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Applying the Technique of Controlling Demolition on Existing Structures

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ABSTRACT

The current conditions in our country regarding the violation of building codes, and misunderstanding and misuse of the law of reconciliation for violations strongly forced the existence of multitype violations such as building implementation without permits, implementation of building on governmental land, and or building additional floors without permits. All of these building violations led to a negative potential for environmental, health, social, and economic aspects. Under the current circumstances, and for environmental, social, and economic conditions, it is important to establish demolition systems and techniques that lead to the optimization of the use of debris in the field of construction. It should also guarantee the safety of the licensed part of the building under demolition as well as the surrounding buildings. This paper presents the characteristics, advantages, and disadvantages of different demolition techniques for existing structures. This research paper delves into the intricate world of demolition techniques for existing structures, with a focus on controlled demolition, and aims to revolutionize this field from a structural, economic, and environmental perspective. Investigating the historical evolution of demolition methods, the study underscores the importance of adaptability and innovation in demolition engineering. To ensure efficiency and ecological sustainability, the paper introduces a comprehensive methodology to examine the feasibility of each demolition technique while emphasizing the potential of debris reuse in the construction industry, It is also an attempt to develop these techniques to maximize the benefit from the debris by reusing it in the field of construction.

Key Words: Demolition, Violation of Building, Controlled Implosion, Building Collapses, World Trade Centre WTC.

1 INTRODUCTION

A building is properly studied and analyzed before it is demolished. The surrounding buildings and structures are evacuated to ensure that no one is affected by the dust and debris from the demolished structure. Following the evacuation, demolition work begins, with the building being torn down utilizing various machinery, tools, and equipment.

Methodology and blast loading and blast effects on Structure reviewed where results were analyzed and discussed the case study of WTC 1. Based on this analysis, conclusions and recommendations were deduced and were given forward. This is presented in this paper under the following headlines:

- Historical overview
- Methodology
- Blast Loading and Blast Effects on Structures
- Key Elements for performing a controlled demolition on a structure
- Case study: The World Trade Center WTC1
- Conclusions and recommendations

2 Historical Overview

The World Trade Center project, initiated in the early 1960s under the influence of David Rockefeller, aimed to revitalize a part of the city that had experienced downturns. The vision centered on using the trade facility and urban renewal as a means to rejuvenate what had become a "commercial slum." The construction of the twin towers not only ushered in a new era for business but also provided landfill for the creation of new shorelines along the Hudson River. Since the early 1980s, the World Trade Center Towers 1 and 2, standing at 110 stories each, became the most prominent symbol of this vision's success in revitalizing trade and finance on the island. Until recently, this remarkable transformation was regarded as an enduring part of New York City's landscape, as steadfast and unwavering as the towers themselves—a vivid and unshakable testament on the confident horizon of American capitalism.

The World Trade Center was an complex that spanned 16 acres and consisted of seven buildings, developed and managed by the Port Authority of New York and New Jersey (PANYNJ). Positioned at the core of the complex, Towers 1 and 2 soared above the surrounding skyline, extending over 100 feet higher than the gleaming spire of the Empire State Building. No one could have anticipated that these architectural marvels would stand for a mere 30 years.

3 Methodology

In order to conduct a secure and efficient demolition of a building, demolition experts must meticulously plan and delineate each aspect of the implosion process in advance. In certain instances, these experts may employ sophisticated 3D computer modeling techniques to create a digital representation of the structure, thereby facilitating thorough virtual simulations and assessments of their proposed demolition plan before implementation.

The main challenge in bringing a building down is controlling which way it falls. Ideally, a blasting crew will be able to tumble the building over on one side into a parking lot or other open area.

Detonate explosives on the north side of the building first, in the same way you would chop into a tree from the north side if you wanted it to fall in that direction. Blasters may also secure steel cables to support columns in the building so that they are pulled a certain way as they crumble.

