Copy of Paper for the 8th International Conference on Concrete, 9 – 11 July 2012, Dundee, published as part of the Proceedings of the Conference.

LOW CARBON GROUND FLOORS FOR HOUSING: A CASE STUDY

C Shaw

Consultant

United Kingdom

ABSTRACT: The Paper describes the design and construction of the world's first fully integrated super insulated flexibly detailed hybrid reinforced concrete ground floor slabs for a housing development which incorporated 'underfloor heating' within the structural slab. This design provided a low cost low carbon floor which was constructed faster and easier than the previous slabs used for this type of development. The five house types were all designed using the same system. The first layer comprised super insulated carbon enriched units, which were laid on a sand blinded base of previously excavated material. The units each stand on integral legs, giving an air space under the main insulation, and interlock to give a thermal break within the thickness of the insulation. The next layer was the polythene damp proof membrane. New, specially designed soft formwork spacers were placed on the membrane and these hold a mix of flexibly detailed bar reinforcement combined with sheets of welded steel fabric reinforcement for economy. The underfloor heating pipes were fixed to the reinforcement in a specified pattern provided by the manufacturer to give individual heating control to each room on the ground floor of the house. The concrete was then poured and power floated to give the finished floor surface. The thermal mass of the concrete greatly enhances the storage capacity of the floor and reduces the thermal drift, giving a more comfortable environment. This design achieved a low cost low carbon floor.

Keywords: Low carbon, Insulation, Spacers, Hybrid, Flexible detailing.

Chris Shaw is a Chartered Civil Engineer and a Chartered Structural Engineer practising as a Consultant. He has more than 35 years experience in achieving the specified cover to the reinforcement in reinforced concrete structures, and devised the system for achieving this which was subsequently published as British Standard 7973 in 2001. He is now Chairman of the committee that prepared the Standard and gives advice, lectures and training on the subject. He continues to carry out research and development on the products, their applications and innovative uses worldwide.

INTRODUCTION

The increasing requirements of The Building Regulations in England and Wales, together with the rising cost of energy for both the construction and running costs of buildings, has resulted in more attention being given to the Carbon Cost and the Sustainability of new buildings. There is a need to reduce the number of 'goods miles' travelled for building materials as the transport is dependent on oil which continues to rise significantly in price. Progress is being made in the development and implementation of new types of construction. The Paper describes one such development where a new system of ground floors for houses was built. It was the first in the world to be built using this system, and received approval from the United Kingdom National House Builders Council (NHBC). It was started in 2010 and completed in 2011.

BACKGROUND

The development comprised 12 houses of five different designs placed on a steeply sloping site. The sub-soil was chalk. The slope meant that the ground level around the houses varied considerably and suspended ground floor slabs were needed to comply with The Building Regulations.

The architectural drawings initially showed a pre-cast pre-stressed beam and block floor, with a void underneath, and a series of underfloor ventilators. On top of the beams and blocks there was a 20mm self levelling screed, and on this a polythene damp proof membrane (dpm). On the damp proof membrane there was 50mm of rigid insulation board, and on this another 50mm thickness of insulation with the heating pipes fixed in pre-formed grooves within the insulation. The top layer was a 50mm thick self levelling screed.

The foundations for the first few houses had already been cast when the Client was made aware of the Eco-slab insulation system and its advantages over the proposed floor construction. The insulation was changed to the Eco-slab system, and the structural design of the ground floor slabs commenced in conjunction with the guidance of the underfloor heating manufacturer.

The Eco-slab system has many advantages over the design of the originally proposed floor, especially in relation to its low cost and low carbon footprint.

- The pre-stressed beam and block floor requires a lot of energy in its manufacture and transportation, whereas the in-situ concrete for the floor is obtained locally;
- The pre-stressed beams require manual or mechanical handling, including lifting, whereas the concrete floor is placed in-situ;
- The ends of the steel pre-stressing wires of the pre-stressed beams are exposed and vulnerable to corrosion. This starts from the ends and progresses along the circumference of the pre-stressing wires cracking the concrete of the beam and reducing its shear capacity. The ends of the beams and the wires were traditionally coated with a black bituminous coating to protect them, but this practice has ceased in more recent years. Now the ends of the wires are exposed and can corrode in the presence of moisture. The in-situ concrete slab does not have this problem.

