Testing and Analysis of Steel Beam-Column Assemblies under Column Removal Scenarios

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While moment-resisting beam-to-column connections in steel frame construction have been studied extensively for seismic applications, the behavior of such connections in progressive collapse scenarios has only recently been studied. Progressive collapse refers to the collapse of a disproportionately large portion of a structure as a result of localized initial damage. Loss of a single column at ground level is a prototypical initiating event. As structural members undergo large displacements and rotations in such scenarios, the connections are subjected to large tensile forces in addition to bending moments. Connection forces are expected to increase monotonically in progressive collapse scenarios, rather than cyclically as in seismic events. Accurate characterization of the failure modes and the resulting nonlinear load-deformation behavior of connections in such scenarios is critical for determining whether or not a collapse can be arrested. Analytical models that capture these connection behaviors can be used to assess the vulnerability of various structural systems to progressive collapse.

This paper presents an experimental and analytical investigation of the behavior of beam-column assemblies with two types of moment-resisting connections: (1) a welded, unreinforced flange, bolted web (WUF-B) connection, and (2) a reduced beam section (RBS) connection. The test configuration in both cases consisted of two beam spans and three columns. The two exterior column bases were anchored to the strong floor of the testing laboratory, and two diagonal braces were rigidly attached to the top of each exterior column to simulate the bracing effect provided by an upper story. The center column was laterally restrained but unsupported from below, and a downward vertical displacement of this column was imposed using a hydraulic ram, to simulate a column removal scenario. Load was applied under displacement control until connection failure occurred, and the failure modes for the two connection types are shown in Figure 1.

For both the WUF-B and the RBS subassembly tests, two finite element models were developed: (a) a detailed model, consisting primarily of shell elements and/or solid elements, and (b) a reduced model, consisting of beam elements and nonlinear spring elements. The detailed and reduced models of the WUF-B connection are shown in Figures 2(a) and 2(b). The detailed models are capable of resolving the nonlinear behavior and failure in great detail, while analyses with the reduced models can be executed much more rapidly, facilitating implementation in models of entire structural systems. Figure 3 shows plots of the applied vertical load against the vertical displacement of the center column from the experimental results and the two finite element models, and for both the WUF-B and the RBS test specimens. The plots show good agreement between the experimental and computational results and provide validation for the detailed and reduced models.

