FINITE ELEMENT MODELLING OF HOLLOW-CORE CONCRETE SLABS

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ABSTRACT

Light weight plastic spheres from recycled plastics have been commonly used in the design and construction of lightweight hollow-core concrete slabs. While this approach is regarded as an effective method to reduce the dead load of slabs and to increase the imposed load carrying capacity, limited technical information exists about the benefits of hollow core concrete slabs and their structural performance. A literature review on the engineering databases uncovered some awards and application articles on the technologies, but little analysis about its structural performance can be found. In this paper, *Strand 7* Finite Element Analysis in conjunction with *Rhinoceros* 4 3D CAD software was used to create composite FEA models of concrete slabs. These composite models were loaded to observe stresses and cracked section behaviour in both hollow-core concrete slabs and solid concrete slabs to determine the relative merits of hollow core concrete slabs over regular solid concrete slabs.

KEYWORDS

Hollow Cobiax core; Concrete slabs; FE analysis; Cracked and uncracked sections;

INTRODUCTION

Cobiax is a Sweden company specialising in the design and construction of lightweight structural hollow-core concrete slabs. Cobiax manufactures light plastic spheres from recycled plastics that may be embedded inside different concrete slabs. It is hypothesize that this technology would dramatically reduce the dead load of slabs and yet increase the imposed load carrying capacity.

Figure 1 A Cobiax slab before concrete pour

In a regular solid concrete slab, bending stress tends to cause slabs to deflect and ultimately fail. The majority of the bending stress is carried by slabs' extreme fibres on each tension and compression side. Cobiax works by lowering the slabs' dead load with an insignificant effect on the stresses at the extreme fibres. Based upon the reviewed literature, there was very little information available on the structural analysis of Cobiax-core concrete structures. The existing literature is mostly around articles on the basic parameters of the product and its awards for successful or innovative use. However, the most relevant references are discussed in this section.

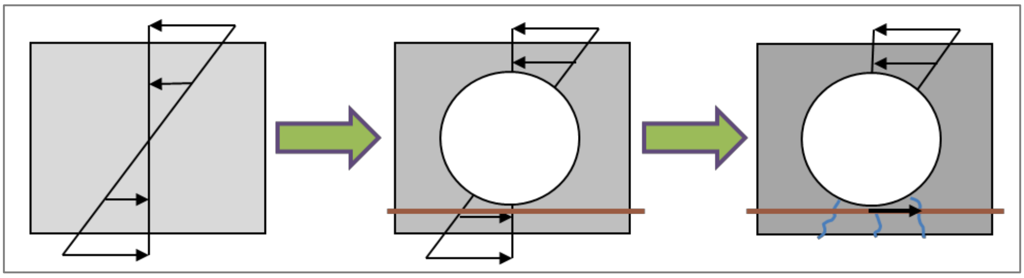


Figure 2 A slab in bending, and the concept behind Cobiax: solid slab (left), Cobiax slab (middle) and cracked Cobiax (right).

In 2007 the London Concrete Association released a paper about the construction of a library leading to the pattern of semi-precast Cobiax slabs (Stephenson, 2007). According to this reference, the construction time for the decks was reduced by abound 40%, dead load was reduced by 35% and carbon dioxide emissions were also cut by 1/3. Natural frequency of Cobiax slabs was investigated by Wolski et al. (2006). It was found that Cobiax slabs show relatively lower natural frequencies relative to the other types. Biaxial hollow slabs (including new types of voids) were investigated by Churakov (2014). The structural performance of the new slabs was obtained very similar to the solid slabs.

The environmental performance of precast slab with a void forming was examined by Hajdukiewicz et al. (2014), where the structural performance of Cobiax slabs were discussed. Bearing response of biaxial hollow-core slabs were set forth by Abramski et al. (2010). It was elaborated that shear strength of a two way hollow core slab is significantly smaller than a solid slab, while the bending capacity is gained by and large the same as a solid one. Marais (2009) expounded upon the economical application and the design adjustment factors of slabs with spherical voids. Cobiax was found to be quite appropriate where a flat soffit is needed in high multi-storey buildings – wherein large spans with a light load application are predominantly seen.

