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Mini-Piles and Composite Ground Floors for Housing

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FOREWORD

This publication was written to explain the advantages of the use of mini-piles and composite ground-floor slabs in housing construction. These components are relatively new to house building but are able to offer significant benefits to the efficiency and quality of construction and in the performance of the foundation throughout the life of a house. It is hoped that this guide will help builders and specifiers to become more familiar with mini-piling methods and to encourage their use.

This publication was written by Tony Biddle of The Steel Construction Institute and by Mark Gorgolewski, Consultant Architect. During its development, regular reviews of the text have been carried out by the Industry Steering Group comprising the following persons and organisations in order to check the technical accuracy and to provide 'peer' comment on the acceptability of the engineering details presented:

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Mr Adrian Cole	Bexley Council
Mr Mike Crilly	BRE Geotechnics
Dr Geoff Card	CARD Geotechnics Ltd
Mr Dennis Coward	Catnic
Mr Derek Mullett	Corus Panels & Profiles
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Mr Francis Atkins	NHBC
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SUMMARY

Mini-piling for houses is becoming the cheaper and more reliable foundation option on poor ground or ‘brownfield’ sites where it can minimise excavation, avoid spoil to tip and landfill tax. Also, the advent of climate change with periodic droughts and floods can badly affect supporting soils and this requires changes to traditional methods of house foundations to prevent structural damage; mini-piling provides a more reliable foundation. This guide presents technical aspects of mini-piles to improve builder familiarity with this foundation component and thereby encourage its use.

The work has involved a partnership with the BRE, who have contributed a research study on the geotechnical design rules for mini-piles (defined as having a diameter of less than 300 mm. BRE advice on the particular problem of design of mini-piles to cater for shallow heave and subsidence effects in swelling and shrinking clays is also included.

The Guide also describes a new generic type of suspended ground-floor construction for housing comprising a composite light gauge steel decking with concrete slab topping. This offers many potential benefits for house building (particularly on ‘brownfield’ sites), as compared to most other types of ground floor currently used in the UK. It has been developed and its performance tested over recent years on several housing sites and has obtained Lantac and BBA approval.

The composite ground floor is suitable for support to all types of wall construction and can be used equally well on strip footings or mini-pile foundations. The light steel edge beams provide the accurate template required for internal timber or light steel wall frames to minimise fitting time and eliminate rework. The level and floated slab surface will accept floor finishes directly and thermal insulation can easily be fitted beneath the floor, thus avoiding the cost of floor screeds and damp proof membranes (dpms).

1 INTRODUCTION

The UK Government has announced a number of initiatives to improve the quality and efficiency of house building in the UK. New and improved construction methods are needed to respond to those initiatives, to permit improvements in productivity and to meet the requirements of the recent changes to the Building Regulations that are intended to improve quality of house building.

This publication presents technical details of two construction methods where steel components may be used to achieve the above objectives:

- Mini-piles
- Composite ground floors

1.1 The UK housing market

The National House Building Council (NHBC) compiles a quarterly survey of the number of new house construction starts in the UK. This covers all house types including detached and semi-detached houses, bungalows, maisonettes and flats, and terraced houses. An approximate breakdown of each type within the total housing stock in Great Britain in 2004 is given on Figure 1.1. The portion of apartments and maisonettes has increased and that bungalows and detached houses has decreased as they are inefficient in land use.

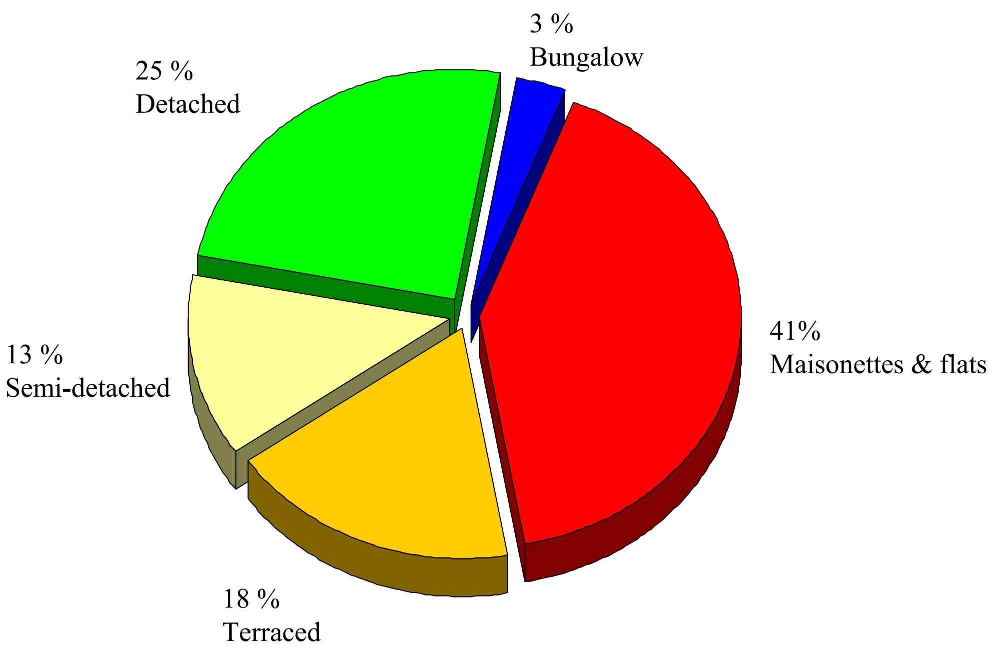


Figure 1.1 *Market proportions of house types in the UK in 2004 according to the NHBC*

In January 1998, the Government announced its policy to encourage an increase in house building to achieve 3.8 million new homes by the year 2020 to accommodate the growth in the UK population and changes in society. This equates to an average target new build rate of 275,000 dwellings per annum. Data from new build house construction returns to the DETR shows that over the period 1989 - 2002 an average total of only 160,000 units were completed per annum, with no improving trend, and therefore large productivity improvements are required to increase the build rate to match demand. The latest Government enquiry in 2004 states that there has been little improvement and an increase in build rate of 100,000 houses is still required to satisfy demand.

The first step in improving the house build rate has been a simplification and speeding up of the current planning procedures in Local Authorities and a Government directive on designated development areas in July 2003. The ODPM decided to release the first areas designated for new housing developments in the South East that will form corridors fanning out from London. This will result in a boost to large-volume house building but will need more efficient construction methods if the target 275,000 units per year is to be achieved.

1.2 Improving the house construction process

1.2.1 Use of prefabricated construction

There are finite limits to the improvements in productivity that can be made using traditional house construction techniques and the existing workforce. To achieve greater improvements, it will be necessary to adopt new methods of construction. One such method is to prefabricate large house components in the factory and thereby reduce some of the site work to assembly. This will permit a reduction in house build time and lessen the dependence on site construction, where most of the delays to programme occur. Additional drivers to the use of new technology in house construction include the EGAN report *Rethinking Construction*[39], the establishment of the Movement for Innovation (M4I) and the recent changes to the Building Regulations, particularly to Parts L[18] and E[17].

A move to prefabrication will need: an acceptance of alternative house construction methods by builders and the public; the development of new building products and systems with BBA approval; and more technical guidance to Building Control surveyors on the new methods.

The DETR have supported the development of new prefabricated house construction methods with either timber or steel framing. These building methods are gaining favour for houses, because of their higher quality and faster building programmes. Several volume house builders are now involved in developing their own prefabricated housing systems.

1.2.2 Adopting interface details suitable for prefabricated walls

Prefabricated wall frame systems need to be fixed down to floor plates or into the ground-floor slab. Where suspended ground-floor construction is used, the wall frames need to be fixed into the edge of the floor, where it is supported on the inner leaf masonry wall. However, most builders use a precast concrete beam and block ground-floor construction that will not accommodate the wall frames without considerable adaptation. This adaptation requires new techniques and training of bricklayers to fit holding down straps (Figure 1.2) and where this is not done, there is troublesome and expensive rework to fix the wall frames. This will deter builders from adopting wall frame systems unless the problem of interface details is resolved.

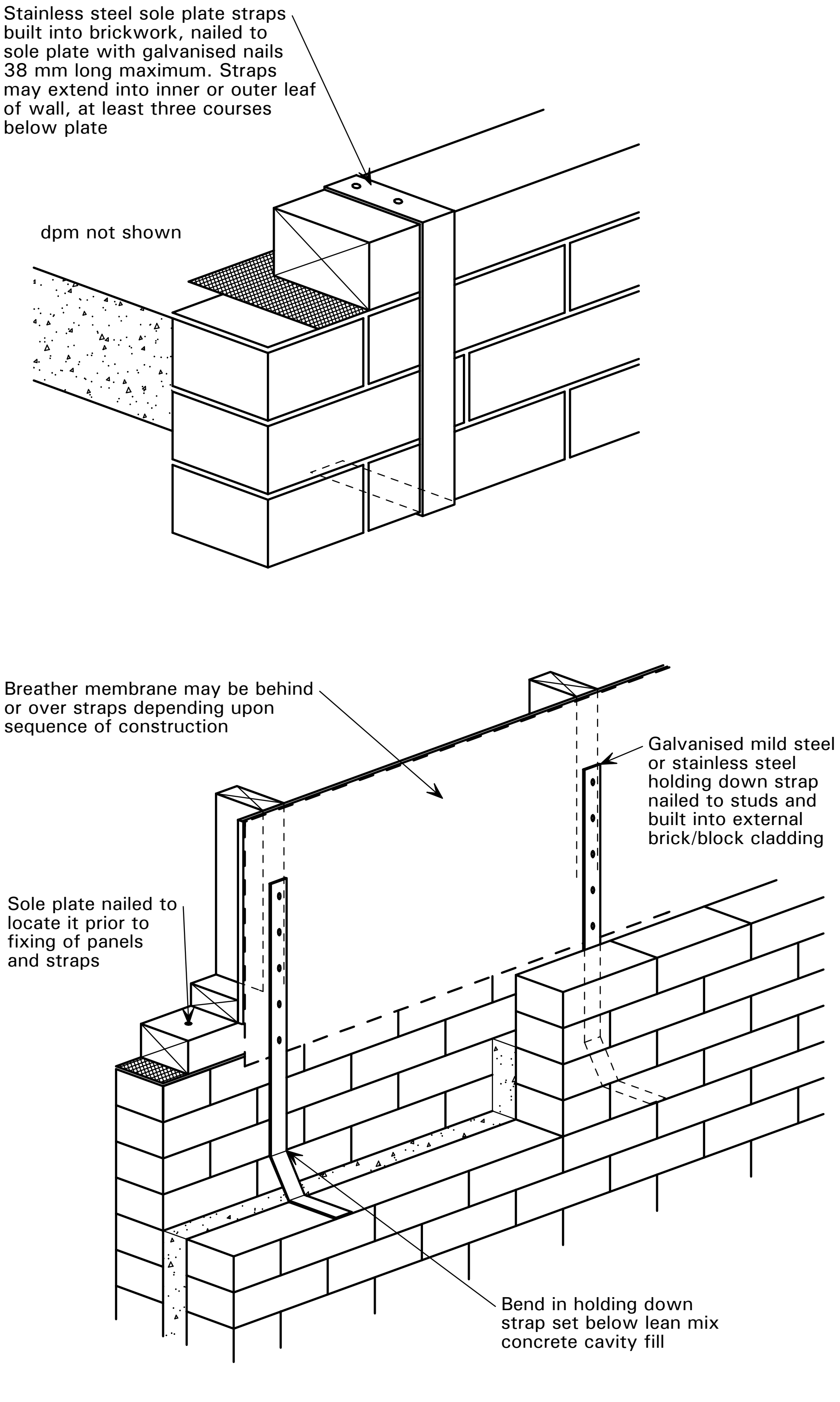


Figure 1.2 *Stainless steel straps to secure sole plates and studs of timber wall frames (courtesy of TRADA Timber Frame Construction)*

The house building industry is increasingly using steel or timber wall frame construction, but the use of precast concrete beam and block floors has given problems with poor line and level and is not suited to secure connection of the frames at the floor edge. Figure 1.2 shows the additional holding down straps that are required for timber wall frames on beam and block floors to provide secure fixing and avoid damage to the precast concrete floor components by nails or the hole drilling required for holding down bolts. However, installation of these straps require close supervision in order to get them in the right place for the frame studs during the inner skin block laying below dpc level.

Use of the new suspended composite ground-floor construction system shown in Figure 1.3 will solve this problem because the wall frames can be resin bolted into the concrete slab that projects onto the foundation wall.

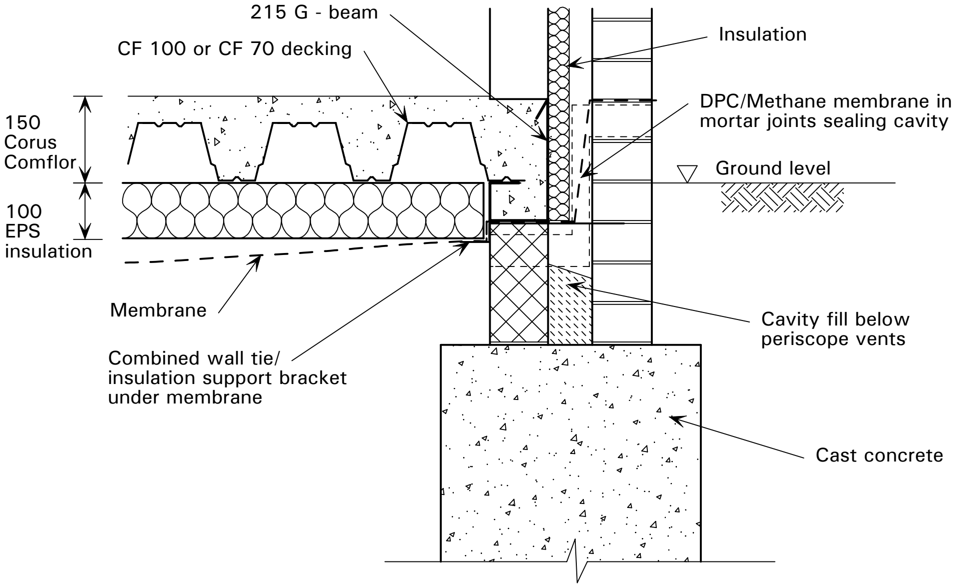


Figure 1.3 *Suspended composite ground-floor system on blockwork and trenchfill foundation*

1.2.3 Innovative application of existing technology

Mini-piling

Mini-piling is already extensively used in underpinning repairs to existing houses that have suffered subsidence damage. The techniques of piling for housing are therefore well developed, the technology well understood and there is a body of knowledge available in the mini-piling industry that can be applied to the new-build housing industry. There are many specialist piling companies that can compete to provide an economic foundation for new housing using existing equipment and skills. Several companies have already developed their own house foundation systems comprising mini-piles and precast concrete ground beams.

The take-up of piled foundations for housing has been slow because builders do not seem to be aware of the economic benefits and not familiar with the mini-piling industry. Mini-pile foundations can be cheaper than conventional trenchfill.

Composite ground-floor solutions

Composite flooring using steel decking and an in-situ concrete slab has been used in industrial and commercial multi-storey buildings for many years. Research and development has been carried out since 1980 into the application of this type of flooring to residential suspended ground-floors, where it offers many technical benefits. Demonstration buildings have been built to assess its buildability and durability. The cost has become competitive with other flooring types, now that quality standards have been raised by the new Building Regulations Approved Document Part L1[18].

To achieve the objective in the UK to use more prefabricated house components and to improve U-values, requires the development of new types of ground floor construction. The composite steel and concrete suspended floor system shown in Figure 1.3 offers an efficient solution for the following reasons:

(a) Suspended ground floors are more suitable over the poorer ground and sloping sites that have now to be used and provide an elevated platform above ground that is subject to periodic surface storm water inundation or flooding from rivers. (In recent years the changes in climate have become more extreme, creating a greater awareness of the need to build houses at a higher elevation to prevent damage from such flooding).

(b) Precast concrete beam and block floors currently dominate the market for suspended ground-floor slabs and these are put in by 'ground workers' (Figure 1.4). When used with framed wall construction, this type of floor can cause problems with the attachment of the frames, since the precast pre-stressed concrete beams are narrow and are easily damaged when drilled for the holding-down bolts. At worst, may lead to spalling and exposure of the prestressing wires can cause corrosion and premature failure of the beam.

(c) The poor accuracy in line and level of beam and block floors leads to the need to pack up wall frames with spacers and make adjustments to the interface which is time consuming, unpredictable and costly.

Figure 1.4 *Bullivant precast groundbeam and mini-piling foundation*

In ground-floor applications, as shown in Figure 1.5, composite slabs provide a suitable suspended floor that can assist accurate installation of the wall frames and can easily accommodate the holding down fixings. Although ground workers will be unfamiliar with this form of construction, they are comfortable with erecting timber shuttering and placing concrete even though the steel decking would be new to them. However, proprietary products are made to form the edge beams/stop ends, sheets can be overlapped to minimise cutting and it does not take long to become experienced with the use of a self drilling screws and light steel assembly methods.

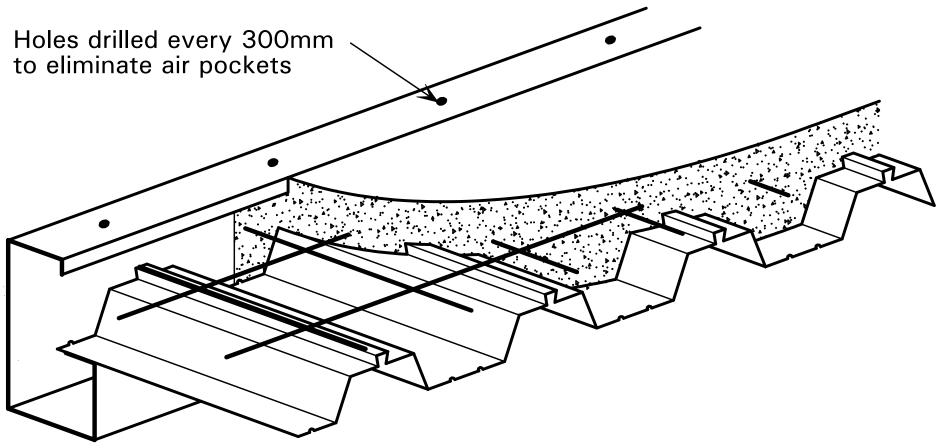


Figure 1.5 *Composite ground-floor system and G section edge beams*

Composite slabs, using in-situ concrete on a steel decking

Steel decking is lightweight and individual sheets can be easily manhandled from the off-loading position for site assembly. Economic advantages of composite ground floors include:

- Faster construction to ground floor level.
- Elimination of the need for site cranes.
- Reduction in the number of site trades required up to ground floor level.
- Insulation can be fixed below the ground floor to avoid the need for a finishing screed.
- Better line and level to reduce interface work with framed wall construction.
- Improved quality of wall finishes due to better corners.
- Enables ground floor installation to be part of a house frame construction.
- Enables ground-floor construction to be part of the foundation work.
- A reduction in road transport loads, resulting in reduced pollution and environmental nuisance.

A crew of two can fit the edge beams, floor decking and reinforcement, all the connections and any below floor insulation for one house in a day, without a crane or other mechanical assistance. The decking tray will be ready for concreting on the following day (see Figure 4.1). The arrangement of composite floor and in-situ ground beams is shown in Figure 1.6.

From the Health and Safety at Work aspect, the new composite floor is lighter; uses proprietary components; requires a less onerous procedure for assembly than the beam and block floors; and provides a safer working platform than alternative proprietary systems that use polystyrene insulation as infill blocks between floor beams.

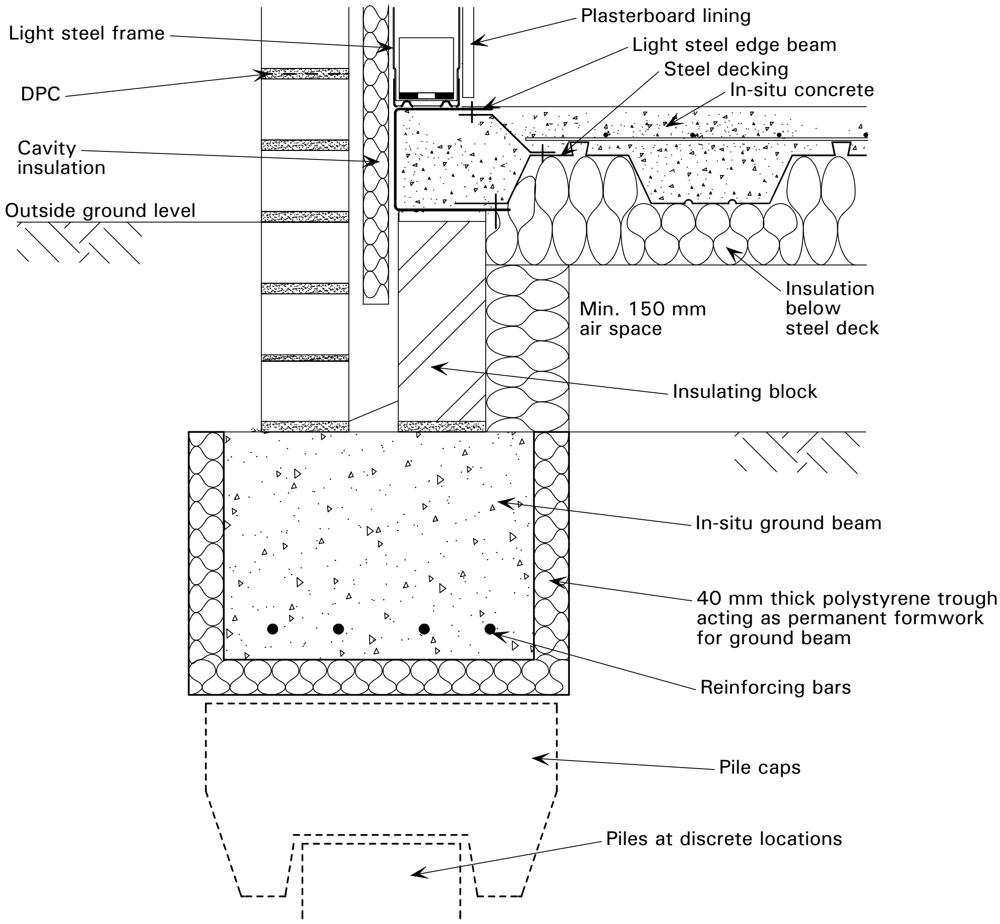


Figure 1.6 *Piled composite ground-floor system with in-situ ground beams formed within polystyrene trough*

1.3 Improving construction quality

1.3.1 Avoidance of settlement problems

The Government recognises that the quality of construction has to improve if future problems with house foundations are to be avoided and the mounting costs of foundation repair are to be minimised. House insurers and the NHBC advise builders to adopt deeper foundations that will be safer in areas of ‘brownfield’ land and on poor ‘greenfield’ sites.

The increasing need to use ‘brownfield’ sites and marginal land for new housing development means that ground conditions are more variable and more prone to differential settlement under traditional trenchfill foundations. Generally, the only safe method of foundation on such sites is to use mini-piling.

Another structural problem that is getting worse with the use of traditional concrete strip footings and trenchfill, is that over recent years the warmer climate and more erratic rainfall are causing an increasing amount of subsidence or heave movement in the supporting clay soils. Mini-piling can transfer the structural support to lower layers of soil that are below the zone of seasonal moisture change and thereby isolate the house from these soil movements. Much more attention is required by builders to the foundations to houses in order to prevent future damage from soil movement.

1.3.2 Avoidance of durability problems

Currently, beam and block floors give rise to other problems apart from that of poor line and level and connection of wall frames at floor edge, Furthermore, the provision of floor insulation above the floor may lead to durability problems in kitchen, utility and toilet areas. The protective screed above the floor insulation is not waterproof and so when there is a spillage, water penetrates through to the insulation that soaks it up becoming less resilient and resulting in floor damage. House builders have complained about extensive rework to relay the floors and fitting membranes above and below the insulation.