- It is well known that the actual size of a building varies from its design size due to tolerances and variability in its construction. The pre-stressed beams are ordered from the numerical size on the drawings, so they may not be of the correct length when placed on the walls below. If the walls are too close together the end of the beam will project into the cavity and locally reduce the thickness (and therefore effectiveness) of the thermal insulation, resulting in a 'cold bridge', which can result in condensation forming on the end of the beam causing corrosion of the pre-stressing wires. If the walls are slightly further apart than the designed dimension then the bearing of the end of the beam on the wall, which is usually only 100mm wide, can be significantly reduced and the masonry of the wall becomes overstressed and can ultimately fail in shear locally. The in-situ slab has none of these disadvantages and is formed to the actual size of the supporting walls below, thus ensuring a continuous bearing of the full width. As the support is continuous the bearing stress on the wall below is greatly reduced.
- The originally proposed system had a total of eight operations to complete the floor. The Eco-slab system had only five, giving a significant saving in the cost of labour, which is the most expensive part of the construction. The system used readily available site skills, and no special tools were needed to place the insulation.
- The Eco-slab system is much quicker to construct from start to finish and this has cost savings in both the programme time and the financing of the project.
- The originally proposed floor would be vulnerable to the weather for much longer than the Eco-slab system which, apart from the actual placing of the concrete, is independent of the weather conditions as it is an all 'dry' construction.
- The finishing screed of the proposed construction has a thickness of 50mm and a density of approximately 2,000kg/m3. The Eco-slab system for this project had a typical concrete floor thickness of 200mm and a density of approximately 2,300kg/m3. The thermal storage capacity of the Eco-slab floor is therefore greatly superior to that of the originally proposed design. This results in less thermal drift in the air temperature in the house, resulting in greater comfort and a better environment for the occupants.

THE INSULATION

The increasingly stringent thermal insulation requirements of The Building Regulations (as applied in England and Wales), together with the introduction of 'soft' permanent formwork had previously led to problems in ensuring that the formwork provided the steel reinforcement with the specified cover at all locations within the concrete. 'Soft' formwork is defined as either expanded polystyrene (EPS), (such as Eco-slab used for insulation purposes in low carbon construction), cellular plastic sheet (CPS), or plastic encapsulated welded steel fabric (PEWSF). Both CPS and PEWSF have no useful thermal insulation properties. 'Soft' formwork is usually used as permanent formwork. It is sometimes used for ground beams, ground bearing and suspended ground floor slabs, and foundations. In contrast 'hard' formwork is normally either plywood, timber or steel etc. and is usually temporary and removed after the concrete has set. Only expanded polystyrene provides both the formwork function and the thermal insulation. It is therefore a much more sustainable product than CPS or PEWSF, both of which use the increasingly expensive oil in their manufacture and do not have the thermal insulation benefits of expanded polystyrene.

Expanded polystyrene is a lightweight, totally inert foam material made by the polymerisation of styrene, and consists of approximately 98% air by volume. It is traditionally white in colour, and does not use the ozone depleting Chlorofluorocarbons (CFC's), Hydrochlorofluorocarbons (HCFC's) or Hydrofluorocarbons (HFC's) in its manufacture.

The insulation was formed with Eco-slab carbon enriched super insulation units. Carbon enriched expanded polystyrene is about 17% more thermally efficient than plain EPS of the same density. The carbon enrichment of the expanded polystyrene significantly increases its thermal insulation and this, together with the design of the units incorporating an air space beneath them, results in a 'super insulation'. The Eco-slab won the Shell Springboard 2010 Award for Innovation in Carbon Reduction, and has a Local Authority Building Control Type Approval Certificate. The Eco-slab units are made with up to 5% of recycled material and they can be recycled at the end of their life.

The insulation complies with BS EN 13163:2008, [1], and is manufactured under a Quality Management System to BS EN ISO 9001:2008, [2]. The polystyrene is of 100 grade (previously Heavy Duty (HD) grade).