This paper aims at a Finite Element Modelling of Cobiax slabs, whereby the structural performance is assessed to quantify the relative structural responses of the solid slabs to be evaluated against their hollow core Cobiax counterparts. Promising results are obtained through this FE set of analyses which as a point of departure can inspire many researchers to get further into the present topic.

FE MODELLING

Modelling was carried out using a combination of *Strand 7* Finite Element Analysis package and *Rhinoceros 4* 3D CAD software. *Strand 7* has been chosen as the FEA package due to its elemental model setup. This setup allows *Strand 7* to be utilized in creation of the concrete body and steel reinforcement as beams attached to the nodes which also join and employ the required concrete in this study.

Due to the complex geometry of the created models, *Rhinoceros 4* was chosen as a 3D CAD modelling software. *Rhinoceros 4* (also known as *Rhino 4*) is a powerful CAD package which can easily generate different 3D models and has the capability of exporting created models as an *IGES* file type, which can be directly imported into the *Strand*. A typical cracked model with corresponding dimensions is presented through Figure 3.

Parameter	Dimensions (mm)
D	230
d	210
b	210
Sd	180
Cw	15
Ch	160

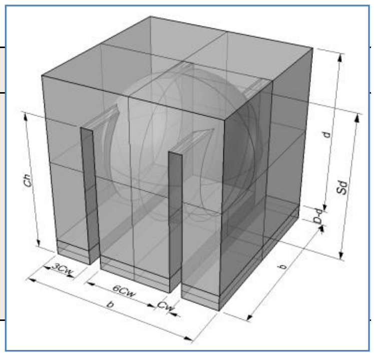


Figure 3 Geometry and dimensions of a typical cracked model.

UNCRACKED AND CRACKED MODELS

The slabs must be modelled such that the steel and concrete are sufficiently bonded along the length of the interface. To achieve this, a straight line of nodes is adopted within the concrete shell. Due to the random nature of Strand 7's solid auto-mesh facility, the steel cannot be modelled directly through the solid simulation. Rather, it has to be applied to the solid edge so that concrete can be applied to form the capping of the entire model (Figure 4).

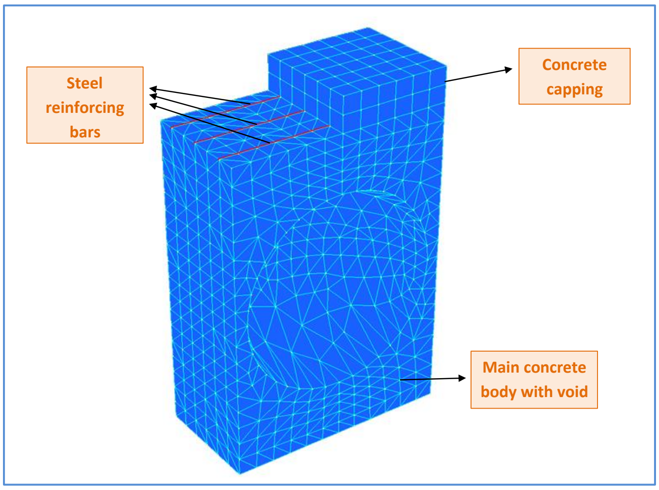


Figure 4 A basic concrete element (half section)

Once a concrete '*shell element*' has been modelled it can be exported from *Rhino 4* as an *IGES* file and in turn imported into the *Strand*. To auto-mesh the model surface, nodes and plate elements are created on each targeted face. The mesh is created as square 4 pt meshes so that a straight line of nodes is made, which properly allows the attachment of steel. Material properties are entered into *Strand 7* for each material, i.e. concrete (as bricks) and steel (as a beam element). Steel element is applied between nodes on the lower face of the solid by 'create element' linking each node along the path of the steel (Figure 5).

