Cascade Control for Hybrid Simulation

Shawn You, X. Shawn Gao, Brad Thoen - MTS Systems Corporation

Catherine French, Evan Cosgriff, Paul Bergson - University of Minnesota

Content

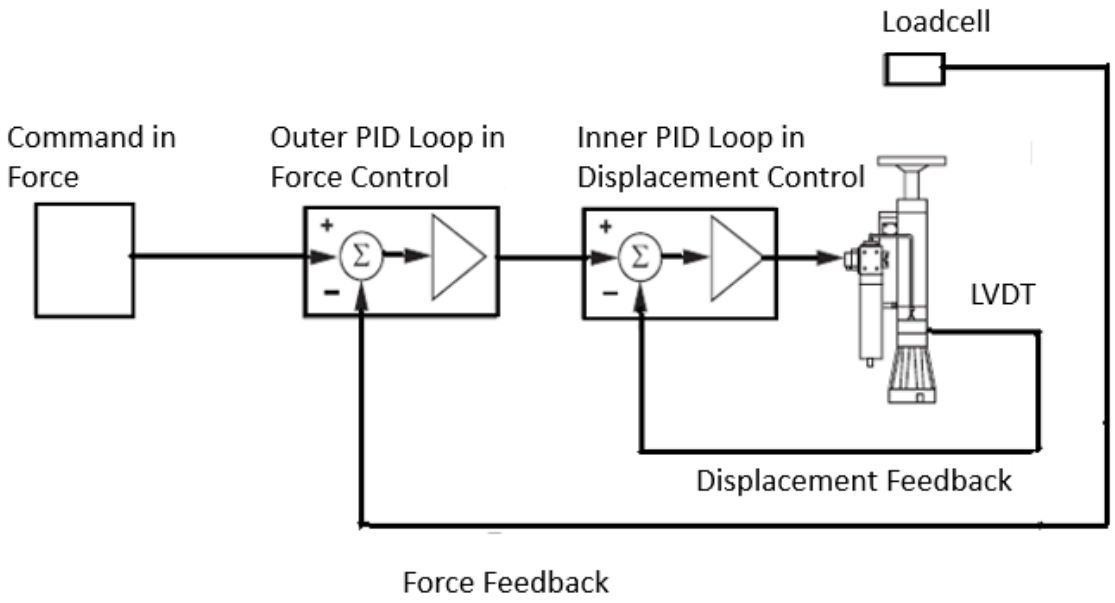
- What is cascade control?
- Why use cascade control in hybrid simulation?
- Three test cases to compare hybrid simulation with cascade control and displacement control
- Conclusion

What Is Cascade Control?

- Cascade control is a control method that has two layers of PID control that have different control modes.
- Both inner and outer control loops have their own tuning parameters that can be adjusted to achieve optimum control effect.

