APPLIED SCIENCE INTERNATIONAL SUCCESS STORY

A.P. MURRAH BUILDING

Oklahoma City, USA, 1995

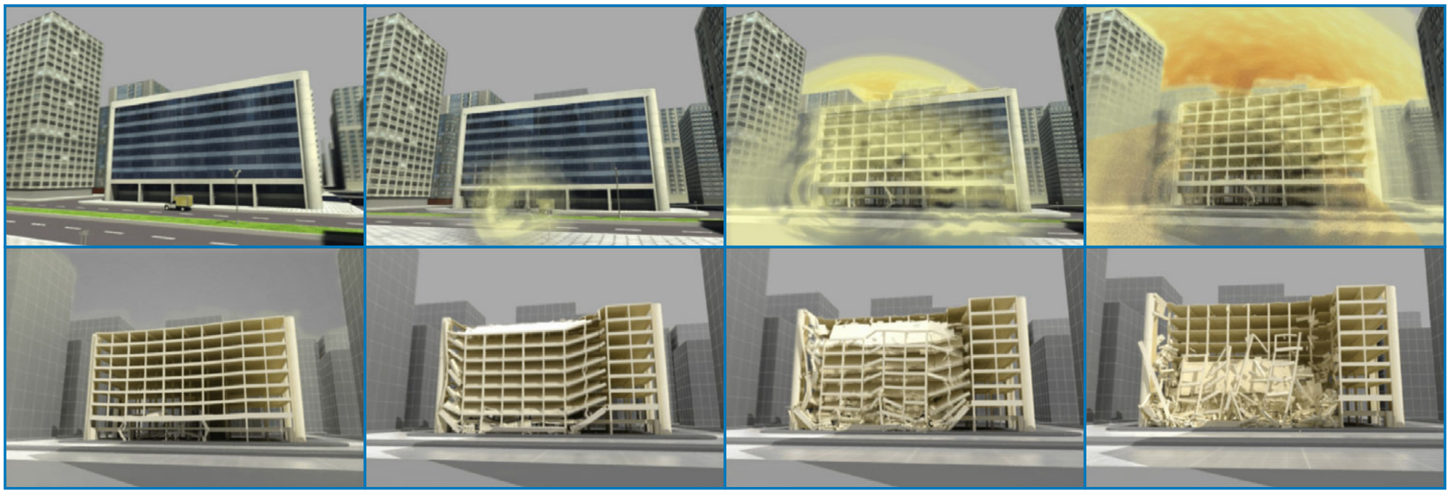
The New Structural Vulnerability Assessment Standard

After the tragic terrorist bombing of the Alfred P. Murrah Building in Oklahoma City, the resistance of civil structures to blast loads became an area of great interest to structural engineers and scientists around the world. One main objective of blast-resistant design is to prevent disproportionate or progressive collapse of structures when subjected to extreme loads such as blast or impact. The following case study forensically reviews the events of the catastrophic collapse, evaluates potential mitigating actions, as well as other potential scenarios that may have occurred that morning.

Simulated Collapse Area

A.P. Murrah Building Bombing

The collapse of the Murrah Building was caused when the structure was subjected to an estimated 4000 pounds of explosives approximately 14 feet from the structure. When the bomb went off, some structural elements of the building were destroyed due to direct exposure to the pressure wave. The nearest column to the bomb location and is destroyed directly due to explosion. The transfer girder, carried by 6 columns at the building front has the collapses due to curtailment of reinforcement bars and the re-distribution of bending moments in the transfer girder. After collapse of the transfer girder, excessive loads at the girders on the 4th to the 9th floor levels caused a disproportionate collapse of a significant portion of the structure.



Simulation of the A.P. Murrah Building Bombing

Potential Collapse Scenarios

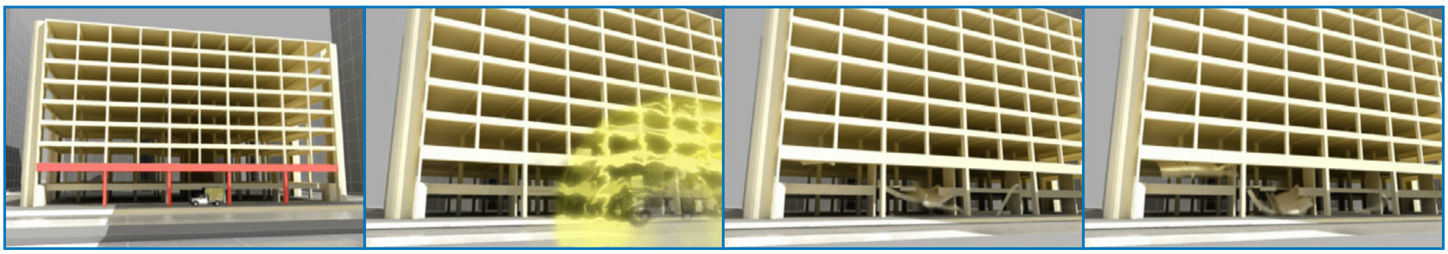
In addition to the forensic study of the Alfred P. Murrah building bombing, ASI also studied in a series of *what if* scenarios to study the effects of potential mitigating solutions in reducing the effects of a blast on the structure. The main question raised here is “How will the structure behave if standoff distances prevented the blast from occurring so close to the structure or the transfer girder was additionally reinforced?” The Answer to this question will help in determining the safety of both existing and new structures.

