Reduction Methods for Real-time Simulations in Hybrid Testing - DTU Orbit (07/01/2019)

Reduction Methods for Real-time Simulations in Hybrid Testing

Hybrid testing constitutes a cost-effective experimental full scale testing method. The method was introduced in the 1960’s by Japanese researchers, as an alternative to conventional full scale testing and small scale material testing, such as shake table tests. The principle of the method is to divide a structure into a physical substructure and a numerical substructure, and couple these in a test. If the test is conducted in real-time it is referred to as real time hybrid testing. The hybrid testing concept has developed significantly since its introduction in the 1960’, both with respect to the size and the complexity of the physical and numerical substructures. However, due to a rapid increase in the computational time, a further increase in the size and complexity of the numerical substructures is challenged. In this thesis a number of elements that can help to improve the size and complexity of kinematic nonlinear numerical substructures are presented, with special emphasis on the use of basis reduction methods. Three elements that can help to improve the accuracy are presented and illustrated.

In kinematic nonlinear systems, various deformation modes are coupled through a nonlinear strain measure. If these coupling-activated modes are not represented in the basis reduction, a significant increase in the structural stiffness can appear, which can ruin the numerical accuracy. One way to represent the coupling-activated modes is by use of so-called modal derivatives. Equations to evaluate these exist. However, due to singularities these can only by solved approximately. A modified and a novel set of system of equations of motion governing the modal derivatives are, therefore, derived. From these a set of improved modal derivatives are found. By use of an example it is, furthermore, illustrated that the modal derivatives determined from the novel system represent the exact modal derivatives.

One of the most time consuming tasks in the numerical time integration is the evaluation of the internal restoring forces. Due to its nonlinear format, a time consuming element-by-element assembling is used. It is shown, that by adopting an existing mathematical reformulation technique, the costly element-by-element assembling is replaced by a significantly more efficient global assembling in a reduced co-ordinate system.

By use of the novel modal derivatives an efficient basis formulation is arranged, combining linear modes with modal derivatives. The basis is based on a Taylor series, and is, therefore, referred to as a Taylor basis. The basis predicts a relation between the linear normal modes and the modal derivatives. Utilizing this basis formulation, the modal derivatives are included without introducing further unknowns into the system. The basis formulation is shown to exhibit high precision and to reduce the computational cost significantly. Furthermore, the basis formulation exhibits a significant higher stability, than standard nonlinear algorithms.

A real-time hybrid test is performed on a glass fibre reinforced polymer composite box girder. The test serves as a pilot test for prospective real-time tests on a wind turbine blade. The Taylor basis is implemented in the test, used to perform the numerical simulations. Despite of a number of introduced errors in the real-time hybrid testing loop, the test confirms the high stability and efficiency of the Taylor basis.

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