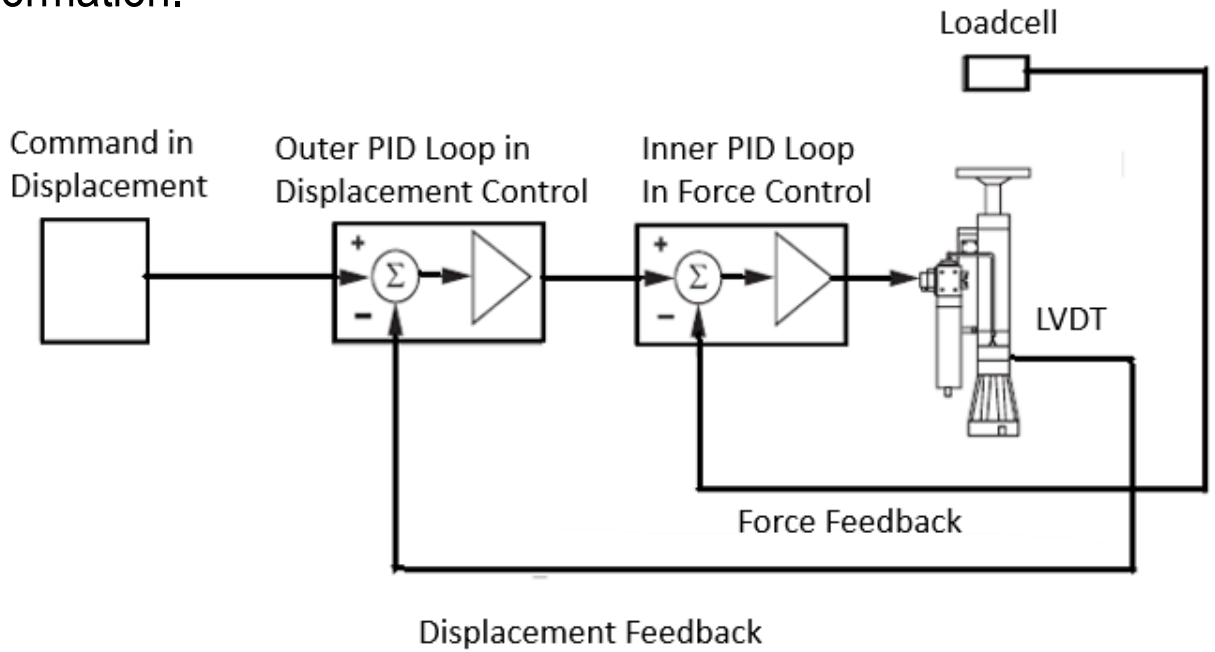
Cascade Control Type 1

- Inner loop displacement control and outer loop force control.
- Widely used in testing components that have hard-to-control resonance in the control band.
  - Outer loop accepts force command
  - Inner loop provides displacement control, which is more stable.



Cascade Control Type 2

- Inner loop force control and outer loop displacement control.
- This type of cascade control is for hybrid simulation with a stiff specimen.
  - Outer loop accepts displacement command from displacement-based FEA models.
  - Inner loop force control, which is more sensitive than displacement control with a tiny amount of deformation.



Previous Force Control Method

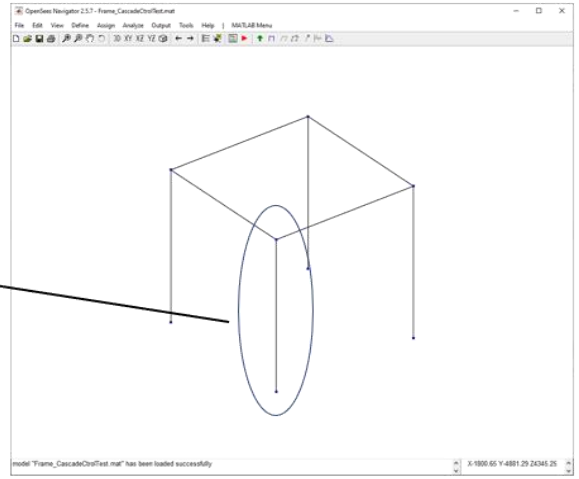
- Convert displacement command to force command first, then send the force command to the test controller that has force control mode.
  - Tangent stiffness matrix method
  - Krylov subspaces method
- Create force formulated FEA software
  - A lot of work!

Advantage of Cascade Control Method

- Fundamentally, it is a force control.
- Convert displacement command to force command through an automatic iteration with system close loop rate. There is no need for an extra step to convert displacement command to force command
- Standard option in 793 software.