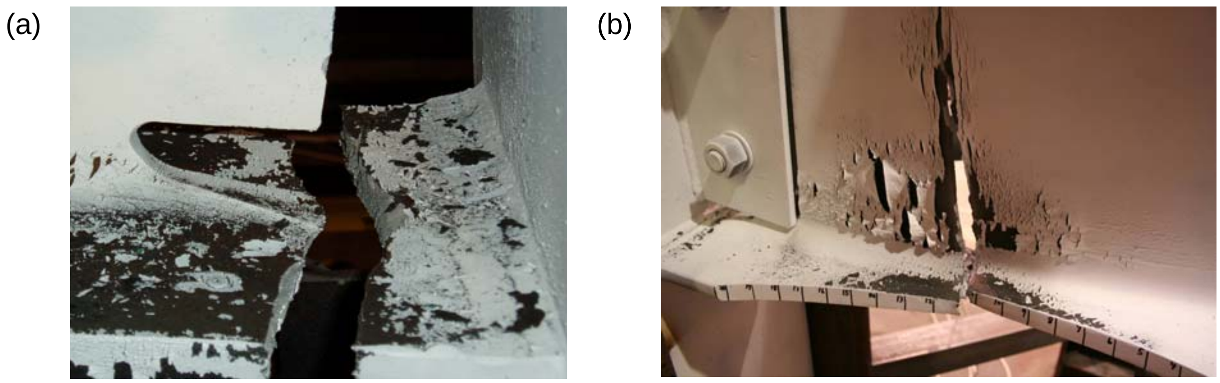

Figure 1: Failure modes of (a) WUF-B and (b) RBS test specimens

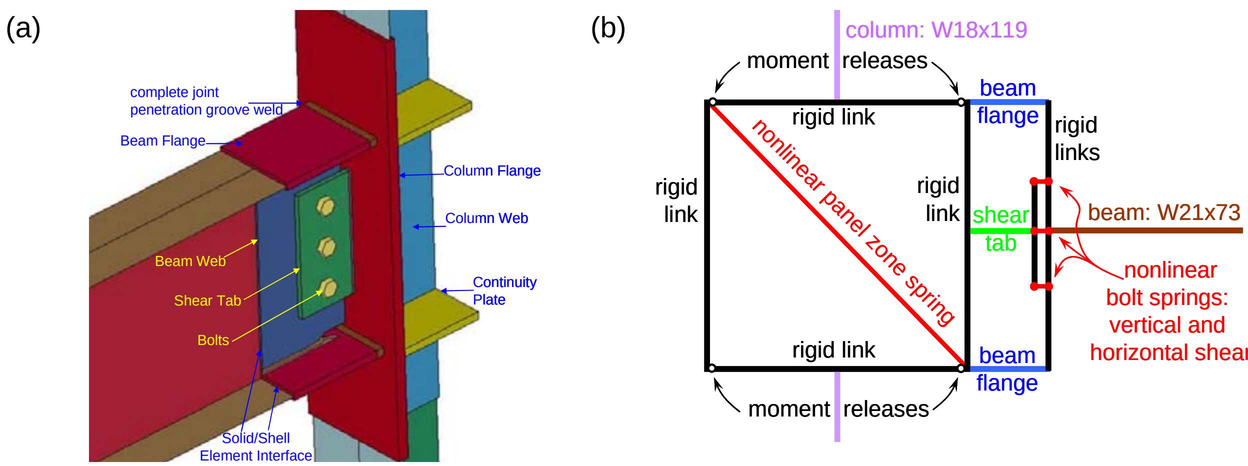

Figure 2: Finite element models of WUF-B connection: (a) detailed; (b) reduced.

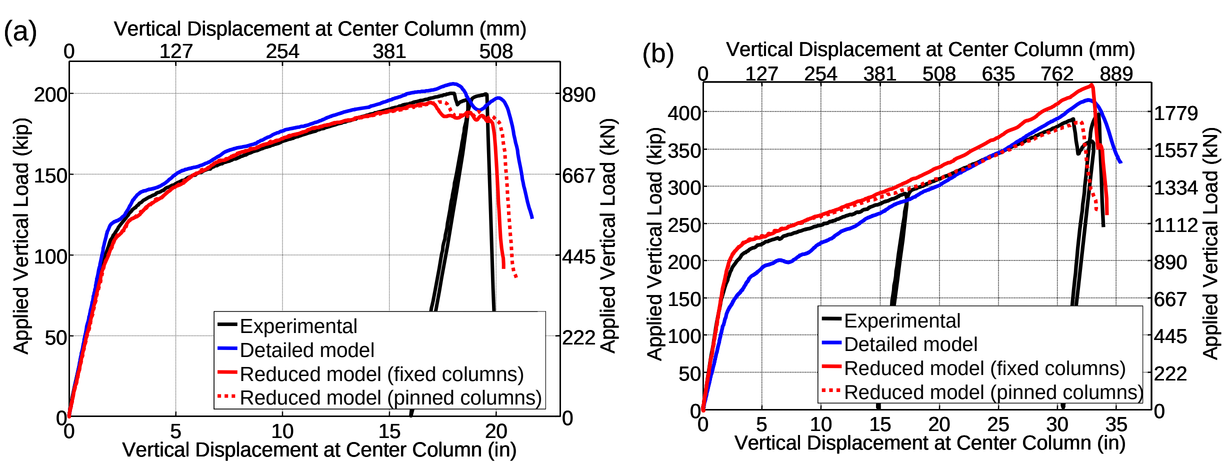

Figure 3: Applied vertical load versus vertical displacement at center column: (a) WUF-B test specimen; (b) RBS test specimen