

## LOAD INTRODUCTION ASPECTS AND LOCALISED BENDING PHENOMENA IN LIGHTWEIGHT SANDWICH STRUCTURES

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### Extended abstract

Structural sandwich elements with metal or FRP face sheets and polymeric foam, Nomex or aluminium honeycomb cores are used extensively for lightweight spacecraft, aircraft and marine structures. This is owing to the possibility of achieving lightweight structures with high stiffness and strength. However, owing to the layered structure of sandwich elements, where two rigid, strong and relatively dense face sheets are separated by a compliant and lightweight core material, structural sandwich panels are notoriously sensitive to the application of localised external loads, localised support conditions and discontinuous changes of geometry and material properties. In such areas strongly localised bending phenomena are induced, where the face sheets tend to bend about the neutral plane of the face sheets rather than about the neutral plane of the complete sandwich assembly. These localised bending effects cause the inducement of severe stress concentrations, which may be the cause of a premature structural failure, as sandwich panels with transversely flexible cores such as polymeric foams or honeycombs are highly susceptible to failure due to local stress concentrations. Under such conditions, sandwich panels usually fail owing to delamination, owing to shear rupture of the core or to direct bending of the face sheets.

The local bending effects causing such structural failures cannot be accounted for using classical “*antiplane*” sandwich plate theories (“*weak core*” assumptions), summed up in the monographs by Plantema [1], Allen [2], Stamm and Witte [3] and Zenkert [4], as such theories do not include the transverse flexibility of the core material. A more advanced transverse bending theory for sandwich plates is presented in the monograph by Librescu [5], in which also sandwich plates with “*weak*” and “*strong*” cores are treated separately. The terms “*weak*”, “*anti-plane*” or “*compliant*” cores are equivalent concepts and are used to describe an idealised core in which the stretching and shearing stiffnesses in planes parallel with the face sheets is zero but the shear modulus perpendicular to the face sheets is finite [2], [4], [5]. As opposed to a sandwich panel with a “*strong*” core (or “*rigid*” core) is characterised by the fact that the core in-plane stretching and shearing stiffnesses are taken into account [5]. For most structural sandwich panel applications the “*weak*” core assumptions can be adopted, since very lightweight core materials such as polymeric foams and honeycombs are usually used.

In the theory developed by Librescu [5] the sandwich panels treated are assumed to be symmetric and the core material is modelled as a moderately thick plate, where the presence of core transverse normal stresses is included in the modelling. The sandwich plate model presented in [5] does not, however, include the transverse flexibility of the core material since it is assumed *a priori* that the transversal deflection of the core is uniform through the core thickness (i.e. the core transverse normal strain  $\varepsilon_z=0$ ).

The importance of including the transverse flexibility of the core (i.e. allowing the core thickness to change during deformation of the sandwich panel) when addressing load introduction problems, support problems, and problems involving material and geometric discontinuities in sandwich beams was pointed out by Frostig and Baruch [6], Frostig [7] and Frostig and Shenhar [8]. This was done by formulating a “*high-order*” sandwich beam theory, which includes separate description of each face sheet and separate description of the core material. The core material is modelled as a special type of transversely isotropic solid where only the out-of-plane stiffness is accounted for. In other words, the core type considered in [6]-[8] is a transversely isotropic “*weak*” core where the plane of isotropy is parallel to the core middle plane. The high-order sandwich beam theory inherently incorporate both global and localised bending effects, and the basic assumptions as well as the quality of the predictions of the theory was verified experimentally by Thomsen and Frostig [9] through photoelastic measurements.

To illustrate the characteristic features of the “*high-order*” sandwich theory, as applied for the analysis of localised bending effects in sandwich plates, the presentation addresses the problem of analysis of sandwich plates with inserts of the “*through-the-thickness*” and “*fully potted*” types as shown in Figure 1 and Figure 2.

The problem is formulated by adapting and extending the principles behind the sandwich theory developed for sandwich beams in refs. [6]-[8] to circular sandwich plates. Full details about the mathematical formulation can be found in recent publications by Thomsen [10] and Thomsen and Rits [11].

The suggested “*high-order*” sandwich plate theory accounts for the transverse flexibility of the core material, and the formulation includes separate descriptions of the elastic responses of the two face sheets that may deflect differently, separate description of the elastic response of the core material and specification of different material properties for the “*potting*” and the “*honeycomb*”/“*foam*” core regions in the sandwich plate (relevant for the potted insert problems studied). Arbitrary external loading and boundary conditions can be specified.

