ANYAGVIZSGÁLÓK LAPJA Elektronikus folyóirat
MINŐSÉGBIZTOSÍTÁS * ÁLLAPOTELLENŐRZÉS 2008/1

# Studies on Buckling of Panels with Initial Deformations Made of Composite Materials *

# Kiinduló deformációval készült kompozit panelek kihajlási viselkedésének elemzése

***Ionel Chirica[1], Elena-Felicia Beznea[1], Raluca Chirica,[1]Doina Boazu[1],***
***Alexandru Chirica[1], Carl Christian Berggreen[2]***

*Keywords: Composite panels, Buckling, Postbuckling, FEM method, experimental method*
*Kulcsszavak: Kompozit panelek, kihajlás, kihajolt állapot, FEM módszer, kísérleti módszer*

## Összefoglalás

A hajófedélzetek lemezborításának viselkedése számos tényező függvénye, úgy, mint geometriai méretek, terhelési körülmények, korróziós hatások, kifáradási tényezők által okozott elhasználódások, stb. Jelen dolgozat a síkjában egytengelyű igénybevétellel terhelt, befogott, laminált, négyzet alakú kompozit lemezek viselkedését mutatja be. Az analízis kiterjed a gyártási egyenlőtlenségek hatásaira, bemutatja a peremfeltételek sajátosságait. Az analízis összeveti a számított, és méréssel meghatározott eredményeket a lemezek viselkedésének feltárására.

## Summary

The behaviour of ship deck plating normally depends on a variety of influential factors, namely geometric/material properties, loading characteristics, initial imperfections, boundary conditions and deterioration arising from corrosion and fatigue cracking. The analysis is presented for a uniaxially in-plane loaded, clamped, composite laminated quadratic plate. The imperfection is considered as the initial deformation due to the manufacturing operations: cosine shape in both of the longitudinal and transverse direction. Usually, the initial deformation mode appears in the form such as the fundamental mode of the buckling or vibration. The boundary conditions are considered, as the usual condition of the structural composite ship panels. At the side x=a, the plate is loaded with the uniform pressure. Variation of the maximum transverse displacement regarding the inplane load (displacement controlled after nonlinear buckling analysis) for three cases, obtained so numerically and experimental, are performed.

## Introduction

In the actual shipbuilding industry, the increasing interest in minimum weight designs for ship structures has generated important studies in the analysis of the elastic buckling and post-buckling behavior of structures subjected to in-plane compressive loads. Due to their high strength and stiffness-to-weight ratios, laminated composite materials are increasingly being used in the shipbuilding industry.

The overall failure of a ship hull, considered as a girder, is normally governed by buckling and plastic collapse of the deck, bottom or sometimes the side shell stiffened panels. Therefore, the relatively accurate calculation of buckling and plastic collapse strength of stiffened plating of the deck, bottom and side shells is a basic requirement for the safety assessment of ship structures. In stiffened panels, local buckling and collapse of plating between stiffeners is a primary failure mode, and thus it would also be important to evaluate the buckling and collapse strength interactions of plating between stiffeners under combined loading.

The behavior of ship plating normally depends on a variety of influential factors, namely geometric/material properties, loading characteristics, initial imperfections (i.e., initial deflections and residual stresses), boundary conditions and deterioration existing local damage related manufacture imperfection or fatigue cracks.

For thin homogeneous (metallic) plates, classical plate theory predicts deformations and inplane stresses that are comparable to those of three-dimensional elasticity. In thin plates, transverse stresses are generally small compared to in-plane stresses, and thus, both classical theory and first-order shear deformation theory give satisfactory results. However, since both theories are two-dimensional, they are not accurate enough to predict transverse stresses directly.

---

[*] A 24. Duna-Adria Szimpóziumon elhangzott előadás szerkesztett változata

[1] University Dunarea de Jos of Galati, Romania

[2] Technical University of Denmark, Denmark

Generally, composite$\alpha$ plates support greater compressive load beyond the buckling load. Therefore, buckling and post-buckling behaviors of composite plates are very important factors of structural designs. There are more studies of buckling behavior than those of post-buckling behavior of composite plates. VandenBrink et al. in [1] investigated post-buckling behavior of graphite/epoxy composite plates of [qn–qn]s layup with a hole. Englestad et al. in [2] analyzed post-buckling response and failure of graphite/epoxy panels with and without holes. In this paper, a progressive failure (buckling) analysis was introduced into the nonlinear finite element analysis. Post-buckling behavior and compressive strength of composite plates was studied through analyses.