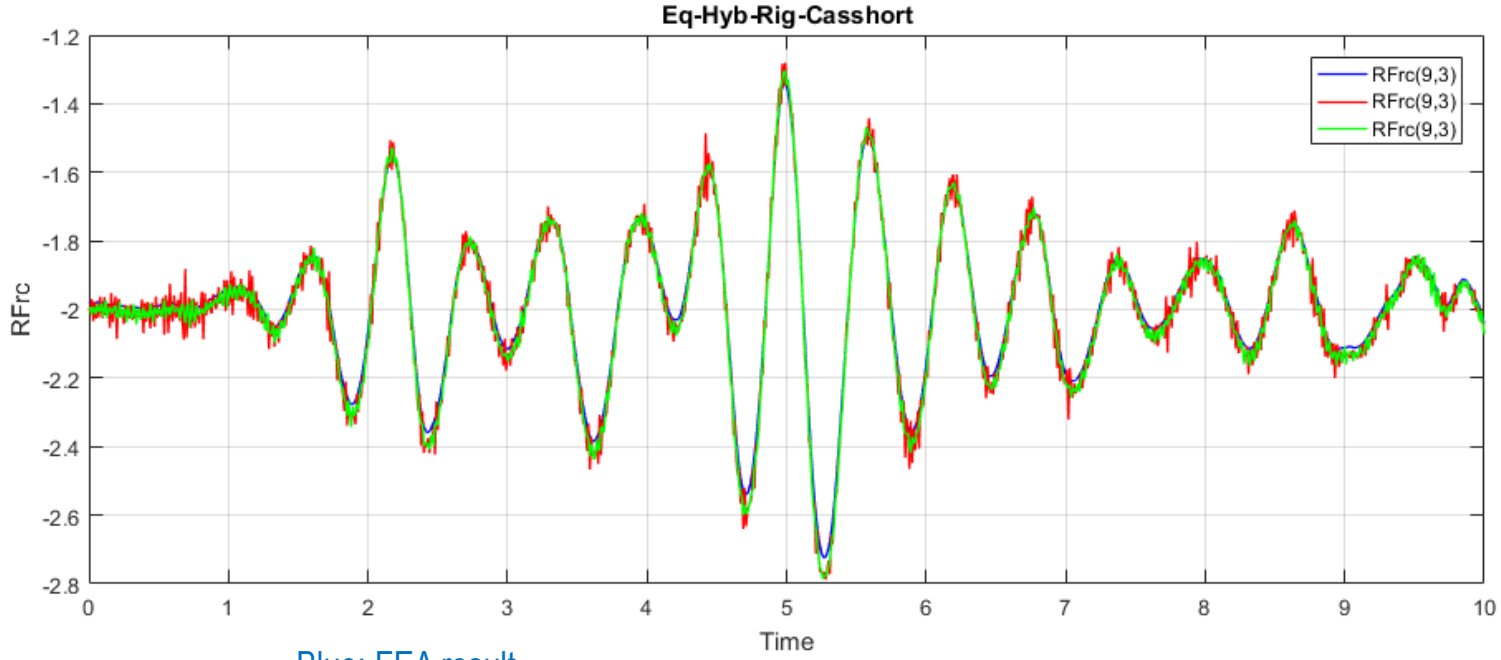
Test Case 1 Setup

- A 3-D frame structure with one column represented by a test specimen.
- 50% of the El Centro earthquake to keep the specimen in elastic range.
- Displacement system noise level: 0.003 mm. Force system noise level: 0.05 kN.
- Specimen vertical stiffness of 110 kN/mm.



Test Case 1 Result

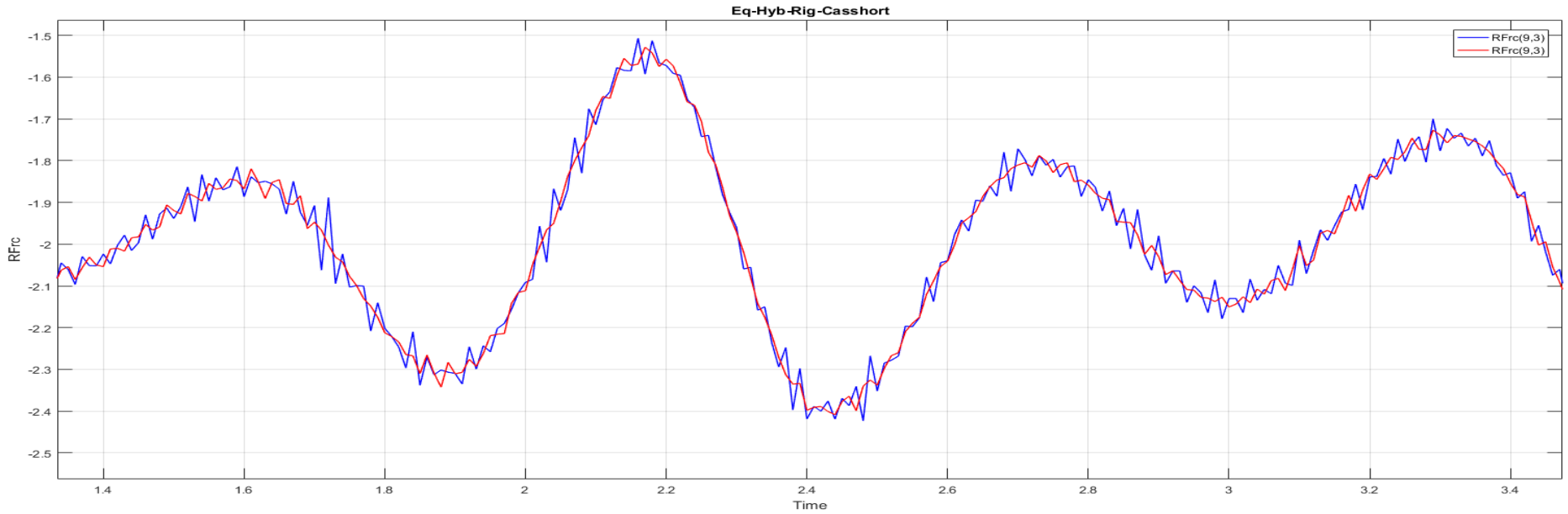
- Vertical forces in the experimental element is compared.
- Both hybrid simulation with cascade control and displacement control matched well with the FEA result.



