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Developing an innovative lightweight concrete flooring system for sustainable buildings

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Abstract

This project brings together modern developments in computational design, materials and construction methods to propose a novel thin-shell concrete flooring system for multi-storey buildings, aiming to create a low embodied energy and lightweight alternative to traditional reinforced concrete flat slabs.

Keywords: Concrete shells, multi-storey buildings, innovative structural systems, form finding, structural optimisation, textile reinforced concrete, sustainable design, finite element analysis.

1 Introduction

Recent developments in technology, legislation and industrial practice are significantly improving the operational energy efficiency of new buildings. As a result, embodied materials are increasingly the main contributor to the total lifecycle energy [1]. The largest proportion of this typically comes from the structural elements, with the floors being the main contributor [2]. Concrete flat slabs are commonly adopted for these, due to their simple formwork, design flexibility and low structural depth. However, their prismatic form disregards the variable forces within the structure, leading to large reinforcing steel requirements and inefficient use of materials [3].

This paper discusses the ideas influencing the development of a novel, sustainable alternative structural system.

2 Inspiration & Guiding Principles

2.1 Structural behaviour

It has been shown that restraining flat slabs laterally can increase their loading capacity by almost three times due to an arching effect known as ‘compressive membrane action’ [4]. This supports the hypothesis that an alternative approach to slab design, using thin compression shells, could significantly improve material efficiency (Figure 1).

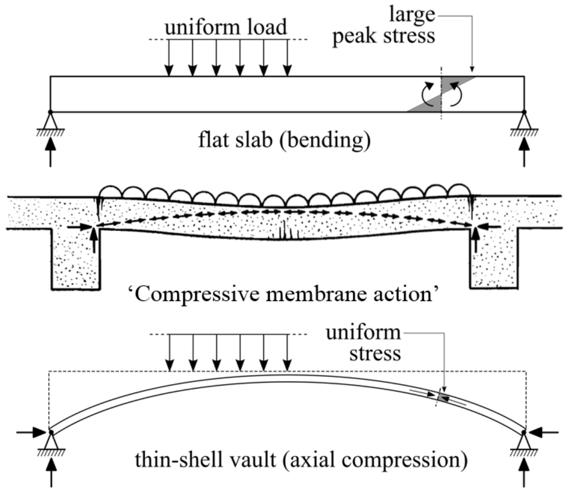

Figure 1. Structural efficiency through arching

2.2 Historical Examples

The ability of concrete shells to cover large spans efficiently was demonstrated by the famous shell builders of the 20th century, including Eduardo Torroja, Felix Candela and Heinz Isler. Examples of historical vaulted floors include traditional Catalan tile vaults, masonry barrel vaults and jack arches.

2.3 Modern Technological Developments

More recently, renewed interest in concrete shells has been driven by advances in analysis, manufacturing and materials. For example, fabric formwork enables concrete to be cast into curved geometries [5]. Another development is textile reinforced concrete (TRC), which combines a fibre reinforcing mesh with concrete in layers to create a ductile composite material. TRC is well suited to forming thin shell structures since there are no minimum cover requirements.

3 Proposed Structural System

In the proposed system, thin pre-cast TRC shells span between column supports to create a vaulted ceiling (Figure 2). In order to create a usable floor surface, a self-levelling fill of lightweight, low-strength concrete is then applied. Horizontal thrust is resisted by steel ties between columns. By integrating the services within the structural zone, the total depth is similar to an equivalent flat slab.

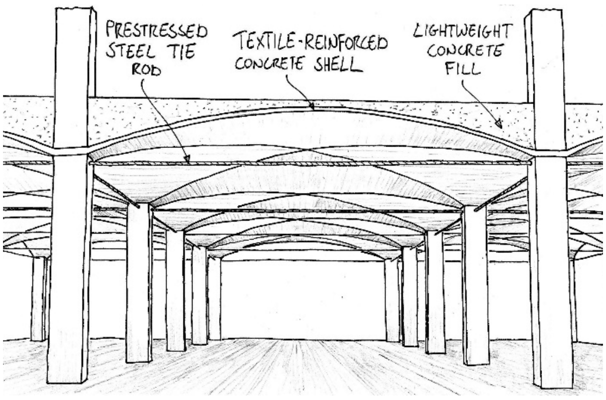

Figure 2. Proposed shell flooring system

3.1 Preliminary Design Investigations

Initially, hand calculations were undertaken to determine simple relationships between span, loading, compressive stress and lateral thrust. A parametric finite element analysis model was then created in order to quickly assess a number of design aspects in some detail (Figure 3), including:

- Shell geometry
- Tie stiffness, prestress and height
- Lateral and rotational restraint from columns
- Point and non-uniform live loading
- Differential column settlement

This allowed key design variables to be identified and gave a fuller picture of the structural performance, indicating a 47% reduction in self-weight compared to a flat slab.

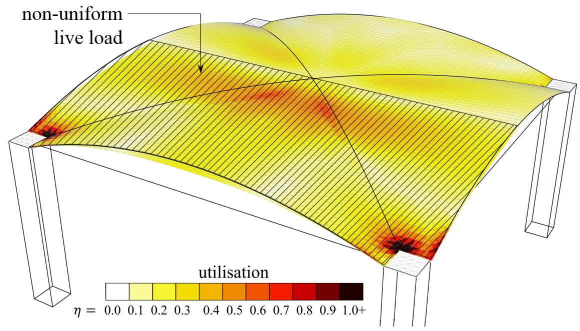

Figure 3. Example of preliminary analysis results

3.2 Future Work

A more detailed computational analysis model is under development, which will be verified through prototyping and physical testing.

4 Conclusion

This project demonstrates how theoretical understanding, historical inspiration and modern technological developments can be combined to develop innovative structural solutions.

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5 References

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