Composite ground floor types of construction avoid this problem by placing the insulation below the floor.

1.4 Scope of the publication

This publication presents summaries of recent research and development regarding the civil engineering aspects of mini-pile foundations and suspended composite ground floors that can be applied to new housing construction.

It explains that mini-piling and composite ground-floor construction can:

- deliver more reliable house foundations in an erratic maritime climate
- cure interface problems between floors and walls
- provide a more efficient construction process.

The objectives of this publication are:

- To increase understanding of the potential benefits of using mini-pile foundations in residential construction, and the potential cost savings they can offer compared to concrete trench fill.
- To explain the construction details of composite ground floors and their technical and economic advantages.

Section 2 presents a brief review of recent Government initiatives to encourage innovation and more efficient house building methods in the UK. It also contains a summary of the recent changes that have been made to the Building Regulations to produce better quality in housing.

Section 3 describes the technical aspects of mini-pile foundations and their advantages.

In Section 4 composite ground-floor systems are presented for consideration and development by the building industry. Design details and construction issues are explained and a review of the durability and projected working life of the galvanized light steel components used in composite ground-floor construction is presented.

In Section 5 the estimated costs of different ground floor and foundation systems are compared.

Appendix A presents recent BRE reports on mini-pile design and overcoming the technical problems with swelling clays and trees.

2 GOVERNMENT INITIATIVES AND REGULATIONS

There have recently been a number of Government initiatives and changes to the Building Regulations that are causing the building industry to rethink the way it constructs ground floors and foundations for housing. These include:

a) The Egan Report[39], which contains a recommendation to consider innovation that will improve the efficiency and quality of house construction in the UK.

b) Implementation of the EEC Construction Products Directive[29], which defines the essential requirements for construction components.

c) Direction by the DETR (now ODPM) on developing ‘brownfield’ sites (PPG3[36] and the Urban White Paper[43]), and demonstrations (initiated by DETR) of brown-field site redevelopment for housing. Provisions include the clean up of any contaminated land.

d) Extension of the requirements of Approved Document C[16] of the Building Regulations concerning ground gases over a larger area of the country. (The requirements are to make ground floors gas-tight and to provide under floor ventilation to prevent any accumulation and permeation of radon gas and methane.) Further revisions are possible.

e) Revision of Approved Document L[18] of the Building Regulations to improve the thermal insulation of the house fabric including the ground floor. Lower U-values and thicker insulation have been required since April 2002.

f) The introduction of a new Approved Document M[19], effective 1999, to achieve level access to buildings for the disabled.

g) The Landfill Construction Waste Tax.

h) The introduction of a new Aggregates Tax from 2001.

Many of these measures need new construction solutions that can be satisfied by applications of mini-piling and composite construction in suspended ground floors.

2.1 The Egan Report

The UK Government published the Egan Report *Rethinking Construction*[39] in July 1998. The objectives of the report were to investigate current UK construction industry practice and to outline ways in which it could be made more efficient and competitive.

The Egan Report contained a recommendation for the building industry to form a Housing Forum to consider innovation, to improve the efficiency and quality of UK housing construction and to decide how to re-develop ‘brownfield’ sites. This was seen as a priority in order to limit the consumption of ‘Greenbelt’ land for new housing.

The Housing Forum was formally constituted in April 1999 and consists of a network of companies involved in building or developing or operating housing in the UK. The Forum will exchange views and pass information relating to the improvement of quality, efficiency of construction and the in-service performance of housing. The Housing Forum is seen as a means by which the building industry can be encouraged to participate in the collective purpose to improve quality and efficiency in house building.

2.2 EEC Construction Products Directive

The European Commission issued Construction Products Directive 89/106/EEC in 1989[29]. It defines the essential requirements for components used in building houses and defines their required durability in terms of their *'working life*'. Where a material or product has a CE marking, this is an *'attestation of conformity with the technical specifications given in the European Construction Products Regulations 1991'* as stated in the UK Building Regulations *Approved Document to support Regulation 7:1999.*

The most appropriate requirement for a steel product is its strength but there is, of course, an implied requirement that this strength should be available throughout its working life and hence it relates to durability. The required working life is defined as: *'the economically reasonable life'* and depends upon the criticality of the product to the safety of the building and the ease of access to it for maintenance. Ground-floor components are considered to be inaccessible and therefore have to last the expected lifetime of the house, i.e. between 60 and 100 years. The durability of all floor components has to satisfy that requirement.

Where a material or product has a CE mark, it is deemed to assure the purchaser of its fitness for purpose, provided that the specification is appropriate to the intended purpose. The CE mark is not mandatory in the UK or in non-EU parts of the world but if the product is to be offered for sale in Europe then the CE mark is mandatory. A CE mark can be achieved for the product through a UK approval body such as the British Board of Agrement (BBA) or WIMLAS.

2.3 Building on 'brownfield' sites

Available 'greenfield' sites in the UK are currently inadequate to meet the need to find space for more than 3.8 million new homes by 2020, which is the Government's projected housing demand. The scarcity of prime housing sites, together with the reluctance by planning authorities to release green-belt land for development, has resulted in more developers turning to 'brownfield' sites, and also to marginal or poor 'greenfield' land for housing, leisure and light commercial use.

The DETR's policy is to encourage use of 'brownfield' land, i.e. to redevelop old industrial and landfill sites for new housing and thereby to ease the pressure on new 'greenfield' development, as well as achieving an 'Urban Renaissance' to remove inner city dereliction. A target has now been set for local authorities to raise the proportion of development on urban, mainly 'brownfield', sites to 60% of the total. Recent reports from the NHBC suggest that this target is already being met in many areas, creating a potential market of over 100,000 dwellings per annum that are suitable for mini-pile foundations.

One of the major problems faced by the UK building industry in using 'brownfield' land is that existing foundation methods such as concrete trenchfill and rafts are generally not suitable because the fill and rubbish is too thick. Apart from piling, all the other types of ground treatment have been found to leave a certain degree of risk of future settlement and are therefore of questionable value. Piling is the only form of foundation that can assure house builders, insurers and the house-buying public that their houses are secure on such sites.

Figure 2.1 *Mini-piles for houses on 'brownfield' site in flood plain*

It is estimated that by the year 2006 nearly all the more easily developed 'brownfield' sites (with only thin layers of 'poor ground') will be used up. This will leave the major problem sites, where higher foundation costs will have to be accepted because of the lack of any alternative land for housing. For such sites, it is foreseeable that piled foundations will become the most economic solution and therefore this solution needs to be encouraged in the building industry.

Contaminated land

Many inner city sites that are in prime locations for housing development are not contaminated nor are they landfill sites but they are 'brownfield' because of previous light industrial or residential use. Legislation was passed in July 1999 and came into force in April 2000 compelling Local Authorities to investigate and classify all 'brownfield' sites within their jurisdiction according to the level of contamination or 'suspected' contamination. The investigation will include risk assessments on the likelihood of contamination that will require special treatment to render it suitable for residential development.

The British Standard Draft for Development DD 175:1988 *Code of Practice for the identification of potentially contaminated land and its investigation*[13] gives guidance on site investigation. Further general information on sites is given in BS 5930[3].

Some ‘brownfield’ sites are heavily contaminated and therefore probably unsuitable for housing development. Various publications (e.g. CIRIA Reports SP101 to 108 *Remedial treatment for contaminated land* [27]) deal with the remediation of such land. However, the Local Government Planning Authorities have recently turned their attention to inner city ‘brownfield’ sites that are generally just lightly contaminated and therefore potentially suitable for housing.

The Urban Task force has concluded that housing on ‘brownfield’ sites is likely to involve the following:

- More careful ground investigation, design and costing of foundations.
- More negotiation between developers and planning authorities on the feasibility of using ‘brownfield’ sites.
- Predominant use of suspended ground floors.
- Greater use of mini-piled foundations in preference to other ground improvement techniques.

Building on flood plains

A recent issue of refused planning permission in flood plain areas after the widespread flooding in 1998 and 2000 has stifled new housing development. The Environment Agency is currently working on this problem. Mini-piled foundations may be the most suitable foundation solution to new buildings that are planned for these areas. Building consent may only be granted if the living and sleeping accommodation is always on the first floor and above so that the living floors are never subject to wetting from flood waters. The ground floor would then be used for recreational use, garages etc.

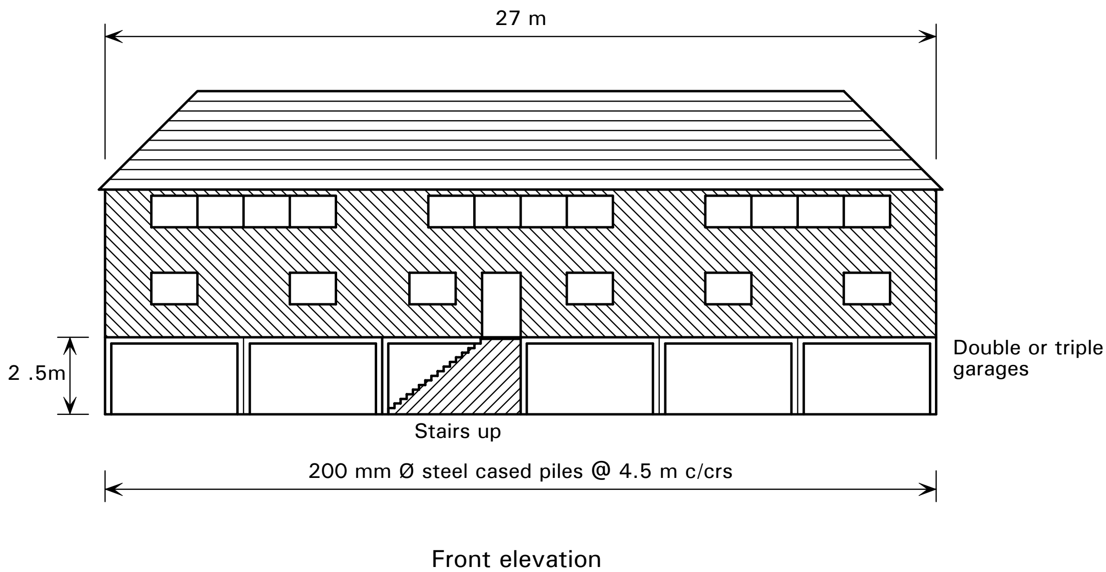


Figure 2.2 *Stilt pile concept for houses on flood plains*

In addition, composite ground floors provide an impermeable barrier against rising groundwater and can either be incorporated into the design of new houses or installed during the refurbishment of flood-damaged property. Where the maximum floodwater level is not likely to exceed 800 mm above ground level, an extended G-beam (see Figure 2.3) is proposed to provide an impervious barrier within the walls.

A composite ground floor may be used to replace a flood-damaged suspended timber floor or an unsealed concrete beam and block floor during refurbishment. Steel hangers are placed over the inner leaf of brickwork or blockwork in the space created by the removed old timber joists as shown in Figure 2.3. This hanger then supports a new light steel edge beam, which in turn supports the steel decking to a new in-situ concrete slab.

It is expected that this option will be used in conjunction with the extended G beam to provide a barrier against any future flooding, in which case, the upstand will be situated inside the inner leaf of brickwork, and then hidden from view behind the new plasterboard dry lining as shown in Figure 2.3.

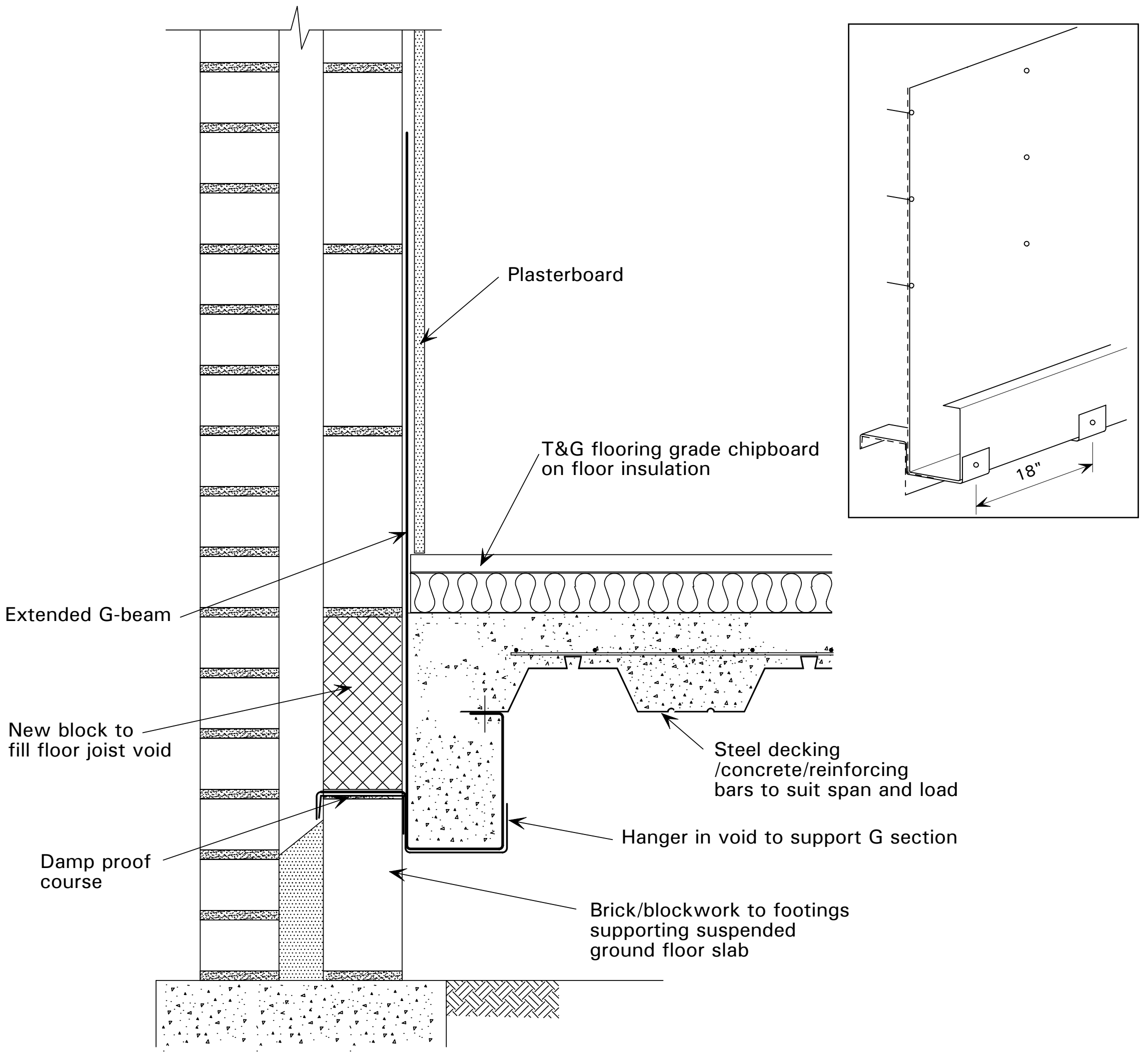


Figure 2.3 *Composite ground floor with upstand light steel edge beam (extended G-beam) to replace flood damaged timber floor. Inset shows the extended G-beam.*

2.4 Building Regulations

The Building Act 1984 forms the statutory framework for controlling the standards of building construction. The Act is implemented by means of the Building Regulations 2000[14], together with a number of formal amendments to the Regulations. The Building Regulations generally set performance requirements for building work, including the erection of new buildings and material changes of use to existing buildings. Practical guidance on ways of meeting these requirements is given in separate *Approved Documents*.

2.4.1 Approved Document A - Structure

Guidance on meeting the requirements of the Regulations for foundation design is given in Approved Document A[15] which deals with structure. Guidance for ground-floor construction is given in Approved Documents A[15], C[16], L[18], and M[19].

2.4.2 Approved Document C - Site preparation and resistance to moisture

The changes to the requirements for radon barriers in year 2000 to Part C have affected ground floor and foundation design.

Part C of Schedule 1 to The Building Regulations states fundamental requirements that affect ground-floor construction as follows:

C1 The ground to be covered by the building shall be reasonably free from vegetable matter.

C2 Precautions shall be taken to avoid danger to health and safety caused by substances found in the ground to be covered by the building.

C3 Subsoil drainage shall be provided if it is needed to avoid:

- the passage of ground moisture to the interior of the building
- damage to the fabric of the building.

C4 The walls, floors and roof of the building shall resist the passage of moisture to the inside of the building.

Approved Document C presents an interpretation of these requirements and gives deemed-to-satisfy ways in which they can be achieved based on traditional masonry and brick building components and best practice to date.

The damp-proof course (dpc)

The *damp proof course* is a layer of impermeable material that is built into a wall at an appropriate level to prevent the upward migration of moisture from the ground. There are associated components such as plastic cavity trays, which ensure that the dpc is not compromised or bypassed by penetrating rainwater splashing or dripping from above.

Best practice details for the position of the dpc in relation to the ground level, and in relation to the cavity are presented in the NHBC Standards.

The damp-proof membrane (dpm)

The *damp proof membrane* has become a standard detail for resisting the passage of moisture from the underlying soil up through a dwelling's ground floor. It is particularly appropriate to porous concrete floors and is used beneath ground-bearing slabs. There are best practice details that relate to the most effective ways of placing the dpm and of ensuring the continuity with dpcs in walls and below door thresholds.

The light steel decking in the composite ground-floor slab, (see Section 4), will act as the dpm (as confirmed by the NHBC) and no other membrane is necessary either above or beneath it. A dpc is used beneath the edge beams.

Ventilation of the void below suspended ground floors

There are several requirements in the Building Regulations and the NHBC Standards relating to the provision of an adequate flow of air beneath the ground floor to control condensation in the floor void.

A ventilated space of at least 150 mm height from the top of the ground cover to the underside of the floor must be maintained, and the external walls should have ventilation openings equivalent to 1500 mm^2 per metre run of wall.

Provision of a drainage outlet is required to a suspended ground floor void where the ground level outside the house is higher than that beneath the floor void in order to prevent the risk of flooding. Such drainage should be sufficient to prevent ponded water in the void and any risk of bridging over the dpc and dpm that could enable the migration of moisture up into the ground floor and walls of the building. The drainage outlet should not be connected directly to the sewers or if it is, there should have a non-return valve fitted to a sewer connection to prevent any risk of backflow.

There is a general move towards external ground levels being higher than the site-strip level below suspended ground floors, in order to reduce floor construction height and to comply with the new Part M for level access into the building. However Part M also permits access to be via steps or ramps and this will be essential in low-lying areas that are prone to surface flooding. The provision of sub-floor venting and drainage will probably be controlling factors affecting the level of suspended ground floors.

Soil gases

Many ‘brownfield’ developments in the UK are being constructed on old landfill sites or on poor ground where the breakdown of organic material has produced methane and carbon dioxide in the ground. In some areas of the UK there is a significant risk of radon (a radioactive soil gas) entering a building via the ground floor but the degree of radon exposure varies by location.

Part C of the Building Regulations requires that precautions shall be taken to avoid changes to health and safety caused by substances in the ground. This covers the precautions to prevent any soil gases from entering a building by seepage through the ground.

There are two common methods of protecting dwellings from soil gas infiltration:

- The passive system consists of an airtight barrier that runs across the whole building including the ground floor and walls (including any wall cavity). This barrier is usually a polyethylene membrane placed above the floor structure and lapped under the cavity tray at the wall intersections. Where a suspended floor is used, secondary protection is also provided with the introduction of extra air bricks to provide ventilation of the void beneath the floor. Openings of at least 1500 mm^2 per metre run of wall on two opposite sides are required.

- Alternatively, an active approach requires the installation of a pumped radon extraction system that needs to be maintained throughout the life of the dwelling.

A composite floor using steel decking and an in-situ concrete slab provides an intrinsically non-permeable barrier to these gases and it is only the wall cavity that needs to be sealed over. However, most designers of soil gas prevention systems will specify a radon proof membrane to be placed under the composite ground floor and extending over the cavity wall for assurance.

Good design should ensure that service pipe and cable entry points through the ground floor do not permit leaks through the radon-impermeable membrane and airtight seals should be provided.

The guidance in Approved Document C refers to BRE document *Radon: Guidance on protective measures for new dwellings*[38].

Additional information is available in the *House Building Manual*[44], published for HomeBond®, Dublin, which contains house construction advice for the Radon prevalent areas of Ireland; the problem is much more widespread than in the UK.

2.4.3 Approved Document L1 - Conservation of fuel and power

The guidance provided in Approved Document L is designed to encourage energy efficiency in housing by:

1. limiting the heat loss through the roof, walls, floors, windows and doors,
2. limiting unnecessary ventilation heat losses by reducing air leakage around openings and through the building fabric.
3. providing minimum insulation thicknesses in Appendix B for solid floors in contact with the ground; for suspended timber ground floors and suspended concrete beam and block ground floors.

The Approved Document L1[18] was revised in 2002 and specifies considerably lower U-values for building elements, in particular, for ground-floor slabs. The value has been reduced from 0.45 to 0.25 which will increase the thickness of EPS insulation from 50 mm to 90 mm This is affecting the design and construction details of floors. Furthermore, junctions between ground floors and walls need more attention to detail to prevent cold bridging (see Section 4).

Part L1 of the Building Regulations states that “reasonable provision shall be made for the conservation of fuel and power in buildings”.

The requirements for resisting the loss of heat from buildings and for the insulation of heating services are given in Approved Document L1. The requirements are specifically aimed at reducing energy wastage and avoiding condensation. The DETR's stated policy is one of progressively lowering the U-values in order to encourage more thermally efficient homes to reduce energy consumption and to reduce the levels of CO_2 produced by home heating.

Position of insulation

For conventional suspended ground floor types, e.g. for precast concrete beam and block floors, the insulation has been generally placed above the floor and the degree of unsealed open jointing in the structural floor will be a key factor in determining the overall U-value.

For suspended composite ground floors, the thermal insulation can either be placed above or below the floor. It has no open joints and is therefore more thermally efficient.

Cold-bridging

Approved Document L states that provisions should be made to limit the cold-bridging which can occur at the junction of the ground-floor and the external and internal walls. The purpose is to avoid excessive heat loss and the possibility of local condensation and mould growth at the ground floor edge on cold surfaces.

2.4.4 Approved Document M - Access to dwellings

Recent changes to the requirements for level thresholds in Part M can affect ground-floor construction and groundworks for dwellings.

Approved Document M of the Building Regulations came into force in June 2004[19] and requires all new buildings and dwellings to have a main entrance door that facilitates access by the disabled. Only one entrance needs to be so provided and the remaining doors can be traditional. People who use wheelchairs, sticks or crutches and those who are blind or partially sighted will require adequate space when approaching the building, and paths and doors should be at least 0.9 m wide.

For new houses, there are three categories of approach to the principal entrance that can apply, dependent upon the topography of the site:

1. A level approach, where the site slope from the point of access to the entrance is less than 1 in 20.
2. A ramped approach, where the site slope from the point of access to the entrance is between 1 in 20 and 1 in 15.
3. A stepped approach, where the site slopes are greater than 1 in 15.

4. For steeply sloping sites, a practical solution can be to provide disabled access within an adjacent garage or off a driveway that has enough space to permit transfer of the disabled person in a wheelchair from a road vehicle or by provision of a lift.

Industry Provision for disabled access

The new Part M requirements will in general increase the amount of excavation because ground floors are now thicker to comply with Part L but have to be depressed to give an access door threshold that is level with the approach.

Ground-bearing concrete slabs will not be significantly affected but this can complicate the building construction details for suspended ground floors because sub-floor venting, thermal insulation and damp-proof course levels will have to be adjusted to accommodate the access door.

The ground does not have to be raised up immediately adjacent to the door if there is a ramp to the property and a bridging drain at the threshold. In order not to compromise the dpcs in the outer wall either side, the approach path will need to be just the width of the door frame.