Parametric studies were performed in order to investigate the effects of initial deformation sizes on buckling load and post-buckling compressive strength.

Buckling and post-buckling analysis are essential to predict the capacity of composite plates carrying considerable additional load before the ultimate load is reached, and manufacturing-induced geometric imperfections often reduce the load-carrying capacity of composite structures. The nature of initial geometric imperfection induced during manufacturing is accounted for in the analysis. The stiffeners presence induces the cosine shape of the initial deformation. Examples of post-buckling analyses of symmetric cross-ply, angle-ply are presented, and the accuracy and performance of the method are examined. The numerical methodology presented can be used as an accurate and efficient tool for post-buckling analysis of imperfect composite plates.

## Numerical and experimental analysis

Numerical and experimental studies were performed on the buckling and post-buckling behavior of the imperfect ship hull plate. In this case, the initial deformation is in the form given by the first buckling modal shape for the same plate but considered as a perfect one.

As it is seen in figure 3, the coordinate system has the origin in the middle of the plate.

Maximum initial deformation magnitude is considered as a rate from the thickness, *t*, that is

$$w_o = \alpha t.$$

In the analysis, for the rate $\alpha$, the following values were chosen: 0.002, 0.32 and 0.96.

The FEM model, composed of shell elements, for geometric representation of a plate sized (axb) 320×320, thickness of 10 mm, having an initial deformation, was made.

**Table 1** Plate lay-up

| Layer type | $\theta$ | t [mm] |
|---|---|---|
| Biaxial | $+45^0$ | 0.195 |
|  | $-45^0$ | 0.195 |
| UD | $4 \times 0^0$ | 2.360 |
| Biaxial | $+45^0$ | 0.195 |
|  | $-45^0$ | 0.195 |
| UD | $6 \times 0^0$ | 3.540 |
| Biaxial | $-45^0$ | 0.195 |
|  | $+45^0$ | 0.195 |
| UD | $4 \times 0^0$ | 2.360 |
| Biaxial | $-45^0$ | 0.195 |
|  | $+45^0$ | 0.195 |

The material used for the plate has the characteristics:

- E-glass/epoxy

$E_1 = 46$ GPa, $E_2 = 13$ GPa, $E_3 = 13$ GPa;

$G_{12} = 5$ GPa, $G_{13} = 5$ GPa, $G_{23} = 4.6$ GPa;

$\mu_{12} = 0.3$, $\mu_{23} = 0.42$, $\mu_{13} = 0.3$;

- UD layers: $t_1 = 0.59$ mm;

- Biaxial layers: $t_2 = 0.39$ mm, modeled as two UD layers having thickness $t_2/2$, at ±45°;

- lay-up is presented in Table 1.

Numerical studies, non-linear analysis (large displacements), were performed with COSMOS/M code. Boundary conditions introduced were as the plate is clamped on the all sides, except *x*-translation on *x*=*a* edge.

For numerical analysis, before to perform the calculus, a study on the optimum mesh and optimum type element was made.

The results are presented in the figures 1 and 2. As it is seen, the variation of the buckling pressure is about a constant, starting from the mesh having 64 elements per plate side.

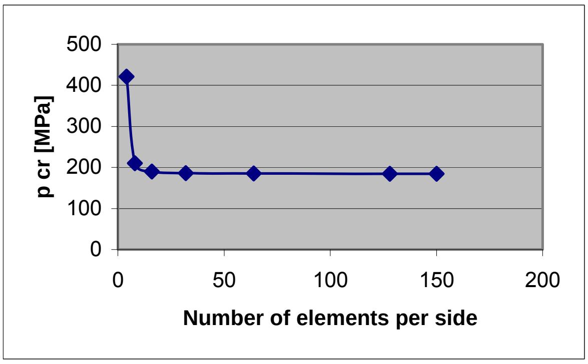

**Fig. 1.** Variation of the buckling pressure function of number of elements
**1. ábra** A kihajlást okozó nyomás változása az elemek számának függvényében

From figure 2 it is seen a good accordance between the shell type elements. So, For FEM analysis, 3-node structural layered shell element (SHELL3L) were used.