Sometimes, though, a building is surrounded by structures that must be preserved. In this case, the blasters proceed with a true implosion, demolishing the building so that it collapses straight down into its own footprint (the total area at the base of the building). This feat requires such skill that only a handful of demolition companies in the world will attempt it.

4 Blast Loading and Blast Effects on Structures

The damage to man-made structures caused by the bombs was due to two distinct causes: first, the blast, or pressure wave, emanating from the center of the explosion, and second, the fires which several ingenious methods were used by the various investigators to determine, upon visiting the wrecked cities, what had actually been the peak pressures exerted by the atomic blasts. These pressures were computed for various distances from X, and curves were then plotted which were checked against the theoretical predictions of what the pressures would be. A further check was afforded from the readings obtained by the measuring instruments which were dropped by parachute at each atomic attack. The peak pressure figures gave a direct clue to the equivalent T.N.T. tonnage of the atomic bombs since the pressures developed by any given amount of T.N.T. can be calculated easily.

One of the simplest methods of estimating the peak pressure can be obtained from the crushing of oil drums, gasoline cans, or any other empty thin metal vessel with a small opening. The assumption made is that the blast wave pressure comes on instantaneously; the resulting pressure on the can is more than the case can withstand, and the walls collapse inward. The air inside is compressed adiabatically to such a point that the pressure inside is less by a certain amount than the pressure outside, this amount being the pressure difference outside and in that the walls can stand in their crumpled condition.

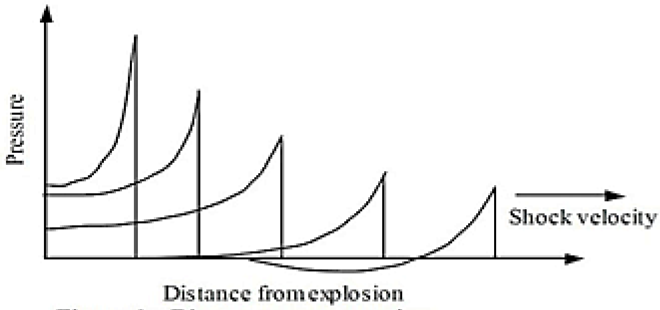

Figure 1: Blast wave propagation

The uncertainties are that some air rushes in via any opening in the can, helping to build up the pressure within; and that as the pressure outside declines, the air inside cannot leave quickly enough to prevent the can's walls from being blasted out again to some extent. Because of these uncertainties, pressure predictions based on this method are on the low side or understated.

Another method of calculating the peak pressures is obtained by bending of steel flagpoles, or lightning conductors, away from the explosion. It is possible to calculate the drag on a pole or rod in an airstream of a certain density and velocity; by connecting this drag with the strength of the pole in question, a determination of the pressure wave may be obtained.

Still another method of estimating the peak pressure is through the overturning of memorial stones, of which there is a great quantity in Japan. The dimensions of the stones can be used along with known data on the pressure exerted by wind against flat surfaces, to calculate the desired figure. An explosion is defined as a large-scale, rapid, and sudden release of energy. Explosions can be categorized on the basis of their nature as physical, nuclear, or chemical events.

In physical explosions, energy may be released from the catastrophic failure of a cylinder of compressed gas, volcanic eruptions, or even the mixing of two liquids at different temperatures. In a nuclear explosion, energy is released from the formation of different atomic nuclei by the redistribution of the protons and neutrons within the interacting nuclei, whereas the rapid oxidation of fuel elements (carbon and hydrogen atoms) is the main source of energy in the case of chemical explosions.

Explosive materials can be classified according to their physical state as solids, liquids, or gases. Solid explosives are mainly high explosives for which blast effects are best known. They can also be classified on the basis of their sensitivity to ignition as secondary or primary explosives. The latter is one that can be easily detonated by simple ignition from a spark, flame, or impact.

Materials such as mercury fulminate and lead azide are primary explosives. Secondary explosives when detonated create blast (shock) waves which can result in widespread damage to the surroundings.