2.5 Landfill Tax

Even on 'greenfield' sites, there is a growing problem with traditional trench-fill and strip foundations, because of the considerable volume of excavated spoil that has to be removed from site to tip, see Figure 2.3. This incurs Landfill Tax and tipping charges. Disposal of all spoil and waste has become a country-wide problem and will suffer increasingly high taxes by the Government to encourage alternatives. Use of bored mini-piling minimises spoil and driven mini-piles incur no spoil generation.

Figure 2.3 *Trenchfill foundations on 'brownfield' site*

The economic benefits of minimising spoil by using mini-piling on 'greenfield' sites can be greatest on those where foundations have to be deeper. These include deep alluvium near rivers and the shrinkable and expansive clays (swelling clays) that have caused subsidence and heave problems beneath older houses in recent years particularly in southeast England.

On 'brownfield' sites, trenchfill can be deep and the spoil may be contaminated thus incurring additional charges for disposal.

There are increasing reports in the building journals that such 'greenfield' sites are already being economically mini-piled by specialist piling companies, who are expanding into that market using systems developed for underpinning repairs. The increased market will lead to cheaper prices for mini-piling and eventually make it the preferred foundation method.

2.6 Aggregates Tax

Concrete will be more expensive because a new Aggregates Tax is now being levied by the Government on all quarried and dredged sand and gravel being used in the construction industry. This is in order to encourage more use of recycled aggregate from crushed demolition material and less use of primary aggregate resources.

This is a more sustainable policy because it minimises damage to the environment, reduces the rate of use of primary aggregate (a finite resource), and reduces the volume of demolition spoil waste taken to tip.

Use of mini-piling instead of trenchfill will assist this policy of more sustainable practices in the building industry and reduce environmental damage by reducing the volume of concrete used.

2.7 Health and Safety on site

Deep trenches not only generate large volumes of spoil but also need shoring and support to maintain stability until the trenchfill concrete is poured. Lives have been lost due to of unshored deep trenches.

Mini-pile foundations obviously eliminate this type of risk.

In respect of hazards to operatives on site, the beam and block type floor is particularly hazardous because the precast elements are heavy and have to be manhandled into position. Alternative types of floor such as composite floors are safer for site operatives because the elements are lighter.

3 MINI-PILE FOUNDATIONS

3.1 Use of piles for house foundations

Traditionally, piling has not been used for housing. Foundations have been either trenchfill or reinforced concrete strip footings. Most houses were built on 'greenfield' sites with good quality ground. For the reasons discussed in Section 2, many future houses will be built on 'brownfield' sites and on poor quality 'greenfield' sites. In such circumstances, better quality foundations will be needed. Mini-piling offers a more reliable and economic solution.

On brown-field sites, piling or other ground treatments will be necessary to provide a safe support to housing.

Most ground treatment processes can improve the average bearing capacity of soils but they can never eliminate the possibility of future settlement. Research by BRE found that even after ground treatments of dynamic compaction and vibroflotation, houses still require strong concrete raft foundations to spread structural loading and to bridge over any weak spots. Ground treatment and raft foundations increase the cost but there is still some risk of soil movements that can damage the house structure.

The most reliable foundation system for poor ground uses piling to transfer the structural house loads to a sound bearing stratum below the site. The piling used for housing foundations is relatively small section (no more than 300 mm dimension) and is termed 'mini-piling'.

Before a builder can use a piled foundation, the specialist piling subcontractor must obtain clearance from the local authority environmental control department and the building control department. The builder must obtain the permission of the construction insurer (such as the NHBC).

The local authority environmental control department will need to be reassured that the piling method does not cause unacceptable noise or vibration to any existing nearby housing. The building control department will need assurance on the verification of the load-bearing capacity of the selected pile type and the ground-floor construction system.

The specialist piling contractor will need an adequate site investigation report, on which to base the pile design. This investigation may require additional testing where there is a 'swelling clay' on the site, particularly in the proximity of trees. Guidance on pile design, both in the presence of such clays and in the design for housing is included in the BRE report included in Appendix A and in Section 3.7.

3.2 The advantages of mini-pile foundations

The advantages of using mini-piling are:

- Avoiding settlement and heave problems.
- Avoiding subsoil excavation, spoil to tip and landfill tax.

- Faster construction. (1 to 2 weeks can be saved from the total house construction time. This is valuable because foundation construction is always on the critical path.)
- Cheaper than concrete trenchfill, where the trench exceeds 1.2 m deep.

Of the types of mini-pile available, preformed piles (either steel cased or precast concrete) offer further advantages:

- Piles can be sleeved through prebored holes in the problem surface soils on clay sites.
- Preformed piles are a high quality prefabricated product.

On 'brownfield' land, piling transfers house loads to natural soils below fill and avoids costly excavation for trench footings. Cost comparisons are given in Section 5. Preformed displacement piles avoid creation of arising spoil and can penetrate with minimal disturbance through any clay capping layers that may have been placed over fill.

Avoiding settlement and heave

On 'greenfield' sites, there is an increasing incidence of house foundation problems with traditional trenchfill on clay sites and hence a need for builders to consider alternatives. Attention has been focussed in recent years on the unreliability of trenchfill following the widespread subsidence damage that has occurred to house walls in many parts of the UK and Europe in swelling clays (see Section 3.7). These clays occur over some 50-60 % of the UK landmass, particularly in southern England. Often the traditional trenchfill foundations have performed perfectly satisfactorily with acceptable movements for 30-40 years, but then have been cracked by subsidence in the freak droughts that have occurred in 1947 and more recently in 1987-1990. These extreme swings in climate have been investigated and it has been concluded by the DETR that better quality house foundations should be encouraged to cope with the expected continuance of such extremes in the future. Mini-piles can provide more reliable foundation performance in such areas.

The NHBC has been developing its guidance to builders for highly shrinkable clay sites and has steadily increased the depth of trench fill concrete required in its Building Standards [34]. In these Standards, the recognition of clay movements due to trees has led to a greater depth requirement for trenchfill ($>$1.5 m) than is often practical. Cost investigations during this research project based on a housing development of 4 or more houses (to spread the cost of the initial piling rig set-up) have shown that, at such depths, it is generally much cheaper to use mini-piled foundations instead of trenchfill (see Section 5). In fact, where trenchfill is required to be greater than 1.2 m deep, the mini-piled composite ground floor alternative would be cheaper.

3.3 Choice of mini-pile type

Technical advice on pile types that are suitable for a particular site is available from specialist piling contractors who are members of the Association of Underpinning Contractors (ASUC). Some are also able to advise an appropriate type of ground floor and ground beams to suit the site conditions and type of housing being planned. Input at this stage will permit the developer to optimise his ground floor layouts in relation to pile spacing and ground floor type, thereby economising on foundation cost and permitting more competitive pricing. For instance, the provision of a bay window can add an extra 2 piles to each house.

General information on the types of mini-pile available, the design process and the consequences of choosing mini-piles are given in the following Sections.

For low-rise housing of up to three storeys, pile positions are governed by the plan geometry of ground beams, and loading is generally so light in comparison with the potential full pile capacity that it is classed as 'nominal'. The design of the pile is often regarded as non-critical and the choice of pile type is therefore made purely on cost. However, there can be a tendency to disregard other factors that govern pile suitability, such as the minimum length to avoid the effects of heave and subsidence from swelling clays (S/E clays). Certain types of pile, such as screw piles, may not be appropriate in such situations and builders should check with the BBA Certificate for the specified applications of the pile type.

There are several types of mini-pile that can be used for house foundations. Their technical suitability depends partly on soil conditions, and partly on the method of installation that is acceptable for the site, and the basis for selection will be explained below.

Factors in pile type selection

ASUC registered piling contractors will be able to design and select a pile type to suit the soil and the site location taking account of the requirements of the local authority building control and environmental health departments. The following aspects are important in pile selection:

Soils data: a comprehensive site investigation should be carried out to BS 5930 and Eurocode 7 with sufficient soil strength testing data to permit a piling contractor to bid a confident price for the work.

Ground conditions: groundwater, swelling clays or existing trees will all affect the choice of pile. For a swelling clay, sleeves will be required around the pile near the surface and this is only feasible with driven or jacked piles.

Site access: the piling rig should suit the pile type and the site access constraints. A complete range of piling rigs is available from the underpinning market to suit even the most restricted access.

Installation: the piling rig and installation method should comply with the noise and vibration limits specified by the environmental health department.

Pile testing: the piling contractor will specify his method of pile installation; the pile testing procedure to verify load capacity; and the provisions he will make to ensure that any predicted heave or subsidence is designed for in the pile support to the house.

Cost: comparison should only be made between types of pile that are suited to the particular site ground conditions.

3.4 Mini-pile types

The generic types of mini-pile available are:

(a) Driven or jacked preformed piles (precast concrete, steel cased).

(b) Bored and Continuous Flight Auger (CFA) cast-in-place concrete piles.

(c) Other proprietary types of mini-pile e.g. CFA displacement piles.

(d) Driven grouted steel cased piles.

(e) Screw piles.

3.4.1 Driven or jacked preformed piles

Driven or jacked piles (displacement piles) are suitable for most types of soil. They avoid any excavation or creation of spoil as they displace their volume within the ground mass while being driven. This is particularly useful on 'brownfield' sites and can save the cost of waste removal to tip and the consequent landfill tax. The site can also be kept cleaner and in drier condition by not boring the piles.

Where long piles are predicted, use of driven preformed concrete or steel tube piles can permit an economy in the number and length required because the piles can be dynamically load tested during installation. The 'set' from the driving hammer or the force from the jack can be measured and related to the required static load resistance (load capacity) of the pile by means of load test calibrations. The load test calibrations are either taken from standard correlations for a particular soil type if the pile size is 'nominal' for house loads, or from a trial pile on the site if the pile loads are high.

The usual relatively short mini-piles for housing can easily be vibrated in because only low installation forces are needed to achieve the small penetration required for the relatively light design loads. Steel cased piles are lighter to transport and handle on site than concrete piles and hence no site craneage is required.

Figure 3.1 *Hydraulic pile driver on precast concrete mini-piles*

Steel pile casings are filled with concrete after driving and, in order to permit the easy filling of the tube, a minimum size of 150 mm diameter is used. Many cased piles are now 220 mm diameter which permits a 19 mm reinforcing bar to be tapped into the fresh concrete. An upstand of the bar is left at the top of the pile to provide a shear connection through the pile caps and into the ground beams; this is tied in with an in-situ concrete 'stitch'.

Figure 3.2 *Driven precast concrete piles for housing*

The choice between precast concrete piles or steel cased piles depends on the predicted severity of driving, and the likelihood of obstructions in the ground (steel cased piles are more durable and less prone to damage). Precast concrete piles can crack or split below ground when striking obstructions or due to tension stresses under hammer driving. Hence, the importance of first obtaining good soil information before selecting the type of pile. Precast concrete piles should always be tested for integrity after driving on sites where buried obstructions or underlying rock layers may be found.

The cost of hiring special piling rigs on site can often be avoided by using pile driving adaptors that fit on a standard excavator arm in place of the bucket. Examples are the Dawson EMV (Excavator Mounted Vibrator) or Unisto TPH (Tube – Piston Hammer) pile drivers, as shown in Figures 3.3 and 3.4.

Figure 3.3 *Dawson EMV pile driver mounted on excavator arm*

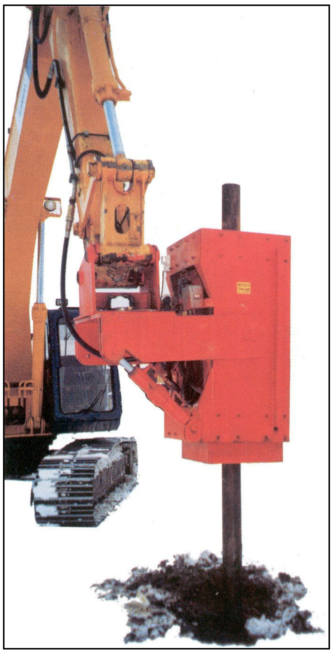


Figure 3.4 *Unisto (TPH) hammer mounted on excavator arm*

3.4.2 Bored cast-in-place concrete piles

Bored cast-in-place concrete piles can be an alternative to driven piles where the soil conditions permit a stable hole to be formed that allows the concrete and the reinforcement to be placed in the hole without wall collapse. Such piles are most suitable in clays and in chalks.

Bored piles may be formed by Shell & Auger equipment or by a CFA (Continuous Flight Auger) technique. The Shell & Auger equipment is light and quite compact and can traverse poor ground easily. CFA piles are faster to construct but need a large rig and tall mast to hold the continuous auger. Their cost is dependent on the number that can be installed at each visit to site because transport of the large rig is expensive and the day rate is high. A CFA rig also needs wider site access, a good approach road and site roads already in place to manoeuvre between house plots quickly; they are therefore better suited to large sites with good access. On most housing sites there may not be sufficient number of pile positions available at one time to make it economic for a CFA rig to be used.

Figure 3.5 *Small auger bored piling rig*

Both types of bored pile create spoil from the hole excavation and this must either be removed from site to tip or accommodated in a landscaping plan. On 'brownfield' and landfill sites the soil may be contaminated and will require special removal to designated tips, incurring a higher landfill tax charge and increased tipping charges. This often makes a driven preformed type of pile cheaper overall.

3.4.3 CFA displacement piles

A new type of CFA pile uses a '*displacement*' auger to rework the augured soil into the surrounding ground and thereby avoid the creation of 'arisings'. The auger head is in the shape of a corkscrew helix which can form similar shaped indentations to the ground in the wall of the bore which is then all filled with in-situ concrete as the auger is retracted.

The object is to maximise the soil resistance by a combination of shaft and bearing resistance due to the increased bearing surface created by the wide helix 'flanges'. The load resistance of such piles is high all down the shaft length because of the high 'key' with the adjacent soil.

These piles are therefore unsuitable for swelling clays because there would be a very high transmittance of any heave or shrinkage movements to the pile from the adjacent soil near the ground surface without any chance for 'slip' to occur.

3.4.4 Driven grouted cased piles

A new type of steel cased pile from Ruukki in Finland called CSG (Driven Cased Grouted) involves filling the casing with an in-situ concrete whilst driving and forcing out the concrete into an annular space formed around the pile casing created by using an oversized driving shoe. This type of pile has an enhanced bearing capacity above that of a straight wall steel pipe pile as a result of increasing the effective diameter and is particularly effective in relatively loose alluvial granular soils.

Such piles are particularly useful in underpinning work and for more heavily loaded positions beneath multi-storey apartment housing to maximise the load capacity of each pile and thereby minimise the number of piles required.

However in the UK, where mini-piles need just 'nominal' soil resistance for low house loads and the number of piles is more dictated by the number of support points to a given type of floor, wall geometry and the ground beam arrangement then straight shafted piles are generally cheaper.

3.4.5 Screw piles

A new type of pile is available that has a flanged helical head. One version has a screw auger shape that is rotated into the ground and the hole then backfilled with concrete on withdrawal; and the other leaves a permanent cast iron screw head in the ground with concrete being placed above it on withdrawal. They are both claimed to save pile length because of the enhanced soil bearing area on the flanges.

Either version is only suitable for housing where the surface soils will support the hole without collapse. Screw piles are also not suitable for swelling clays (see Section 3.7).

3.5 Site investigation for mini-piling

It is established best practice to obtain thorough soils data at each site and accurate data on house loads as a prerequisite to the design and realistic costing of foundations. The builder or developer should accept the cost of a comprehensive site investigation as a necessity to arrive at a safe, practical and economic foundation for the site.

The site investigation contractor should be told that data is required to permit confident mini-pile length prediction as an alternative to trench fill on every site, so that proper economic comparisons can be made. This may require slightly deeper soil sample boreholes. The builder will be familiar with Chapter 4 of the NHBC Standards[34] (which covers the appraisal of ground conditions at a site proposed for housing. Where piling is to be considered, there are several references that can be used to decide the scope of soil tests required for pile design, and reference can be made to previous experience in the area as part of the desk study for the Environmental Impact Report that is prepared for the local authority planning procedure to obtain planning consent for new houses.

The most important reference is BS 5930 but this is not as specific in respect of piling as the guidance contained within the SCI publication *Steel bearing piles guide*[22] and an extract from the latter is therefore reproduced below:

"It has been found that in-situ testing of soils is particularly relevant to all types of driven pile. Soil strength testing should apply a method of loading to soils that resembles as closely as possible that to be applied by the pile to the soil. In this respect, soil tests are needed to predict the soil resistance for the following types of loading:

- Pile driving.
- Pile support to the structure dead loads during working life.

- Possible ground heave or shrinkage loads.
- Pile live loading (transient) during working life e.g. wind loads and flood flow lateral forces.

In practice, this is achieved by correlating standard soil tests to each physical phenomenon by research on test piles."

3.5.1 Soil test data for design

Granular soils

Soil testing should include use of the following in-situ types:

- The Standard Penetration Test (SPT) as specified by BS 1377-9: *Methods of test for soils for civil engineering purposes: In-situ tests*[1]. The SPT is a well established universal test applicable to all types of granular soil for which it has been extensively calibrated for the prediction of pile driving resistance, shaft friction and end bearing correlation.
- The Cone Penetration Test (CPT) also specified by BS 1377-9, has been extensively calibrated against steel pile design parameters in fine-grained granular soils (sands, silts and clays).
- Dynamic probing is used extensively in Scandinavian and Baltic States and has been correlated directly to pile static and driving resistance.

Laboratory testing should include:

- Saturated and unsaturated bulk densities (unit weight).
- Shear box tests to determine the angle of internal friction (ϕ').
- Particle size distribution classification tests.

Cohesive soils

For cohesive soils, the geotechnical pile design and resistance prediction methods for axial loading generally rely on the correlation of pile behaviour with the unconsolidated undrained cohesive strength (c_u), but care should be taken to select the soil strength at a consistent strain to failure. This has been addressed in the Norwegian Offshore specifications for triaxial soil testing[35] and is taken as the strength at failure or at a strain of 4%, whichever occurs first.

3.5.2 Selection of soil parameters

Many geotechnical design and prediction methods require the judgement of average soil parameter values for each soil layer. This requires experience because there are several processes involved in making the judgement, including:

- Classifying and characterising the soils and selecting the principal soil layers.
- Collating and interpreting the soils data, including checking the validity of each data point, e.g. an undrained soil strength value (c_u) for a clay may be too low due to disturbance and may therefore not be representative of the layer.

- Selecting the soil properties that are the best suited to the purpose and the geotechnical pile design or resistance prediction method that is most appropriate to the type of soil and to the ground conditions at the site e.g. if there are swelling/shrinking clays or trees present.

The designer should ensure that an engineer with relevant geotechnical experience and knowledge of pile design and performance is involved in this judgement process at the concept design stage, otherwise uneconomic or unsafe judgements of soil parameters may result. It is recommended that builders should seek the advice of specialist piled foundation companies who are registered with the Association of Underpinning Contractors (ASUC) or of the Federation of Piling Specialists (FPS) who have engineers with the necessary expertise in driven pile design.

3.6 Pile foundation design

3.6.1 General

The design and installation of piling is a specialist business, and there are many reliable piling contractors who can offer a comprehensive design-supply-install service. The larger companies are members of either ASUC, or of the FPS (Federation of Piling Specialists) and are run by professionally qualified civil engineers. Other smaller piling contractors would need to be vetted first or the design done independently by a qualified geotechnical engineer.

Mini-piles are more influenced by soil phenomena such as subsidence (causing a dragdown force) and heave (causing an uplift force) than would be expected on the longer, more heavily loaded piles that are used for heavy civil engineering structures. This is due to the lighter loads from a house and the concentration of subsidence/heave soil effects at shallow depth. Specific advice on design for these phenomena is given below, based on the most recent research and reports by BRE (see Appendix A).

Straight shafted mini-piles

The design of straight shafted driven or bored piles is similar and well established. Standard design methods are well known and can be independently verified by geotechnical engineers and expert piling contractors. However, there has been a need to confirm the applicability of the general design methods to the smaller diameter mini-piles that are used for housing and cater for the problems with swelling clays. Therefore, as part of the research for this publication, verification of design methods for straight-shafted mini-piles has been carried out by the BRE and the results are presented in their Report No 80203[24] that is reproduced in Appendix A.

The BRE report recommends the geotechnical design methods that should be used to determine the load resistance of mini-piles in different soils based on the interpretation of a database of pile load test results obtained from research and construction site testing. A summary of the findings is as follows:

1. In clay soils the same prediction method can be used for all types of straight-shafted mini-piles regardless of whether they are driven steel cased, driven precast concrete or bored cast-in-situ concrete piles. The method is independent of diameter and calculates the shaft friction and end bearing capacity separately.

2. In granular soils, however, there are significant differences in load capacity that can be achieved by using different pile types. Driven or jacked piles will achieve higher shaft friction and higher end bearing because they do not loosen the soil than bored piles.

3. In buried rock, the end bearing resistance that is possible with driven piles is often an order of magnitude higher than with bored piles because driven piles compact the rock whereas bored piles loosen it. Recent international research has shown that the current recommendations in BS 8004:1984[9] for the end bearing capacity are only appropriate to bored piles but is too conservative for driven piles. The recommendations given in the *Steel bearing piles guide*[22] published in 1997, should be used instead which will result in fewer piles being needed.

Dynamic pile testing as recommended in the *ICE Specification for piling and embedded retaining walls*[32] can be used in granular soils and rock to give the capacity of driven preformed piles. Research has shown that the high cost of static testing is generally unnecessary for house piles.

Other types of mini-pile

For other types of proprietary pile such as screw piles, 'displacement' CFA or driven 'grouted' piles, the design methods are very different because they have a different load-transfer mechanism to the soil. These special proprietary types of pile can be very efficient in pile length but for housing this may produce very short piles (less than 4 m long) that are not suitable in swelling clays, near trees, or where trees have been recently felled. This is because they derive support from the upper soil layers that are most at risk to heave or subsidence due to seasonal changes in water content.

If such piles are proposed, the builder or his adviser should check their suitability for the soils and conditions at the site by means of a BBA Certificate or similar verification that is acceptable to the building inspector. Alternatively, a pile load test should be carried out to verify that the required load capacity can be achieved, together with a geotechnical assessment report on design provisions in respect of heave or subsidence.

If this assurance is not available then the builder should ask for alternative bids using straight shafted piles that can be sleeved in a conventional way to provide the required provision against heave effects[23]

3.6.2 Design process

The process that is usually followed for the design of mini-piles is shown diagrammatically in Figure 3.6 and descriptions of the stages are given below:

Site investigation

After the Environmental Impact Report, a careful site investigation including boreholes and test pits will identify and examine features in the subsoils and near-surface phenomena that are particularly important to the design of the mini-piles for housing. The specification for the soil investigation will depend upon the size of the site, the complexity of its geology, prior construction experience in the area, and on any disturbance from previous human occupation. No single specification is suitable in all cases.

Stage 1

In the first stage of the structural design of a mini-pile, the required cross-section is determined based on a factored yield strength to support the applied axial and shear loading, assuming in the structural analysis of the building that there is a pin joint at the connection with the pile.

Stage 2

Determine the length of the pile section that is required to generate a factored soil resistance equal to the factored axial load, using an appropriate geotechnical prediction method and the soil tests at the site to determine the shaft friction and end-bearing. Additional pile length may be needed to allow for any zone in heavy clay soils where heave or shrinkage may occur, see Section 3.7. Equally, an allowance should be made for any negative shaft friction load on the pile due to any settlement of compressible soils, e.g. peat, organic clays or fill over the life of the house.

Stage 3

Assess the practicality of installing the chosen pile to the depth required employing available driving hammers by using a wave equation programme such as GRLWEAP[30] for a more precise analysis, or using a pile driving formula such as Hiley[31] or Flaate[33] for an approximate check. Pile stresses should remain below yield strength during the highest predicted driving force required.

For friction piles, the possibility of changing the cross-section to suit other available pile sizes can be judged by checking the length required in the various soil profiles across the site and ensuring acceptable driveability.