The select-by-region tool may be used to select each plate element on the lower face of the solid and extrude the plates to form bricks, which can essentially model the concrete capping on the lower side of the steel. With the assembled element of the desired slab configuration, the element can now be mirrored about the front axis of the solid to complete a full void. It has to be noted that all models were adopted as simply supported with only edge supports where the code calculated the deflections based upon the effective centre-to-centre span of the supports.

The same process is followed in transverse direction to complete simulation of a slab model. Unlike the solid slab though, the steel cannot be continuously fixed to the concrete on the slab's underside. In a cracked section, it is required that breaks in the concrete cause no tension stress in the concrete. This allows the steel to carry all tension loads. The nodes however, remain in a straight line such that the steel is modelled as a straight bar.

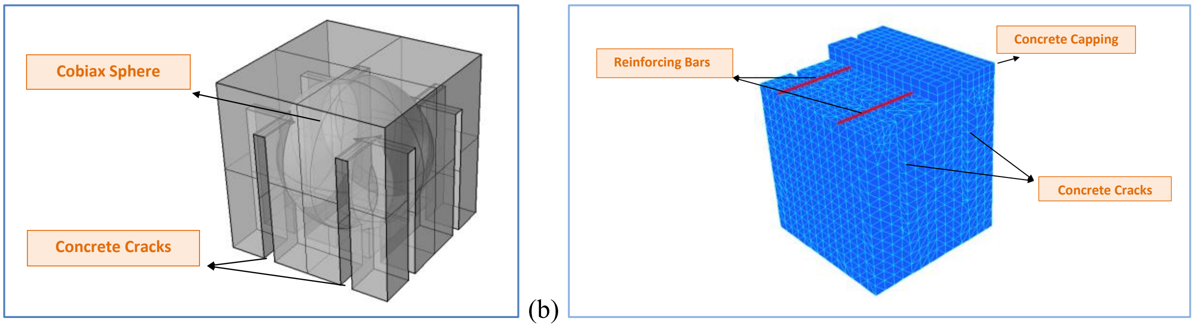


Figure 5 (a) cracked wireframe concrete section with a Cobiax sphere (b) cracked solid concrete section

RESULTS AND DISCUSSIONS

It is found that physical removing of predefined space from inside of the slabs does not lead to significant effect in the bending capacity as bending is predominantly carried at the extreme fibres. Shear however is carried across the entire depth of the slab in order that the increase in the shear stress is definitely quite proportional to the amount of employed material.

A modelled section was closely looked into via *Strand 7* and directly compared with a solid slab to determine the mentioned difference. Based upon the FEA results it appears that the shear capacity of a Cobiax section is approximately 55% lower than the shear capacity of a regular solid slab (Figure 6). It is fitting to note that the shear stress is not usually the limiting factor in structural slabs, while bending is a quite critical element. Notwithstanding this though, it is always required that the shear strength is verified in regions of high shear stress vulnerability.

