

# Analysis of sandwich wall panels with GFRP skin and polyurethane foam core used for cladding of buildings

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## 1. Introduction

Modern sandwich panels consisting of GFRP skins and polyurethane foam core have an excellent potential to replace conventional precast concrete cladding walls in buildings. This study presents a nonlinear high order strain compatibility analytical model developed to predict the behavior and strength of the sandwich panel under different loading configurations. Classic linear analyses [1, 2] have ignored the localized effects under the applied loads and the core flexibility. To model nonlinear large deflections due to shear deformation, the equivalent single layer approach was used to model the panels, neglecting the geometrical nonlinearities [3]. On the other hand, the variational approach was used to model the panels [4], taking into consideration the effect of core flexibility which affects the sandwich panel overall thickness. The variational approach results in a series of complex nonlinear partial differential equations.

This paper presents a simpler yet rigorous model to predict the flexural response of sandwich panels without internal ribs. It accounts for both material and geometrical nonlinearities. Also deformations due to shear stresses are considered since the sandwich panel core was made from soft polyurethane foam. The Winkler hypothesis for beam on elastic foundation was used to model the top skin behavior under concentrated loads. The strain variation through the panel depth was assumed to vary quadratically. The shear deformations were found to be of a great significance in the determination of load-deflection response of this type of sandwich panels.

## 2. Analytical Model

An incremental approach has been adopted in this model, where the concepts of force equilibrium and strain compatibility are satisfied at each loading step. From best fitted data of coupon tests, the stress-strain curve of the GFRP skins is slightly nonlinear. Also, significant nonlinearities were observed for the polyurethane foam coupons in tension, compression and shear. These material curves were also fitted using mathematical expressions. The numerical procedure was carried out using FORTRAN90 code and incorporated four possible failure criteria: (a) flexural tension or compression failure in skins, (b) flexural

tension or compression failure in the core material, (c) core shear (diagonal tension) failure, and (d) wrinkling failure of compression skin under concentrated loads.

## 3. Illustration of Key Features of the Model

In order to illustrate the significance of the various features incorporated in the model, the load-deflection responses of four uniformly loaded (eight loads) experimental sandwich panels (Fig. 1) were predicted. The predictions are executed for five different cases. In case (1), the model neglects material and geometric nonlinearities as well as the effect of 'beam on elastic foundation' of the loaded skin. In case (2), material nonlinearity is considered for both GFRP and Polyurethane foam in flexural and shear, but geometric nonlinearity, essentially the reduction in thickness due to excessive shear deformations, is neglected. In case (3), both materials and geometric nonlinearities are considered. In case (4), in addition to the previously mentioned features, the effect of core compressibility under the loads is taken into account by applying Winkler principle of beam on elastic foundation. In case (5), all the features are considered, but the failure criteria are also employed.



Figure 1 Experimental setup of uniformly loaded panels

Figure 1 shows the experimental response along with the analytical responses for the five cases, for a panel with soft core (density of  $0.31 \text{ kN/m}^3$ ). Figure 2 shows similar comparisons but with three identical panels with hard core (density of  $0.62 \text{ kN/m}^3$ ). The figures clearly show that ignoring the material and geometric nonlinearities (case (1)) would grossly overestimate the stiffness and will not provide the highly nonlinear behavior near failure. All other cases (2) to (5) had slight differences, except in case (5) the termination point due to failure is established, due to a core shear failure and agrees well with the experiments.

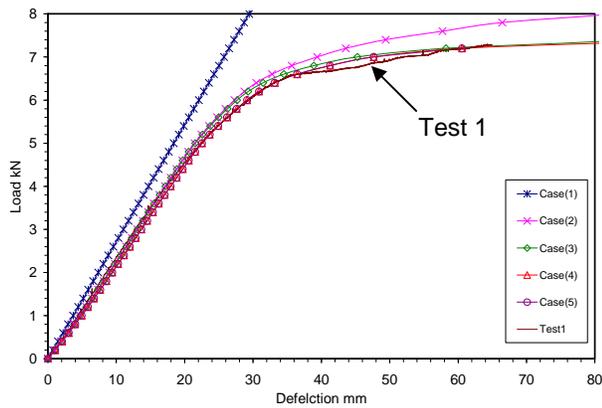


Figure 1 Illustration of significance of various features of the model for soft polyurethane foam core sandwich panels