Blue: FEA result
Red: Hybrid simulation with displacement control result
Green: Hybrid simulation with cascade control result

Test Case 1 Result

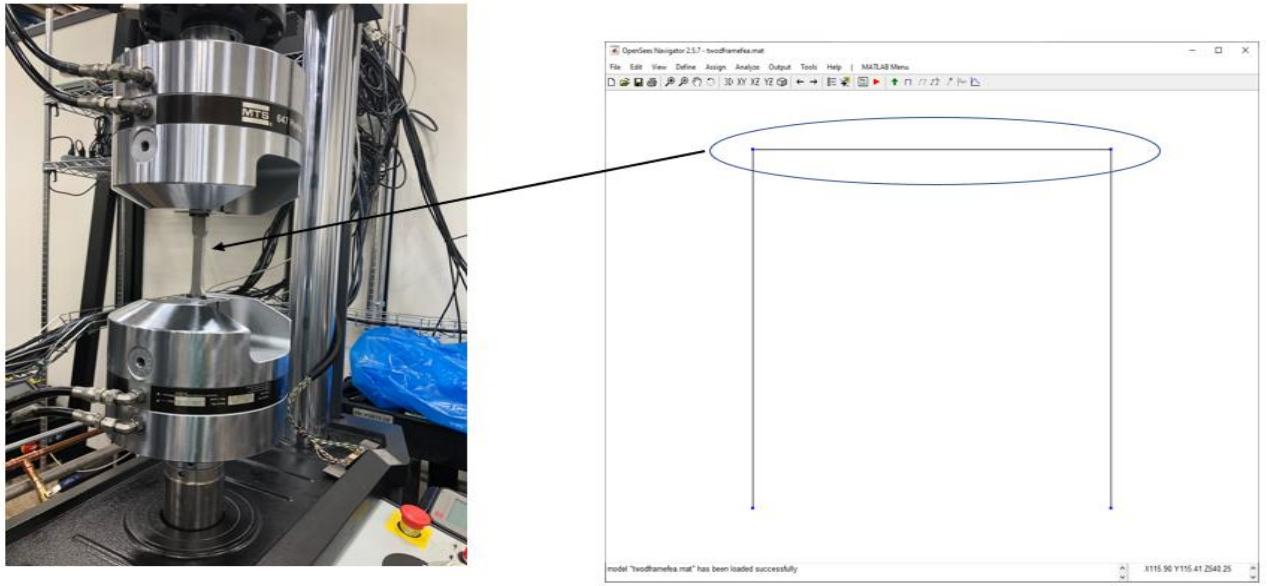
- Vertical force in the experimental element obtained by cascade control hybrid simulation is much smoother than the same signal by the hybrid simulation with displacement control.
- Cascade control is a better control method for conducting hybrid simulation in this case.



Blue: Hybrid simulation with displacement control result
Red: Hybrid simulation with cascade control result