For end-bearing piles, it may be considered desirable to provide a driving shoe at the toe of the pile in order to provide assurance to the designer that penetration into rock or other sound stratum can be achieved whilst avoiding local buckling of the pile base. Advice from other previous experience of piling in the area should be sought if it is available. An oversize shoe should not be used where pile shaft friction is also to be relied upon because it will reduce shaft friction by causing disturbance to the adjacent soil.

Stage 4

Assess the possible bending stresses that the pile may attract with various possible connections to the ground beams and provide appropriate steel reinforcement in the pile. For steel cased piles, a loss of 1.5 mm steel casing thickness can be assumed to the end of a 100 year design life for a house in UK natural soils (see Section 3.11). Research has shown that corrosion products will effectively replace the volume once occupied by the pile steel wall, thus maintaining the shaft frictional resistance against the soil during its life.

Stage 5

Evaluate the cost and construction duration for different types of pile and their effect on practical connections to the ground-beams before selecting the preferred solution.

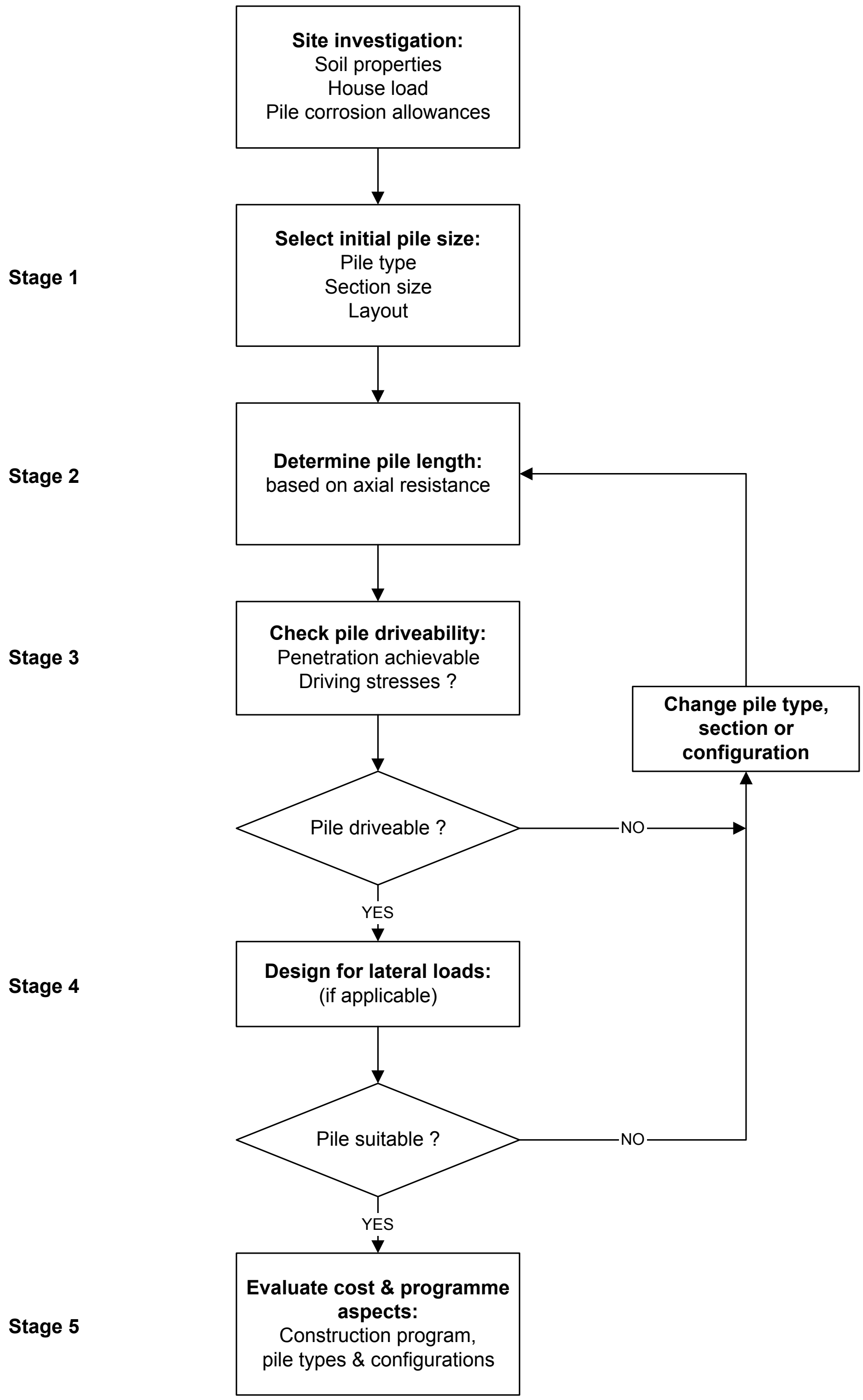


Figure 3.6 *Single pile design procedure flow diagram*

3.7 Foundation design in swelling clays

The Building Research Establishment (BRE) has researched and published *The behaviour of lightly loaded piles in swelling ground and implications for their design*[23] to help solve the pile design problems associated with shrinkable/expandable clays ('S/E' clays or 'swelling' clays), the effect of trees and shrubs adjacent to houses and their effect on house foundations.

Recommendation from BRE is that concrete trenchfill is not used in these conditions (to avoid the significant risk of damage to the house structure), and that piling is used instead as a more reliable, practical, and economic foundation. The potential heave or subsidence should be predicted and allowed for in the design of the piles and the ground beams.

The foremost authority on house building foundations near trees is Dr. Giles Biddle, whose book *Tree root damage to buildings*[21] is a standard reference on the subject in the UK. In it he recommends pile foundations as the best solution on shrinkable clays near trees.

The degree of swelling or shrinkage of plastic clays is impossible to predict with any accuracy since it depends on several very variable factors that interact, including: the climate; tree type, size, and proximity to the building; different clay types; and the drainage of the land. In addition, it is known that the climate is changing due to global warming so this may create worse conditions in the future. Therefore, if swelling clays are identified on the site, house foundations should be protected from the effects of subsidence or heave.

Precautionary measures to isolate the house from these foundation soil movements can include providing an appropriate clearance below a suspended ground floor, and a compressible surround to buried ground beams such as that illustrated in Chapter 4.2 of the NHBC Standards[36]. Piles should be sleeved with an annular compressible material through the major clay zones near the ground surface that are most prone to changes in water content. Information on construction methods to achieve this can be obtained from ASUC member companies.

General advice is given in BRE Digests Nos. 240, 241, 298 and 412 [25].

3.8 Pile installation and environmental considerations

Pile installation by a drop hammer or vibratory hammer can be a noisy operation and is a potential nuisance to existing occupants of nearby buildings. However, mini-pile driving is fast and several houses can be completed in one day, so the nuisance is of short duration. Although jacking might be preferable where noise is a critical aspect, available jacking equipment is currently in short supply and is still being developed.

There is hence a need for those involved in specifying piling plant to be realistic and pragmatic in their application and interpretation of the regulations in order to permit piling on urban sites. They should also be aware of the recent research that has demonstrated lower noise and vibration from pile drivers and permitted improvements in prediction of noise and vibration levels.

The noise from percussive driving hammers has been greatly reduced in recent years by redesign and shrouding (see the Bullivant 'silent-piler' in Figure 3.2), so that the major source of noise is now the diesel powerpack for the driver.

Noise and vibration can now be reliably predicted by specialist piling contractors based on extensive research by the TRL[42] in recent years and this will form the basis for confident negotiations with neighbouring residents in the vicinity. This is now a routine procedure and should not be seen as an impediment to the adoption of piling as an alternative to more expensive trenchfill. In the event that an independent assessment of noise and vibration is required or a practical specification of limits to comply with legislation, a pile testing specialist company can be consulted. The additional effort involved in performing a competent noise and vibration prediction is worthwhile to the builder or developer in securing a driven pile solution that can be cheaper than a bored or augured alternative.

Overcoming the understandable resistance of nearby residents and a cautious Local Authority requires tact and skill by experienced personnel. The public need reassurance that the noise and vibration will be controlled to acceptable limits and of short duration. The Environmental Health Officers of the local authority will need reassurance that the noise and vibration will not exceed the statutory thresholds laid down in the Environmental Protection Act and in British Standard BS 5228-4[2].

Some housing sites have restricted access. This will obviously be a constraint to all deliveries of construction materials as well as for piling equipment. However, to jack or drive mini-piling only requires small plant and tracked chassis rigs, which can negotiate small entrances and narrow sites without a problem, (Figure 3.7). Many of these have been especially developed previously for the underpinning pile market where access is generally much more restricted than new build sites.

Figure 3.7 *Small mini-piling hammer rig*

Some of the mini-piling systems use segmental piles to minimise the necessary height of the piling rig and to avoid the need for cranes during the work (see Figure 3.7). Normal site excavators can be adapted for driving short piles using vibratory drivers as illustrated in Section 3.4 (see Dawson EMV and Unisto TPH in Figures 3.3 and 3.4).

3.9 Pile load testing

Generation of frictional load resistance requires a small pile head movement to generate relative movement between the pile shaft and the adjacent soil. This is only a few millimetres and less than 10 mm for friction piles of up to 20 m long. Piles that are end bearing into rock will only displace 2 or 3 mm due to elastic shortening of the pile material in transmitting load down the pile. In addition, designers should bear in mind that a prediction of pile movement based on a load test should be for the unfactored service loads from the house.

The most efficient and economic form of pile load testing is a dynamic test during or at the end of driving. This is less than 5% of the cost of a static pile load test and is just as valid (see *ICE Specification for piling*[35]). Where piles can be jacked, their load capacity can be determined during the installation using a load cell above the jack.

If piles are driven by a drop hammer, then dynamic testing needs a small strain gauge and accelerometer to be bolted onto the head of the pile to record the load in the test pile during or at the end of driving. The latter is now a routine visit of a few hours by a technician from an established independent testing company, with a mobile test computer and reliable software that has been validated by the civil engineering profession world-wide. CAPWAP[26] is the standard software and can deliver a record of the test result onsite for an immediate decision on pile suitability, thus minimising any delay. Use of this technique has revolutionised pile acceptance during installation and permitted pile length to be decided during the work. On sites with variable geology or varying depths of fill, this can facilitate pile acceptance and also serve as a basis to resolve any doubts about pile capacity.

3.10 Pile to ground beam connections

3.10.1 Precast concrete ground beams

The type of ground beam should suit the ground-floor construction and the connection to the pile top. Precast concrete pile caps and ground beams are often used to span between the mini-piles and support a suspended ground floor and house structure above.

Careful attention to connection details is needed when building on landfill or ‘brownfield’ sites or low-lying poor ground on flood plains where there is a potential for flooding. Many of these sites will have a final layer of fill to regrade the site, bringing the ground level up above potential flood level and permitting an effective surface drainage to be laid. On such sites, there will be a high water table and excavation is to be avoided, so pile heads will be left protruding well above the site strip level (see Figures 3.11 and 3.12) and precast concrete ground beams may be preferred for practicality.

Figure 3.8 shows the layout of a typical precast concrete ground beam system supplied by Roger Bullivant Ltd. The precast systems permit high quality and precise dimensioning of foundation elements with minimisation of site time and avoiding waste. However, they do require much more planning in the foundation construction process than builders are used to. This requires close cooperation between the piling contractor and the builder's ground workers who install the site drainage and service connections below ground floor. The builder must facilitate the coordination that is needed between these subcontractors to gain maximum economic benefit from precast foundation systems.

Figure 3.8 *Precast ground beams awaiting precast ground floor*

It is generally most efficient to contract for the supply and installation of both piles and ground beams from the same contractor as he will then be responsible for designing the connection at the interface between them.

Precast concrete pile caps need a level surface at the pile head for even seating and a recess of the correct diameter. Figure 3.9 shows details of a precast concrete ground beam system. This system has been widely used with precast concrete beam and block floors but can also be used with composite floor systems. The driven precast concrete or steel cased mini-piles used with this system have a central vertical protruding reinforcement bar provided, over which the pile cap is placed before the groundbeams are placed between piles.

The pile, pile cap and ground beam are then tied together with an in-situ concrete 'stitch' as shown in Figure 3.10. This provides a degree of structural integrity that can survive any minor relative movements that could be expected in the soils beneath the house.

On sites where the soil conditions are variable, precast concrete piles will often need cropping back to the desired level and then made good at the time the pile caps are placed. Figures 3.11 and 3.12 show precast concrete piles and pile caps before and after cropping, and Figure 3.13 shows the hydraulic cropping device suspended from an excavator and in action on a pile.

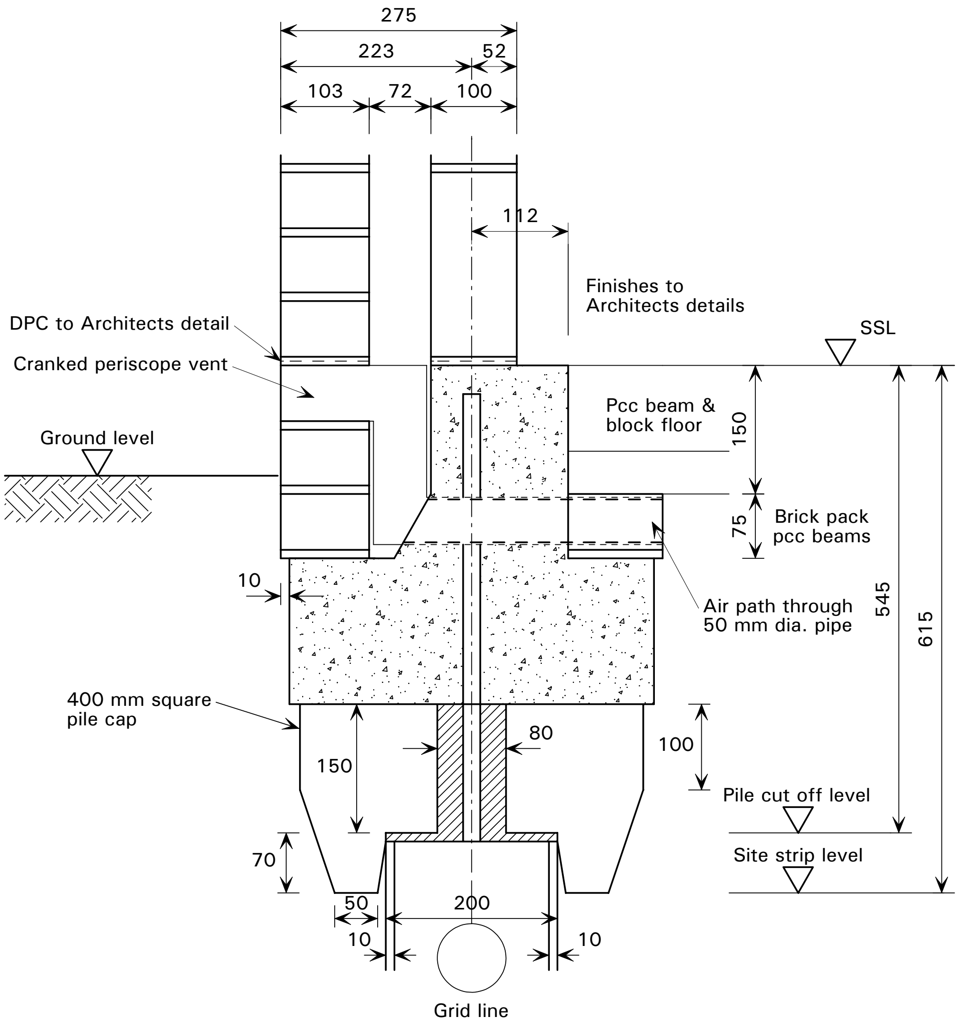


Figure 3.9 *Bullivant precast concrete ground beam system*

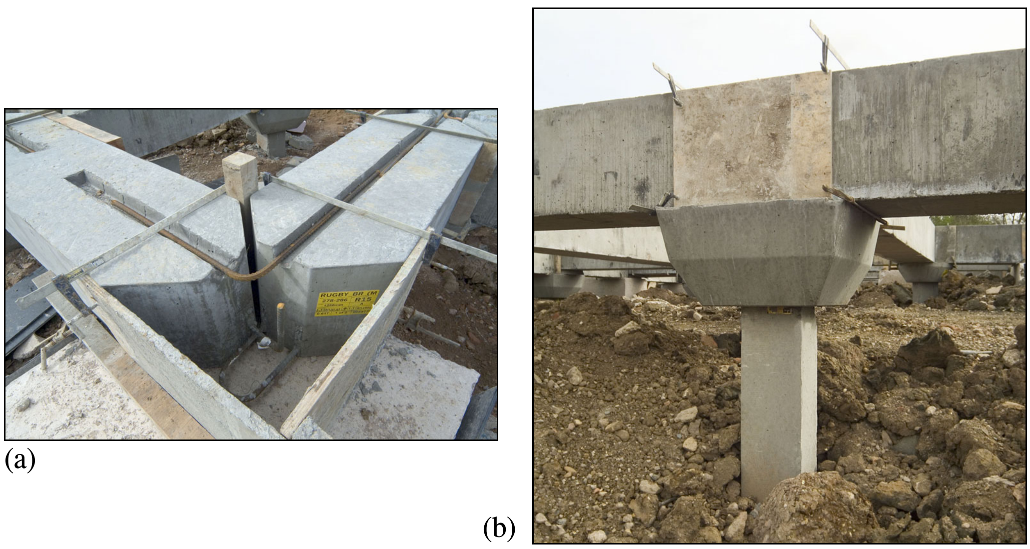


Figure 3.10 *The pile, pile cap and ground beams are tied together with an in-situ concrete 'stitch'. (a) Corner joint before concreting (b) Completed joint between precast concrete beams*

Figure 3.11 *Driven precast piles before cropping*

Figure 3.12 *Precast concrete mini-piles on 'brownfield' site after cropping and capping (Courtesy of Bullivant Ltd)*

An alternative in-situ concrete pile capping system is available from some contractors. This comprises a conical mandrel driven into the ground around the projecting pile head, which forms a conical hole into which a reinforcement ring is placed before placing in-situ concrete to the desired level. This may be suitable if the ground levels at site strip level are at pile head level.

Figure 3.13 *Driven precast concrete piles being cropped*

3.10.2 In-situ concrete ground beams

A different arrangement is needed for bored shell or CFA concrete piles because they require an in-situ concrete ground beam to cap and connect them.

Bored piles are formed from in-situ concrete with a reinforcement cage placed into the wet concrete column below ground. The top level is generally higher than required and the set concrete is then cropped to the correct level later when the ground floor is constructed. This leaves an uneven surface with the reinforcement bars sticking out that will not readily accept a pile cap. To accommodate this uneven interface, pile caps are not used and an in-situ ground beam is used instead.

In-situ concrete ground-beams need a sacrificial shutter, which may be made of polystyrene or a plastic board that can be formed to the required shape (Figure 3.14).

The steel reinforcement cage for the ground beam is either constructed inside a polystyrene trough shutter (Figures 3.15 and 3.16) or is put together first over the cropped pile heads (Figure 3.17). Either method needs care to be taken to ensure that there is adequate concrete cover to the reinforcement and the photographs show plastic cover strips to achieve this. The excavated base surface has been levelled off to form a base shutter using a layer of blinding concrete. Where there are swelling clays, a layer of compressible corrugated polystyrene is generally laid as the base shutter to prevent transmission of heave forces during the life of the house.

The diagram in Figure 3.15 shows the details for a polystyrene shutter trough for an in-situ concrete groundbeam beneath a suspended composite ground floor.

Figure 3.14 *Plastic sheet formwork, reinforcement and cover strips for in situ ground beam over two piles*

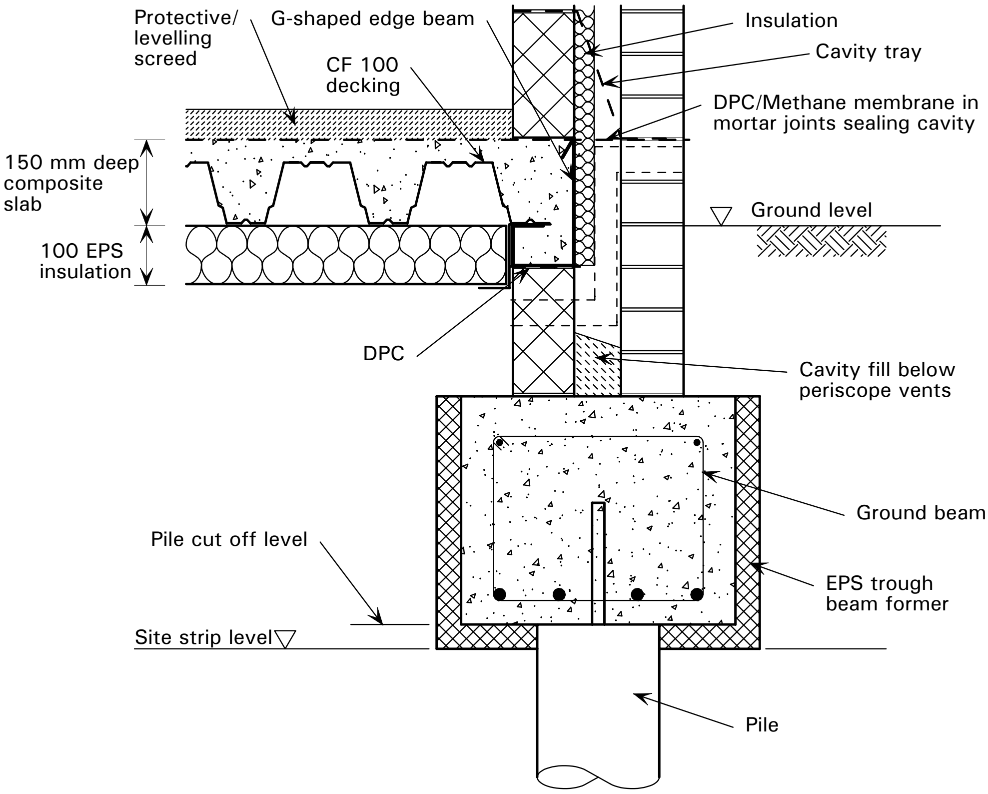


Figure 3.15 *Piled composite ground floor with in-situ concrete ground beams*

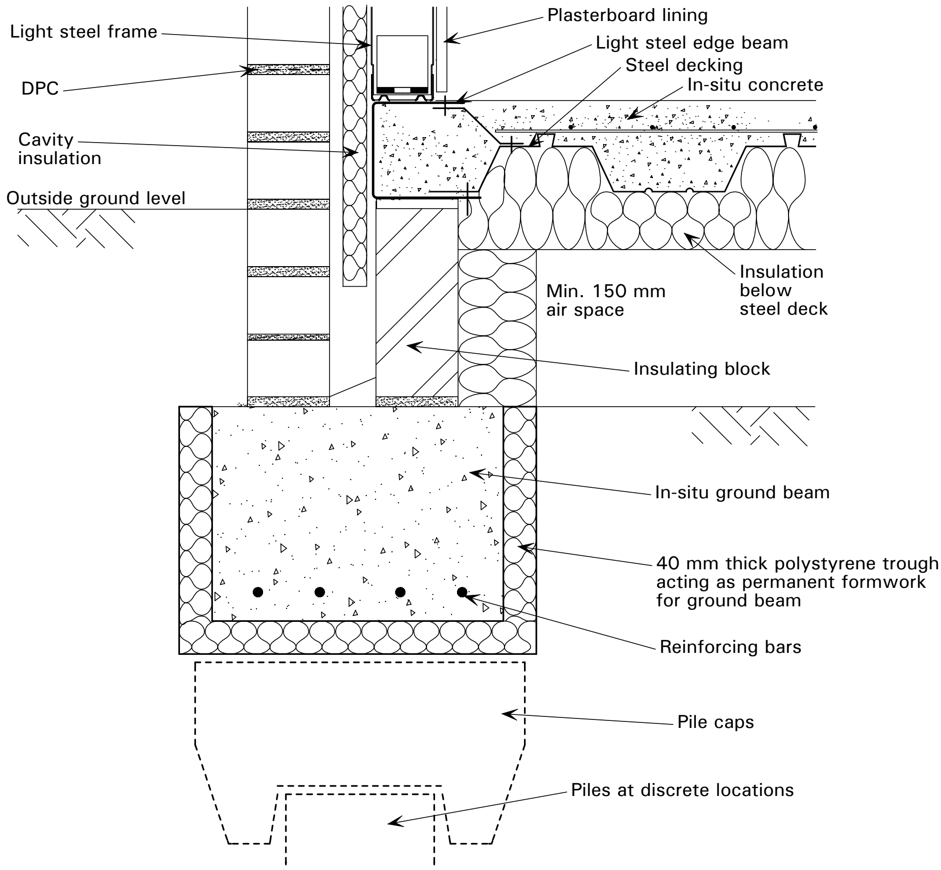


Figure 3.16 *Piled composite ground-floor system with in-situ ground beams formed within polystyrene trough*

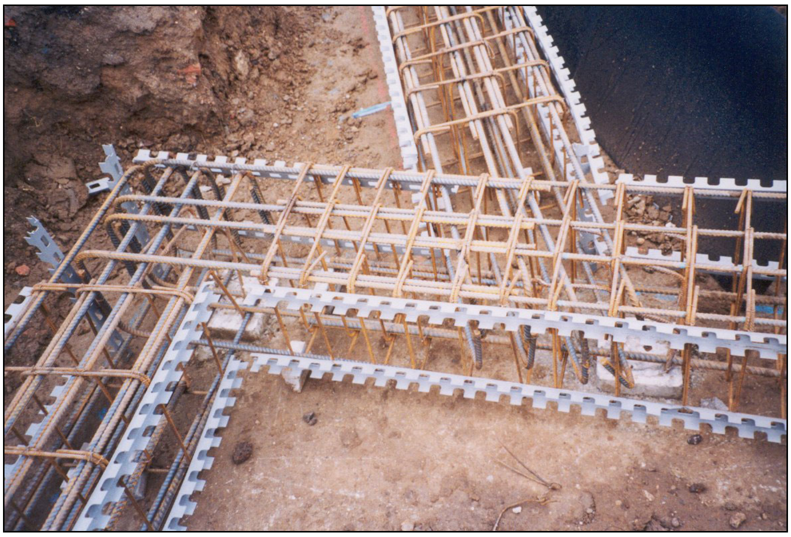


Figure 3.17 *In-situ ground beam over two piles showing cover strips and reinforcement over a blinding layer*

3.10.3 Piled composite ground floors

Composite ground floors can be supported by mini-piles either directly (as in the Abbey Pynford '*Housedeck*®' system (Figure 3.18) or indirectly on concrete ground beams spanning between piles. Both the internal and external skins of a cavity wall need to be supported. The choice of ground beam will depend on the practicality of installation and assembly on the particular site and its ground contours at site strip level at the time when the foundation is installed. The object should be to minimise any excavation for the foundation or to construct above an oversite concrete blinding layer on the house plan area e.g. in the *Housedeck*® system.

