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Original
High-Fidelity modeling and dynamic analysis of damaged tapered composite structures / Carrera, E.; Viglietti, A.; Zappino, E.. - (2017). (Intervento presentato al convegno ICCM 21 - 21st International Conference on Composite Materials tenutosi a Xi'an, China nel 20-25 August,2017).

Availability:
This version is available at: 11583/2704010 since: 2018-03-22T10:29:24Z

Publisher:
ICCM

Published
DOI:

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04 March 2024

High-fidelity modelling and dynamic analysis of damaged tapered composite structures

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The aerospace structures are caracterized by a complex frame composed by several components such as thin skins and reinforcements on the traversal and longitudinal direction. To offer determined aerodynamic performances, these structures are characterized by particular shapes. The classical one is the tapered shape of the wing and the plane tail. Moreover, since their development, the composite materials have been widely used in the aerospace field to increase the weight saving. These features lead to a higher complexity of the structural problems, which are usually solved by the Finite Element Method. The use of three-dimensional models, despite accurate results are obtained, requires an huge computational cost. 1-D FE models based on the Carrera Unified Formulation (CUF) are able to provide accurate results for static and free vibration analyses of reinforced thin-walled structures, reducing this cost. This model uses the Lagrange expansion to describe the cross-section displacements field of the beam[1][2]. The use of LE expansions allows us to describe the cross-section with high-order elements where each node has only translational displacements. In this way, the following advantages can be obtained:

- the present model permits to describe the structure geometry without introducing approximations (High-Fidelity Model);
- the present model introduces a deformable cross-section;
- considering that the problem unknowns are only translational displacements, the orientation and the connection of several beam structures can be done very easily;
- the present model is able to describe multi-component structures where each component can be described with an independent beam description (Component-wise approach).

For example, in Table 1 the frequencies of a tapered box with the two extremities clamped are showed. Figure 1 shows the considered case. The structure is made of CFRP: Carbon Fiber Reinforced Polymer. The geometry dimensions are: $L = r_1 = 0.5\ m$, $l_1 = 0.25\ m$, $h_1 = 0.2\ m$, $h_2 = 0.1\ m$ and $r_2 = 0.2\ m$. The thickness of the panels are $t = 0.01\ m$. The lamination of each panel is reported in the Figure 1. Using (x_G, y_G, z_G) is identified the global reference system and y identifies the axis of the beam description. The results are compared with those obtained from a Nastran Shell Model. The present model, using a lower number of degree of freedom, provides errors about few percentage points.

Modes		1	2	3	4	5	6	7	8	9	10
Present Model	16434 DOF	296.8	323.73	471.49	530.23	583.44	670.5	730.1	819.69	839.54	960.46
Nastran Shell	94545 DOF	291.38	317367	444.46	521.67	551.71	648.47	694.53	801.37	829.64	936.7
Err%		1.86 %	1.91 %	6.08 %	1.64 %	5.02 %	3.4 %	5.12 %	2.29 %	1.19 %	2.54%

Table 1: Frequencies of Tapered Box.

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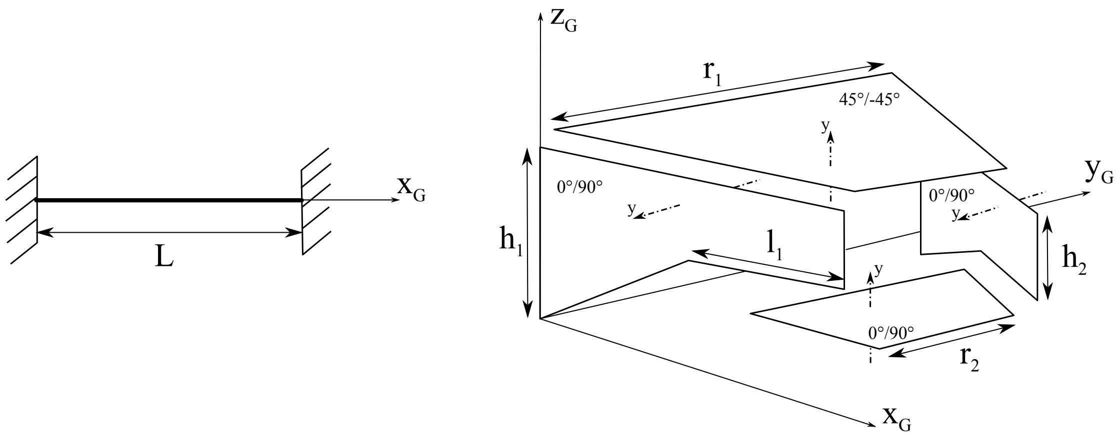

Figure 1: Tapered Case.

The analysis of the effects of the failure of a srtuctural component is of prymary interest in the design of complex structures. The damages in a structure affect the displacement and stress fields, and also the dynamci resposne can be strongly afflicted. The classical theories are not suitable for the damage detection. The used techniques for these tasks are based on the 3-D solid elements in order to provide accurate displacement and stress fields. The 1-D CUF models are able to describe the modal behavior of a metallic structure with the presence of one or more damaged components [3]. This appraoch can be extended easily to a structure made of a composite material characterized by tapered shapes. The present work present the dynamic analysis of complex tapered composite structures including the effects of the total or partial failure of a structural components. The high fidelity in the model representation allows the failure of single layer as well as the failure of whole structural component to be considered.

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