Examples include trinitrotoluene (T.N.T.) and ANFO. The detonation of a condensed high explosive generates hot gases under pressure up to 300-kilo bar and a temperature of about 3000-4000C°. The hot gas expands forcing out the volume it occupies.

As a consequence, a layer of compressed air (blast wave) forms in front of this gas volume containing most of the energy released by the explosion. The blast wave instantaneously increases to a value of pressure above the ambient atmospheric pressure. This is referred to as the side-on overpressure that decays as the shock wave expands outward from the explosion source.

After a short time, the pressure behind the front may drop below the ambient pressure (Figure 1). During such a negative phase, a partial vacuum is created and the air is sucked in. This is also accompanied by high suction winds that carry the debris for long distances away from the explosion source.

4.1 Explosive Air Blast Loading

The threat for a conventional bomb is defined by two equally important elements, the bomb size, or charge weight W, and the standoff distance R between the blast source and the target (Figure 3). For example, the blast that occurred in the basement of the World Trade Centre in 1993 had a charge weight of 816.5 kg T.N.T.

The observed characteristics of air blast waves are found to be affected by the physical properties of the explosion source. (Figure 2) shows a typical blast pressure profile. At the arrival time tA, following the explosion, pressure at that position suddenly increases to a peak value of overpressure, Pso, over the ambient pressure, Po. The pressure then decays to ambient level at time td, then decays further to an under pressure Pso-(creating a partial vacuum) before eventually returning to ambient conditions at time td + td-. The quantity Pso is usually referred to as the peak side-on overpressure, incident peak overpressure or merely peak overpressure (TM 5-1300, 1990).

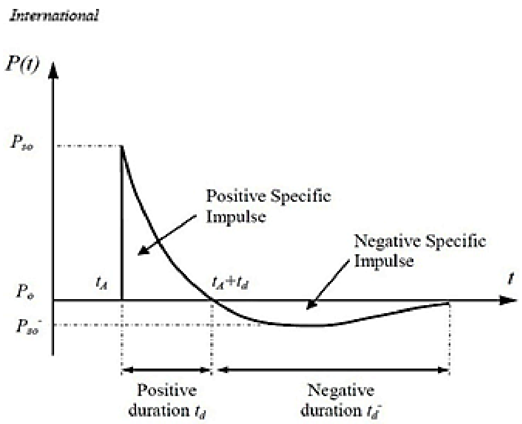

Figure 2: Blast wave pressure – Time history

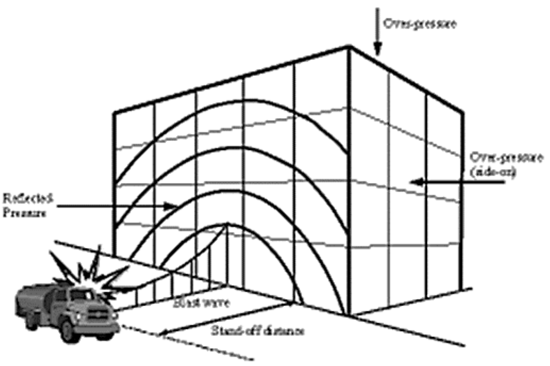

Figure 3: Blast loads on a building

The incident peak overpressures Pso are amplified by a reflection factor as the shock wave encounters an object or structure in its path. Except for specific focusing of high-intensity shock waves at near 45° incidence, these reflection factors are typically greatest for normal incidence (a surface adjacent and perpendicular to the source) and diminish with the angle of obliquity or angular position relative to the source. Reflection factors depend on the intensity of the shock wave, and for large explosives, at normal incidence, these reflection factors may enhance the incident pressures by as much as an order of magnitude. Throughout the pressure-time profile, two main phases can be observed; the portion above ambient is called the positive phase of duration td, while that below ambient is called the negative phase of duration, td-.