Builders are advised to consult ASUC or the FPS for the accredited specialists in their area who can also supply house foundation systems that include composite ground floors. Independent professional advice can be obtained from the SCI.

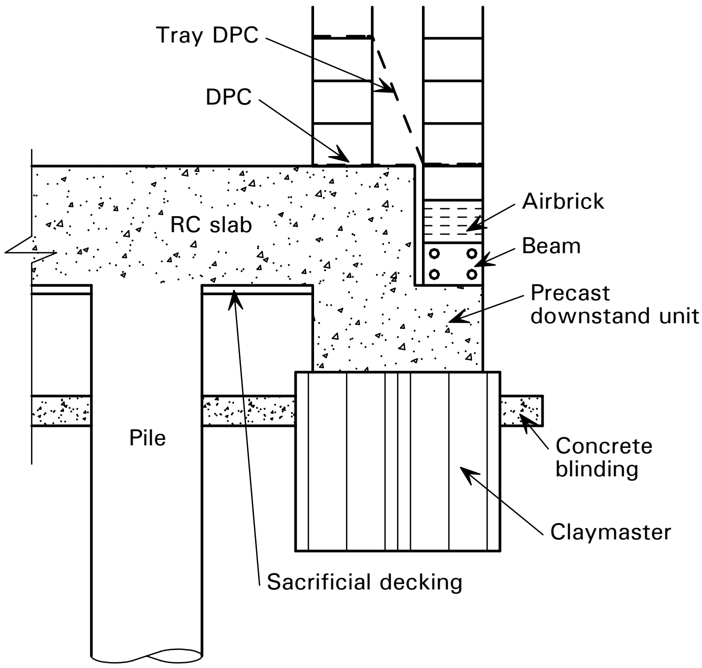


Figure 3.18 *Housedeck® foundation system developed by Abbey Pynford PLC*

3.11 Corrosion protection for steel piling

Where steel cased driven piling is used, the wall thickness is governed by the stiffness required to enable the tube to be driven or jacked into the ground to the specified penetration, and not by design loads or corrosion allowances. The outer casing generally requires a minimum wall thickness of 6 mm but is often 10-12 mm thick. Although steel piles could be coated for additional durability, it is not cost-effective because of the potential for scratching damage during installation, which will destroy effectiveness of the coating. The steel pile casings are filled with concrete after driving, so there will be no internal corrosion.

Extensive research by the steel industry has shown that corrosion of this outer steel casing is only significant in the upper soil layers above the groundwater table, where a continual supply of oxygen is present due to diffused air and there is continual re-supply of oxygen via rainwater. The corrosion rates for bare steel in the ground are detailed in BS 8002[10], where the accepted maximum rate for steel buried in the ground in the upper zone is 0.015 mm/year, i.e. a 1.5 mm loss of thickness over 100 years. The remaining 4.5 mm wall thickness of a nominal 6 mm thick pile will be more than adequate to take the light loads from housing.

Research on piles which have been installed over the last 40 years, shows that corrosion does not reduce the shaft friction along the pile. This is because the corrosion products form an iron-bound compound with the soil, which results in a cemented layer on the steel surface that remains in contact with the soil to maintain the load transfer from pile to soil.

An alternative type of cased steel tubular pile is produced in Finland by Ruukki called CSG (Driven Cased Grouted) in which an oversize shoe is driven to create an annular space around the casing. Concrete grout, under pressure, is exuded from holes in the pipe wall during installation to create a complete annular layer around the steel pile thus protecting it from corrosion in the soil. The additional diameter increases the frictional capacity of the pile.

4 COMPOSITE GROUND FLOORS

4.1 Composite ground-floor construction

Suspended composite ground-floor slabs are formed by casting concrete onto a steel 'tray' that comprises galvanized steel profiled decking screwed to an edge beam template (see Figure 1.3). This 'tray' supports construction loads and then acts compositely with the in-situ concrete placed on it to minimise the concrete volume required. The composite slab has high integrity and bending strength, and is suitable for use on either 'brownfield' or 'greenfield' sites. It has many advantages that include:

- Cost competitive with other ground-floor constructions.
- Good buildability. The lightweight components may be supplied in 'kit' form for ease of packing, delivery, handling and assembly on site.
- Enables secure fixing of wall frames.
- Provides an accurate line and level to permit first-time fitting of wall frames without need of packers or wedges.
- Components are man-handleable without cranes.
- Insulation can be above or below the floor.
- Below-floor insulation avoids need for screeds or a dpm above the floor.
- Impervious to ground gases (i.e. suitable on radon and methane prone sites).
- Uses easy assembly procedures. No special craft retraining is needed.
- Uses existing steel decking products that are already extensively used for commercial buildings and car parks.

Figure 4.1 *Light steel decking and edge beams before casting concrete slab*

Figures 4.2 and 4.3 show typical fixing and assembly of wall frames on the 'connection-friendly' interface that is provided by the composite slab, which also creates an accurate template to ensure a true line and level for the frames.

Figure 4.2 *Attaching steel wall frames to the edge beam*

Figure 4.3 *Assembling steel wall frames on composite ground floor*

A suspended composite ground-floor slab can be supported by conventional mass concrete trenchfill foundations (see Figure 1.3) or on ground-beams that span between discrete mini-pile foundations (see Figure 4.4). The slab has high bending strength and will tolerate a degree of differential settlement in the foundations, which will protect the house superstructure from cracking damage throughout its life. This is particularly important in the variable ground conditions that are found on 'brownfield' sites and marginal land where settlement under house load may not be uniform.

Figure 4.4 shows the permanent light steel soffit decking in a prototype composite ground-floor slab used for a student accommodation building at Oxford Brookes University. The durability life of this has been proven by monitoring the annual zinc coating loss from decking installed in composite ground floors in this and other test houses over many years.

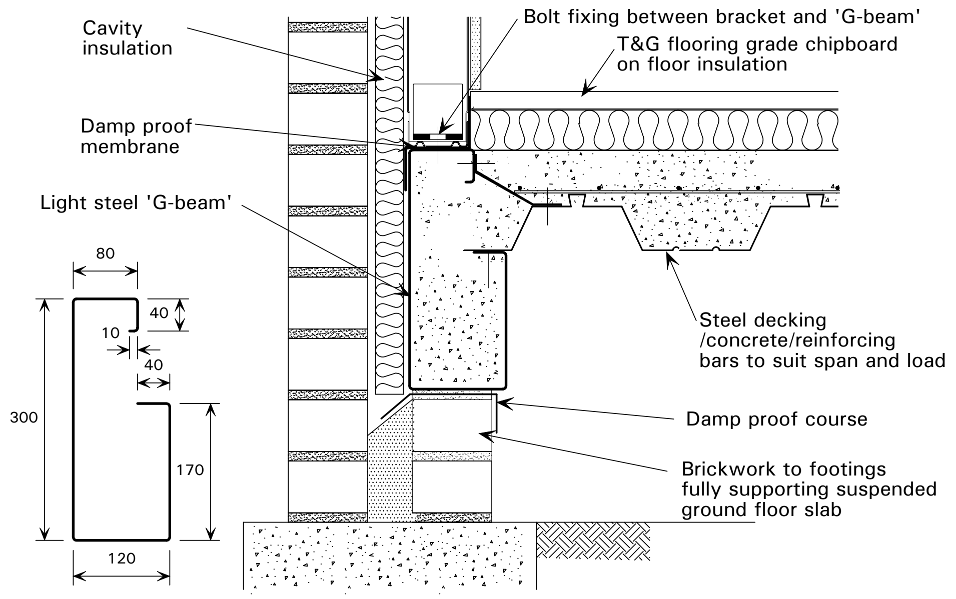


Figure 4.4 *Suspended ground-floor system with light steel 'edge-beam' as used for the Oxford Brookes demonstration buidling*

4.2 Thermal insulation

4.2.1 Current floor insulation provision

The two most important factors to consider for the insulation of ground floors are:

1) the location of the insulation within the floor structure and

2) the thickness of insulation.

The location of the insulation will depend on the characteristics of the chosen method of heating:

- If there is to be intermittent heating then the insulation should be positioned above the slab to ensure that the building will heat up quickly.
- If the building is heated continuously, the insulation should be positioned below the slab. This will increase the thermal capacity of the building so that the internal temperature remains more even. This will improve occupier comfort and reduce the risk of condensation within the 'warm envelope' of the building.

The thickness of insulation material is determined from the U-value required to comply with Approved Document L1[18].

Insulation above the slab

Conventional practice for suspended ground floors in the UK has been to place the insulation above the slab (see Figure 4.4).

In this location it must either have a sufficient compressive strength for the intended floor loading or a layer of a more robust material above to protect it. The particularly onerous loads are those from furniture feet, kitchen appliances etc., which can cause local indentation and permanent damage to the floor surface. Conventionally, the insulation panels are protected by either a concrete screed or by flooring grade chipboard.

A screed has to be well compacted and thick enough to distribute the applied loads to avoid local depressions and the insulation must be sufficiently rigid to support it. In housing, a minimum screed thickness of 65 mm has been found necessary. The insulation panels must now be properly jointed (see the 2002 edition of Part L1) and their contact surfaces free of projections like mortar or plaster droppings before the screed is laid. Great care needs to be taken to ensure that neither the insulation board nor the underlying membrane is damaged during installation.

Systems with the insulation placed beneath flooring grade chipboard have been used for many years as 'floating floors' over structural suspended floors to control impact sound and vibration transmission in multi-occupancy buildings. The insulated floor can be constructed in one of three ways:

- Composite panels using chipboard and a rigid insulant.
- Loose laid systems with the chipboard or plywood boards and the rigid insulant installed separately.
- Timber battens supporting boards with a resilient insulant between the battens.

The surface of the structural sub-floor has to be as even as possible (less than 5 mm irregularity over 3 m). In many cases, precast concrete beam and block ground floors do not comply with this and a levelling screed or compound has had to be laid first to eliminate any 'rocking' of the insulation panels and floor boarding that can otherwise cause damage. The screed is an expensive additional cost to the structural floor.

Conventional suspended precast concrete beam and block floors are heavily jointed and their thermal mass is unavailable to the building because of the open joints in the construction that permits heat to escape rapidly. To meet the more stringent U-value requirement in the 2002 edition of Part L1, it is calculated that approximately 100 mm thick expanded polystyrene insulation will be needed over the ground floor. This will require an even thicker protective screed to cover it and will make above-floor insulation even more expensive.

Insulation below ground floors

Insulation has traditionally only been used below ground floors when it is possible to use a ground bearing concrete slab. However, for suspended ground floors, no feasible method has yet been devised to attach the insulation beneath precast concrete beams or blocks. The new composite construction with a steel decking soffit overcomes this problem since the insulation can be permanently fixed by 'Alupins' through drilled holes in the deck (see Section 4.2.4).

4.2.2 Properties required of insulation materials

Insulation materials differ in their strength, stiffness, thermal conductivity and durability in various environments. The selection of a suitable insulation for use in ground floors requires careful specification of the conditions during construction and of the performance properties required during service life.

The factors include:

- Non water-absorptive and rot-proof.
- Durable and stable inert structure that does not deteriorate under the sub-floor environment, including methane and atmospheric mixtures.
- Known thermal conductivity over 100 years derived from testing.
- Resistant to fungi, moulds and microbial organisms.
- Vermin and insect proof.

Depending on construction type and location, insulation materials may have to withstand the applied loads with minimum compression. Applied loading has three components:

- The dead load due to the weight of the materials laid on the insulant.
- Construction loads and conditions.
- The in-service design loads.

An imposed load of 1.5 kN/m^2 is recommended in BS 5950-4[4] for the construction stage, in addition to the dead load of the deck and wet concrete. A similar loading has to be allowed for cases in dwellings, as suggested in BS 6399-1[7]; Table 4.1 gives the dead-weight loads of various construction layers.

Table 4.1 *Dead loads for various building components*

Element	Dead Load (kN/m^2)
Flooring grade chipboard	0.1 to 0.2
65 mm concrete screed	1.50
75 mm concrete screed	1.75
100 mm concrete floor slab	3.50

Insulation beneath a ground bearing slab is required to support both self-weight, screeds and imposed loads. Insulation above the slab will be required to support the self-weight of the screed and the imposed loads.

4.2.3 Durability of insulation material

Most insulation materials suffer a reduction in their thermal conductivity (λ) over a period of time. This is not widely known and there is currently no Building Regulation requirement to use the fully degraded value of a material when calculating U-values, although the reduced value has to be measured and be available. Common-sense dictates that the insulating material should either be stable for the lifetime of the house or that the U-value should be calculated on the basis of the fully degraded thermal properties that will operate during the service life. The introduction of the Construction Products Directive 89/106/EEC in 2001 by the EU has improved the requirements in this respect.

Expanded polystyrene (EPS) is the most commonly used insulation in construction and suits the purpose for composite ground floors. EPS is a stable, rigid lightweight cellular plastics insulation material manufactured by moulding beads of expanded polystyrene and which has a substantially closed cell structure. The blowing agent employed in the manufacture of EPS is Pentane which is neither a CFC nor a HCFC.

As the structure of EPS consists of 98% air, its initial thermal properties are maintained throughout its working life. It can be manufactured in a wide range of densities, shapes and sizes. It is non-toxic, moisture resistant and rot proof. The material is slightly water- absorbent (up to 6% by vol.) Standard duty EPS material (density 15 kg/m^3), normally used for domestic floor applications has a compressive strength at 10% strain of 70 kPa (21 kPa at 1% strain). EPS material with densities of up to 30 kg/m^3 and compressive strengths of up to 205 kPa at 10% strain are also available.

4.2.4 Insulation of a composite ground floor

It is desirable to include the insulation for composite ground floors at the most advantageous position where it will minimise the cost and overall thickness of the floor and maximise the insulation effect. To be consistent with current site practice, one option is to screed over insulation placed above the concreted slab, but this is not judged to provide the best solution in terms of thermal efficiency nor for economy.

The best position for the insulation on a composite slab is below and in continuous contact with the light steel decking (Figures 4.5 and 4.6). This not only keeps the slab warm but also provides a physical barrier to prevent moist air coming in contact with the decking, which would otherwise erode the galvanized finish. If a good quality finish is ensured by power floating the slab, there will be no need for a levelling screed. Thus under-floor insulation avoids the need and cost of screeds and also ensures better durability of the decking.

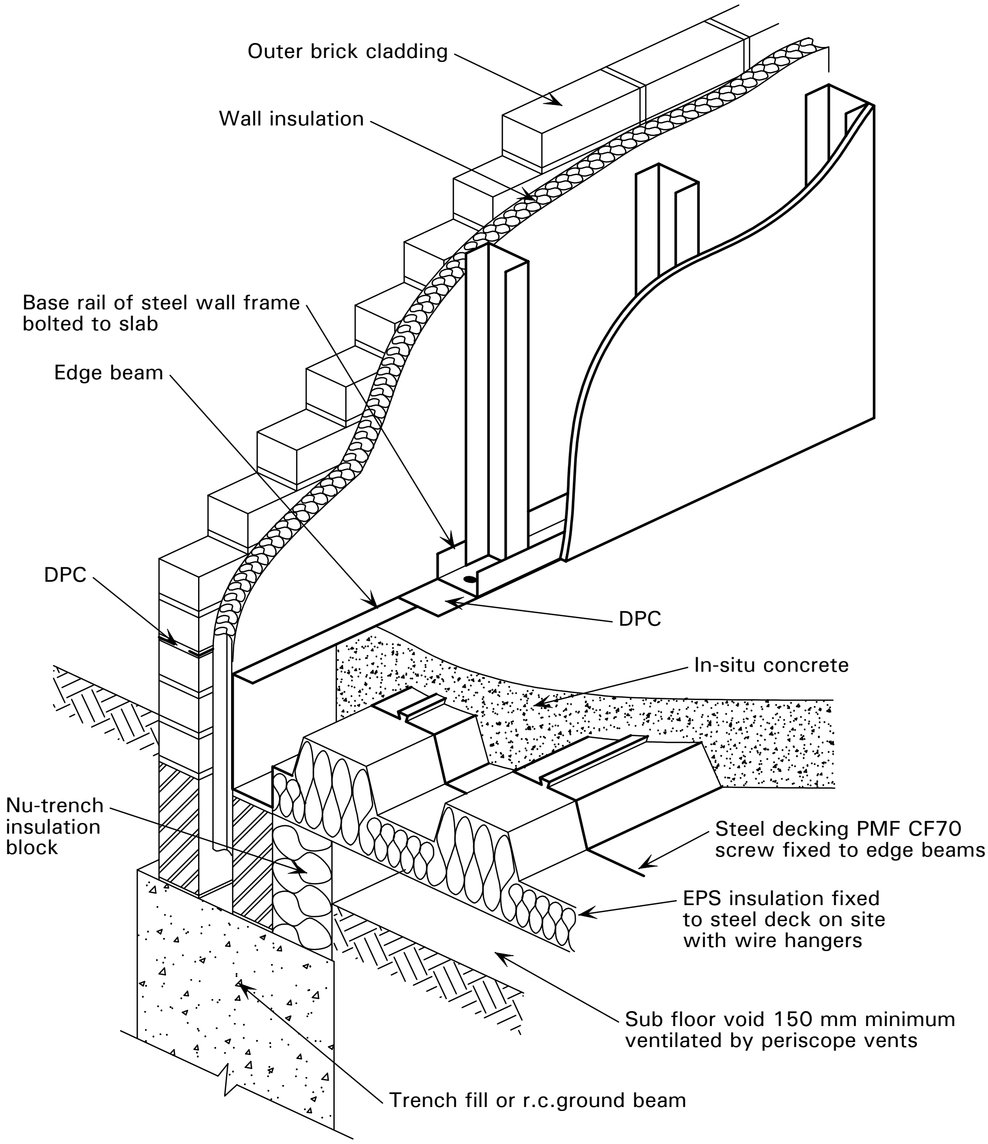


Figure 4.5 *Profiled insulation placed below composite ground floor*

The insulation is mechanically fixed using durable aluminium pins called Alupins that comprise a 125 mm long spike fitted with a base plate that are pushed through drilled holes in the decking and hold up the insulation panel with a one way grip washer.

Where the insulation is loose fitted in panels, the installation is by operatives standing on the ground, within the floor area, and moving across the floor without the need to climb onto the decking or lean across previously fixed panels. This ensures safety of the operation, speed of installation and minimises risk of damage to the panels. There is also good access to make a thermally efficient joint between adjoining insulation panels and to fit the Alupins to fix each panel.

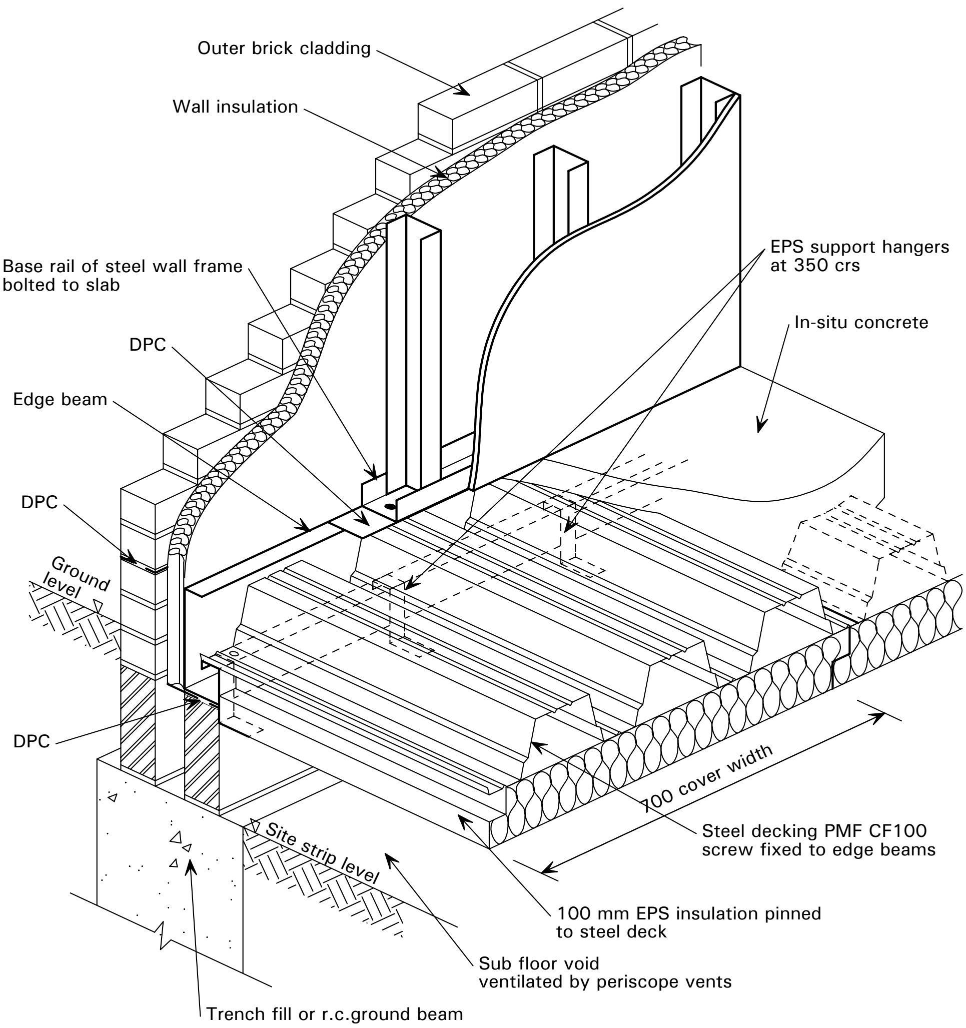


Figure 4.6 *Isometric detail of a flat panel insulation layout*

4.2.5 Cold-bridging

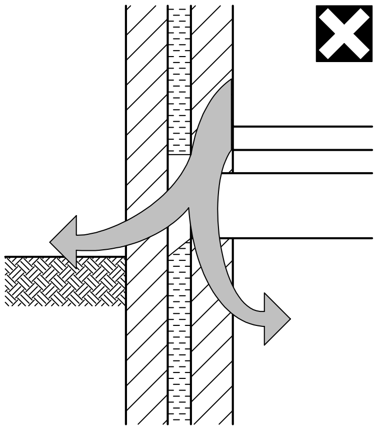
Typical cold bridge positions are shown in Figures 4.7(a) and various alternative means of insulating the walls and ground floors are shown in 4.7(b) and (c). Cold bridges need to be eliminated by good design of insulating systems and good practice during site assembly as required by the new Part L1[18].

