Sub-Structure

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Introduction and Background

Sub-structure generally refers to those components of the building that are constructed below ground, although there are circumstances when sub-structure can also include components above ground such as supporting columns on steeply sloping ground. *Barry's Introduction to Construction of Buildings* (Emmit and Gorse 2005:37) defines the foundation of a building as "that part of walls, piers and columns in direct contact with, and transmitting loads to, the ground." For purposes of this chapter sub-structure includes only those components constructed below ground.

Sub-structure components

Construction activities and components included in the term sub-structure include excavations, foundations, foundations walls, and ground floor slabs. These components are described here within the context of sustainable construction, and do not include structural or other technical contexts. For the structural requirements refer to the National Building Regulations Parts B, G, H, J and K.

Excavations

The depth and width of excavations is determined by the structure and size of the building it supports and also the nature and bearing capacity of the ground supporting it. Ground, as defined in *Barry's Introduction to Construction of Buildings* (Emmitt and Gorse 2005:37) is the general term used for the Earth's surface, which varies in composition within the two main groups: rocks and soils.

Generally excavated material is used for backfilling once the foundation walls are constructed unless the soil type is unsuitable. Where excavation takes place in soil it is important to remove the turf and vegetable topsoil and to set this aside for future use on the site. The carting away of topsoil should not be permitted.

Foundations

Typically foundations are cast to a depth and a width required by the nature of the building and the site. Typically foundations for a residential buildings of not more than 2 storeys are 600 mm wide, 230 mm thick, and are cast about 500 mm below natural ground level.

Foundation walls

Once the concrete in the foundations has set, foundation walls are constructed up to the desired level of the ground floor slab. Depending on the nature of the site, this may require a substantially high wall, for example, on sloping sites. Foundation walls may be built from concrete (either cast or in masonry form) or in clay bricks.

Reducing cement content

The cement industry is one of two primary producers of carbon dioxide (CO_2), creating up to 5 percent of worldwide emissions of this gas (Sustainable Concrete, undated). Embodied CO_2 is the amount of carbon dioxide (CO_2) generated during the extraction, harvesting, processing, manufacturing and transport of a product. This is gaining in importance as CO_2 emissions contribute to the greenhouse gases that lead to global warming. This impact can also be expressed as embodied carbon (C) which has a direct relationship to the embodied CO_2 figure by a factor of 27.3%. In either format this figure can used to provide a carbon footprint (Sustainable Concrete, undated). It is also linked to the amount of energy used during these processes but embodied CO_2 is not always directly proportional to embodied energy.

Embodied CO_2 is calculated using Life Cycle Assessment (LCA) methodology where it is important to define the scope of the data. It is most common to report information on products as cradle to gate which will include all CO_2 emissions up to leaving the manufacturing gate. It can also be calculated as cradle to site which would include the implications of the delivery of the product.

Foundations and foundation walls can constitute a significant amount of cement, and thus CO_2, especially if the foundation walls are constructed of cast concrete or concrete masonry. The amount of CO_2 emitted by the cement industry is nearly 900 kg of CO_2 for every 1000 kg of cement produced (Natesan et al 2003). One method of measuring embodied CO_2 is per cubic meter: on a conventional 40 square meter low-income house the volume of concrete in the foundations and the foundation walls is 9.57 cubic meters as shown in Table 1 below. The embodied CO_2 is as follows:

Table 1: Embodied Carbon Dioxide in Conventional Sub-structure

Element	Concrete Volume (m^3)	$kgCO_2/m^3$ (see footnote)	Total CO_2 (kg)
Foundations[1]	3.69	209[2]	771
Foundation walls[3]	1.79	174[4]	311
Concrete slab[5]	4.09	250[6]	1022
Total	9.57		**2104**

Raft foundations, on the other hand, have the distinct advantage of reducing the amount of excavation required, the amount of cement contained (in the foundations and foundation walls) and the amount of construction time (excavation, curing, and construction).

