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AN ASSESSMENT OF THE BLAST RESISTANCE OF SANDWICH BEAMS

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Summary. *An assessment of the underwater blast resistance of sandwich beams with a prismatic Y-truss core is presented, utilizing three-dimensional finite element calculations. Results show a significant performance benefit for sandwich construction when compared to a monolithic plate of the same mass when the sandwich core combines high shear strength with low compressive strength.*

1 INTRODUCTION

Sandwich beam design offers advantages over solid beam construction, for a given mass, in providing resistance to blast loading. The performance improvement in terms of reducing the maximum back face deflection for sandwich designs subjected to impulsive loading has been shown by Xue and Hutchinson[1,2]. For beams subjected to blast loads in water, the effects of fluid-structure interaction (in particular fluid cavitation) become important and the benefits of sandwich construction are more significant. Deshpande and Fleck[3,4] define a multi-stage analytical approach to such blast loads, in which (i) the front face sheet acquires momentum imparted by the blast, (ii) the core of the sandwich crushes and (iii) the clamped structure responds. The benefits of sandwich design thus become clear in such an analysis. The (low) mass of the face sheet facing the blast governs the momentum transfer during (i) while the sandwich-effect retained after (ii) will affect the clamped beam response in (iii).

Periodic, prismatic lattice cores are currently in widespread use in ship-building. In particular, the ‘Y-Core’ sandwich developed by Schelde Shipbuilding will be considered. Finite element analysis inclusive of fluid-structure interaction is used to asses the response of a clamped sandwich beam with a Y-Core to underwater blast loading. The result is compared with that for a monolithic beam of the same mass.

2 FINITE ELEMENT MODELS

The commercially available finite element code ABAQUS/Explicit is employed to construct fully three-dimensional finite element models inclusive of fluid structure interaction. The geometry and boundary conditions for the Y-Core sandwich are as shown in Fig. 1. The dimensions are chosen to be representative of real Y-Core designs currently used in ship-building. The face sheets have thickness 8 mm and the plates making up the core have thickness 5 mm. A half span unit-cell is modeled with symmetry boundary conditions applied at mid span for the core and on all free face sheet edges. The chosen half span of $L = 1$ m is representative of a ‘double-hull’ arrangement. Both the core and face sheets are fully clamped at one end of the half span. In addition to the sandwich beam, a monolithic beam of the same mass per unit area is modeled.

The material properties used for the core and face sheets (and the monolithic beam) follow those for 304 stainless steel, including hardening plasticity but not rate sensitivity. The fluid has properties representative of water, with a density of 1000 kgm^{-3} and a bulk modulus of 1.96 GPa. Cavitation is permitted in the water at zero pressure.