The ground around the perimeter of a building often will be wet and, since water is a better conductor of heat than air, this can cause increased heat loss. Improved drainage immediately adjacent to external walls, such as a gravel backfill, can therefore be beneficial and it will also serve to lower the dampness that is the source of much deterioration of walls in the UK housing stock.

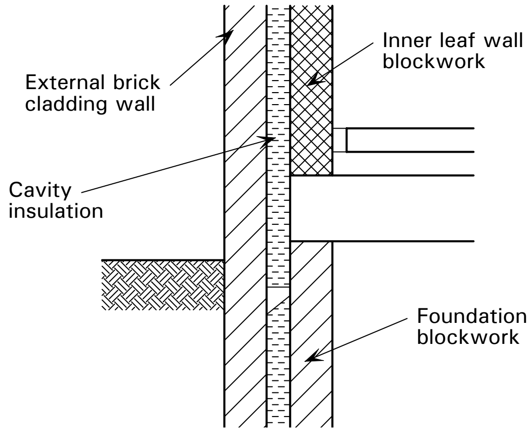
Concrete and composite floors

For insulation below a slab, the greatest risk of cold-bridging occurs at the junction of the floor with the external walls. On ground-supported slabs, a vertical length of insulation is required around the edges of the slab and external wall. On suspended slabs, where floor insulation cannot be turned up on the face of the wall, cavity insulation is required in order to avoid cold-bridges.

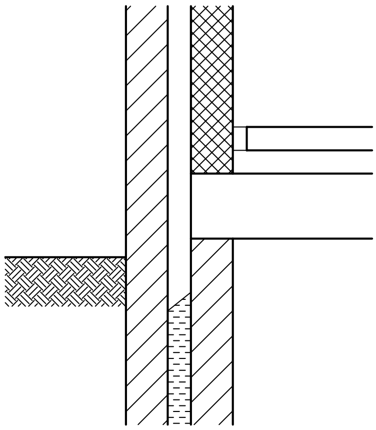
For cavity and insulated walls, the cavity insulation should start some 100 mm below the base of the floor slab.



(a) Cold bridges at wall/ground floor junction



(b) Cavity wall insulation solution



c) Insulated inner wall panel

Figure 4.7 *Cold bridging at wall/suspended ground floor junction and solutions*

Low-density blocks can be used for the inner leaf or an insulated composite walling panel or wall frame.

Correct detailing at the junction of the floor slab and external wall will reduce thermal bridging and thus reduce the risk of condensation, see Figure 4.6.

4.2.6 Service penetrations

Where service entry points penetrate ground-floor slabs care must be taken to thermally insulate the pipes or ducts as they pass through the slab, (Figures 4.8 and 4.9). This can be achieved using polystyrene foam from a hand held injection gun to fill the annular apertures.

Figure 4.8 *Service pipe penetrations through the steel decking, - view from void below the decking*

Figure 4.9 *External service pipe penetrations through decking*

4.3 Edge beams

Different geometries of edge beam are used in some systems to form the structural perimeter of composite ground floors within the inner walls of cavity wall construction. A ring of edge beams can be installed, aligned and levelled on the foundation walls or on concrete ground beams for a piled foundation. This provides an accurate template for fixing the light steel decking soffit, and acts as a side shutter and a tamping rail perimeter for levelling the wet concrete in the slab.

In the Oxford Brookes demonstration houses, the edge beam was of 'G' shape, as shown in Figure 4.4. The G-beam has a 50 mm wide ledge at approximately mid-height for the support of the steel decking. The cavity wall insulation is extended down to cover the outer exposed face of the G-beam and eliminate cold bridging. The outer wall of the edge-beam is supported by thin steel straps as shown in Figure 4.10 that are screwed back on to the decking.

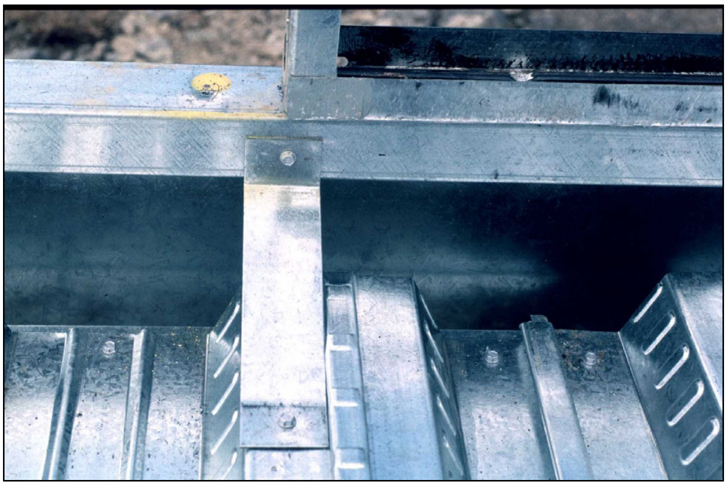


Figure 4.10 *Edge detail of decking showing G-beam and support strap*

An alternative C-beam, with reduced spanning capability, is shown in Figure 4.11. This is for the very minimum composite slab thickness of 115 mm that can be used on spans of up to 3.5 m. Decking trapezoidal ends have to be closed with a folded plastic stop-end to prevent loss of concrete during concrete placement.

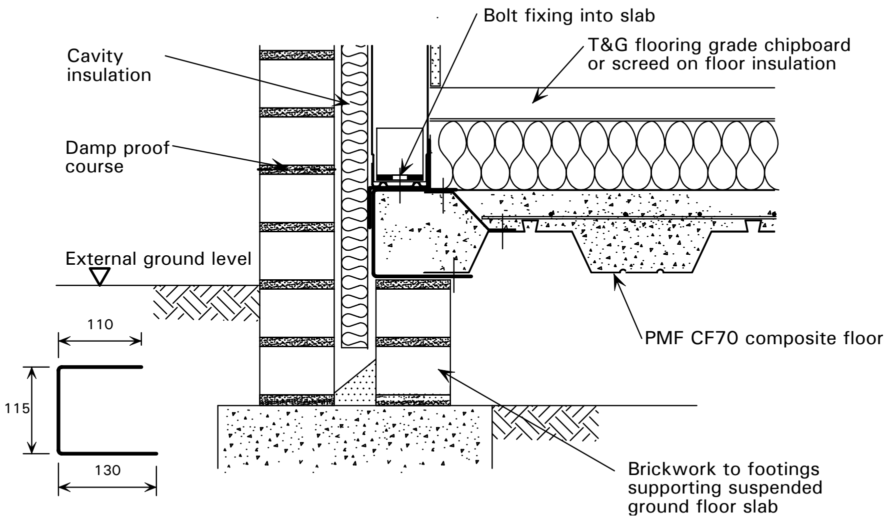


Figure 4.11 *Minimum size of C-beam at floor edge*

For below floor insulation, the trapezoidal shapes under the decking profile will be closed by the under-slung insulation, provided that the insulation is fixed hard against the face of the sub-structure walls (see Figure 4.15).

4.4 Damp proof courses and sub-floor ventilation

To ensure that damage due to moisture and infiltration of ground gases such as methane, carbon dioxide and radon is prevented, the following are required:

- Effective damp proofing for rainwater running down the outside wall or penetrating through to the cavity.
- Effective damp proof course for groundwater rising up the wall.

- Effective closure of the cavity against gases seeping up.
- Effective ventilation of the sub-floor void to remove gases and moisture.

Composite ground-floor construction has been deemed to be gas-tight by the NHBC and BRE without the need for a separate membrane. Sealing of the ground and venting of radon require special measures, as explained in Section 3, and the composite ground-floor slab will be a more economic and a more effective option in such situations. During suspended floor construction, the steel decking will provide a more robust working surface than a conventional dpm or radon membrane. The wall cavity will need to be closed by lapping the membrane under the steel decking and over to the outside wall, as shown in Figures 4.12, and 4.13). A further detail is shown for a piled foundation solution on 'greenfield' sites in Figure 4.14.

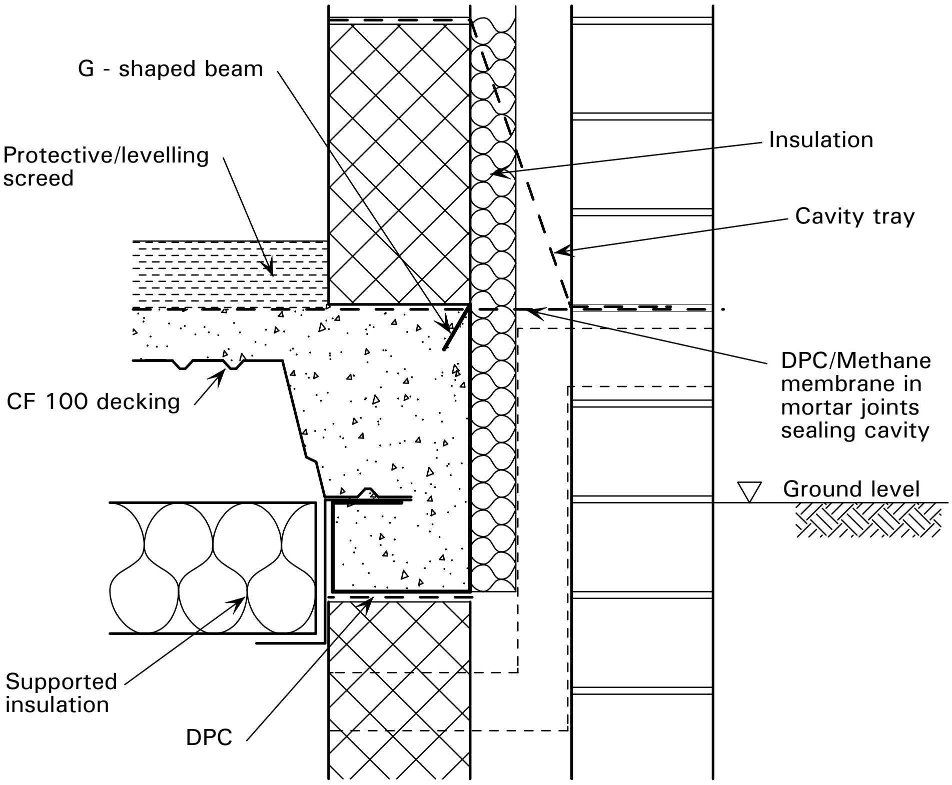


Figure 4.12 *Cross-section through a G-shaped edge beam showing radon proof membrane to seal across external cavity wall*

When the deck is to act as a gas impermeable membrane over 'brownfield' sites, particular care must be taken to ensure a gas-tight seal; this could involve the use of 'puddle flanges' around service pipe penetrations in order to facilitate making the seal using tape (Figure 4.15).

The floor insulation has also to be made good around the pipe after cutting the aperture for the service pipe.

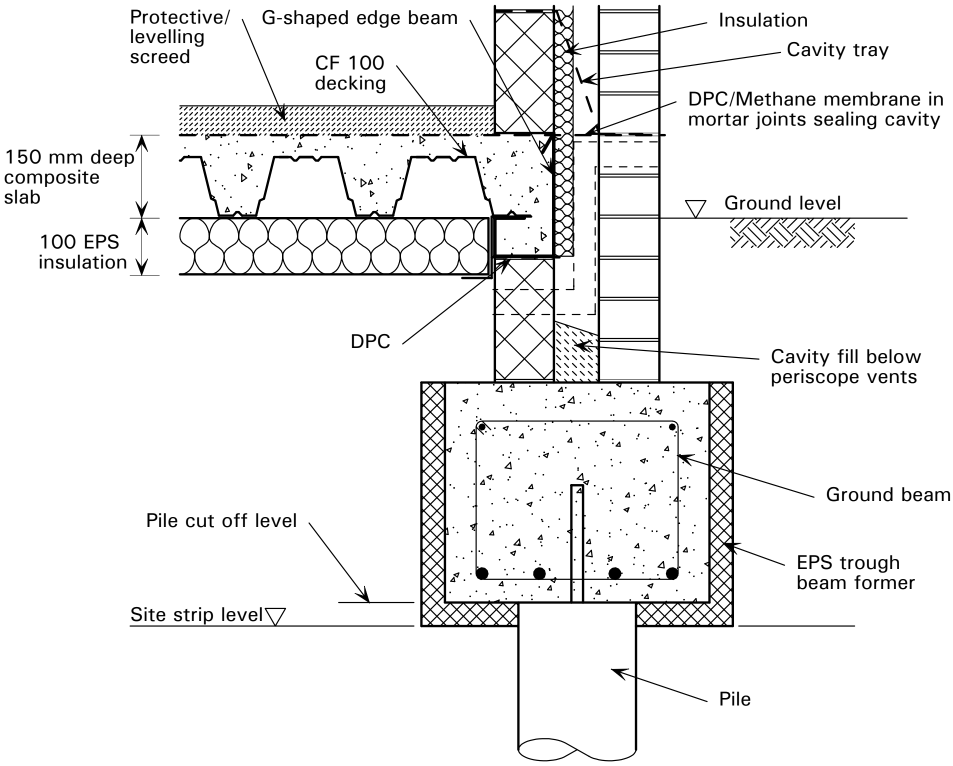


Figure 4.13 *In-situ concrete ground beam eliminating pile caps with G-shaped edge beam for composite floor on 'brownfield' site.*

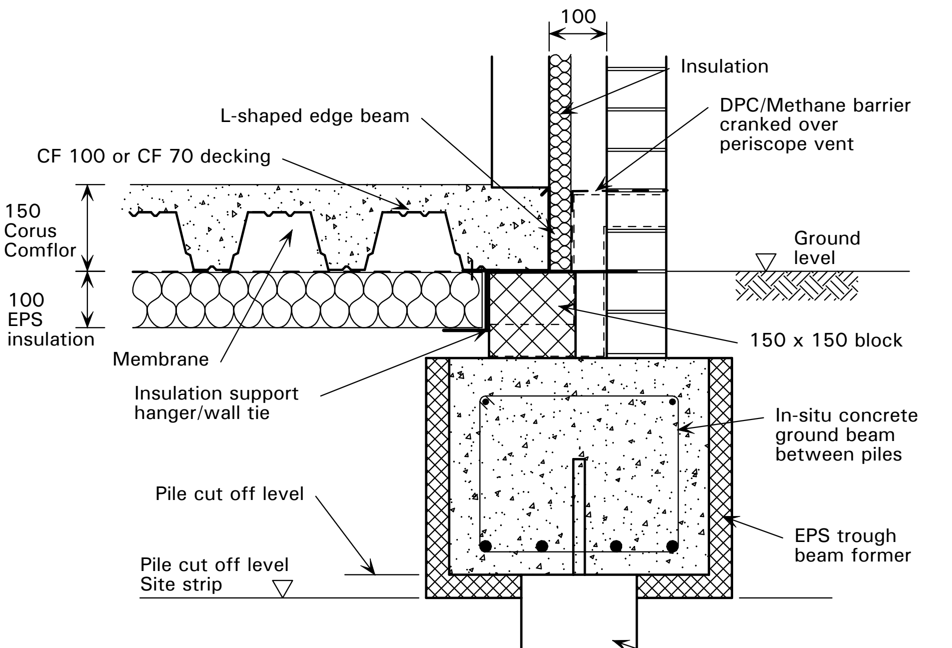


Figure 4.14 *In-situ concrete ground beam on piles with composite ground floor and L-shaped edge beam on 'greenfield' site.*

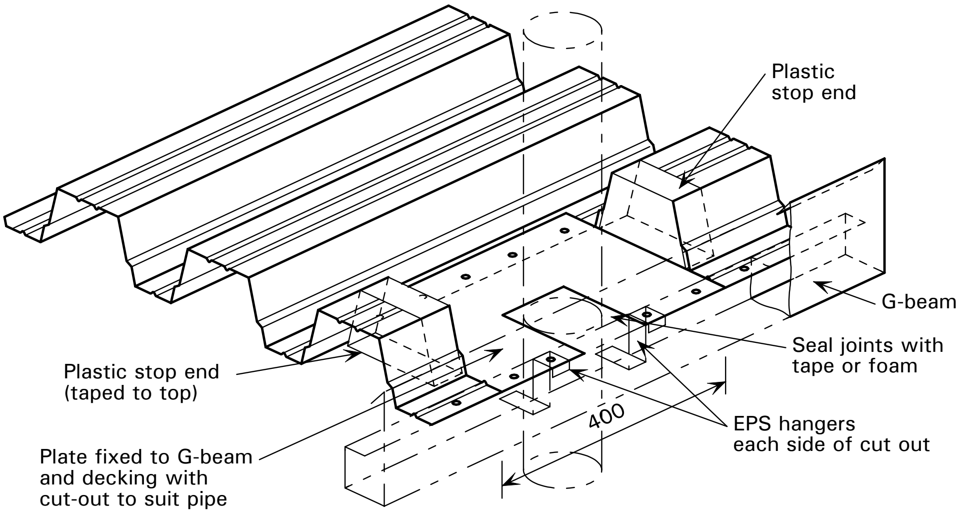


Figure 4.15 *Service penetration cover plate*

4.5 Design of composite ground floors

Composite floors with light steel decking rely on generating the composite action between steel and concrete to minimise the volume of concrete required in the floor slab. There are several different decking profiles available but the trapezoidal profiles provide the maximum economy of concrete in the cross section. The design of composite floors is supported by research on load testing by the manufacturers to comply with BS 5950:Part 4[5] because of the complexity of the floor sections.

Construction loads generally govern the design of the light steel decking elements in a composite floor, whereas in-service loads are resisted by the composite slab. Upper floor slabs are generally designed for a 30 or a 60 minute fire rating to BS 5950-8 [6], but Approved Document B does not require fire resistance for ground floors on houses of two storeys or less.

Composite floor slabs are very efficient in the use of concrete and because they are relatively thin, the design criterion for deflection often governs design.

Lightweight concrete can be used to achieve slightly greater spans, but it is more expensive than normal weight concrete and rarely worth the extra cost. An example of comparisons of slab designs using different decking profiles is shown in Table 4.2.

Table 4.2 *Slab depths to achieve 30 or 60 minutes fire rating on a 3 m span*

PMF Profile sheet type (Grade S 320 steel)	Fire rating (mins)	Slab depth	
		NWC	LWC
CF51 / 0.9	30	-	101
	60	-	101
CF51 / 1.2	30	101	101
	60	101	101
CF70 / 0.9	30	-	105
	60	-	115
CF70 / 1.2	30	115	105
	60	125	115

In multi-occupancy buildings i.e. flats and apartments where floors are continuous over several adjacent dwellings, care should be taken to ensure that the slab is not too dynamically sensitive, i.e. it does not vibrate to a degree that would be disconcerting to the occupiers. Conventional design practice is to ensure that the natural frequency of vibration of the floor is above 4 Hz for domestic houses. Guidance on design for vibration is contained in the computer design software issued by steel decking manufacturers.

Light steel edge beams are used to support the decking during construction of the composite slabs. They also act as end-stops to contain the wet concrete and provide a tamping rail for the vibrating beam compactors.

Figures 4.13 and 4.14 also show how the thermal bridge can be minimised by using continuous polystyrene insulation for the in-situ concrete ground beam shutters between pile caps. In-situ concrete groundbeams can eliminate the need for separate pile caps which is useful where mini-piles have to be trimmed. (The uneven head of such piles is then buried within the ground-beam concrete.)

Other composite floor types generally comprise of precast concrete floor beams with polystyrene soffit blocks in between them or an in-situ concrete slab (e.g. Marshalls *Jetfloor*®, or Springvale *Beamshield*®). The beams are designed to BS 8110[11] for both construction and in service loading.

4.6 Case studies of composite ground floors

4.6.1 Oxford Brookes University

In 1996, as part of a pan-European demonstration project, The Steel Construction Institute, Corus Building Systems and Oxford Brookes University commissioned Taywood Homes to build a semi-detached multi-occupancy building for post-graduate accommodation, using the Corus 'SureBuild' light steel wall framing system (see Figure 4.16).

The building has a useable floor area of 275 m^2 and comprises a two-storey house semi-detached to a three-storey studio apartment building designed so that internal walls may be relocated in the event of the University changing their accommodation requirements.

The project included long-term monitoring of building physics parameters, including energy efficiency of the building envelope and the warm frame, and the durability of the galvanized protection to the various light steel components in the roof, walls and floors.

Figure 4.16 *Oxford Brookes light steel framed houses*

The SureBuild system provided the internal structural framework of the building to which the insulation, plasterboard, flooring, and external cladding were attached. The external cladding wall was conventional brickwork.

The Oxford Brookes test houses used galvanized steel G-beams in combination with light steel floor decking from Corus PMF and an in-situ concrete slab to form a steel-intensive suspended ground floor of composite construction. The G-beams form the supporting perimeter to which the decking is attached by self-drilling, self-tapping screws as shown in Figure 4.4. This system, as devised by SCI, is particularly attractive for steel-framed and timber-framed construction where the steel 'edge-beam' provides a suitable element to receive connection bolts or screws from the inner wall frames.

Insulation was placed above the ground-floor slab at Oxford Brookes with conventional sub-floor ventilation. Monitoring of the building has shown that the steel deck underside of the floor is maintained at a temperature sufficiently above the dew point to avoid condensation for most of the year. Satisfactory performance of the standard G 275 zinc coating is confirmed from the results of monitoring zinc loss from research coupons of galvanized decking steel placed in the void below the ground floor. Details of the performance of the galvanized building elements are given in SCI publication P262 *Durability of light steel frames in residential building*[37].

4.6.2 Test House at Corus Whitehead Works, Newport

The structural performance of the SureBuild light steel wall framing system has been verified in 1996/97 by an extensive series of loading tests on a full-scale house, complete with roof and external brick walls, that was carried out at the Corus Whitehead Works at Newport, Gwent (see Figure 4.17). A composite ground-floor construction was provided and the wall frames were screwed into the light steel G-beams of the composite ground floor.

Figure 4.17 *Load test on light steel frame house at Corus, Whitehead Works, Newport*

4.6.3 Ullenwood House, Cheltenham

A composite ground floor together with SureBuild steel wall frames were used in the construction of a single storey cottage in the grounds of the Star Home for the Disabled at Ullenwood House, Cheltenham in 1982, (Figure 4.18). The cottage has been continuously occupied ever since. The long-term durability of the light steel components used in the ground floor, walls and roof has been monitored and recorded in site visits. The working life or 'service life' of the galvanized components given in Section 4.7 has been interpreted from the data gathered at this site and at the Oxford Brookes site.