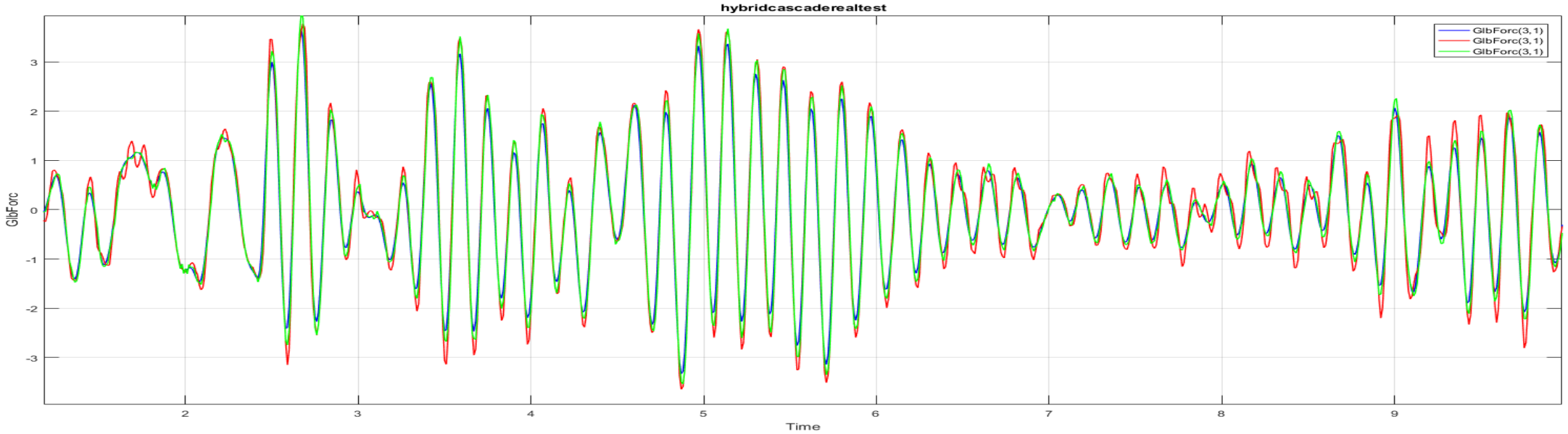
Test Case 2 Setup

- A 2-D frame structure with one beam represented by a test specimen.
- 50% of the El Centro earthquake to keep the specimen in elastic range.
- Displacement system noise levels: 0.002 mm. Force system noise level: 0.03 kN
- Specimen vertical stiffness of 120 kN/mm.



Test Case 2 Result

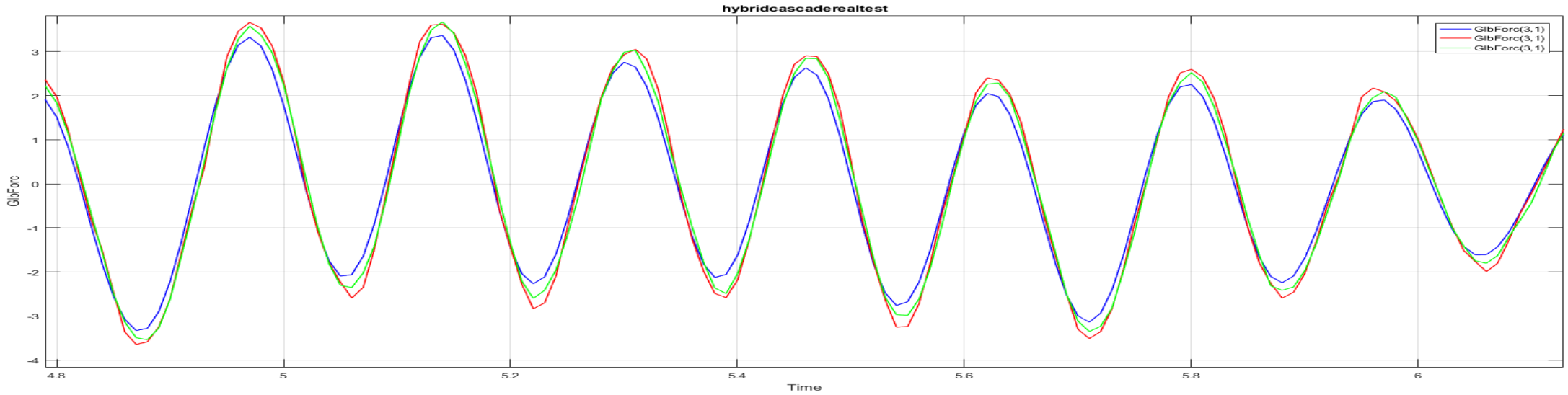
- Axial forces in the experimental element is compared.
- Both hybrid simulation with cascade control and displacement control matched well with the FEA result.



Blue: FEA result
Red: Hybrid simulation with displacement control result
Green: Hybrid simulation with cascade control result

Test Case 2 Result

- When ground motion is relatively high, hybrid simulation with displacement control shows more overshooting than with cascade control.
- Hybrid simulation with displacement control is a better method.