The modular system consists of 1m square interlocking units with overlapping edges. Each unit sits on nine integral legs which create a void beneath the floor for services and ventilation. Testing at the United Kingdom Building Research Establishment (BRE) has shown the system to achieve a 'U' value of 0.19W/m2K. If the density of the polystyrene is increased a 'U' value of 0.10W/m2K can be achieved, and this gives scope for further development of the system as the thermal insulation requirements become more stringent over time. At the perimeter of the floor the insulation units sit on a continuous edge support made from the same polystyrene as the units, and this achieves a linear thermal transmittance of 0.016W/m2K for the edge of the floor. This is several times better than that required by the current UK Building Regulations. The modular units have a flat top surface for the placing of the 1200 gauge polythene damp proof membrane and to support the soft formwork spacers for the reinforcement. The units were easily cut to shape where necessary and the recessed top edges were filled with factory made infill strips of the same polystyrene which are supplied as part of the insulation units.

The units were placed on a sub-base formed by re-using inert excavated material from the foundations, and levelling this within the external walls. This provided support for the insulation units and at the same time reduced the quantity of excavated material that needed to be removed from the works and taken to the landfill site. This saved both on the transport cost and the landfill tax payment that would have been incurred, and reduced the carbon cost and footprint of the project. The re-used material did not need to be fully compacted as it ceased to be loadbearing once the concrete slab had been cast, resulting in further savings in time and cost.

Figure 1 shows a typical example of the insulation units being placed.

Figure 1 Placing the insulation units.

SOFT FORMWORK SPACER

Soft formwork spacers are relatively new to the construction market. They are intended for use with the types of 'soft' formwork previously mentioned, and were originally introduced in 2007 for use with expanded polystyrene insulation for ground beams and foundations where the cover to the reinforcement would normally be either 40mm or 50mm. Details of these spacers were published in an article in the August 2010 edition of Innovation and Research Focus [3]. The soft formwork spacer forms part of the ongoing development of spacers and chairs based on the previously published requirements [4, 5, 6, 7, 8]. This development was the first time that the Eco-slab insulation units had been used with an integrated reinforced concrete floor slab with the heating pipes cast within it.

The cover to the bottom reinforcement was selected at 25mm for economy and cost, but there was no 25mm soft formwork spacer made at that time. One was therefore quickly designed in a collaboration between the manufacturer of the Eco-slab, the manufacturer of the existing 40mm and 50mm cover soft formwork spacers, and the author, who has many years experience in the design and performance of spacers and chairs for concrete. The design was based on the previous experience with the first soft formwork spacers which were designed in 2007. Once the requirement was identified it took just 25 working days to achieve approval, having completed the design, prototyping and testing. Immediately upon receipt of approval the contractor ordered the spacers and production started. The first delivery of spacers, sufficient for the first few floor slabs, was made to the site within days.

The 25mm soft formwork spacer was tested to confirm compliance with British Standard 7973:2001 Part 1, [9], and the design drawings for the reinforcement included the requirement for them to be fixed in accordance with the requirements of British Standard 7973:2001 Part 2, [10].

FLEXIBLY DETAILED REINFORCEMENT

When reinforcement extends through a concrete member to each end the end cover becomes a critical factor in achieving durability. This situation is known as 'reinforcement between fixed faces (of the concrete)'. If the distance between the faces of the formwork is less than the designed dimension and the reinforcement is in one continuous length the specified cover will not be achieved and the durability of the reinforced concrete will be decreased. To overcome this problem it was decided many years ago that flexibly detailed reinforcement was the answer. For a slab this can be achieved by stopping alternate bars of the main reinforcement before the end bearing at one end. One of the problems with the reinforcement in slabs is that if straight bars (shape code 00 in British Standard 8666:2005 [11]) are used the permitted tolerance in Table 5 of British Standard 8666 is ± 25mm. If the bar is 25mm longer than the length specified in the bending schedule the end cover can be significantly reduced. If the specified length of the bar is reduced by 25mm to avoid this problem then the overlap at the bearing may be reduced to a minimal amount. There is also the ongoing problem of locating the bar with the correct end cover within the fixed faces of the formwork. This was solved by including the requirement of Clause 5.2 of British Standard 7973- 2:2001 [10] which specifies that the bar shall be fixed by locating it with the correct end cover and tying it from that end inward. The requirement for flexibly detailed reinforcement was also specifically included in The Standard Method of Detailing Reinforcement [12].

