Online Resource 1: Calculation Process

For the pseudodynamic hybrid simulation, in the hybrid simulation algorithm performance evaluation platform, OpenSees is used to simulate the experimental substructure and the numerical substructure respectively. The calculation process of the pseudodynamic hybrid simulation is shown in Process 1.

Process 1 Calculation process of pseudodynamic hybrid simulation in HSAEP

1) Initial setting.
   1.1) Define the relevant parameters of the numerical model.
   1.2) Define the relevant parameters of the physical model.
   1.3) Define virtual actuators.
   1.4) Define the hybrid simulation algorithm used.
2) Start the OpenSees server running the numerical model.
3) Start the OpenSees server running the physical model.
4) Perform an iterative calculation in the i-th time step until the error requirement is met.
   4.1) In the first iteration, save the current state as the initial state at the beginning of the i-th time step. In other iteration, the current state is restored to the initial state at the beginning of the i-th time step.
   4.2) Based on the historical data, a force vector $F_{predicted}$ or a displacement vector $d_{predicted}$ at the structural interface node at the beginning of the current iteration of the prediction is generated. There are different prediction methods here.
   4.3) This is divided into two cases: predicting force and predicting displacement.
      4.3.1) If predicting displacement vector $d_{predicted}$ at the predicted interface node, perform this step.
         4.3.1.1) $d_{predicted}$ is applied as an external load to the numerical substructure, and then the numerical substructure calculates a time step independently, and the reaction vector $F^N_{predicted}$ at the interface node is obtained.
         4.3.1.2) Apply $d_{predicted}$ as an external load to the experimental substructure, and then calculate a time step independently of the experimental substructure to obtain the reaction vector $F^P_{predicted}$ at the interface node.
         4.3.1.3) Calculate error, $error = f(F^N_{interface}, F^P_{interface})$
      4.3.2) If predicting force vector $F_{predicted}$ at the predicted interface node, perform this step.
         4.3.2.1) Apply $F_{predicted}$ as an external load to the numerical substructure, and then the numerical substructure independently calculates a time step to obtain the displacement vector $d^N_{interface}$ at the interface node.
         4.3.2.2) $d^N_{interface}$ is applied as an external load to the numerical substructure, and then the numerical substructure independently calculates a time step to obtain the force vector $F^P_{interface}$ at the interface node.
         4.3.2.3) Calculate error, $error = f(F_{interface}, F^P_{interface})$
   4.4) When the error satisfies the limit value, the iteration of the i-th step is ended, and the result of the i-th step is output, and the calculation of the next time step is performed.
5) When all time steps have been calculated, the calculation ends.
   5.1) Output calculation results.

5.2) Close the OpenSees server running the numerical model.

5.3) Close the OpenSees server running the physical model.

5.4) Return.

For the real-time hybrid simulation, in the hybrid simulation algorithm performance evaluation platform, EasyFEA is used to simulate the numerical substructure and the experimental substructure respectively. Because there is no iterative process, the calculation process of the real-time hybrid simulation is more than the pseudodynamic hybrid simulation. The calculation process of the real-time hybrid simulation is shown in Process 2.

Process 2 Calculation process of real-time hybrid simulation in HSAEP

1) Initial setting.
   1.1) Define the relevant parameters of the numerical model.
   1.2) Define the relevant parameters of the physical model.
   1.3) Define virtual actuators.
   1.4) Define the hybrid simulation algorithm used.
2) Define the numerical model in EasyFEA.
3) Define the physical model in EasyFEA.
4) Calculate in the i-th time step.
   4.1) The force vector measured at the interface node of the experimental substructure is F_{fb}. If it is the initial time step, it is assumed that the force vector measured at the interface node of the experimental substructure is $F_{fb} = 0$.
   4.2) The external force F_N of the numerical substructure and the force vector measured at the interface node of the experimental substructure are applied to the numerical substructure F_{fb}, and a time step is calculated for the numerical substructure.
   4.3) The displacement d, the velocity v, and the acceleration a at the interface node of the numerical substructure are transferred to the interface node of the experimental substructure through the control system and the actuator, and a time step is calculated for the experimental substructure.
   4.4) Perform the next calculation.
5) When all time steps have been calculated, the calculation ends.
   5.1) Output calculation results.
   5.2) Return.