The negative phase is of a longer duration and a lower intensity than the positive duration. As the stand-off distance increases, the duration of the positive-phase blast wave increases resulting in a lower-amplitude, longer-duration shock pulse. Charges situated extremely close to a target structure impose a highly impulsive, high-intensity pressure load over a localized region of the structure; charges situated further away produce a lower-intensity, longer-duration uniform pressure distribution over the entire structure.

Eventually, the entire structure is engulfed in the shock wave, with reflection and diffraction effects creating focusing and shadow zones in a complex pattern around the structure. During the negative phase, the weakened structure may be subjected to impact by debris that may cause additional damage.

If the exterior building walls are capable of resisting the blast load, the shock front penetrates through window and door openings, subjecting the floors, ceilings, walls, contents, and people to sudden pressures and fragments from shattered windows, doors, etc. Building components not capable of resisting the blast wave will fracture and be further fragmented and moved by the dynamic pressure that immediately follows the shock front. Building contents and people will be displaced and tumbled in the direction of blast wave propagation. In this manner, the blast will propagate through the building.

4.2 Blast Wave Scaling Laws

All blast parameters are primarily dependent on the amount of energy released by a detonation in the form of a blast wave and the distance from the explosion. A universal normalized description of the blast effects can be given by scaling distance relative to (E/Po)1/3and scaling pressure relative to Po, where E is the energy release (kJ) and Po is the ambient pressure (typically 100 KN/m2). For convenience, however, it is general practice to express the basic explosive input or charge weight as an equivalent mass of T.N.T.

Results are then given as a function of the dimensional distance parameter (scaled distance) Z = R/W1/3

Where R is the actual effective distance from the explosion. W is generally expressed in kilograms. Scaling laws provide parametric correlations between a particular explosion and a standard charge of the same substance.

4.3 Prediction of Blast Pressure

Blastwave parameters for conventional high explosive materials have been the focus of a number of studies during the 1950s and 1960s.

W R	**100 kg T.N.T.**	**500 kg T.N.T.**	**1000 kg T.N.T.**	**2000 kg T.N.T.**
1m	**165.8**	**354.5**	**464.5**	**602.9**
2.5m	**34.2**	**89.4**	**130.8**	**188.4**
5m	**6.65**	**24.8**	**39.5**	**60.19**
10m	**0.85**	**4.25**	**8.15**	**14.7**
15m	**0.27**	**1.25**	**2.53**	**5.01**
20m	**0.14**	**0.54**	**1.06**	**2.13**
25m	**0.09**	**0.29**	**0.55**	**1.08**
30m	**0.06**	**0.19**	**0.33**	**0.63**
Peak reflected overpressures Pr (in MPa) With different W-R combinations				

Table (1): Estimations of peak overpressure due to spherical blast based on scaled distance.

Z = R/W1/3 were introduced by Brode (1955) as:

- Pso = $\frac{6.7}{z^3}$ + 1 bar (Pso> 10 bar)

Newmark and Hansen (1961) introduced a relationship to calculate the maximum blast overpressure, Pso, in bars, for a high explosive charge detonates at the ground surface as:

- Pso = $\frac{1772}{z^3} - \frac{114}{z^2} + \frac{108}{z}$

As the blast wave propagates through the atmosphere, the air behind the shock front is moving outward at lower velocity. The velocity of the air particles, and hence the wind pressure, depends on the peak overpressure of the blast wave. This later velocity of the air is associated with the dynamic pressure, q(t). The maximum value, qs, say, is given by

- qs = 5P2so / 2(pso + 7 Po)

If the blast wave encounters an obstacle perpendicular to the direction of propagation, reflection increases the overpressure to a maximum reflected pressure Pras:

- Pr= 2 Pso$\left\{\frac{7P_o+4\ P_{so}}{7\ P_o+P_{so}}\right\}$

A full discussion and extensive charts for predicting blast pressures and blast durations are given by Mays and Smith (1995) and TM5-1300 (1990). Some representative numerical values of peak reflected overpressure are given in the previous table.