Table 2: Embodied Carbon Dioxide in Ultra-thin Concrete Raft Slab[8]

Element	Concrete Volume (m^3)	$kgCO_2/m^3$ (see footnote)	Total CO_2 (kg)
Foundations	0	0	0
Foundation walls	0	0	0
Concrete raft slab	3.57	330[7]	1180
Total	3.57		**1180**

[1] Being 600 mm wide and 230 mm thick.
[2] Being 300 kg CEM IIA/m^3 cement
[3] Taken to be a solid concrete masonry block being 390 mm long, 140 mm wide, and 190mm high.
[4] Being 200 kg CEM IIA/m^3 cement
[5] Being 100 mm thick.
[6] Being 360 kg CEM IIA/m^3 cement
[7] Being 475 kg CEM IIA/$m^{3\ cement}$

The above serves to demonstrate that using rational design rather than relying solely on deemed-to-satisfy can effect substantial environmental improvements. Eliminating the casting of concrete footings and concrete foundation walls and replacing this with a 50mm ultra-thin concrete raft slab with downturn perimeter beams[8] can, in this example, reduce the concrete used by 6 cubic meters thus saving 924 kg of CO_2 emissions as shown in Table 2 above. Clearly the bigger the house, the deeper and wider the foundations, and the wider the concrete masonry foundation walls, the greater this amount will be.

Greening Concrete

The CO_2 emissions of a typical Portland cement may be reduced under certain circumstances by replacing the Portland cement with flyash or bottom ash.

Portland blastfurnace cement may contain up to 95 per cent ground granulated blast furnace slag (see SANS 50197), but ypically in South Africa ther maximum is 65 per cent slag (CEM IIIA). Note that all compositions produce high ultimate strength, but as slag content is increased, early strength is reduced (refer to the Chapter on Structural Concrete).

Portland flyash cement may contain up to 35 per cent fly ash in South Africa. The fly ash is pozzolanic, so that ultimate strength is maintained. Because fly ash addition allows a lower concrete water content, early strength can also be maintained.

Portland pozzolan cement includes fly ash cement, since fly ash is a pozzolan, but also includes cements made from other natural or artificial pozzolans. In countries where volcanic ashes are available (e.g. Italy, Chile, Mexico, the Philippines) these cements are often the most common form in use. Portland pozzolan cement is however not produced in South Africa.

Another alternative, in certain applications, is the use of lime mortar, which is known to reabsorb the CO_2 chemically released in its manufacture, and also has the added advantage of a lower energy requirement in production. Globally there are also newly developed cement types from Novacem and Eco-cement that can absorb CO_2 from ambient air during curing.

Insulation

Foundations can be a significant source of heat loss and require appropriate insulation to ensure proper thermal performance of the building envelope. The proposed new building standards and regulations for energy efficiency in buildings in South Africa will, if approved, require that ground floor slabs are insulated to ensure proper thermal performance.

Exterior below-grade insulation is a unique challenge and opportunity for performance improvement because it performs many functions. It can provide insulation between the building assembly and the ground while protecting the structure from environmental challenges such as compression and expansion due to frost action, and moisture and water from wet soils. This means that particular care must be taken when selecting an effective insulation and damproof system to ensure that it enhances the overall performance of the building and maximises energy savings associated with heating and cooling.

One way of achieving the correct insulation performance is to use a closed-cell spray polyurethane foam (ccSPF) insulation and waterproofing system. A typical application of ccSPF would entail casting a rough concrete slab, covering that with a layer of ccSPF, and applying another layer of concrete to form a sandwich.

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[8] As used in the CSIR Experimental house