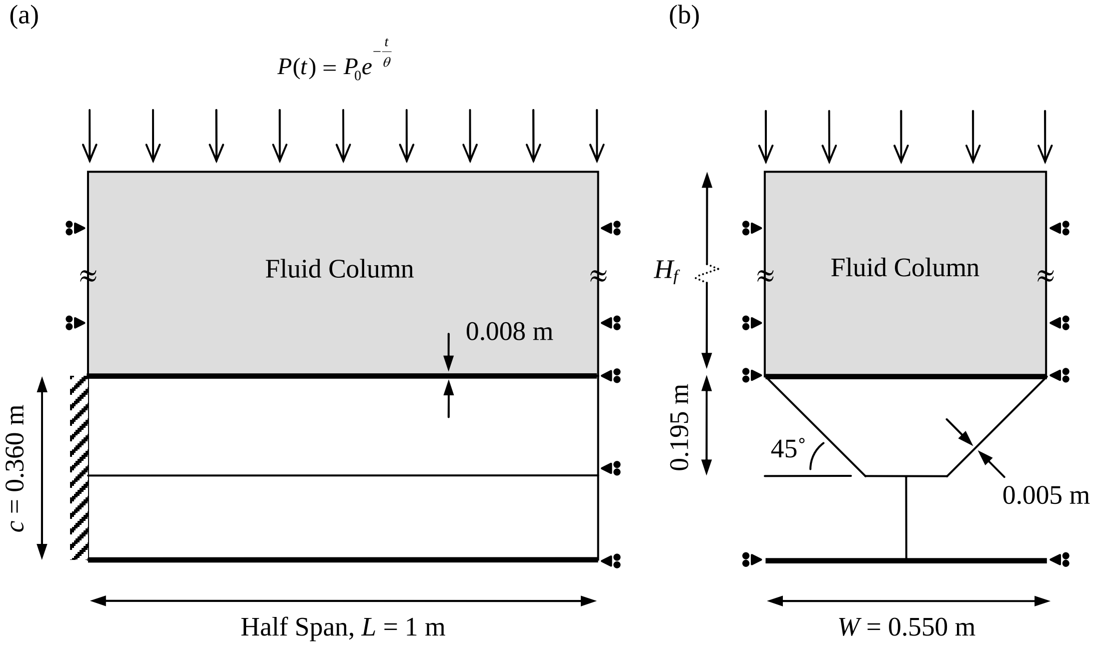

Figure 1: Geometry of the Y-Core clamped sandwich beam (a) side view (b) end view.

Four node shell elements with reduced integration (S4R in ABAQUS notation) are used to mesh the core and face sheets of the sandwich beam. Elements are approximately square and of size 10 mm on the face sheets and 8mm in the core. The monolithic beam is modeled in plane strain, using twelve linear quadrilateral elements (CPE4R) through the thickness. ABAQUS acoustic elements are used to model the fluid column (AC3D8R in three dimensions and AC2D4R in plane strain). A mesh size of 10 mm in the fluid is chosen to allow accurate coupling of the fluid mesh to the structure.

The sandwich beam is loaded by applying a pressure boundary condition representative of a blast load to a fluid surface. An exponential form with decay constant $\theta = 0.1\,\text{ms}$ is chosen as a realistic load:

$$P(t) = P_0 e^{-\frac{t}{\theta}} \tag{1}$$

The magnitude of the applied pressure (P_0) is varied between 60 MPa and 180 MPa. The response of the structure is evaluated from the core compression and the mid-span deflection of the back face.

3 BEAM RESPONSE

Considering the maximum mid-span back face deflection as a measure of beam performance, Fig. 2 shows that when fluid structure interaction is included, the Y-Core sandwich beam significantly outperforms a monolithic beam of the same mass.

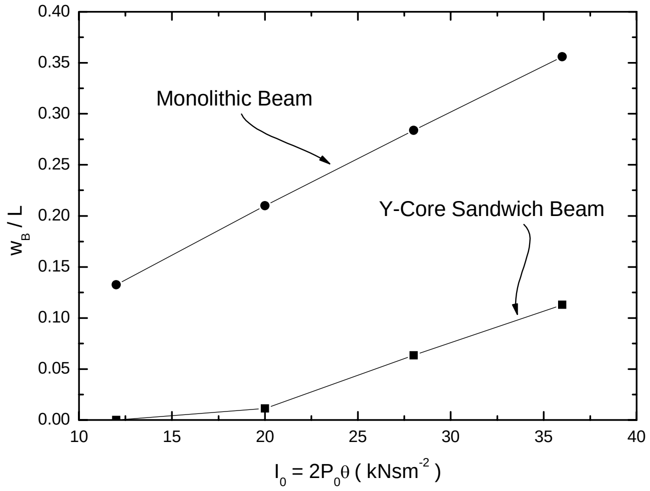

Figure 2: Maximum centre-span back face deflection (normalised with half-span length)

Three key factors contribute to the performance benefit observed for this Y-Core sandwich construction[5]:

(a) The core is initially weak in compression. The core geometry means that no buckling event is required to initiate core compression. This ensures the momentum transferred in the initial stages of fluid-structure interaction are governed by the mass of the front face sheet only and not the complete sandwich (as is the case for the monolithic beam).

(b) The 'double-hull' arrangement. This, in combination with the low core compressive strength, results in a structural response time of the order of the momentum transfer time.

(c) Core shear strength. This close coupling of the three stages (momentum transfer, core compression and structural response) alongside the retention of high core strength in shear, permitting a continued sandwich effect, results in a lower maximum deflection.

Furthermore, at lower impulses, total momentum transfer to the supports can occur before core densification (occurring at a compressive strain of around 0.5 for the geometry considered). The result is a threshold incident momentum below which minimal back face deflection occurs.

The coupling between the stages of fluid-structure interaction for the sandwich demands a fully coupled finite element calculation to capture the response of the beam accurately. In contrast, the timescales of the three stages remain separated for the monolithic beam, permitting decoupling of the momentum transfer from the structural response without loss of accuracy.

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