Figure 4.18 *Moose Cottage, Ullenwood House, Cheltenham*

4.6.4 Detached houses in Burton-on-Trent

A Corus prototype composite flooring was installed in November 2001 as the ground-floor construction for three large detached houses in Burton-on-Trent. The installation was a site assembly trial of the new system of components that was designed to include underfloor polystyrene insulation. The floor comprised a CF 70 decking from and light steel edge beams (Figure 4.19).

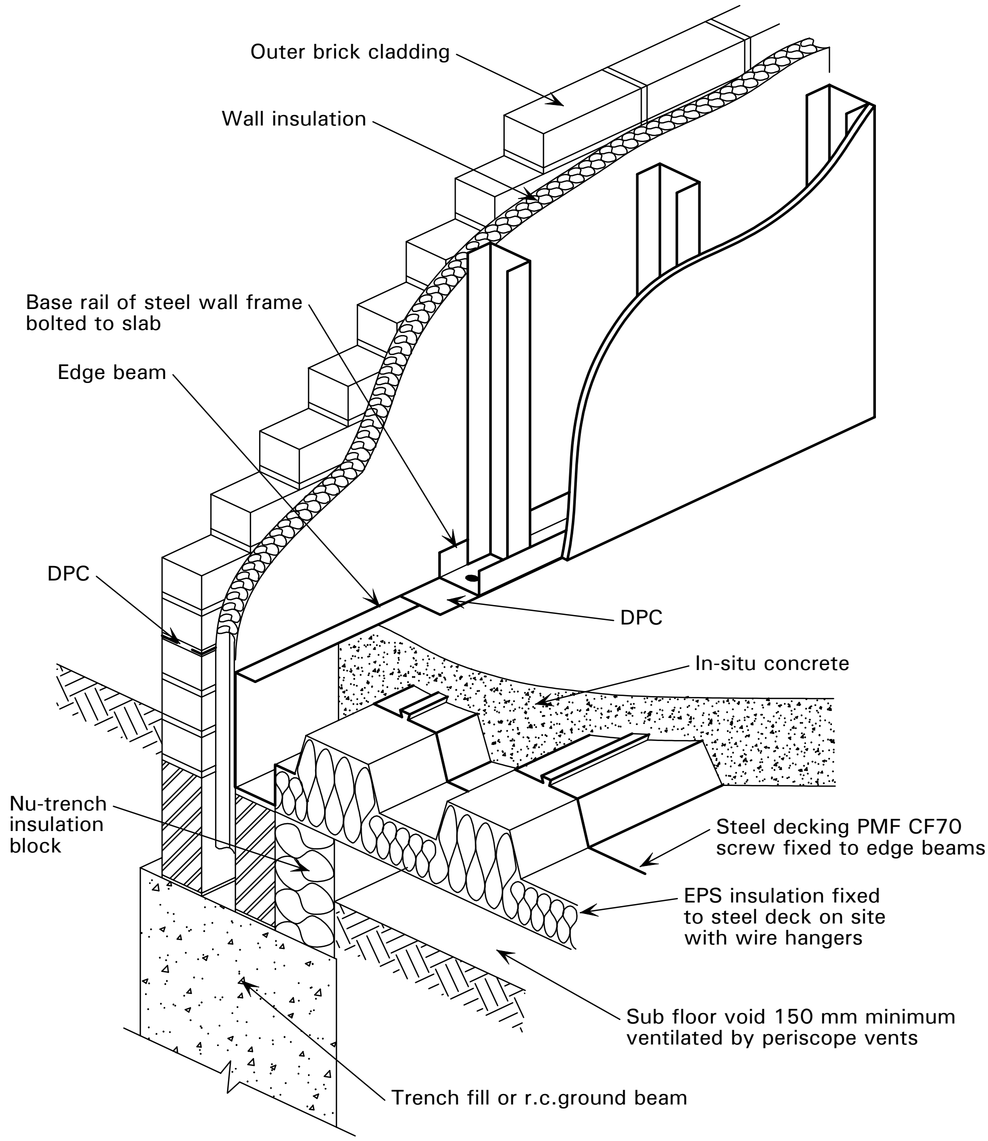


Figure 4.19 *Isometric detail of a profiled insulation system*

The under-floor insulation comprised EPS polystyrene panels of the same 900 mm width as the decking panels, profiled to match the decking and fitted with lap joints. This was supported on Nu-trench polystyrene wall blocks placed within the perimeter blockwork foundation walls.

The installation (Figure 4.20) comprised the following sequence of operations, starting at dpc level:

- First the sub-floor periscope vents were placed together with one external course of brickwork.
- Next the edge beams were assembled on mortar with a dpc strip in it around the inner wall perimeter, aligned and levelled and the mortar was allowed to set whilst the polystyrene wall blocks were placed.
- Once the mortar had an initial set, the polystyrene floor panels were laid one at a time, spanning on to the Nu-trench blocks, followed by a deck panel that was screwed to the edge beams.

- The insulation was then pinned up to the decking with three ‘Alupins’ just behind the joint edge before moving on to the next panel and the procedure repeated to cover the floor area.
- After placing the anti-crack reinforcement mesh the deck was ready for concreting.

The first house ground floor was installed by an experienced two-man team of decking installers who were trained on commercial composite flooring, and the remaining two were then installed by a two-man team of the builder’s subcontract ‘ground workers’. This established that a complete house ground-floor carcase can be completed in a working day by inexperienced site staff, ready for concreting the following day.

Figure 4.20 *Installing a prototype composite ground floor*

4.7 Design Life and durability

4.7.1 Design life requirement

The design life requirements for proposed buildings and individual components or assemblies are defined in BS 7543 *Guide to durability of buildings and building elements, products and components*[8]. Table 4.3 and Table 4.4 show abstracts from the 1992 version of that standard. Note that these tables are not included in the latest (2003) version of the standard.

Table 4.3 *BS 7543 Categories of design life for buildings*

Category	Description	Building Life	Examples
1	Temporary	Agreed period up to 10 year	Non-permanent site huts and temporary exhibition buildings
2	Short life	Minimum period 10 years	Temporary classrooms, buildings for short life industrial processes; office internal refurbishment, retail and warehouse buildings (see note 1)
3	Medium Life	Minimum period 30 years	Most industrial buildings; housing refurbishment
4	Normal Life	Minimum period 60 years	New health and educational buildings; new housing and high quality refurbishment of public buildings
5	Long Life	Minimum period 120 years	Civic and other high quality building

Note1: Specific periods may be determined for particular buildings in any of categories 2 to 5, provided that they do not exceed the period suggested for the next category below on the table; for example many retail and warehouse buildings are designed to have a service life of 20 years.

Note 2: Buildings may include replaceable and maintainable components

It is most likely that the building industry will expect a design life of 100 years for the structure of new houses, although only 60 years is required by BS 7543 and a BBA Certificate. The 100 year design life will be particularly necessary for the foundations and ground-floor construction as given in Table 4.4 below because they are termed ‘inaccessible’ and will then be compatible with the working life defined and required by the EEC Construction Products Directive 89/106/EEC, (see Section 2.2).

Table 4.4 *Categories of design life for components or assemblies*

Category	Description	Building Life	Examples
1	Replaceable	Shorter life than the building life and replacement can be envisaged at the design stage	Most floor finishes and service installation components
2	Maintainable	Will last with periodic treatment for the life of the building	Most external claddings, doors and windows
3	Lifelong	Will last for the life of the building	Foundations and main structural elements

4.7.2 Durability requirement

The Construction Products Directive of the European Commission has defined the required durability for house building products in terms of the working life in Guidance Paper F issued by the working group CPD WG (99) 067 in July 1999 as follows:

"The working life of a product is the period of time during which the performance of the product to the essential requirements has to be sustained within the working life required of the works. The working life should be 100 years for components that cannot be inspected or repaired due to inaccessibility".

The 'essential requirements' are performance aspects such as strength, stiffness, thermal performance and impermeability, which should not be impaired during the working life.

In respect of light gauge steel elements of a composite ground floor, conservative load factors have been applied during design to ensure adequate strength and these, in turn, mean that the thickness of the steel section has a reserve of strength against working loads. Even when the protective coating has broken down, steel components still have a significant life before failure dependent on the degree of conservatism in the structural design and the severity of the environment causing corrosion.

4.7.3 Durability of steel building components

The durability of steel components in house building has been a fundamental issue for decades and has raised doubts in the minds of specifiers about their suitability.

Light steel components used in building are coated to ensure their durability and this permits maximum use of the high strength of the metal and its lightweight for handling. Coatings are more expensive than the steel so the minimum specification coating consistent with adequate performance is selected for any particular application in order that the component can be competitively priced.

Galvanizing, a hot dipped zinc coating, has proved to be the most effective and economic corrosion protection. As a result, the steelworks have invested in the coating plant to deliver high quality galvanized strip steel that is then cold-formed by fabricators into light gauge steel building components.

To decide on the thickness specification for the zinc coating, the steel industry has invested in a comprehensive research programme.

Galvanized light gauge steel elements have been used over the last 40 years in certain locations within buildings, e.g. lintels and joist hangers, and there is now considerable experience of their durability. Since the 1980s, light gauge steel components have been used in steel framed houses that were at first prototype but are now a proven construction alternative. Monitoring of the coating performance in the prototype houses and other research has permitted an understanding of the corrosion rates and confident prediction of working life.

The durability of the galvanizing depends upon the rate of loss of zinc from the steel surface, which is in turn dependent on the degree of exposure to moisture.

Hence an aggressive exposure would be a continuous stream of rainwater across the surface and a benign environment would be a warm, low humidity atmosphere inside a building.

Extensive research has been conducted by the steel industry and the BRE into the expected working life of galvanized components used in brick walled houses. This has entailed monitoring of the prevailing weather and of the rate of corrosion loss of the zinc coating on steel components at many house sites across the UK. A relevant and verified thickness of galvanizing can now be selected according to the degree of exposure that the component will experience. This is described in British Steel Report No. WL/SMP/R/1106E/10/91/D: *Durability of galvanized steel building components in domestic housing*.

As a result of the monitoring of prototype houses, the SCI provides guidance in publication P262, *Durability of light steel frames in residential building*[37] and in the technical report RT815 *Monitoring of durability of cold formed sections in modular housing*[41]. These record the data obtained and analyse the results to derive working life predictions for the coating. A standard G 275 g/m^2 galvanising coat has been established as adequate for light gauge steel elements where the soffit of the steel decking and the inner surface of the edge-beams are exposed to moisture-laden air in the ventilated void beneath the suspended ground floor, where there is no under-floor insulation. The steel is pre-galvanized to the specification given in BS EN 10147[12]. The standard coating is a G275 where 275 is the minimum weight of zinc coat in g/m^2 over both sides of the roll.

To achieve a working life in excess of 100 years, G 275 quality galvanized steel components below a ground floor should not be in direct contact with the ground. For the suspended composite floor, this entails using a damp proof course or damp proof membrane beneath the edge beams.

Where insulation is used beneath the floor, (as proposed in Section 4.3), a much improved design life can be achieved. The insulation layer will bring the ground floor within the ‘warm frame’ building envelope away from circulating air where the low levels of moisture give design lives in excess of 200 years.

Composite floor systems like Corus ‘Datum’ have a BBA Quality Assurance Certificate for which a minimum 60 year working life is required, and the standard G 275 zinc coating provides that.

5 COST COMPARISONS

5.1 Costing method for ground-floor construction

The comparison of cost for the constructing of different types of ground-floor system cannot be realistically performed without a knowledge of the construction methods involved, a realistic allowance for the site team and ancillary equipment needed, and the time taken to complete the site tasks. Composite ground floors offer economy but require a different and more integrated approach to procurement than is currently practised by builders and developers.

It is possible that the new composite ground floors should be installed together with the foundation by the same groundwork or piling specialist contractor who can then prevent delays and rework by controlling one complete subcontract up to ground floor level. The builder can then minimise his risk by using a subcontract all-in price.

Traditional QS accountancy procedures given in Spon's *Architects' and Builders' Price Book*[40] consider standard material purchase costs with an allowance for construction or assembly. These require further realistic addition of overheads for site management, Health and Safety procedures and also allowances for schedule delays due to not getting the various trades at the right time. For instance, bricklayers needed to lay sub-ground-floor courses of blocks and plasterers to lay the concrete screeds.

The builder's or developer's cost engineer may well miss a vital aspect that can cause a cost overrun on site and he therefore may need help to understand the potential cost savings of adopting composite ground floors. Only those subcontractors specialising in groundwork and foundations are in a position to give realistic costs of the whole operation of doing the foundation and ground floor together. These could be either ground workers or mini-piling firms and they should be asked to price a scheme comprising both composite ground-floor and mini-pile foundation.

Health and Safety aspects of house construction have become a very important issue and many site methods and procedures have to be changed to perform the work in a safer manner for the site operatives. For instance, the laying of the beams for a beam and block floor requires appropriate craneage on site (see Figure 5.1).

Any misjudgement of the period of days for crane hire will add a cost that can eliminate any estimated cost saving on the basic floor materials. Conversely, any system that does not require cranes on site for assembly, such as the new composite ground floor, has little risk of cost or time over-run to the developer and the construction procedure is inherently safer. This aspect will become more attractive to developers taking account of the true cost risks of conventional ground-floor construction systems.

Figure 5.1 *Essential use of crane for beam and block floor laying*

Also, the new composite ground floor permits better line and level to be achieved for the installation of walls in light steel and timber framing. This results in cheaper wall construction with an improved quality of wall finish. If the interface between the ground floor and the wall system are ignored, then additional cost and delays will be incurred in overcoming the problems on site.

5.2 Eliminating call backs and rework

Call-backs or rework are the correction of construction defects in new houses that have been caused by faulty workmanship or poor design. It is now widely recognised in the Building Industry that some 5% to 10% of the total cost of a new house is due to wasted materials and craftsmen's time in rework.

The most frequent areas of such construction defects are:

1. Ill-fitting doors.
2. Cracks in wall plastering.
3. Uneven ground floors.
4. Internal damp patches.

Many of the defects originate from poor ground-floor construction methods.

Use of precast concrete 'beam and block' floors is popular with the large house builders because it has dry construction and offers the cheapest structural material cost. However, the overall cost of beam and block floors including the insulation, membrane and protective screeds is the same as alternative types of composite floor (e.g. *Jetfloor*, *Beamshield*, *Datum*) that have a higher quality. (The beam and block floors often have a poor quality in line and level and have open joints as described earlier which have to be sealed with a membrane and then covered with a protective screed.)

The initial attraction of the 'dry construction' of beam and block floors is eliminated by the cost of the wet trade for the concrete screed afterwards that needs highly skilled men and is expensive. Wet trade costs are increasing due to the shortage of skilled labour and this is set to continue for the foreseeable future. Screed material is not ready-mixed but made on site to suit the plasterer's method of working. This is a labour-intensive trade requiring labourers to cart and mix the screed material, and needs space on site for the sharp sand, cement and the mechanical mixer. Experienced building tradesmen are becoming scarcer and tend also to be the most expensive due to their enhanced negotiating position with builders. There is much competition for tradesmen between new build and refurbishment work on old housing. Site conditions are more pleasant on refurbishment work and new build work often struggles to find experienced craftsmen at the required time in the construction schedule.

Any floor system that can eliminate the need for a screed should therefore be welcomed by the large builders and developers.

Solution

The *Catnic* composite ground floor incorporates light steel edge beams that provide an excellent 'tamping rail' so that the in-situ concrete slab can be 'floated off' level ready to take the floor finish directly. This eliminates the need for any *levelling screed* as required in beam and block floors (minimum of 35 mm thick). There is no need for a vapour barrier membrane either because the *Catnic* floor has an impermeable light steel soffit tray

The accurate setting out of the edge beams in the composite floor also establishes a template for the line of walls and thereby permits the efficient fitting and fixing of prefabricated wall panels afterwards.

5.3 Cost analysis of ground-floor constructions

Cost comparisons for different ground-floor construction types have been carried out and then for combinations of ground floors with different foundations to compare the cost of trenchfill with that of mini-piling for the house foundations.

The estimation of costs was performed by building Quantity Surveyor, Dr Alan Rogan, who used a typical ground-floor layout for a detached house of 8 m × 6 m in plan, similar to the one used in the Oxford Brookes demonstration building. Further costings have been performed by Bullivant and the SCI.

5.4 Cost comparisons

Professional building QS estimates have been made to compare the costs of the current highest quality insulated composite ground floor type namely the Marshalls '*Jetfloor*' supported on conventional trenchfill foundations with a composite floor supported on steel cased piles. The study has considered three different soil conditions which need different trenchfill depths but for which the piled alternative would use 6 m long piles for all of them. The results including material and labour costs are shown in Table 5.1.

Table 5.1 *Cost comparison of Marshalls Jetfloor on trenchfill with Catnic composite ground-floor on mini-piling*

Depth	Traditional foundation	Composite floor and mini-pile foundation	Cost difference
1.0 m deep foundation	£3937	£3972	£35 more
1.5 m deep foundation	£5074	£3972	£1102 less
2.0 m deep foundation	£5836	£3972	£1864 less

The study then compared costs of four types of ground-floor construction without any consideration of the foundations supporting them and the results are as shown in Table 5.2.

Table 5.2 *Cost comparison of different ground floor types*

Description	Cost	Cost difference
Marshalls '*Jetfloor Super*' system	£1765	Standard
Beam and block system with concrete slab	£1707	£58 less
Beam and block system with timber floor	£1630	£135 less
Catnic composite floor inc. light steel decking and G-beams	£1729	£36 less

5.5 Conclusions

Where a suspended ground floor is required, it is apparent that a light steel composite floor of the type investigated for this publication is competitive with other popular types of construction. It should therefore be seriously considered as an alternative in order to make use of its benefits to the builder. Manufacturers of the composite floor system have obtained Lantac and BBA approval in the UK and have continued to refine the details in order to suit all house and foundation types.

It is also apparent that a mini-pile foundation is cheaper than unreinforced concrete trenchfill where the depth to a sound bearing stratum is greater than 1.2 m deep. Where ground conditions are variable and the water table is high, a mini-pile foundation gives a more reliable foundation at a predictable price.

Mini-piles also permit an economic and more reliable solution to building foundations in flood plains. Houses can be built on piles at an elevation above the maximum flood level so that the habitable accommodation is not at risk to flood damage. SCI is currently researching these building solutions.

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APPENDIX A BRE REPORT

This Appendix presents facsimile of a document produced by the BRE in support of the Steel Construction Institute for this project. It is:

> M.S.Crilly: Piles for housing: a review of capacity under static vertical load. Addendum Report No. 80203 BRE October 1999.

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Approval to reproduce the report was given on behalf of BRE by R M C Driscoll (Head of Geotechnics Division.)

Piles for housing: a review of capacity under static vertical load
Addendum report

Prepared for:

Steel Construction Institute

Prepared by:

M S Crilly

Centre for Ground Engineering and Remediation

October 1999 **Client report no 80203**

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EXECUTIVE SUMMARY

BRE Client Report 17/99 describes the formation of a database of results of static load tests carried out on small cross-section piles. The database was analysed in the context of design methods for piles for low-rise housing. This report, which forms an addendum to that report, adds data from industry to the original data set.

The main conclusions that can be drawn from this and the previous report are as follows.

- The data did not show up any clear systematic differences between the load carrying capacities of in-situ concrete piles, precast concrete piles and steel piles.
- The issue of pile buckling has sometimes been raised in the context of small cross-section piles in the past. However, in this study, none of the sources examined contained any evidence of buckling.

For piles in clay soils:

- For design purposes, shaft resistance is adequately calculated by an α factor approach. It appears reasonable to use an α value of 0.3 for prediction of a lower bound shaft resistance with a 90% confidence level, or to use an α value of 0.45 in conjunction with a suitable factor of safety. Lower α values may apply for stiff tills.
- Higher values of shaft friction may be available if piles are statically tested.
- On the basis of very limited data, $9S_U$ gives a reasonably cautious estimate of the unit end-bearing value.

For piles in granular soils:

- Unit shaft resistance, calculated from SPT N-value using f=2.5N (kPa), appears to be a reasonably cautious design rule.
- On the basis of limited data, unit end-bearing seems to be reasonably described by q=400N (kPa), though a cut-off value of, say, 8-10MPa is recommended.

INTRODUCTION

BRE Client Report 17/99 to the Steel Construction Institute (SCI) reported on the analysis of published research data on small cross-section piles in terms of means of estimating their capacity under static vertical load.

Further static vertical load test data have been obtained through results provided by industry, through the Association of Specialist Underpinning Contractors, in particular Roger Bullivant Ltd. This report provides an addendum to the preliminary report and re-examines some of the conclusions drawn from that report.

The industry data are examined in the same way as the previous report on research data, looking separately at shaft and base capacities for cohesive and granular soils. As before, a cut-off of maximum cross-sectional dimension of 300 mm has been used to define piles of interest.

There are considerably fewer usable data in the industrial data set than in the research data set for a number of reasons:

- It is relatively rare for small cross-section piles to have static load tests carried out on them;
- Even when static load tests are carried out, these will often only have been taken to working load – extrapolation to ultimate conditions may be unreliable;
- Ground conditions for working piles are often variable, and it can be difficult to be clear about which strata are contributing to the shaft capacity;
- Site investigations for housing projects are often lacking soil tests for pile design purposes.

INTERPRETATION OF RESULTS

For the additional industry pile load tests, shaft and base capacity were estimated from the load-displacement curves using the procedure described by Fleming (1992) ('Cemsolve'). The data required for input to the Cemsolve procedure were predominantly obtained by estimating values from the site investigation data; in particular, initial estimates of base stiffness were obtained from the relationships based on SPT and given by Stroud (1989). The key information from the pile load tests is tabulated in BRE Client Report 17/99.

The sections that follow look at the industry data superimposed on the research data reported previously; the results are presented in a similar format. As before, methods relating unit shaft friction, f, and unit end-bearing, q, to S_U and SPT N-value are examined against the database for cohesive and granular soils respectively.

Cohesive soils

Shaft capacity

The simplest methods of estimating a pile's shaft capacity in cohesive soils relate f to S_u by an empirical coefficient, α, so that

$$f = \alpha S_u \quad (1)$$

Data from load tests on bored piles presented by Skempton (1959) suggest that α is in the range 0.3 to 0.6; Skempton recommended using a mean value of α = 0.45 for estimating load carrying capacity[1]. Current UK design practice is to use α values of between 0.4 and 0.6 for bored piles in overconsolidated sedimentary clays (Findlay et al, 1997), while slightly higher values might be used for driven piles.

Other values of α have been suggested elsewhere. For the design of offshore steel piles, the American Petroleum Institute (API) Design Code RP2A suggest using α=1 for S_U<24kPa and α=0.5 for S_U>72kPa, with a transitional zone between. Biddle (1997) suggests that for steel H-piles, α=0.25 is a suitable general design rule for predicting the capacity available within two weeks of driving for small displacement steel piles.

Figure 1 shows calculated values of f plotted against S_U for all of the relevant piles in the research database, together with the additional results obtained from the industrial database. The figure also shows lines corresponding to α=0.3, 0.45, 0.6 and 1.0.

The lowest value of f obtained from the industrial piles was obtained from a tension test that was not taken to failure; therefore, this result is an absolute lower-bound

[1] These values of α were intended to apply to 'quick' unconsolidated undrained strength determinations on 38 mm diameter test specimens and not necessarily to larger diameter specimens or other test techniques.

value. Consequently, the four relevant piles from the industrial database tend to be towards the higher values of α.

On the basis of the research results, the earlier report suggested that it would be reasonable to use an α value of 0.3 for prediction of a lower bound shaft resistance with a 90% confidence level. This is a lower value than might be used for larger cross-section piles under similar circumstances. It was suggested by members of the Steering Group for this project that, even though α=0.3 might provide a more cautious value than current practice, checking authorities would be unlikely to accept factors of safety or partial factors significantly different to those currently used. This suggestion has prompted a comparison of data obtained for small cross-section piles with two data sets for which 'normal' α values might be considered to apply:

- the data on driven piles given in Fleming et al (1992); and
- the data for bored piles in London Clay given by Skempton (1959) which formed the basis of the commonly used α=0.45.