For design purposes, reflected overpressure can be idealized by an equivalent triangular pulse of Maximum peak pressure brand time duration td, which yields the reflected impulse (ir)

- ir = $\frac{1}{2}$Pr td

Duration td is related directly to the time taken for the overpressure to be dissipated. Overpressure arising from wave reflection dissipates as the perturbation propagates to the edges of the obstacle at a velocity related to the speed of sound (Us) in the compressed and heated air behind the wavefront. Denoting the maximum distance from an edge as S (for example, the lesser of the height or half the width of a conventional building), the additional pressure due to reflection is considered to reduce from Pr– Psoto zero in time 3S/Us. Conservatively, Us can be taken as the normal speed of sound, which is about 340 m/s, and the additional impulse to the structure is evaluated on the assumption of a linear decay.

After the blast wave has passed the rear corner of a prismatic obstacle, the pressure similarly propagates onto the rear face; linear build-up over duration 5S/Us has been suggested. For skeletal structures, the effective duration of the net overpressure load is thus small, and the drag loading based on the dynamic pressure is then likely to be dominant.

Conventional wind-loading pressure coefficients may be used, with the conservative assumption of instantaneous build-up when the wave passes the plane of the relevant face of the building, the loads on the front and rear faces being numerically cumulative for the overall load effect on the structure.

Various formulations have been put forward for the rate of decay of the dynamic pressure loading; a parabolic decay (i.e. corresponding to a linear decay of equivalent wind velocity) over a time equal to the total duration of positive overpressure is a practical approximation.

4.4 Gas Explosion Loading and Effect of Internal Explosions

In the circumstances of a progressive build-up of fuel in a low-turbulence environment, typical of Domestic gas explosions, flame propagation on ignition is slow and the resulting pressure pulse is correspondingly extended. The specific energy of combustion of hydrocarbon fuel is very high (46000 kJ/kg for propane, compared to 4520 kJ/kg for T.N.T.) but widely differing effects are possible according to the conditions at ignition.

Internal explosions likely produce complex pressure loading profiles as a result of the resulting two loading phases. The first results from the blast overpressure reflection and, due to the confinement provided by the structure, re-reflection will occur. Depending on the degree of confinement of the structure, the confined effects of the resulting pressures may cause different degrees of damage to the structure.

On the basis of the confinement effect, target structures can be described as either vented or unvented. The latter must be stronger to resist a specific explosion yield than a vented structure where some of the explosion energy would be dissipated by breaking of window glass or fragile partitions.

Venting following the failure of windows (at typically 7 KN/m2) generally greatly reduces the peak values of internal pressures. The study of this problem at the Building Research Establishment (Ellis and Crowhurst, 1991) showed that an explosion fueled by a 200 ml aerosol canister in a typical domestic room produced a peak pressure of 9 KN/m2 with a pulse duration over 0.1s.

This is long by comparison with the natural frequency of wall panels in conventional building construction and quasi-static design pressure is commonly advocated.

Much higher pressures with a shorter timescale are generated in turbulent conditions. Suitable conditions arise in buildings in multi-room explosions on passage of the blast through doorways, but can also be created by obstacles closer to the release of the gas. They may be presumed to occur on release of gas by the failure of industrial pressure vessels or pipelines.

5 Key Elements for Performing Controlled Demolition on A Structure

5.1 Inspection

Prior to carrying out any building demolition, detailed building appraisal by means of surveys and appropriate assessments shall be required. In general, the surveys shall include a Building Survey and a Structural Survey with photographs or videos taken for future reference. Based on the findings of these surveys, a demolition plan shall then be prepared and submitted to the Buildings Department for approval.

The demolition plan must also be accompanied by a report together with structural calculations assessing the Stability of the building to be demolished and all affected buildings, structures, streets, land, and services,

These steps of Building inspection shall be applied to both the Milestone Target and the Neighbored Buildings.

5.1.1 Record Drawings

Prior to the Building Survey, the existing record plan, including a layout plan, showing adjoining properties, pedestrian walkways, roads, streets, etc. shall be retrieved.