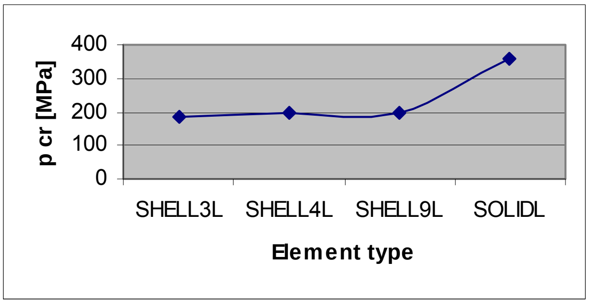

**Fig. 2**. Variation of the buckling pressure function of element type
**2. ábra** A kihajlást okozó nyomás változása az elemek típusának függvényében

For the perfect plate, the critical value, obtained by FEM calculus, is $p_{cr}$=181.66MPa.

Buckling load values obtained, so numerically and experimental, for the three cases of imperfect plates are presented in Table 2.

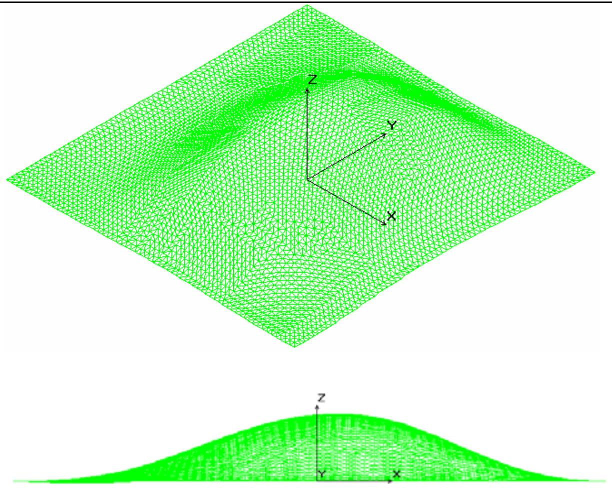

**Fig. 3.** The initial geometry of the plate
**3. ábra** A lemez kiinduló geometriája

In figures 5, 6 and 7, the post-buckling behaviour of the imperfect plate for the three cases are presented. The results obtained after non-linear analysis show that the collapse does not occurs at buckling load value. The vertical dashed line corresponds to the buckling load for the perfect plate (181.66MPa).

As it is seen, the buckling load is increasing with the increasing of the initial deformation.

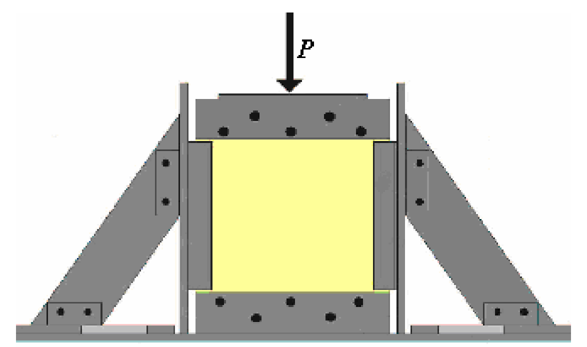

**Fig. 4.** The compression test rig
**4. ábra** nyomóvizsgálati keret

**Table 2** Buckling load

| Case | | Buckling load $p_{cr}$ [MPa] | |
|---|---|---|---|
| Perfect | | analytic | 277.00 |
| | | num. | 181.66 |
| | | exp. | 179.00 |
| Imperfect | Case 1: $w_0$=1.06mm | num. | 183.66 |
| | | exp. | 189.00 |
| | Case 2: $w_0$=3.2 mm | num. | 201.99 |
| | | exp. | 199.00 |
| | Case 3: $w_0$=9.6 mm | num. | 285.22 |
| | | exp. | 295.00 |