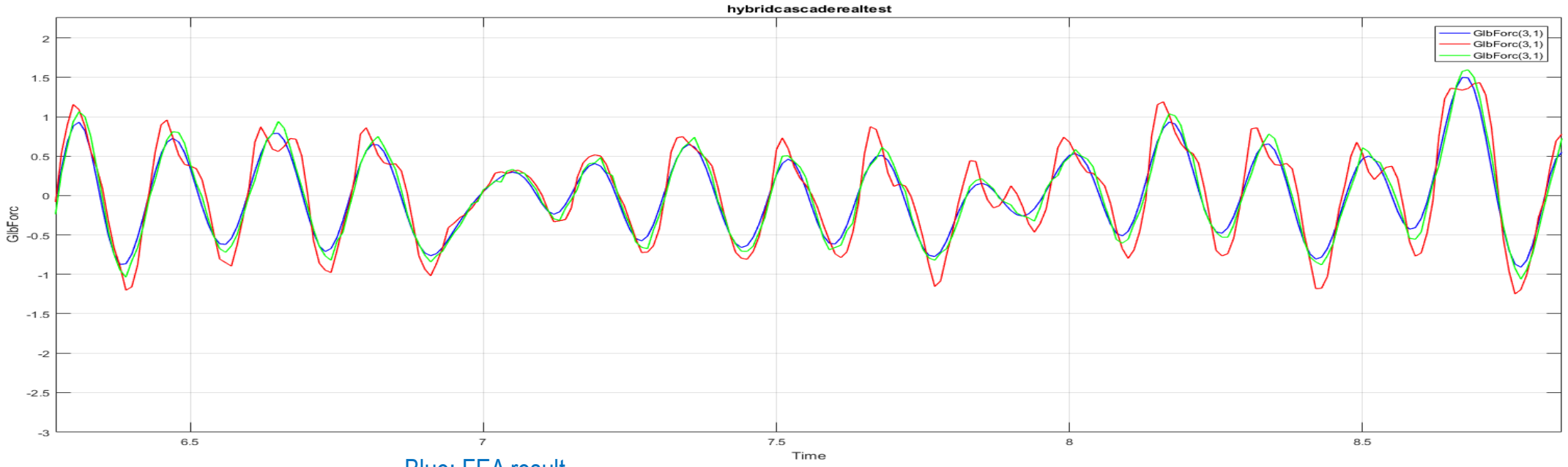


Blue: FEA result
Red: Hybrid simulation with displacement control result
Green: Hybrid simulation with cascade control result

Test Case 2 Result

» When ground motion is relatively low, hybrid simulation with displacement control shows waveform distortion while hybrid simulation with cascade control does not.

» Hybrid simulation with displacement control is a better method.