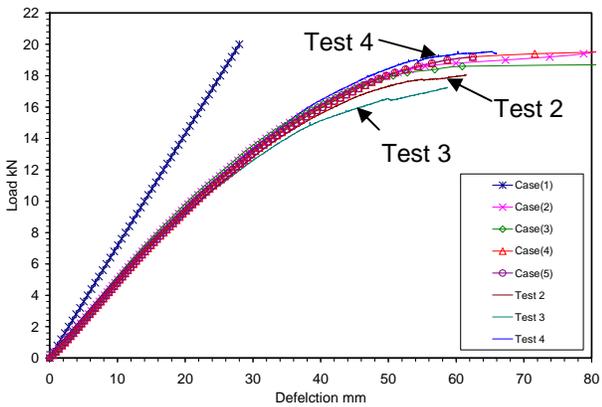


Figure 2 Illustration of significance of various features of the model for hard polyurethane foam core sandwich panels

Figure 3 isolates the contributions of flexure and shear to mid-span deflection of the soft core panel. As a result of the low shear rigidity of the soft polyurethane foam core, the shear deformations and elastic foundation assumption resulted in deflections about three times the flexural deflections (about 75% of the total deflection within the linear part and almost 87% at failure). Figure 4 shows a similar graph but for the hard core panels. It can be seen that using hard polyurethane foam core reduced the effect of shear deformations and in fact delayed that shear deformation up till about 42% of the maximum load of the panel. Also, the deflection due to flexure was almost 33% of the total deflection, which is larger than the 13% in the case of soft core. Figure 5 shows the actual deflected shape of the panels.

#### 4. Conclusion

This study summarized key features of a new analytical model capable of predicting load-deflection responses of sandwich panels with soft or hard cores. It accounts for material and geometric nonlinearities, compressibility under loads and the excessive shear deformations of the core material. The model was successfully validated using experimental results. It was shown that ignoring the material nonlinearity could grossly overestimate the stiffness and underestimate deflections, particularly near ultimate.

Also, it was shown that shear deformation of core material could contribute up to 87% of the mid-span deflection, depending on core density.

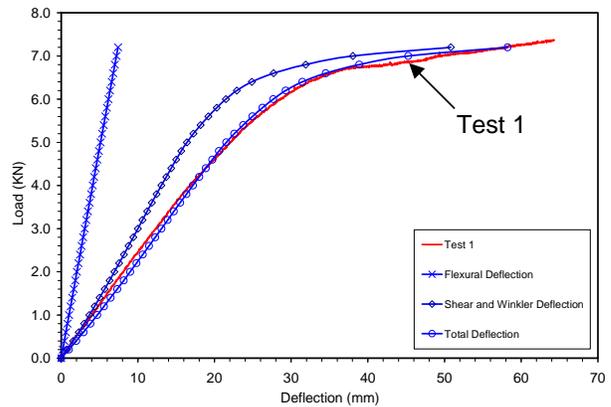


Figure 3 Contribution of shear deformation to mid span deflection in soft polyurethane foam core panels

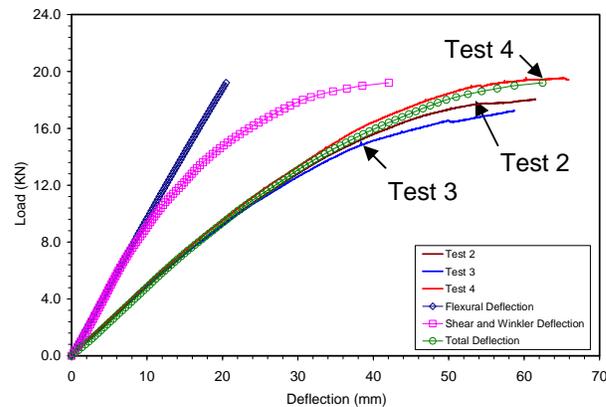


Figure 4 Contribution of shear deformation to mid span deflection in hard polyurethane foam core panels



Figure 5 Deflected shape of sandwich panels

#### References

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