Bond Enhanced Sandwich Shells for Arctic Offshore Structures

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ABSTRACT

A previous paper (Marshall et al 2009) describes the Singaporean concept for an Arctic caisson, consisting of a pre-fabricated hollow steel shell, transported to site on a submersible heavy-lift vessel, and filled with concrete after being set on a prepared foundation. The resulting curved sandwich shell, steel-concrete-steel (30-500-30 mm), was designed to resist the full range of broad-area and higher localized patch loads specified in the draft ISO 19906. However, finite element analysis and large-scale testing of the latter showed it to be vulnerable to early disbanding and loss of serviceability, even though its ultimate strength exceeded the ISO guidelines. Various methods of bond improvement have been proposed, with the goal of approaching the shear and tensile strength of the fiber-reinforced bulk concrete. Recent small scale testing (shear push-out) will be reported, exploring two methods of surface treatment which improve strength and ductility at the concrete-steel interface. They are called "hairy epoxy" and "steel Velcro."

KEY WORDS: ice wall; ice load; sandwich structure; adhesive; bond strength.

INTRODUCTION

In this paper we present a concept for an ice-resistant offshore platform with a steel and concrete sandwich structure, intended for water depths between 10 and 100 m. The scheme is sketched in Figure 1.

The outer skin and the inner skin are welded steel plates sparsely connected to each other. They form the outer and inner layers of a "sandwich". The filling is concrete. Much research on sandwich structures of this kind has been carried out since they were first studied some 40 years ago. The steel layers are positioned so that they contribute strongly to the bending resistance of the sandwich. In addition, the steel layers serve as formwork for the concrete, so that no additional formwork is required.

A particular advantage for the Arctic is that the steel component of the structure can be built first, at some convenient and economically attractive location such as Singapore, China or Korea. The 'empty' structure is light enough to float, and can be moved in place either on a heavy-lift vessel or by a wet tow. It can be towed to an Arctic location during the Arctic summer, and ballasted down until it rests on and penetrates the seabed. It will then be filled with concrete.

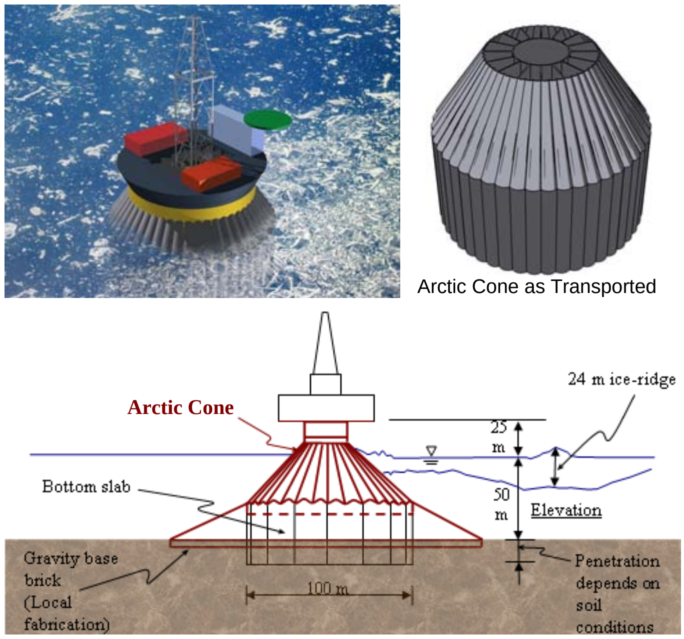

Figure 1. Generic Arctic oil & gas platform.

STRENGTH OF CURVED SANDWICH SHELL

Reinforced and SCS sandwich barrel shells are particularly efficient in resisting distributed external compressive loads due to ice and seawater, as well as the internal pressure of wet concrete. The ice wall concept being studied at the National University of Singapore (NUS) has the following properties:

- Sandwich: 30-500-30 mm
- Grout: 30 MPa (3000 psi) compressive strength
- Steel: 355 MPa (50 ksi) yield strength
- Cylindrical shell segment, 5m span, 10m length along axis.
- 45-degree rise angle at the haunch (rise/span of 0.21).

Ice loading is not uniform like soil or hydrostatic loading, and may be characterized as dancing high pressure zones, with different regions of the encroaching ice mass failing sequentially in a quasi-brittle manner. ISO 19906 prescribes higher loading pressures as the loaded patch gets smaller, while the efficiency of the barrel shell is reduced under asymmetric partial loading.

Resulting ultimate capacities for various loaded patch sizes on a plain unreinforced steel-concrete-steel sandwich shell are summarized in Figure 2, along with ISO design pressures, pL, versus loaded area, A..

