Aeronautics and Astronautics - AIDAA XXVII International Congress Materials Research Forum LLC
Materials Research Proceedings 37 (2023) 404-408 https://doi.org/10.21741/9781644902813-89

Dynamic buckling structural test of a CFRP passenger floor stanchion

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Keywords: Composite Material, Transient Analysis, Test Validation, Dynamic Buckling

Abstract. The work focuses on the study of the structural behavior of a composite floor beam in the cargo area of a commercial aircraft subjected to static and dynamic loads. Experimental tests have been performed in the laboratories of the Dept. of Industrial Engineering (UniNa) jointly with the development of numerical models suitable to correctly simulate the phenomenon through the LS-DYNA software. The definition of a robust numerical model allowed to evaluate the possibility of buckling triggering. The test article was equipped with potting supports on both ends of the tested beam, filling the pots with epoxy resin toughened with glass fiber nanoparticles. This allowed to uniformly load the beam ends in compression and to carry out the tests loading the specimen statically and dynamically, to observe the differences in the behavior of the beam in correspondence with the two different types of applied load. The result obtained through the comparison between the numerical model and the experimental test is that the dynamic buckling is triggered by a quantitatively smaller load than in the static case. Furthermore, it has been observed that the experimental compressive displacement to trigger the dynamic buckling instability is greater than the displacement observed in the static case.

Introduction

Buckling is an instability phenomenon that is common in "thin" structures. Buckling was formerly thought to be a totally static occurrence. The classic example is the Euler column buckling, in which a beam properly restrained and statically loaded in compression at the ends experiences the equilibrium instability usually in the linear elastic material behavior range.

Depending on the applied load, the beam can return to the initial equilibrium configuration (stable equilibrium), move to a new equilibrium condition different from the initial one (indifferent equilibrium), or move away from the initial equilibrium configuration indefinitely (unstable equilibrium). The buckling load is the smallest load for which equilibrium is indifferent.

Buckling can, however, be produced by varying loads over time. Many writers [1-3] have explored the application of a time-dependent axial stress to a beam, which causes lateral vibrations and can eventually lead to instability.

Dynamic buckling is a relatively new phenomenon. One of the first researchers to investigate dynamic buckling was [4], who proposed a theoretical solution for the situation of a simply supported rectangular plate exposed to variable floor loads over time. A criterion that connected dynamic buckling to load duration was developed in [5] and [6] where it was investigated the effects of a high intensity, short duration load. According to the findings, long-term critical dynamic buckling stresses may be less intense than matching static buckling loads.

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In this study, the structural behaviour of a composite floor beam subjected to low-frequency cyclic load conditions has been explored. Three distinct loads—below, near to, and over the static critical buckling load—have been taken into account to determine the structural response.

The aim is to conduct an experimental numerical investigation of the dynamic buckling phenomenology on a composite material beam. It was important to modify the test object to make sure the experimental test was carried out correctly. In specifically, two pottings were attached to the ends of the bar using epoxy resin castings toughened with glass fibre nanoparticles to guarantee that the compressive force was applied symmetrically.

The department laboratory's test equipment was used to conduct the experimental experiments. LS-DYNA software was used to mathematically recreate the treated phenomena. The Matlab working environment was used to process the results.

Case study description

The geometrical model and the numerical model, discretized in the Finite Element (FE) environment, are reported in Figure 1, while the mechanical properties of the composite lamina are reported in Table 1. The stacking sequence of the beam is [-45; 45; 90; 45; -45; 0; 0; 0; 0; 0; -45; 45; 90; 45; -45].

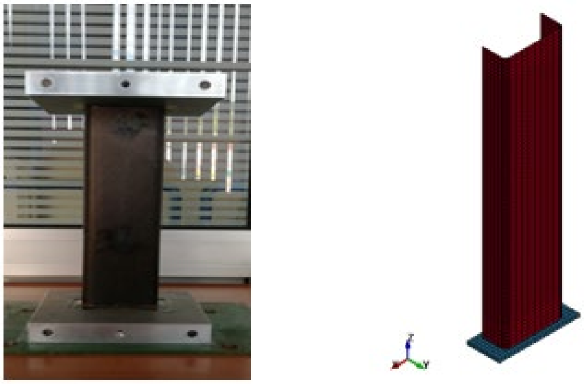

Figure 1. Left: geometrical model; right: numerical model.

Table 1. Mechanical properties of the lamina.

ρ [g/cm^3]	th [mm]	E_{11} [MPa]	E_{22} [MPa]	G_{12} [MPa]	G_{13} [MPa]	G_{23} [MPa]	ν_{12}	Xt [MPa]	Xc [MPa]	Yt [MPa]	Yc [MPa]	Sc [MPa]
1.6	0.186	135000	8430	4160	4160	3328	0.26	2257	800	75	171	85

To find the optimal balance between computational costs and the correctness of the findings in terms of expected stiffness, a preliminary mesh convergence study has been performed. As a result, several static linear studies with varied in-plane and through-the-thickness element sizes have been carried out. Particularly, three distinct mesh element sizes—coarser (8 mm), moderate (4 mm), and finer (2 mm) were taken into consideration. Nine mesh configurations have been examined, and analyzed, three through-the-thickness mesh configurations having been researched for each in-plane element size.

Results

The numerical model has been verified by comparison with the stiffness and failure findings of an experimental test programme, the compressive experimental test up to ultimate failure and reported in the last work [8] underlined the results:

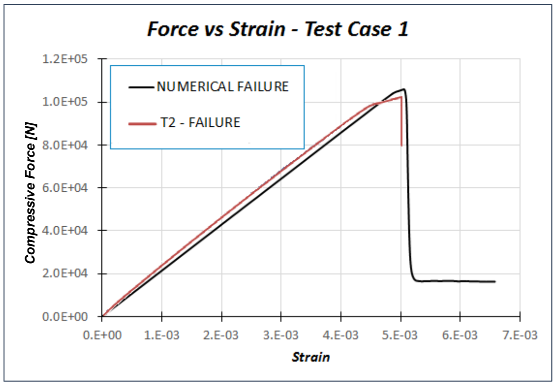

Figure 2. Numerical-experimental comparisons: Load vs. strain.