In this project four of the house types had simply supported floor slabs spanning between the side walls of the houses. The width of the slabs varied from 5,493mm to 6,041mm, and averaged 5,767.5mm. The slabs had 100mm bearing on the blockwork of the inner leaves of the external walls of the houses. The end cover to the reinforcement was specified as 40mm. The cover value therefore represented only 0.69% of the width of the slab. If a straight reinforcing bar had been used, without flexible detailing, then the end cover could have been reduced to 15mm by the +25mm tolerance on the length of the bar, a reduction in the cover to less than 38% of the specified value. In accordance with the flexible detailing requirement the main reinforcing bars were scheduled as shape code 11 to British Standard 8666:2005 [11], with a standard bend to Table 2 of British Standard 8666:2005 at one end, and the 'B' length reduced to give a greater end cover at the other (straight) end.

This flexible detailing of the reinforcing bars meant that tolerances in the setting out of the houses, the positions of the internal leaf of the walls, the formwork, and any out of square tolerances could all be accommodated within the layout of the reinforcement by locating the bent end of the bars with the correct cover and tying them from the bent ends inwards. The bent ends of the reinforcing bars were fitted with 40mm soft formwork spacers because the edge formwork was formed with rigid polyisocyanurate (PIR) foam insulation strips.

HYBRID REINFORCEMENT

Bar reinforcement was used for the main reinforcement because the span of the floor slabs was greater than the 4.8m length of standard sheets of welded steel fabric to British Standard 4483:2005 [13]. However, bar reinforcement takes longer to fix than sheets of fabric. The main bar reinforcement was therefore overlaid with a sheet of welded steel fabric with its main wires on the lower face and located between the main bar reinforcement. The area of main tensile reinforcement comprised the area of the bar reinforcement plus the area of the main wires of the fabric reinforcement, giving an economical solution. The combining of bar and fabric reinforcement in this way is called hybrid reinforcement. The distribution reinforcement for the slab was provided by the cross wires of the welded steel fabric. The reinforcement for the perimeter around the sheets of welded steel fabric was constructed with flexibly detailed individual reinforcing bars.

When using welded steel fabric there has been a problem where adjacent sheets are lapped together, and where the corners of four sheets are lapped there can be up to eight thicknesses of wires. This can move the wires up to, or sometimes above, the neutral axis of the slab. This problem is solved by butting the edges of the sheets together and using loose splice bars, tied to the wires of the fabric. In this way the wires of the fabric all remain in their correct planes.

Four types of house used a simply supported single span for the floor slabs, requiring only bottom reinforcement. The fifth type of house, which was the largest, required a partly two and partly three span slab which spanned from the front to the back of the house. This slab required both top and bottom reinforcement, and sheets of welded steel fabric were used for the top reinforcement. Normally the top reinforcement would have been supported from the bottom reinforcement by means of continuous steel wire chairs to British Standard 7973:2001 Parts 1 and 2. However, in this project the central heating pipes were wired to the distribution reinforcement and there were no standard height continuous steel chairs available to give the correct cover to the top reinforcement. This was solved by using a hybrid comprising 500mm lengths of continuous cementitious spacers fixed to the distribution reinforcement of the slab at right angles to the main reinforcement, with lengths of goalpost type continuous steel wire chairs wired to the spacers at right angles. The top wires of the chairs supported the main wires of the top sheets of the welded steel fabric, giving the correct top cover.

All of the reinforcement was tied together in accordance with the requirements of British Standard 7973-2:2001, Clause 5. A combination of traditional 16 gauge black annealed soft iron tying wire and proprietary wire loop ties were used for the tying. Slash ties were used for tying both the reinforcement and the sheets of welded steel fabric together.

Figure 2 shows a typical example of the reinforcement and heating pipe layout.

Figure 2. Typical example of the reinforcement and underfloor heating pipe layout.

UNDERFLOOR HEATING

The underfloor heating was originally proposed to comprise a flexible pipework system placed in pre-formed grooves in 50mm thick insulation, with a 50mm thick self levelling screed laid on top of it. In the improved design the heating pipes were cast into the structural concrete floor slab. This is an established practice in mainland Europe for floors above ground level, but relatively new in the UK. Ground floors in Europe are often formed of ground bearing slabs with the heating pipes cast in the top part of the slab. The combination of all of the elements of this low carbon ground floor design is unique, and this site is the first to be constructed in this manner. The layout of the heating pipes was specially designed to ensure the integrity of the structural concrete floor slab.