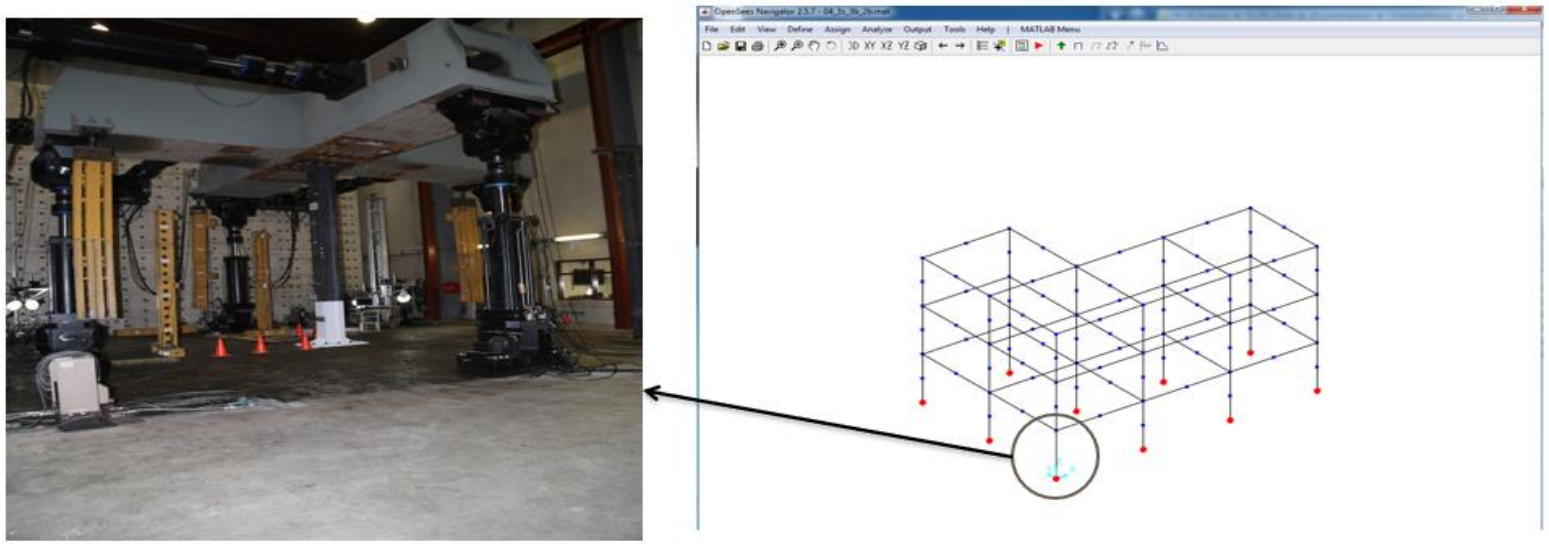
Blue: FEA result

Red: Hybrid simulation with displacement control result

Green: Hybrid simulation with cascade control result

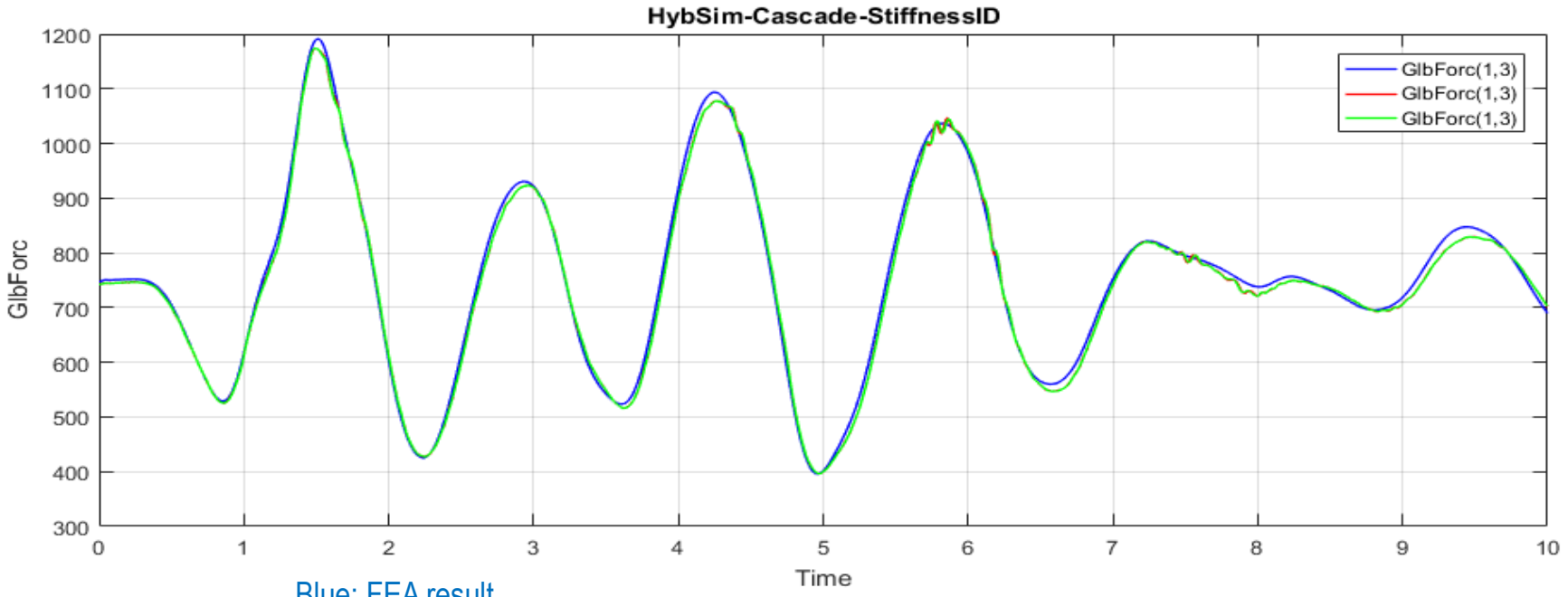
Test Case 3 Setup

- A 3-D 3-story L-shaped frame structure with one column represented by a test specimen.
- 50% of the Northridge earthquake to keep the specimen in elastic range.
- Displacement system noise levels: 0.003 mm. Force system noise level: 0.07 kN.
- Specimen vertical stiffness of 418 kN/mm.



