sufficient strength to support equipment under loading specified by Item 20 in Table 4-1.

Equipment housed within a fixed compartment need not be analyzed, provided it can be shown that contained equipment will not penetrate the walls of a fixed compartment when exposed to the specified acceleration loads in Item 20 of Table 4-1. For any portion of the proposed design that is based on a service-proven vehicle, data from previous tests, historical data from operations, or structural analyses as required to satisfy the corresponding portion of these requirements may be provided in lieu of new analyses or tests.

9.1 Structural Renderings

Structural renderings shall be provided in order to clearly define the primary carbody structure. The structural renderings shall include a side view; a top view, showing one longitudinal half of the roof and one longitudinal half of the underframe; and typical carbody cross-sections, which may include side frame and door frame posts; end, side, draft, and center sills; belt rail, top, and roof rails; collision and corner posts; antitelescoping plate; bolsters, floor beams, and cross bearers; roof carlines and purlins; roof sheathing or corrugation; and side frame sheathing and/or corrugation.

9.2 Stress Analysis

The carbody stress analysis shall consist of a finite element analysis (FEA) using a recognized computer FEA code, supplemented as appropriate by manual stress analyses. The results of the stress analysis shall include calculated stresses, allowable stresses, and margins of safety for all structural elements at all design loading conditions required by this Standard. The stability of plates, webs, and flanges shall be calculated for members subject to compression and shear. For results that are not efficiently analyzed by finite element analysis, such as weld connections, welded and/or bolted joints, and column and plate stability, manual stress analyses may be performed. The format and content of these analyses shall include the following as a minimum:

(a) load case description
(b) rendering of the item to be analyzed, with dimensions, applied forces, and other boundary conditions
(c) drawing references
(d) material properties
(e) allowable stress
(f) detailed stress results and analyses
(g) conclusions

9.3 Crashworthiness Analysis

A crashworthiness analysis shall be performed using a nonlinear, large-deformation explicit, time-dependent, finite element software program. The simulation results shall be provided in various forms, including video animation, static images of the calculated response, graphs of collision forces, displacements, accelerations, and energy balance data. The documentation of results shall demonstrate progressive crush response and the ability of the structure to maintain survival volume required for operator and passengers. The force deflection curves shall show the crush response of the front-end structure, where force is measured at the interface between the cab end structure and passenger compartment. The acceleration history for each car of the train shall be determined as defined by the average collision acceleration definition. Energy data shall be included to demonstrate conservation of momentum, conservation of energy, and minimization of computational energy loss such as might be caused by computational errors in element deformation.

The performance of the energy absorption components shall be validated by the collision conditions and scenarios specified in Table 4.9-1 and paras. 9.3.1 through 9.3.4.

9.3.1 Collision Conditions. Train crashworthiness analysis simulation conditions are as follows:

(a) A moving train colliding into a stopped, braked train (wheel/rail friction coefficient of 0.5) of identical design shall use the train initial velocities and loading conditions identified in Table 4.9-1 and occurring on level tangent track.

(b) A vertical height offset between colliding vehicles as specified in Table 4.9-1, Items 2 and 3 only, with the stopped train in the lower (below nominal) height position shall be modeled by a vertical offset movement of the track.

(c) Both trains shall be configured to the maximum train length used in operation.

9.3.2 Collision Acceptance Criteria: Scenario 1. The results of the simulation for collision conditions and Scenario 1 as referenced in para. 9.3.1 and Table 4.9-1 shall conform to the following criteria for any train:

(a) The energy shall be absorbed by a recoverable or an easily replaceable element.

(b) There shall be no permanent deformation to any vehicle structural member or side sheathing.

(c) There shall be no damage to vehicle equipment other than the recoverable or easily replaceable elements.

NOTE: This scenario is intended to maintain vehicle availability and reduce repair costs.

9.3.3 Collision Acceptance Criteria: Scenario 2. The results of the simulation for collision conditions and Scenario 2 as referenced in para. 9.3.1 and Table 4.9-1 shall conform to the following criteria for any train:

(a) Vehicle interactions do not exhibit override or telescoping responses.

(b) Progressive structural crush begins at vehicle ends.