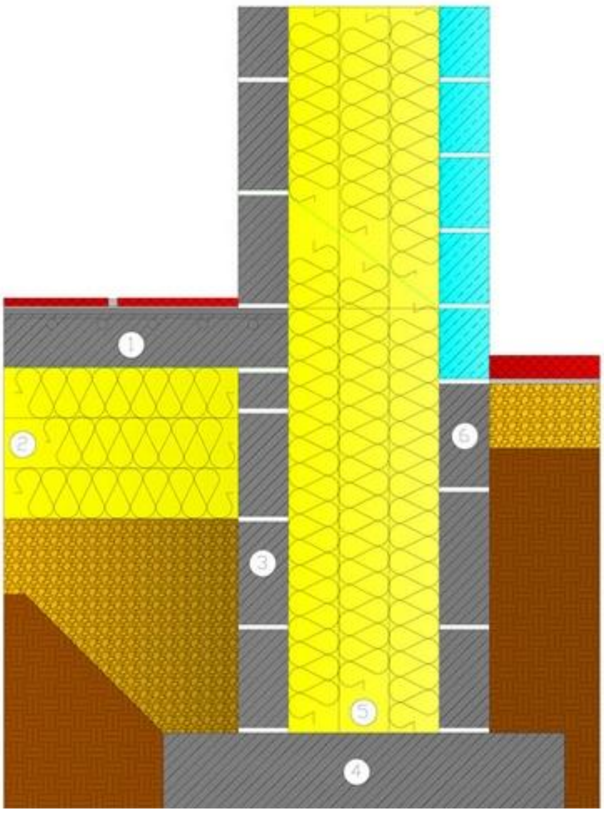
In addition a layer of ccSPF can be applied to both sides of the foundation walls: this method provides excellent thermal performance while also providing moisture and water resistance to the below-ground building-envelope construction. Particular attention must be paid to choosing the appropriate foam density and thickness especially in sub-structure applications.

An alternative approach is to wrap the entire sub-structure in a damproof membrane, and lay a 75mm screed on 75mm non-compressible insulation on the concrete slab. This is more risky than the former method and the risk of damaging the dampproof membrane is high and the slab remains exposed to thermal differences and moisture penetration.

A better alternative is to lay the hardcore (crushed stone, not building rubble) in compacted layers of 150mm, followed by a sand blinding layer, followed by 225 mm polyfoam insulation, a damproof membrane, and finally the concrete slab.

Care must be taken with the detailing of the junction between the slab edge and the foundation wall: the slab should be poured across the inner leaf of masonry to minimise the subsequent shrinkage cracking between the wall and the floor elements, an area where significant airtightness problems are likely to arise. To further reduce thermal bridging between the inner leaf of the foundation wall and the slab, use can be made of a lightweight insulated block.

Figure 1: Typical Sub-Structure Insulation Detail



Legend

1) Concrete slab
2) 225mm polyfoam insulation
3) Lightweight insulating block
4) Concrete footing
5) Underfloor insulation in cavity
6) Dense concrete masonry

Source: http://www.building.co.uk/passivehausdiaries_foundations

Conclusions

The sub-structure of a building presents as many opportunities for greening a building as any other component, although very little thought is often given to this component within the context of green building. Fundamentally, reducing the impact of construction on the natural environment can be achieved through reducing the amount of material used, and reducing the embodied content of greenhouse gases.

Lastly, the insulation values of the sub-structure should be at least equal to that of the building.

References

Concrete Centre (undated). From the website of the Concrete Centre, http://www.concretecentre.com/ Retrieved December 15, 2009.

Emmitt, S., and Gorse, C., (2005). *Barry's Introduction to Construction of Buildings*, Blackwell Publishers, Oxford.

Mahasenan, Natesan; Steve Smith, Kenneth Humphreys, Y. Kaya (2003). "The Cement Industry and Global Climate Change: Current and Potential Future Cement Industry CO_2 Emissions". *Greenhouse Gas Control Technologies - 6th International Conference*. Oxford: Pergamon. pp. 995–1000. ISBN 9780080442761. http://www.sciencedirect.com/science/article/B873D-4P9MYFN-BK/2/c58323fdf4cbc244856fe80c96447f44 Retrieved 2008-04-09.

USFHA (undated-a). U.S. Federal Highway Administration. "Ground Granulated Blast-Furnace Slag". http://www.fhwa.dot.gov/infrastructure/materialsgrp/ggbfs.htm Retrieved December 15, 2009.

USFHA (undated-b). From the website of U.S. Federal Highway Administration. "Fly Ash." http://www.fhwa.dot.gov/infrastructure/materialsgrp/flyash.htm. Retrieved December 15, 2009.

Sustainable Concrete (undated). From the website of Sustainable Concrete, http://www.sustainableconcrete.org.uk/ Retrieved Dec 15, 2009.