Test Case 3 Result

- Axial forces in the experimental element is compared.
- Both hybrid simulation with cascade control and displacement control matched well with the FEA result.



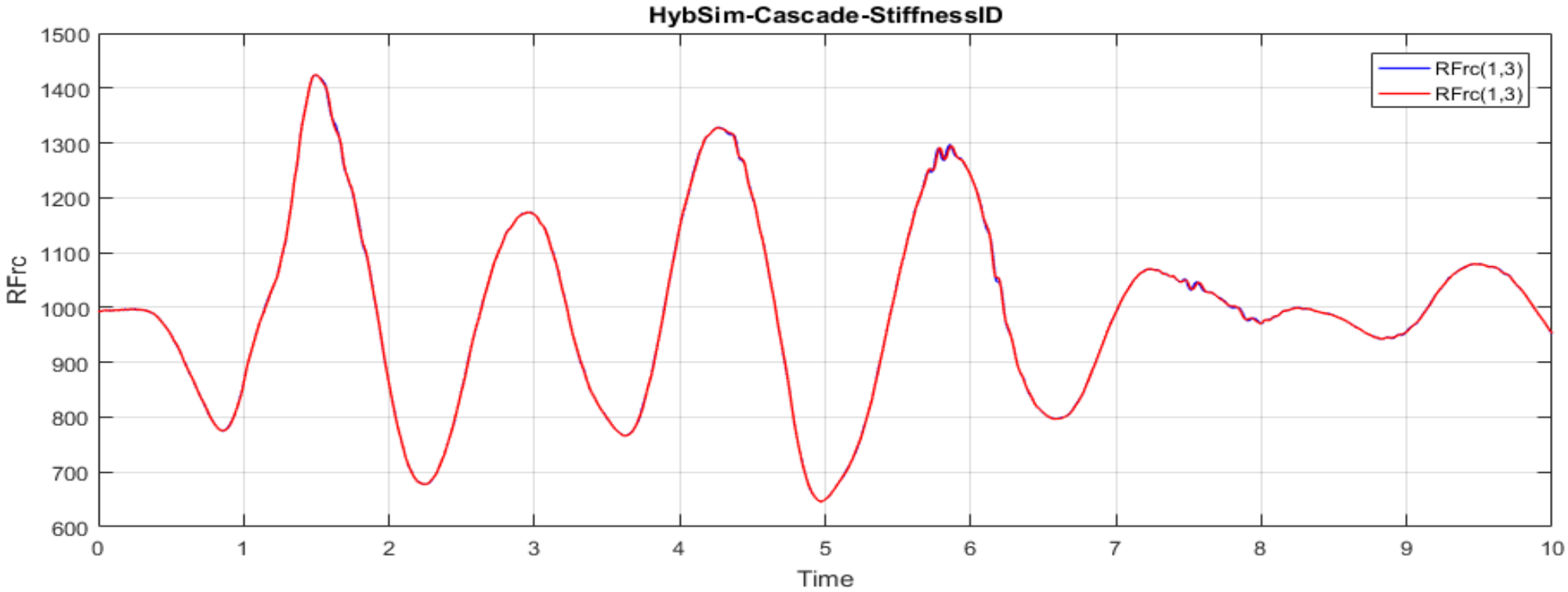
Blue: FEA result

Red: Hybrid simulation with displacement control result

Green: Hybrid simulation with cascade control result

Test Case 3 Result

» Hybrid simulation with cascade control generated identical result as with displacement control.



Blue: Hybrid simulation with displacement control result
Red: Hybrid simulation with displacement control result

Conclusions

- Cascade control with inner loop force control and outer loop displacement control can implement force control while accept displacement command
- Cascade control worked for all three test cases. Compared with displacement control, cascade control:
  - Reduced noise level in Test Case 1
  - Improved amplitude and waveform in Test Case 2
  - Generated same result as displacement control in Test Case 3
- Cascade control is a good method to conduct hybrid simulation with a stiff specimen