The pipes were 16mm overall diameter and made principally from polybutylene (PB) which is more flexible than other materials commonly used for underfloor heating. The pipes have a 75 year design life and guarantee, and so they can be expected to last for at least the design life of the house. Each room on the ground floor had a separate heating circuit and the pipes were terminated at a manifold. Heat was provided from a gas boiler. The pipework complied with British Standard BS EN ISO 15876 Parts 1,2, 3 and 5 [14,15,16,17], and the system was designed to British Standard BS EN 1264 Parts 1 – 5, [18,19,20,21,22], under a Quality Management System to BS EN ISO 9001:2008 [2].

The pipes were fixed to the reinforcement in the bottom of the slabs with plastic cable ties. When complete, the pipes were pressurised to 2 bar and the pressure maintained and monitored until after the concreting had been completed.

CONCRETE AND FINISHING

The concrete mix was a standard RC25/30 N/mm2 mix with Ordinary Portland Cement (CEM1), 250 kg/m3 minimum cement content, 0.65 water cement ratio, 70mm consistence target (previously known as the slump), and a 20mm maximum aggregate size, sourced locally to the site and delivered by ready mixed concrete lorry. The underfloor heating pipes were kept pressurised during the placing of the concrete and checked to ensure the pressure in them was being maintained. The concrete was vibrated with a vibrating poker, levelled off and then finished with a power float and cured with a sprayed curing membrane.

The use of locally sourced concrete saved the carbon cost of producing and transporting pre-cast pre-stressed beams and blocks from the factory to the site. In the United Kingdom (UK) the pre-cast pre-stressed beams and blocks would be delivered from the factory which typically incurs a travel distance of 93 road miles (150 road kilometres) for a Heavy Goods Vehicle (HGV). In contrast the ready mixed concrete would typically be delivered from a local depot involving a distance of just 5 road miles (8 road kilometres) for the lorry to travel [23]. The pre-cast pre-stressed beams would normally require some form of mechanical handling to unload from the delivery lorry and place in position on the foundation walls. In contrast, the ready mixed concrete could be discharged directly into its final position in the slab, saving the cost of the mechanical handling.

COST COMPARISON

The five types of slab are each different due to the design of the various house types, and their resultant size, shape and thickness. The cost per square metre of floor slab therefore varies accordingly. The cost of slabs built using this system would also vary depending upon such factors as the number to be built on a site, and the site location within the UK or elsewhere. A cost comparison for the thickest slab, which was 225mm deep, was carried out using the national rates published in Spon's Architects and Builders Price Book [24]. The beam and block floor design cost £75.61 / m2 and the low cost floor slab design was £49.53 / m2, giving a considerable financial saving as well as a more sustainable and easily built floor. The savings in the energy used for space heating over the life of the house would be significantly more than the cost of the slab.

FURTHER DEVELOPMENTS

These houses were the first in the world to be built using this integrated low carbon system for the ground floor slabs. The slabs were designed and constructed to a very short timescale. As the first floor slabs were being constructed and their construction monitored it became clear that:-

1. The system worked in practice;
2. Now that it had been proven in practice there was considerable scope to develop the system further through the use of, for example, the partial replacement of primary aggregates with recycled aggregates, the use of pumped concrete, and the possible use of self levelling concrete.

There has now been time to consider these further enhancements to this system for low cost low carbon floor slabs on subsequent projects.

SUMMARY

The design and construction of this development project has shown that it is both possible, practical and economical to construct low cost low carbon super insulated ground floors for houses. Savings in the carbon cost of the development have been made at many stages during both the design and construction phases, and these have produced an incremental saving in the financial cost and the carbon cost of the floors. In addition the better insulation provided by this design over the originally proposed design will give significant savings in the energy cost for heating the houses over their lifetime. At the end of their lives almost all of the components of the floors can be easily recycled with currently available technology.

