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IDENTIFICATION OF A FINITE ELEMENT CONNECTOR FOR THE SIMULATION OF BOLTED JOINTS

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Bolted joints are widely encountered in mechanical engineering especially in aeronautics structures (e.g. 3,000,000 joints on a A380, 50,000 on a Rafale). In spite of well-established design rules and assembly procedures, important sources of uncertainty remain due to a high sensitivity of the joint mechanical behavior to dispersions (tightening procedure, frictional effects, geometrical tolerances...). Mass and cost optimizations of bolted assemblies for complex loadings and new materials such as composites, requires more elaborated design strategies that more finely account for phenomena occurring in joints (contact, frictional effects, clearances...). For instance, a 20 grammes mass saving on each bolted joint of a CFM56 aircraft engine (3,000 joints) would result in a 70 kg mass saving and a reduction of 95,000 liters of kerosene and 244 tonnes of CO2 emissions for an annual operating Paris-Toulouse flight (20 round-trip a day) [1].

In this work a two-scale modeling strategy is proposed. The first scale called macroscopic scale, is associated with a characteristic length of the entire assembly. At this level, the components of the assembly are considered as shell structures that remain in their elastic domain. Joints are simply seen as interface elements or connectors between shells, the nonlinear behavior of which being identified thanks to a finer scale study. Generally, such connectors can be easily integrated in FE commercial codes thanks to user-element subroutines.

At the second scale, called mesoscopic scale, only the joint is considered. All the geometrical details (bolt, plates, clearances) and physical phenomena (frictional contact) are described at a level that is too fine for a large scale computation on the entire assembly. Scale coupling is done through the identification procedure of the connector macromodel either from mesoscale simulations on the joint or from joint data tests [2, 3].

The scientific challenge of the approach lies in the proposal of a joint macromodel in quasistatic state that is simple enough for a use at the assembly scale but also robust, considering the nonlinear aspect of the involved phenomena, especially contact and friction which play an important role in the transmission of the forces between the parts of the assembly. Robustness will be achieved by giving a strong mechanical sense to the model parameters [4]. In this work, a rheological model involving design parameters – i.e. friction coefficient, gap between screw and hole, as well as bolt prestress – is proposed and developed into an ABAQUS fortran user-element subroutine. The behavior integration of the contact friction macromodel is obtained by using a separation of the displacement in a sliding part and its complementary part. Using such a separation allows to draw an analogy with plasticity (separation of the strain in elastic and plastic parts) and thus a classical radial return algorithm is used for the behavior integration.

Moreover, a suitable computational strategy is required for the identification process that involves costly 3D mesoscale computations with nonlinear frictional contact conditions. Here, a mixed domain decomposition method which shares similar features with augmented lagrangian method and Uzawa-like solvers is used to efficiently account for frictional contact conditions [5, 6]. Connector model identification is performed on an elementary single bolt jonction. In particular, the dissipated energies obtained with connector and 3D computations will be compared. Sensitivity to the radius of the fasteners that kinematically link the connector with the assembled plates and the element size in the vicinity of the bolted jonction will be also investigated. Finally, the whole strategy will be validated on more complex bolted assemblies.

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