	Solid Slab	Cobiax
Highest Shear.	3.6 MPa	8.0 MPa

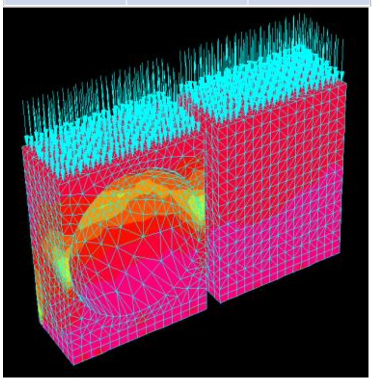
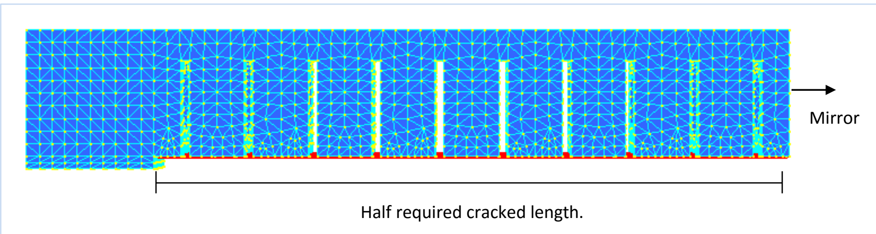
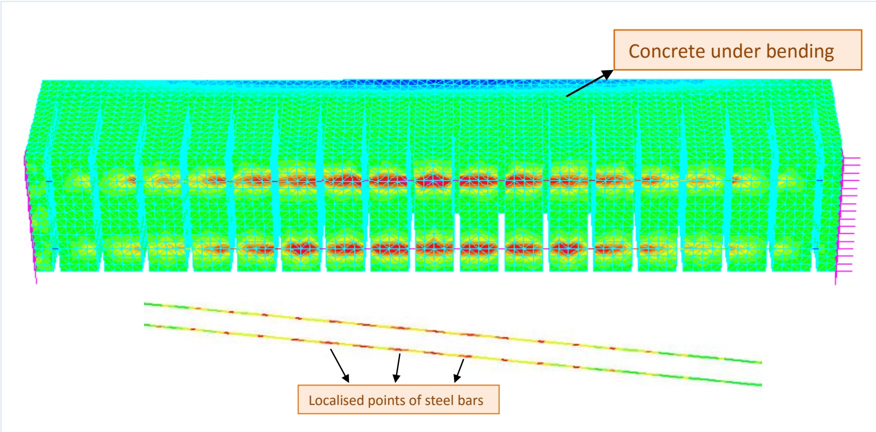


Figure 6 Cobiax and solid sections conducted in shear

Figure 7(a) depicts the cracked slab with a half required length prior to the loading. Figure 7(b) clearly shows a distribution of tensile and compressive stresses within each concrete section bounded by the modelled cracks. This figure also shows the stress distribution in the steel bars respectively. As is seen, the localised regions of high stress are obtained where the crack has been lied in. In turn, areas in the vicinity of high stress zones are the locations where concrete is placed. It is believed that this reduction in the stress of the steel bars may highly reduce the total deflection of the entire model.



(a)



(b)

Figure 7 Cracked slabs before and after loading

Figures 8–10 compare three critical parameters of Cobiax and regular solid slabs. Stresses in the concrete, stress in the steel and deflections were evaluated for the new composite against the solid slabs. The results from each of the reinforcing cases favour hollow-core concretes as a reliable and yet cost-effective light weight structural member.

Composite modelling of concrete sections yielded very good results using a combination of *Strand 7* finite element analysis and *Rhinoceros 4* 3D CAD. Using simplified design formulas – as specified in the *Australian Concrete Standard* (*AS3600)* – the results of the non-Cobiax models were verified. Similarly, critical stresses were verified for the cracked models with a 15 mm mesh. With a mentioned mesh, which was used in most models, the *Strand 7* results were very close to the theoretically calculated results. All three critical stresses, i.e. concrete compression, concrete tension and steel tension, resulted in trivial differences comparing the present model with the theory.

It was found that regardless of the reinforcing configuration in a one-way slab, the use of Cobiax resulted in quite positive results. Cobiax achieved a 30% reduction in concrete used to cast the slab, and for the same imposed load, around 10% reduction in concrete compression stresses, steel tension stresses as well as deflection were achieved.