According to these experimental testing, the breaking load was 103KN, and up to the failure load, there are no buckling events, both experimentally.

The table 2 reports the failure displacements and loads, there is good agreement between the solutions of both formulations.

Table 2. Numerical-experimental comparisons: Failure displacement and failure load.

	Failure Displacement	Failure Load
Numerical	1.59 mm	107.3 kN
Experimental	1.60 mm	104.0 kN
Error	0.06%	3.1%

Then, a compressive experimental test designed to measure the structure's stiffness was repeated without taking the failure into account to confirm the linear deformation on the 315mm-long stanchion made of a composite material that combines carbon fibres with a highly toughened epoxy matrix and a 15-ply lamination sequence.

Figure 3 shows the good agreement in stiffness and failure load between the numerically predicted solutions and the outcomes of the experimental campaign testing. Additionally, the Hashin's failure criteria were used to compute the test article's failure mode, which was then predicted with a high degree of accuracy.

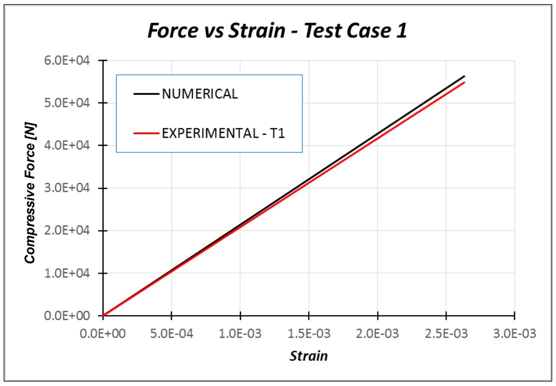

Figure 3. Numerical-experimental comparisons: Load vs. strain.

Once the numerical model is validated by static test, the dynamic experimental test is executed applying a load increase and constant speed of 100 mm/s. The explicit numerical investigations have been carried out to investigate how the dynamic buckling phenomena came to be. Every explicit analysis has been run with a structural dampening of 2%.

In figure 4 is plotted he F(t), from the analysis of the following graphs, the phenomenon of dynamic buckling instability can be observed, which occurs after 0.18 ms. Close to this time value, a buckling load equal to 89 kN and a displacement value equal to 0.063 mm are noted.

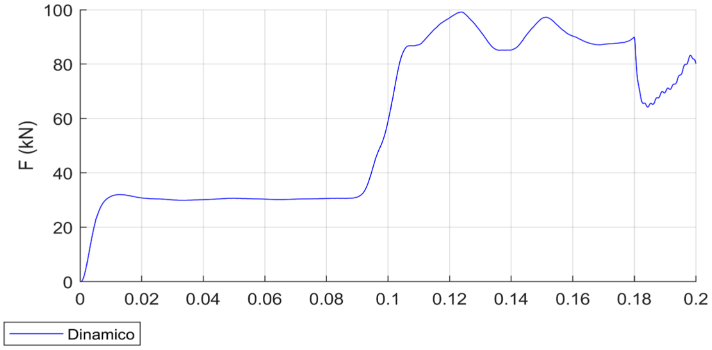

Figure 4. Time history of the force in the dynamic experimental test.

Conclusions

It is clear from an examination of the findings that: for composite materials, the buckling load in a dynamic compression test assumes a lower value than the buckling load in a quasi-static compression test. Additionally, in a dynamic compression test, a larger displacement than that required to cause buckling in a quasi-static compression test is required to cause the buckling phenomena. Finally, it can be shown that during the dynamic compression test, after buckling is attained, the structure does not collapse, but rather the bar tack may continue to operate in post buckling.

The figure 5 reports the differences between the numerical simulation about the post buckling static and dynamic, when the dynamic buckling value is exceeded in the left case, the post-buckling displacements are transmitted by the lower plate throughout the beam, whereas in the quasi-static compression test, the structure collapses and the displacements are not as effectively transmitted.
In the case of the dynamic compression test, it is observed that the curve F(t) exhibits a plateau close to the buckling load. This is because some of the mechanical energy resulting from the application of the load is lost due to the deformation that took place after the beam protruded from its axis.

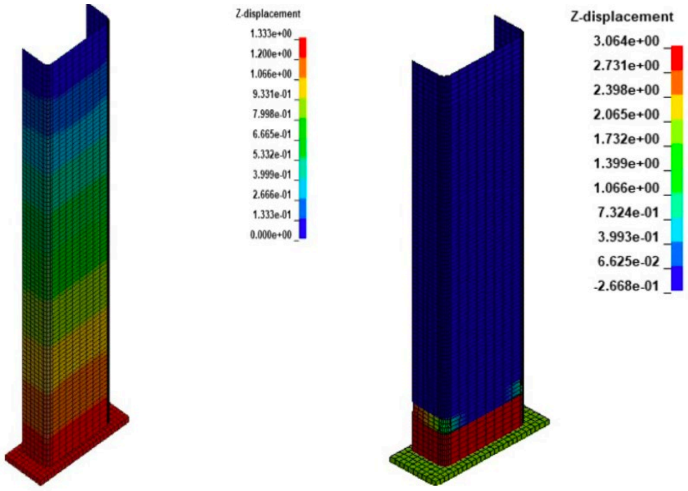

Figure 5. Post buckling in static and dynamic simulations.

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