A.P. MURRAH BUILDING - CONTINUED

Increasing Reinforcement In the Transfer Girder

Engineers tend to use curtailment of reinforcement bars to reduce the weight of steel used in a structure, hence reducing construction cost. In reviewing the original reinforcement detailing of the transfer girder, it is obvious that the top reinforcement ratio was reduced at the mid-spans while the bottom reinforcement is curtailed at column locations. Designers of such buildings at the time did not consider failure of one or more supporting elements which will cause dramatic changes of internal forces and bending moments.

In the real collapse case, the failure of column G20 cause the span of transfer girder to be doubled, hence the bending moment increased to 4 times. Adding the dynamic loads as a result of the direct pressure wave cause the bending moment value to be significantly increased. In addition, the bending moments of the transfer girder at column G20 changed its direction to a negative moment while the reinforcement is curtailed at the failed column location.



Scenario 2: Girder Strengthened

In this case, to show how significant the reinforcement detailing of the transfer girder would be in preventing a disproportionate collapse of the structure, the reinforcement bars are assumed continuous at the transfer girder with 7 square inches at both the top and bottom of the girder. The assumed reinforcement area is almost double the actual design. Although the bending moment due to failure of the transfer girder will increase to more than 4 times the design values. Analysis results shown above show that improving reinforcement detailing of the transfer girder resulted in the localization of the failure to column G20 and some parts of the slabs due to direct pressure wave.

Moving the Bomb 60 feet to the Building Corner

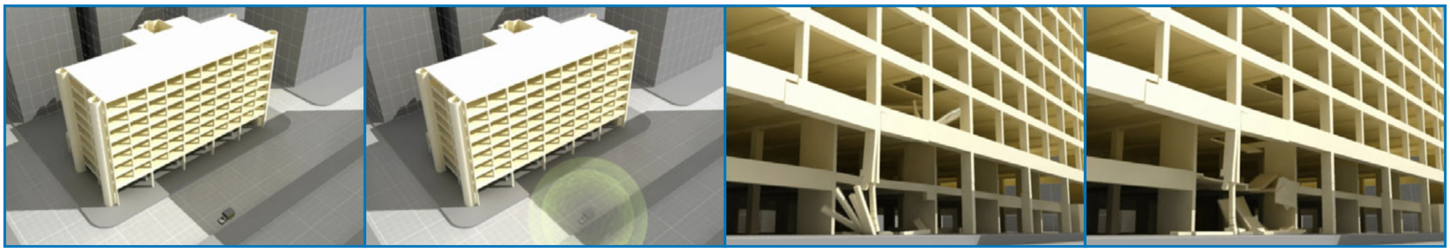
In this scenario, the bomb blast is moved from its original location 60 feet towards the building corner. As shown below, the direct pressure wave cause failure of column G20 and parts of floor slabs due to uplift pressure. Then the girders supported by G28 in upper the upper floors collapses in shear as. This case shows that the collapse propagated in vertical direction only.

Scenario 3: Blast moved 60ft to building corner.

A.P. MURRAH BUILDING - CONTINUED

Moving the Bomb 20 Feet Away From the Building

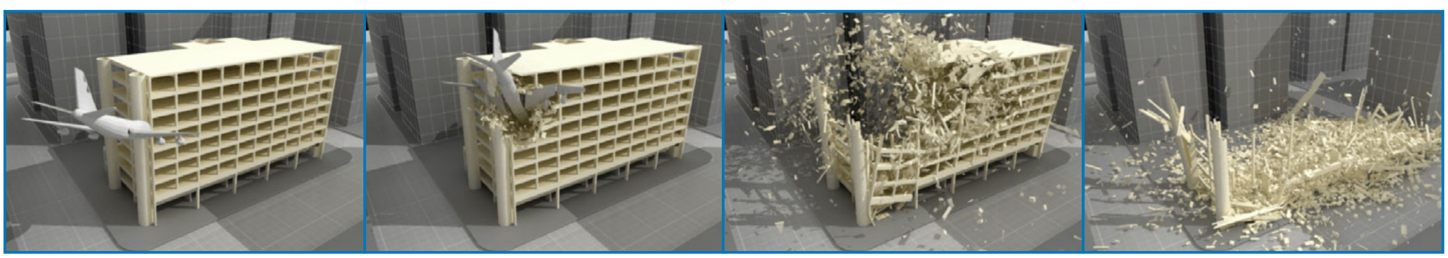
In this case we assume that the truck could not stop in front of the building, due to existence of a barrier for example. The bomb blast is placed 20 feet away from its original location as shown below. The direct pressure wave caused high uplift pressure on the slabs of first floor. However, collapse is limited to floor slabs facing the high uplift pressure and progressive collapse did not occur. This sample shows the importance of having barriers that establish safe standoff distances around critical structures to keep enough distance between vehicles carrying dangerous payloads.



Scenario 4: Blast moved 20ft away from building.

Collision of an Aircraft with the Building

The threat of objects colliding with and damaging structures, whether intentionally or accidentally is of genuine concern. Vehicular collisions with buildings or bridges occur mainly in urban areas and are due to single vehicles unintentionally leaving the roadway. In this final case, an aircraft impact is analyzed as a potential threat. Important facilities must take into consideration aircraft collisions, especially if these structures lie within 10 kilometers (6 miles) of an airport. The resulting damage can be catastrophic, as is the case here. Additionally, impacts of barges or flood debris with bridges or bridge supports are also not uncommon events.



Scenario 5: Plane crashes into building.

ASI can accurately assess the vulnerability of an existing structure subjected to extreme loading cases such as blast, progressive collapse, impact or seismic events. Additionally, ASI can propose and model retrofit schemes for the structure, comparing the behavior of the structure before and after retrofit. This assessment can be done for both structural and non-structural components of the structure.

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