The physical principles behind the “*high-order*” theory, which involves no *a priori* assumptions regarding the sandwich plate displacement field, are discussed in the lecture, and the formulation of the complete set of governing equations is outlined. The question of boundary conditions will be discussed, where the fact that boundary conditions can be prescribed individually for both face sheets and for the core is very important. A few numerical results will be shown, and the validity and applicability of the theory is substantiated by comparison of the predicted displacement fields with experimental displacement fields obtained using *Electronic Speckle Pattern Interferometry* (ESPI) for the case of a circular sandwich plate with a “*fully potted*” insert (the sandwich plate thickness changes significantly near the insert for this case). The lecture will be concluded with a brief discussion of design aspects.

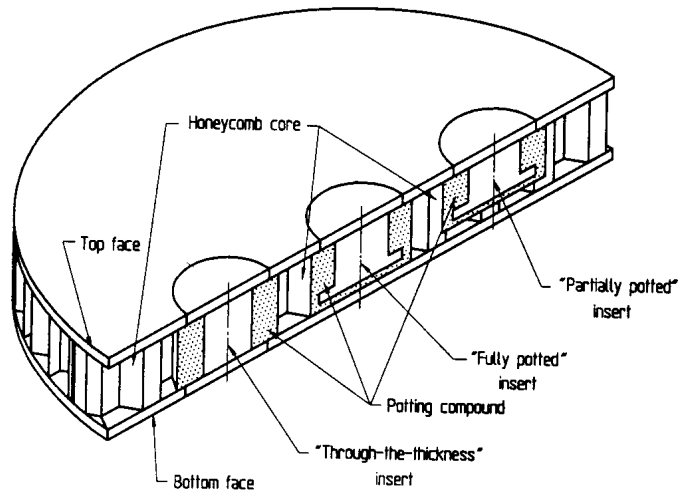


Figure 1: Insert types typically used for structural sandwich panels.

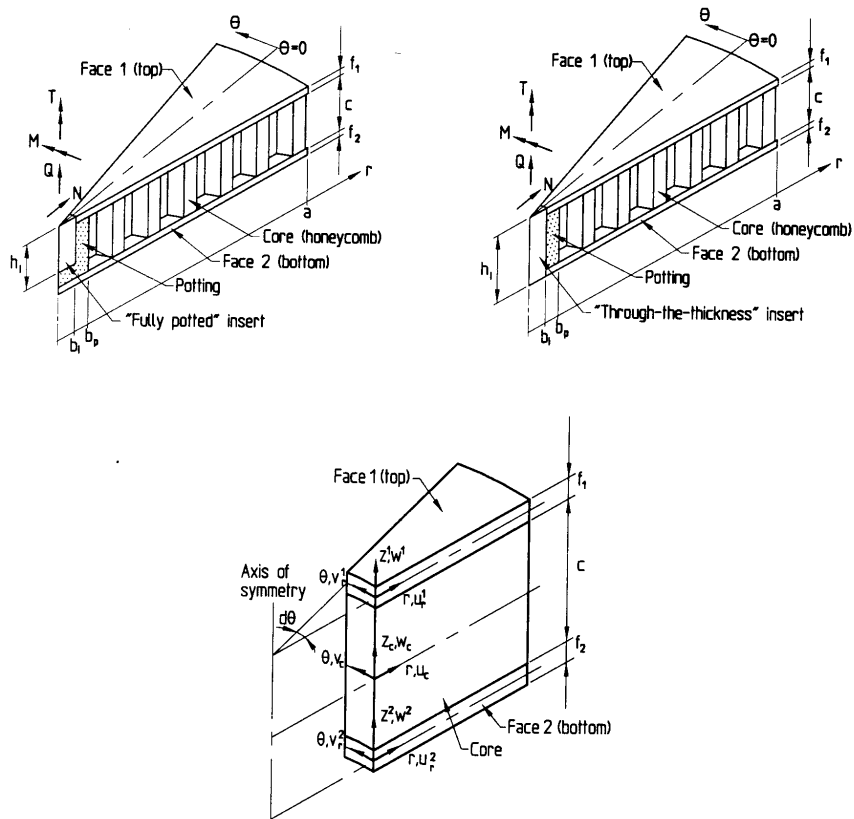


Figure 2: “Cut-outs” of sandwich plates with “fully potted” and “through-the-thickness” inserts subjected to arbitrary loading conditions. Geometrical definition of sandwich plate element in the “high-order” sandwich plate theory.

### References

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