CONCLUSIONS

The development and use of this integrated hybrid system for low cost low carbon ground floors is a major step forward in reducing the environmental impact of this element of construction. The savings accrue both from the energy saved in the actual construction process, and the thermal efficiency energy savings during the life of the houses.

The system has been proved to work in practice and should be adopted for new housing construction. There is potential to develop the system further, and to use it for other types of building applications.

ACKNOWLEDGEMENTS

The author would like to thank the following people for their assistance with this Paper.

Mr Roy Clifton and Mr Bernard Barker of Eco-slab, supplier of the insulation.
Mr John Stirley of Injection Plastics Limited, manufacturer of the spacers.
Mr Tony Crotaz of Siteright Construction Supplies Ltd, supplier of the reinforcement and concrete accessories.
Mr James Wilson of Wavin Underfloor Heating Division, manufacturer of the heating pipework.
Mr Terry White of EQ Builders Ltd for access to the site.
Mr Adam Marshall of Jablite Limited for technical information on the insulation.

REFERENCES

1. BRITISH STANDARDS INSTITUTION, British Standard BS EN 13163:2008, BSI, London, 2008, 52pp.

2. BRITISH STANDARDS INSTITUTION, British Standard BS EN ISO 9001:2008, BSI, London, 2000, 40pp.

3. THE INSTITUTION OF CIVIL ENGINEERS, Innovation and Research Focus, The Institution of Civil Engineers, London, 2010, 8pp.

4. ROBERTS, R F, Spacers for reinforcement, Cement & Concrete Association, Wexham Springs, 1981, 8pp.

5. CONCRETE SOCIETY, Spacers for reinforced concrete, Concrete Society, London, 1989, 30pp.

6. LANCASTER, R I, Spacers for reinforced concrete, 'Concrete' magazine, Vol. 23, November 1989, pp 27-28.

7. COMITE EURO-INTERNATIONAL DU BETON, Bulletin D'Information No. 201, Comité Euro-International Du Béton, Lausanne, 1990, pp 57-79.

8. SHAW, C B, Cover to Reinforcement – Getting it Right, Proceedings of the 6th International Congress on Concrete, 2005, 8pp.

9. BRITISH STANDARDS INSTITUTION, British Standard 7973-1, BSI, London, 2001, 18pp.

10. BRITISH STANDARDS INSTITUTION, British Standard 7973-2, BSI, London, 2001, 22pp.

11. BRITISH STANDARDS INSTITUTION, British Standard 8666, BSI, London, 2005, 32pp.

12. THE INSTITUTION OF STRUCTURAL ENGINEERS, Standard Method of Detailing Structural Concrete, The Institution of Structural Engineers, London, 2006, 188pp.

13. BRITISH STANDARDS INSTITUTION, British Standard 4483, BSI, London, 2005, 18pp.

14. BRITISH STANDARDS INSTITUTION, British Standard BS EN ISO 15876-1, BSI, London, 2003, 18pp.

15. BRITISH STANDARDS INSTITUTION, British Standard BS EN ISO 15876-2, BSI, London, 2003, 22pp.

16. BRITISH STANDARDS INSTITUTION, British Standard BS EN ISO 15876-3, BSI, London, 2003, 22pp.

17. BRITISH STANDARDS INSTITUTION, British Standard BS EN ISO 15876-5, BSI, London, 2003, 16pp.

18. BRITISH STANDARDS INSTITUTION, British Standard BS EN 1264-1, BSI, London, 1998, 12pp.

19. BRITISH STANDARDS INSTITUTION, British Standard BS EN 1264-2, BSI, London, 2008, 48pp.

20. BRITISH STANDARDS INSTITUTION, British Standard BS EN 1264-3, BSI, London, 2009, 22pp.

21. BRITISH STANDARDS INSTITUTION, British Standard BS EN 1264-4, BSI, London, 2009, 18pp.

22. BRITISH STANDARDS INSTITUTION, British Standard BS EN 1264-5, BSI, London, 2008, 16pp.

23. MPA-THE CONCRETE CENTRE, Concrete Credentials: Sustainability, The Concrete Centre, Camberley, 2010, 6pp.

24. DAVIS LANGDON, Spon's Architects and Builders Price Book 137th edition, Spon Press, Abingdon, 2012, 806pp.

8thConcreteConferencev1.1   05.06.2016