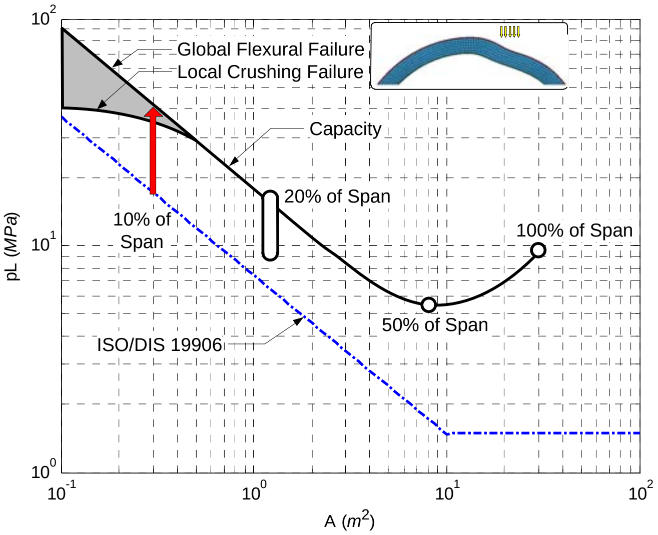

Figure 2. Analytical strength versus patch dimension (prototype scale)

The 10% patch case was also studied experimentally at ¼ scale (Tran & Loo 2009), and exhibited the strength indicated by the bold arrow. Although great care was taken to avoid straining the specimen before applying loads, a flexural crack in the concrete and extensive disbonding (separation of steel on the concave face) was observed before any loads were recorded. It could be surmised that a prototype structure could suffer similar loss of serviceability from shrinkage and thermal strains. No further damage was observed at twice the ISO load.

Ultimate load was 4.8 times ISO, or 78 MPa on the 125mm×125mm model loading patch. At ultimate, Figure 3, drastic separation of both face plates from the concrete can be seen, which accompanied a broad punching shear indentation surrounding the load point.

Figure 3. Plain SCS sandwich failure at ultimate load

Maintaining the bond of a plain concrete core against a broad expanse of steel plate appears to be more problematic than maintaining the bond around embedded reinforcing bars. Although the load levels achieved were satisfactory in terms of ISO requirements, loss of serviceability due to premature disbonding remains a significant concern.

ENHANCED BOND BETWEEN STEEL AND CONCRETE

The structural integrity of a steel and concrete sandwich depends on the bond between the two materials. The interface often has to transmit shear, and sometimes tension as well.

An appealing option is to add to the plates a surface coating that incorporates fibers. The fibers project beyond the coating. The idea is not dissimilar to the shear studs, but on a smaller scale. When the concrete is poured between the steel plates, it flows around the fibers and bonds to them. The shear capacity is determined by the weaker of (1) the adhesive bond strength at the steel surface, (2) the ductile shear strength of the fibrous layer, and (3) the tensile / shear strength of the bulk concrete substrate. The shear force is transferred in a relatively continuous manner. The Singapore-MIT Alliance found that a ductile layer just under the steel is potentially advantageous (Yao 2010).

This bond enhancement concept has been tested by an experimental program at NUS (Ma, 2010). Two steel plates are coated with epoxy, and fibers are placed in the coating before it hardens, Figure 4. Concrete filler is cast between the fuzzy plates. After an appropriate curing time, a push-out test is performed. A platen drives the concrete filler downwards, loading the interface in shear. Load and displacement between the platen and the steel face plates is measured. Test results are shown in Figure 5, and in the ICCE-18 poster presentation. More complete detail will be given at ICETECH-2010.

(a)Surface with steel fiber (b) Surface with 5% PVA fiber

Figure 4. Prepared surface with epoxy and fibers

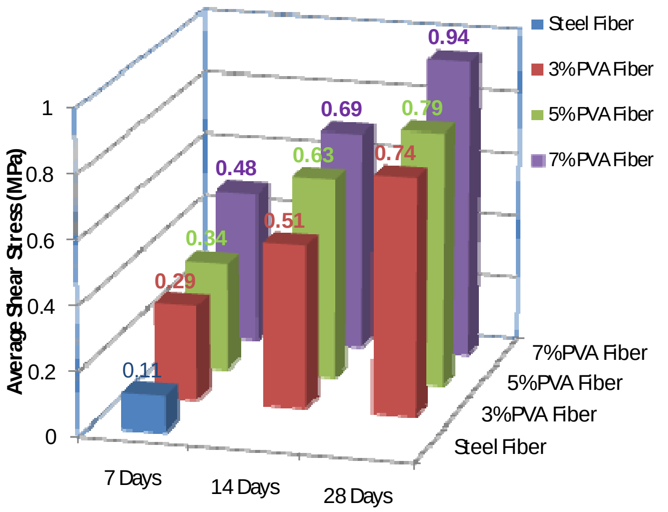

Figure 5. Summary of push-out test results

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