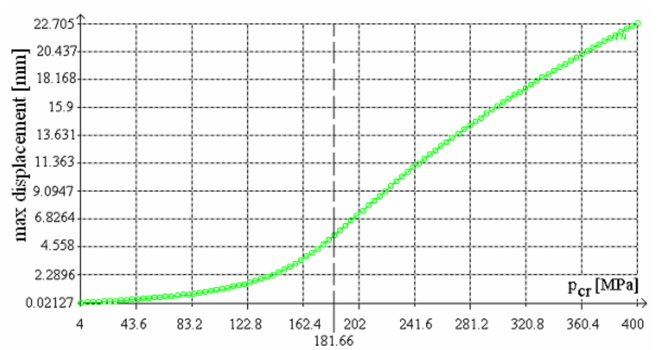

**Fig. 5**. Case 1: Displacement controlled nonlinear buckling analysis
**5. ábra** 1. eset: Elmozdulás vezérelt nem lineáris kihajlási analízis

## Conclusions

Based on the numerical and experimental results, there can be derived out the following conclusions of this study:

Values of the buckling load, $p_{cr}$, are increasing with the increasing of the initial deformation. That is, the stiffness of the plate is increasing with the increasing of the initial deformation.

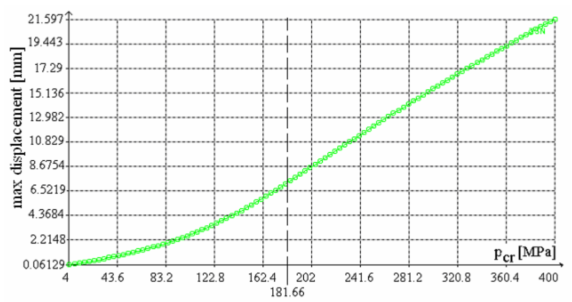

**Fig. 6.** Case 2: Displacement controlled nonlinear buckling analysis

**6. ábra** 2. eset: Elmozdulás vezérelt nem lineáris kihajlási analízis

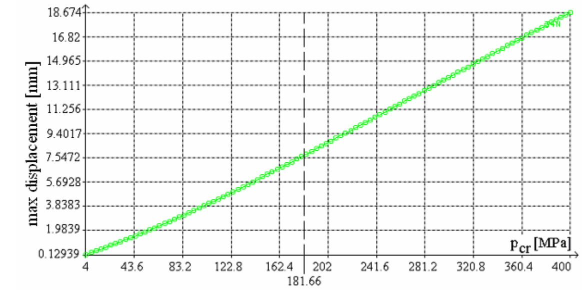

**Fig. 7.** Case 3: Displacement controlled nonlinear buckling analysis

**7. ábra** 3. eset: Elmozdulás vezérelt nem lineáris kihajlási analízis

Studies made for the nonlinear buckling analysis show that the collapse does not occurs at buckling load value, and are in accordance with the experiments.

The displacement controlled nonlinear buckling analysis shows that, at the same post-buckling load, the maximum displacement are decreasing with the increasing of the initial maximum displacement.

The FEM models can deliver the whole range of the eigen modal buckling for the panel structure.

## Acknowledgements

The work has been performed in the scope of the project MARSTRUCT, Network of Excellence on Marine Structures, which has been financed by the EU through the GROWTH Programme under contract TNE3 – CT – 2003 - 506141 (Task 4.3), (www.mar.ist.utl.pt/marstruct/).

## References

[1] VandenBrink, D. J. and Kamat, M. P.: Post-Buckling Response of Isotropic and Laminated Composite Square Plates with Circular Holes, Finite Elem. Anal.&Design, 3:165–174,1987.

[2] Engelstad, S. P. and Reddy, J. N.: Post-buckling Response and Failure Prediction of Graphite-Epoxy Plates Loaded in Compression, AIAA J., 30:2106–2113, 1992

[3] Chirica, I., Beznea, E.F., Chirica, R.: Orthotropic Plates, The University Dunarea de Jos Publishing House, Galati, 2006