Figures 2 (all data) and 3 (S_U < 300kPa) show the small cross-section pile data plotted alongside these two additional data sets. The scatter of the small cross-section pile data appears similar to that of the two other data sets combined. Testing these data sets against an assumption of α=0.45, allows the comparison of the range of values of Q_{SC}/Q_{SM} from each data set, where Q_{SC} and Q_{SM} are the calculated and measured shaft capacity respectively. Table 1 shows values of mean (μ), standard deviation (s), coefficient of variation (COV = μ/s), Ranking Index (RI) as defined by Briaud & Tucker (1988)[2], minimum and maximum of the distributions of values of Q_{SC}/Q_{SM} for each data set.

Table 1. Comparison of reliability measures for shaft friction assessment using α=0.45 tested on three data sets.

	Variation in Q_{sc}/Q_{sm}, calculated using α=0.45		
	Small cross-section pile data	**Fleming et al data**	**Skempton data**
Mean, μ	0.84	0.77	1.16
Standard deviation, s	0.39	0.31	0.32
Coefficient of variation, COV	0.46	0.40	0.27
Ranking Index, RI	0.70	0.77	0.39
Maximum	2.00	1.37	1.89
Minimum	0.26	0.32	0.73

[2] The Ranking Index, RI, described by Briaud & Tucker (1988), provides a means of ranking pile capacity predictions which gets over the problem of the distribution of Q_{SC}/Q_{SM} not being normal. In this case

$$RI = \left|\mu\left(\ln(Q_{SC}/Q_{SM})\right)\right| + s\left(\ln(Q_{SC}/Q_{SM})\right)$$

The lower the RI, the better the performance of the method.

The mean value of 0.84 indicates that, *on average*, global use of α=0.45 provides a slight underestimate of shaft friction for the piles in the small cross-section database. The Fleming et al (1992) measured values for driven piles are more significantly underestimated. It is interesting to note that the measured shaft capacities from the Skempton (1959) data are, on average, overestimated by α=0.45. The COV indicates the variability of the data; as might be expected, the small cross-section data are more variable than either of the other, more selective, data sets.

The lower the RI, the better the performance of the method. On this basis, α=0.45 provides a better method of design for the small cross-section piles than it would for the larger cross-section driven pile data.

The maximum value of Q_{SC}/Q_{SM} for the small cross-section data is 2.0; this would suggest that using a suitable factor of safety or combination of partial factors to give a global factor of about 3, then α=0.45 would provide a reasonable design value. As discussed in the previous report, it would be reasonable, and consistent with the work of Weltman & Healy (1978), to apply lower values of α in stiff tills, or to limit the value of αS_U to, say, 75kPa.

Base capacity

There were no additional data on base capacity in cohesive soils that could be reliably obtained from the industrial database.

Granular soils (and weak rocks)

Shaft capacity

While the shaft capacity of a pile in granular soil would ideally be calculated from considerations of the horizontal effective stress at failure and the angle of friction relevant to the pile-soil interface, it is unlikely that appropriate parameters would be measured in most site investigations for low-rise buildings. It is therefore more appropriate to correlate the capacity of piles in granular soils with soil tests that are routinely performed, like the SPT.

Thorburn & McVicar (1979) suggest that unit shaft friction, f, could be obtained from

$$f = 2N \quad \text{(kPa)} \qquad (2)$$

This relationship has also been adopted by the SCI in their Steel Bearing Piles Guide (Biddle, 1997) and before that by Cornfield (1989) in the previous Guide.

Figure 4 shows unit shaft friction plotted against SPT N-value for the relevant piles from the research and industrial databases.

Figure 4 also shows a line corresponding to equation 2) and a line corresponding to f=2.5N (kPa). All of the data gathered lie above the f=2N line with the exception of one point where the value of f is about 75% of that suggested by the equation. This pile (from Lehane et al, 1993) was only embedded on the ground 1.8m and is therefore untypical of the sort of piles that are being considered. Again, this is the only point that falls any significant distance below the f=2.5N line. Therefore, it would appear that, on the basis of the data available here, equation 2) or even f=2.5N (kPa) are cautious design rules. The data would also imply that it is not necessary to factor the N-value to take account of submersion.

Base capacity

Biddle (1997) suggests that the unit end-bearing, q, of a pile in a granular soil can be related to the SPT N-value at the base of the pile as follows

$$q = 400N \quad \text{(kPa)} \qquad (3)$$

On Figure 5, calculated values of unit end-bearing have been plotted against the relevant SPT N-value; these are plotted for granular soils, glacial till and weak rocks. The research database provided only a limited number of data points, since only a few of the sources had convincing measurements or estimates of ultimate bearing resistance. The industrial database has provided a useful number of additional points. However, there are still no data points for in-situ concrete piles in granular soils. Nevertheless, the industrial data back up the original conclusion that equation 3) gives a reasonable estimate of the unit end-bearing in granular soils with the proviso that there appears to be an upper limit to the data.

It is suggested by Fleming et al (1992), that for practical pile lengths there is an upper limit to the value of q that can be attained of between 10MPa and 15MPa in granular soils for large displacement or replacement piles. Two data points, shown on Figure 5 as a and b, with q approximately equal to 8MPa, may be evidence of such an upper limit.

There are insufficient data to draw any conclusions on end-bearing in weak rocks. However, the data obtained from tests on piles bearing in chalk is consistent with the findings of Lord et al (1994) that q=200N (kPa) was a reasonable lower-bound value for that material. They suggested that q=300N (kPa) be adopted for the design of driven preformed piles on chalk.

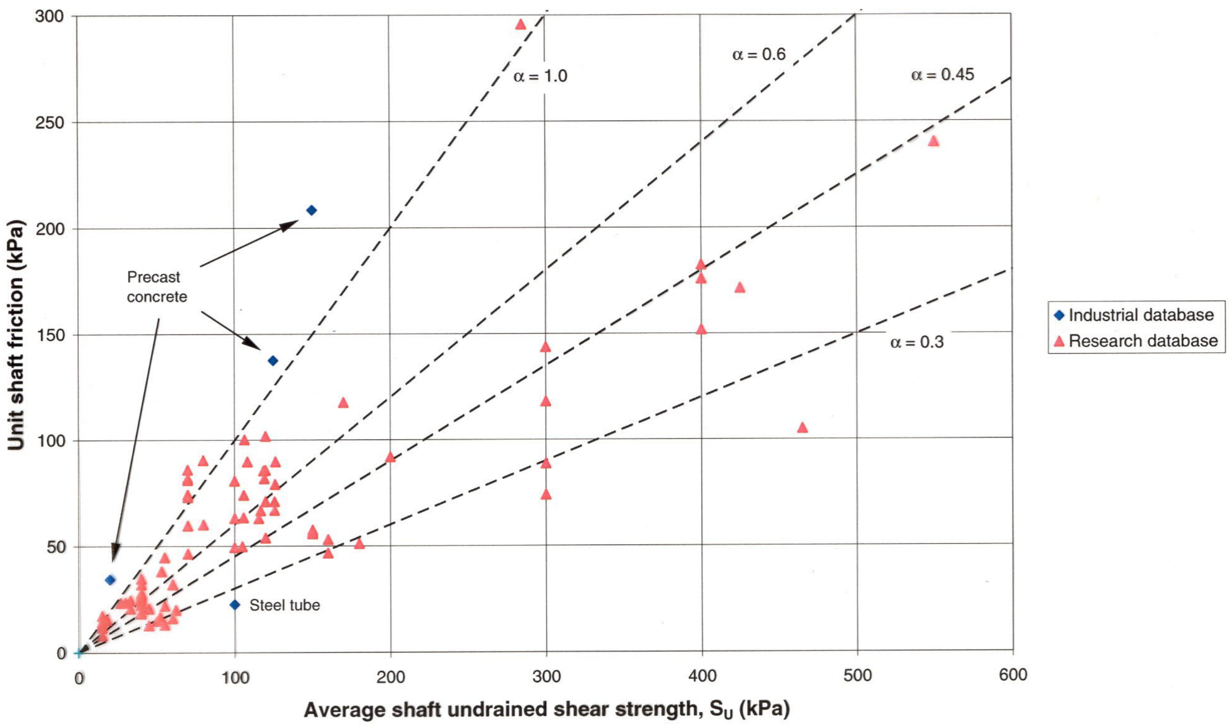

Figure 1

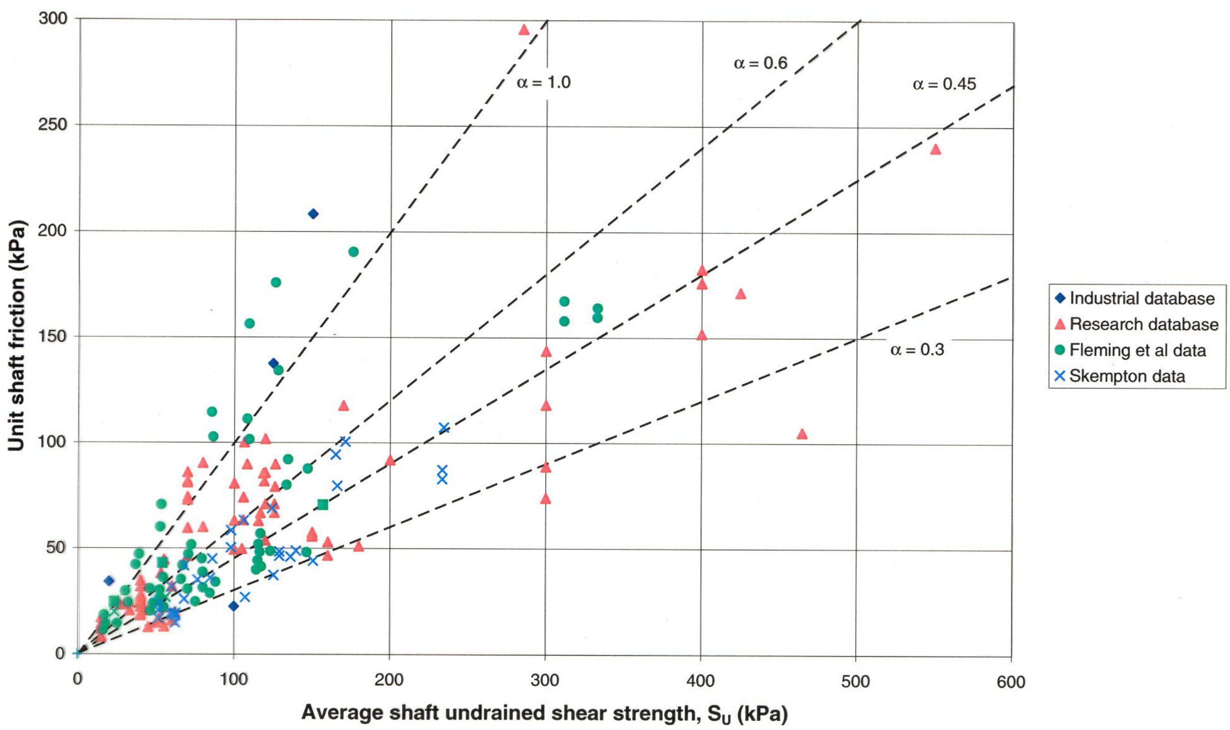

Figure 2

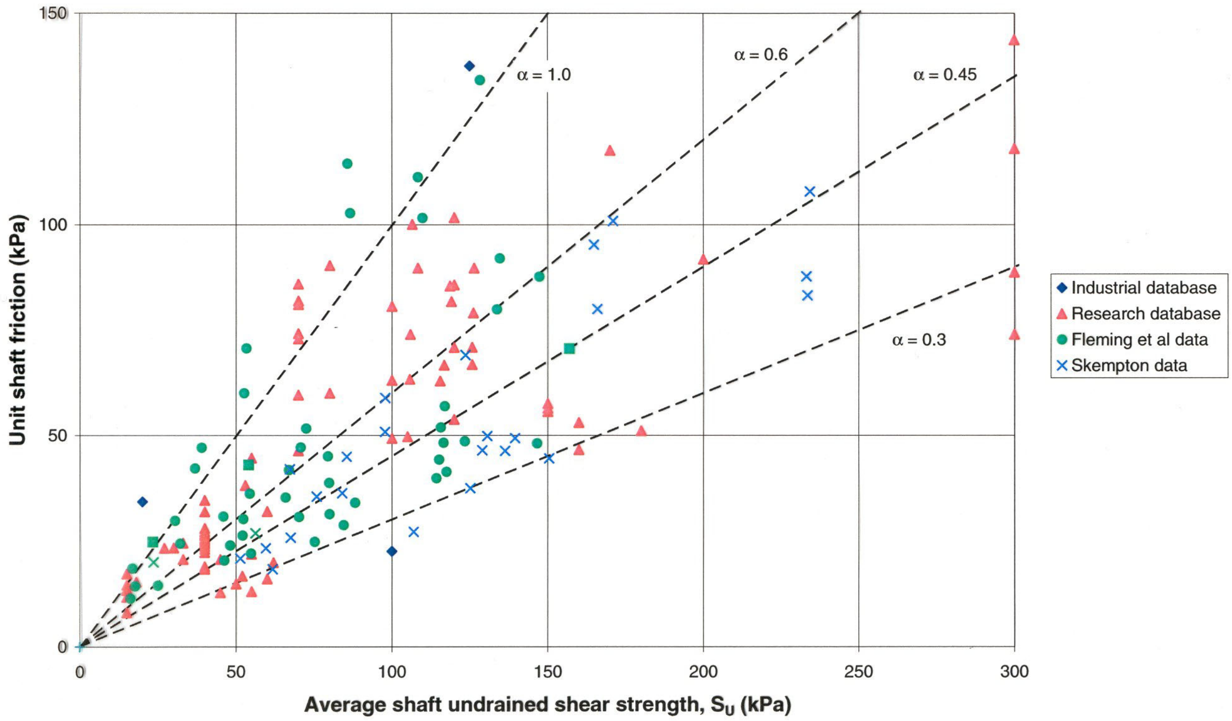

Figure 3

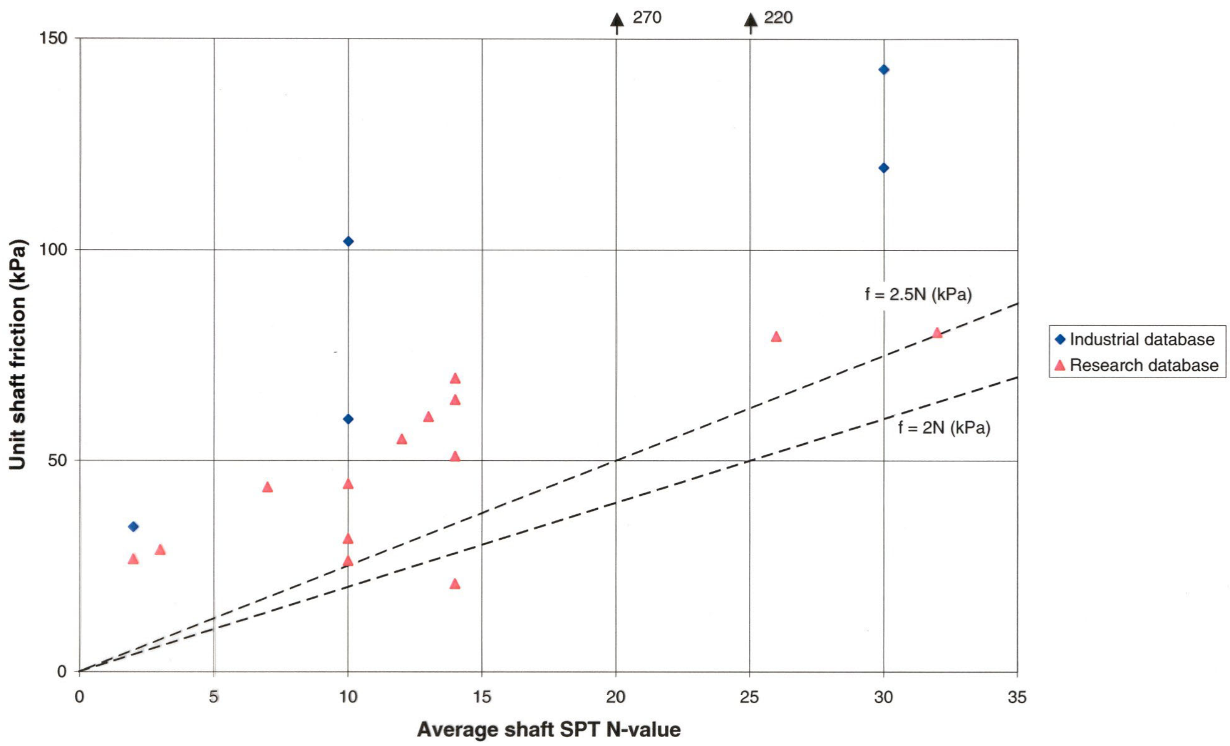

Figure 4

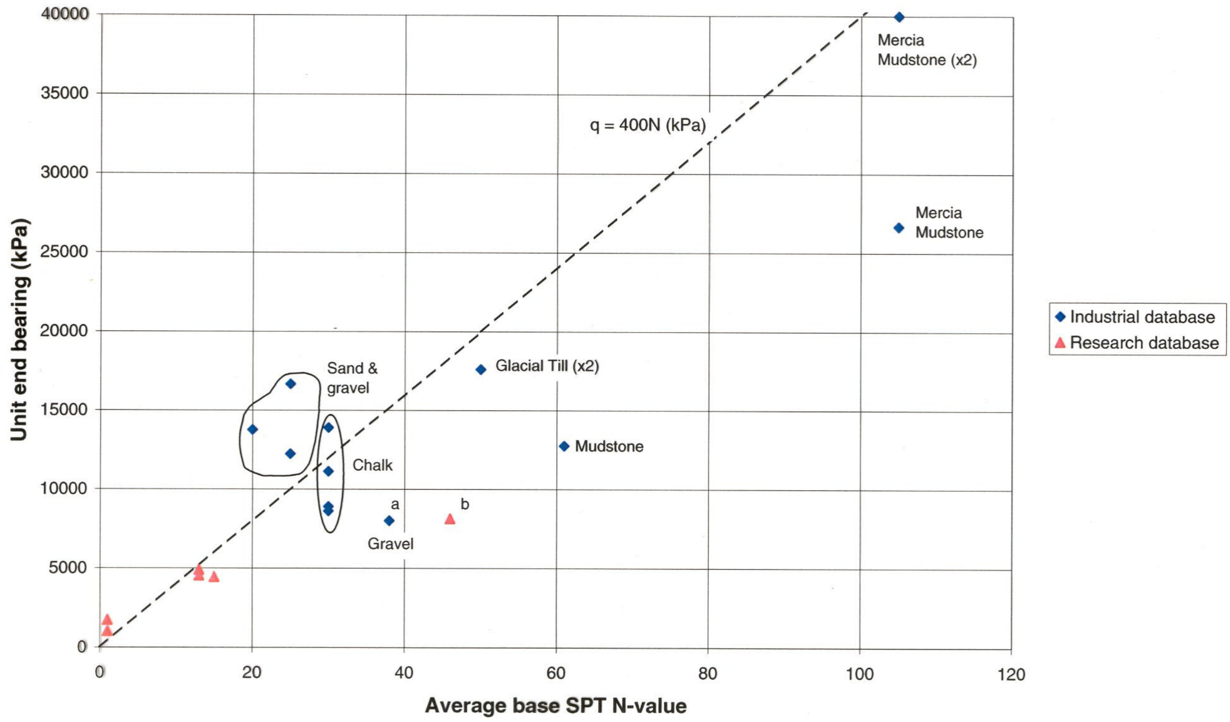

Figure 5

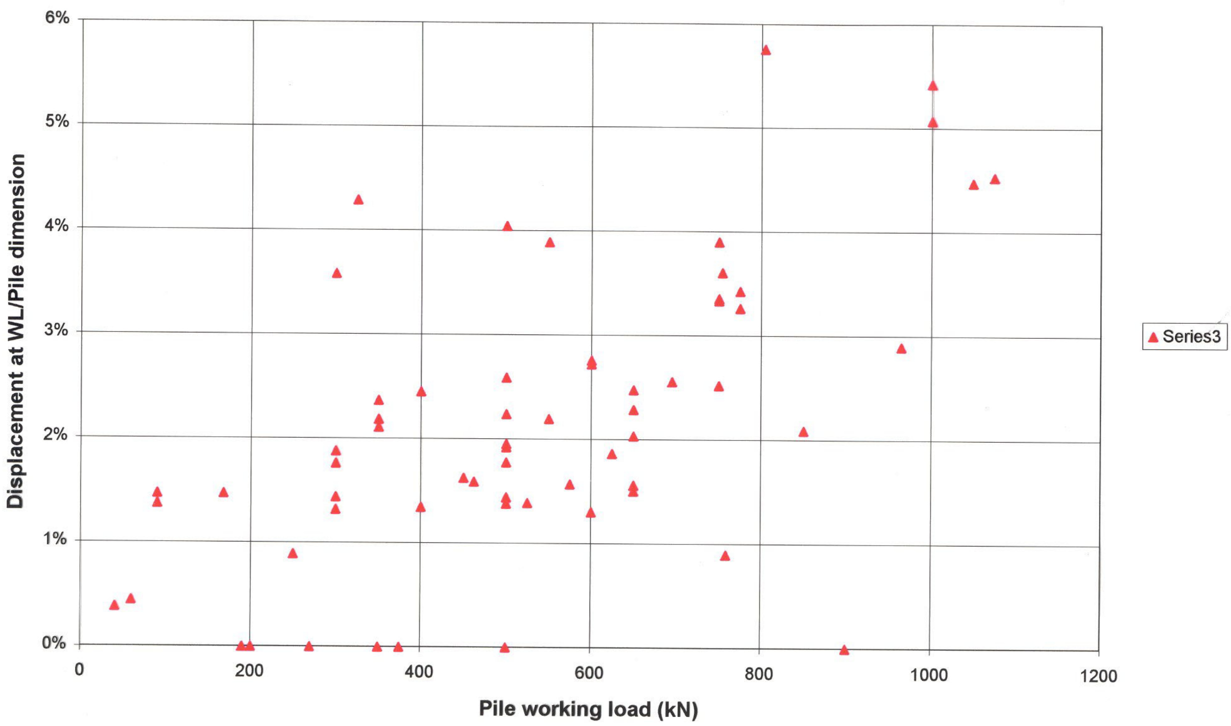

Figure 6

CONCLUSIONS

This report supplements BRE Client Report 17/99 to SCI and the DETR. The main conclusions that can be drawn from this and the previous report are as follows.

- The data did not show up any clear systematic differences between the load carrying capacities of in-situ concrete piles, precast concrete piles and steel piles.
- The issue of pile buckling has sometimes been raised in the context of small cross-section piles in the past. However, in this study, none of the sources examined contained any evidence of buckling.

For piles in clay soils:

- For design purposes, shaft resistance is adequately calculated by an α factor approach. It appears reasonable to use an α value of 0.3 for prediction of a lower bound shaft resistance with a 90% confidence level and an overall factor of safety of 2, or to use an α value of 0.45 in conjunction with a factor of safety of 3. Lower α values may apply for stiff tills.
- Higher values of shaft friction may be available if piles are statically tested.
- On the basis of very limited data, $9S_U$ gives a reasonably cautious estimate of the unit end-bearing value.

For piles in granular soils:

- Unit shaft resistance, calculated from SPT N-value using f=2.5N (kPa), appears to be a reasonably cautious design rule for 95% confident predictions.
- On the basis of limited data, unit end-bearing seems to be reasonably described by q=400N (kPa), though a cut-off value of, say, 10MPa is recommended.

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