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Form finding methodology for force-modelled anticlastic shells in glass fibre textile reinforced cement composites

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ABSTRACT

The reinforcement of a specifically developed fine grained cement matrix with glass fibre textiles in high fibre volume fractions creates a fire safe composite that has – besides its usual compressive strength – an important tensile capacity and omits the need for any steel reinforcement. Strongly curved shells made of textile reinforced cement composites (TRC) can cover medium (up to 15 m) span spaces with three times smaller shell thicknesses than conventional steel-reinforced concrete shells. This paper presents a methodology to generate force-modelled anticlastic shell shapes that exploit both the tensile and compressive load carrying capacities of TRC. The force-modelling is based on the dynamic relaxation form finding method developed for gravity (in this case self-weight) loaded systems. The potential of the presented methodology to develop structurally sound anticlastic shell shapes is illustrated by four case studies.

1. Introduction

The research presented in this paper addresses the renewed design interest in complex curved structural surfaces. After a period of blooming in the 1950s and 1960s with shell builders such as Candela and Isler, the realisation of thin reinforced concrete shells reduced drastically in the 1970s, mainly because of the increase in construction costs [1,2]. Recent advances in textile formwork and composite technology have the potential to make shells economically competitive and lead to innovative shell applications.

Extensive research by West [3], Pronk et al. [4], the Belgian Building Research Institute [5] and Guldentops et al. [6] demonstrates the theoretical as well as practical feasibility of form active shell moulding. Synclastic shells, or domes, can easily be produced with inflated membranes. The force-efficiency of a gravity loaded shell shape, obtained with an inflated membrane under pressure, is limited to shallow domes [7]. Anticlastic concrete shells, however, can be constructed with minimum labour costs on a pre-stressed membrane without slope or curvature restrictions. This technique is particularly economical with re-usable membranes.

The construction of anticlastic shells with high curvature can be even more facilitated through the use of flexible fibre reinforcement. Cement-based composites offer a fire safe alternative for fibre reinforced polymers to construct curved shapes, but are limited in fibre volume fraction when short fibres are used in a premix system, as is usually the case. The use of continuous fibre systems, called textiles [8,9], allows the impregnation of much higher fibre volume fractions if the grain size and rheology of the cement matrix is adapted to the high density of the textile [8]. Researchers at the Vrije Universiteit Brussel developed a fine grained cement matrix, Inorganic Phosphate Cement, that can impregnate dense glass fibre textiles up to 20% fibre volume fraction and more [10], resulting in a high tensile capacity while making any other reinforcement, like steel, redundant. The thickness of noncorroding Glass fibre Textile Reinforced Inorganic Phosphate Cement (GTR-IPC) shells is no longer restricted by corrosion cover regulations, in contrast with the minimum 70 mm thickness for steel-reinforced concrete shells required by Eurocode 2 [11]. GTR-IPC shells can be made as thin as structurally necessary. This fact makes these shells economical in material use for smaller applications. Previous research [12,13] has proven that the application of GTR-IPC to medium span (up to 15 m) shells leads to a considerable thickness reduction in comparison with steel-reinforced concrete.

This paper focuses on an important aspect of anticlastic GTR-IPC shell design: the determination of a force-efficient initial shell geometry. The choice for strongly curved, anticlastic shell shapes does not only take into account the facilitated manufacturing on a pre-stressed membrane, but most of all exploits the most advantageous property of GTR-IPC to carry tensile as well as compressive stresses. With this cement composite, innovative anticlastic shell shapes can be designed that hold the synergy between

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