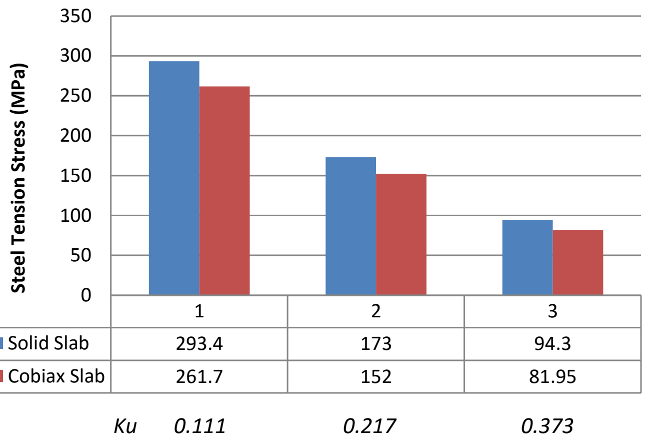


Figure 8 Steel tension stresses between Cobiax and solid slabs

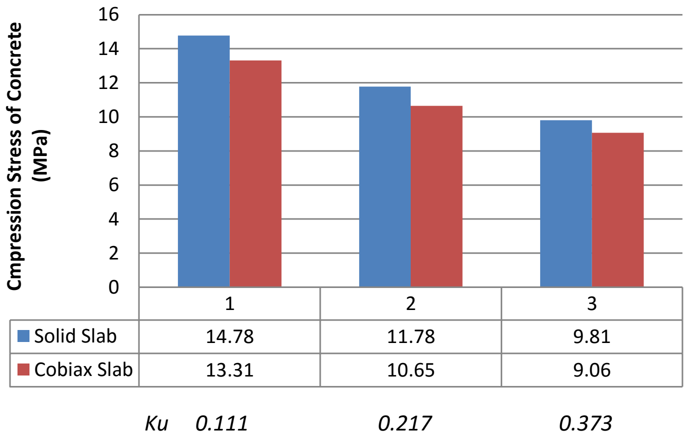


Figure 9 Concrete compression stresses between Cobiax and solid slabs

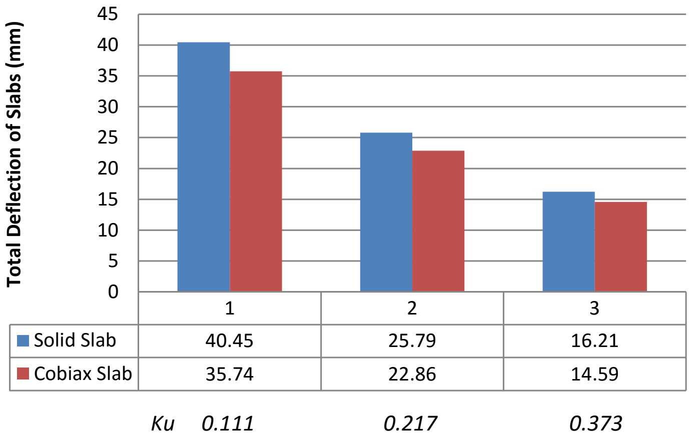


Figure 10 Total deflections of Cobiax and solid slabs

CONCLUSIONS

This paper aims at a Finite Element Modelling of Cobiax slabs, whereby the structural performance is assessed to quantify the relative structural responses of the solid slabs to be evaluated against their hollow core Cobiax counterparts. The summary of the results are outlines as:

It is found that removing the predefined space from inside of the slabs does not lead to significant effect in the bending capacity as bending is predominantly carried at the extreme fibres. Based upon the FEA results it appears that the shear capacity of a Cobiax section is approximately 55% lower than the shear capacity of a regular solid slab. The results from each of the reinforcing cases favour hollow-core concretes as a reliable and yet cost-effective light weight structural member.

Using simplified design formulas the results of the non-Cobiax models were verified. Similarly, critical stresses were verified for the cracked models with a 15 mm mesh which was used in most models. With a mentioned mesh, the *Strand 7* results were very close to the theoretically calculated results. It was found that regardless of the reinforcing configuration in a one-way slab, the use of Cobiax resulted in quite positive results. Cobiax achieved a 30% reduction in concrete used to cast the slab, and for the same imposed load, around 10% reduction in concrete compression stresses, steel tension stresses as well as deflection were achieved. In a nutshell, promising results of the present research can inspire many researchers as a point of departure to get further into the present topic.

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