

2.2.1.5 Progression of Collapse

Construction of WTC 1 resulted in the storage of more than 4×10^{11} joules of potential energy over the 1,368-foot height of the structure. Of this, approximately 8×10^9 joules of potential energy were stored in the upper part of the structure, above the impact floors, relative to the lowest point of impact. Once collapse initiated, much of this potential energy was rapidly converted into kinetic energy. As the large mass of the collapsing floors above accelerated and impacted on the floors below, it caused an immediate progressive series of floor failures, punching each in turn onto the floor below, accelerating as the sequence progressed. As the floors collapsed, this left tall freestanding portions of the exterior wall and possibly central core columns. As the unsupported height of these freestanding exterior wall elements increased, they buckled at the bolted column splice connections, and also collapsed. Perimeter walls of the building seem to have peeled off and fallen directly away from the building face, while portions of the core fell in a somewhat random manner. The perimeter walls broke apart at the bolted connections, allowing individual prefabricated units that formed the wall or, in some cases, large assemblies of these units to fall to the street and onto neighboring buildings below.

Review of videotape recordings of the collapse taken from various angles indicates that the transmission tower on top of the structure began to move downward and laterally slightly before movement was evident at the exterior wall. This suggests that collapse began with one or more failures in the central core area of the building. This is consistent with the observations of debris patterns from the 91st floor, previously discussed. This is also supported by preliminary evaluation of the load carrying capacity of these columns, discussed in more detail in Section 2.2.2.2. The core columns were not designed to resist wind loads and, therefore, had less reserve capacity than perimeter columns. As some exterior and core columns were damaged by the aircraft impact, the outrigger trusses at the top of the building shifted additional loads to the remaining core columns, further eroding the available factor of safety. This would have been particularly significant in the upper portion of the damaged building. In this region, the original design load for the core columns was less than at lower floors, and the column sections were relatively light. The increased stresses caused by the aircraft impact could easily have brought several of these columns close to their ultimate capacity, so that relatively little additional effects due to fire would have been required to initiate the collapse. Once movement began, the entire portion of the building above the area of impact fell in a unit, pushing a cushion of air below it. As this cushion of air pushed through the impact area, the fires were fed by new oxygen and pushed outward, creating the illusion of a secondary explosion.

Although the building appeared to collapse within its own footprint, a review of aerial photographs of the site following the collapse, as well as damage to adjacent structures, suggests that debris impacted the Marriott Hotel (WTC 3), the Customs House (WTC 6), the Morgan Stanley building (WTC 5), WTC 7, and the American Express and Winter Garden buildings located across West Street (Figure 2-23). The debris field extended as far as 400–500 feet from the tower base.

2.2.2 WTC 2

2.2.2.1 Initial Damage From Aircraft Impact

United Airlines Flight 175 struck the south face of WTC 2 approximately between the 78th and 84th floors. The zone of impact extended from near the southeast corner of the building across much of the building face (Figures 2-24 and 2-25). The aircraft caused massive damage to the south face of the building in the zone of impact (Figures 2-26 and 2-27). At the central zone of impact corresponding to the airplane fuselage and engines, six of the prefabricated, three-column sections that formed the exterior walls were broken loose from the structure, with some of the elements apparently pushed inside the building envelope. Locally, as was the case in WTC 1, floors supported by these exterior wall sections appear to have partially collapsed. Away from this central zone, in the areas impacted by the outer wing structures, the exterior steel columns