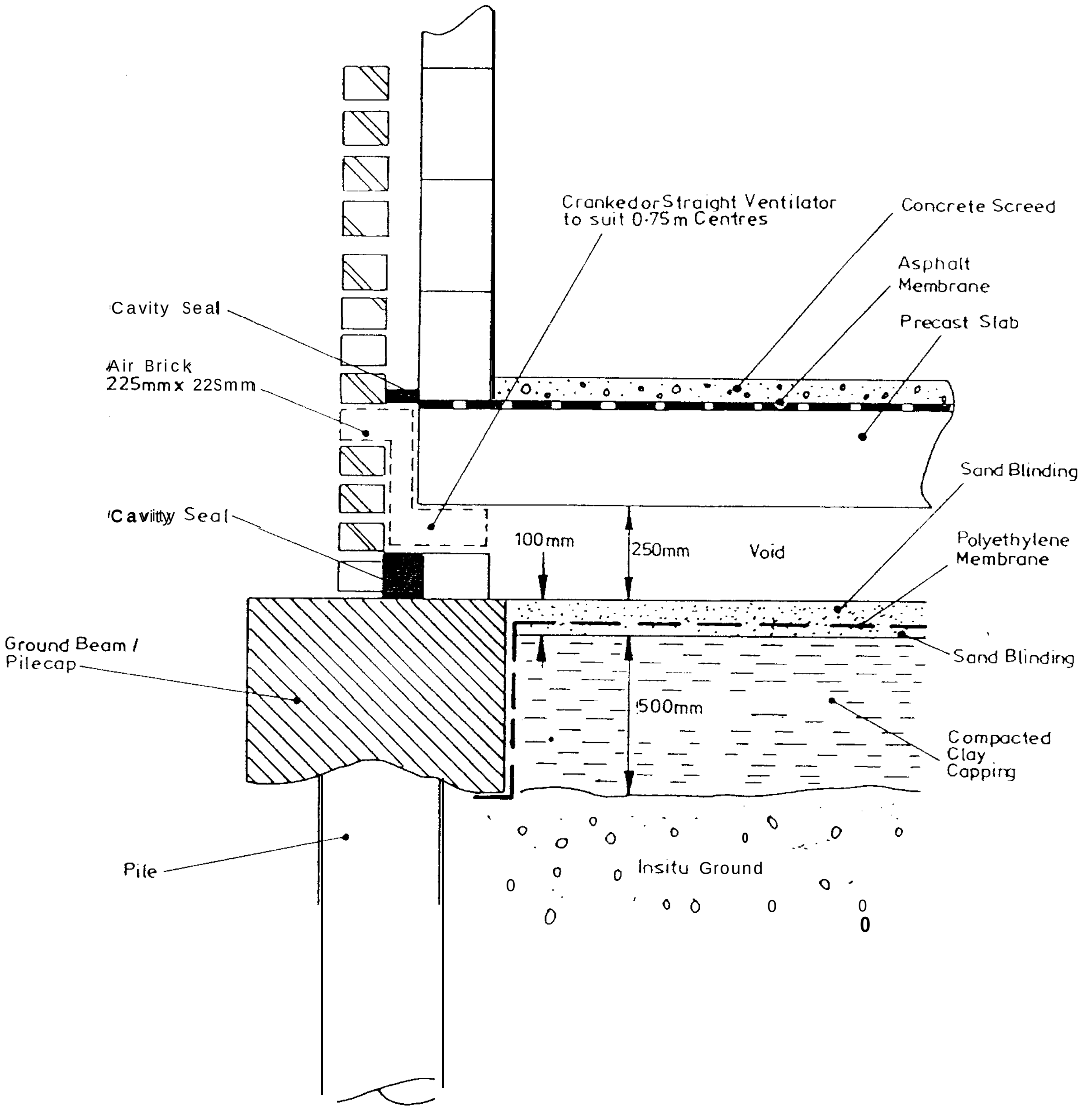
B to suit design requirements for natural ventilation Typically B = 0.5m (18inch)

Z Maximum depth typically 2m for depth greater than 5m (15 feet) gravel filled wells are appropriate

NOT TO SCALE

TYPICAL DETAILS OF PASSIVE VENTING TRENCHES AND CAPPING LAYER

Fig 2



NOT TO SCALE

TYPICAL DETAILS OF GAS CONTROL MEASURES

Fig 3