5.1.2 Survey Items

The Building Survey shall cover the following:

(1) The construction materials.

(2) The existing use and, if possible, the past use of the building prior to demolition.

(3) The presence of wastewater, hazardous materials, matters arising from toxic chemicals, flammable or explosive and radioactive materials, etc., and the possible presence of materials that can contribute to air pollution and soil contamination.

(4) Potentially dangerous areas, e.g., abnormal layouts, presence of enclosed voids, and non-ventilated light wells which may trap obnoxious gas at the bottom.

(5) Adjoining properties and site conditions, such as the existence of slope and retaining wall, wall supporting ground, illegal structures, bridges, underground railway, and its above-ground structures, including entrances, vent shafts, distribution substations, traction substations, plant rooms, overhead railway structures, surface track sections, overhead cables or guy wires, and other utility service connections

(6) Drainage conditions and possible problems on water pollution, flooding, and erosion, especially on sloping sites and water receiving bodies.

(7) Shared facilities with adjoining buildings, including common staircases, party walls, and the possible effect on it, such as self-enclosed walls to the adjoining buildings, during demolition.

(8) Hoarding and covered walkway requirements.

(9) Adjoining pedestrian and vehicular traffic conditions.

(10) Available headroom, clear spaces, and distance of building from lot boundary which may affect the loading operation and transportation of building debris during demolition.

(11) The sensitivity of the neighborhood with respect to noise, dust, vibration, and traffic impact. For building/structures to be demolished, confirm whether it is within the scope of the designated projects specified in schedule 2 of the Environmental Impact Assessment Ordinance.

(12) Available site area to allow on-site sorting of building debris.

(13) Street furniture such as fire hydrants, parking space meters, street lights, street signs, and hawkers' stalls could be affected by the demolition project.

5.1.3 Hazardous Materials

(1) Unless the Building Survey reviews that no obvious hazardous material is present in the building, the Authorize Person shall cause proper sampling and testing for the hazardous materials.

(2) In the case when hazardous materials e.g., asbestos-containing materials, or petroleum, are present, they shall be removed and cleaned/disposed of according to the statutory requirements administered by the Environmental Protection Department, Fire Services Department, Labor Department, and any other Government Departments.

(3) In the case when the site has previously been used to store chemicals, and other dangerous goods, soil contamination assessment shall be required at the pre-demolition stage and/or post-demolition stage.

(4) In the case when the site has previously been used to store explosives, special procedures to ensure no explosives remain on site will be required.

5.2 Cad Drawing of the Structural System

After the Inspection of the Target Building and the Neighbored Ones, A Full Statically System Cad Drawings Shall is drawn for the Milestone Target with Real Dimensions of every Structural Element of the Building including Foundations and roofs.

These Cad Drawings shall be drawn for Every Floor not only for the Top and Bottom Floors, but these Drawings Will also Help us in Evaluating the Structural System by Finite Element Programs Such as Sap2000 and E-Tab in order to calculate the total applied stresses on every Member to Determine the Main Weak points of the whole Structure.

5.3 Evaluation of Structure

5.3.1 Record Drawings

Prior to the Structural Survey, the existing record layout, structural framing plans, and structural details shall be studied. The Registered Structural Engineer shall check the presence of unusual detailing that may cause abnormal structural behavior during demolition, e.g., upward anchor of tensile reinforcement in cantilevered structures. If existing record plans are available, these plans shall be used as a reference and preferably be brought along with the Structural Survey.

5.3.2 Survey Items

The Structural Survey shall cover the following:

(1) The structural materials used;

(2) The original structural system employed in the design;

(3) The method of construction;

(4) Any dilapidation and degree of deterioration on any structural elements;

(5) The structural conditions of adjoining structures and their shoring which may be affected by the proposed demolition work;

(6) The presence of continuous structures that may be truncated by the demolition;

(7) The structural system and structural conditions of basements, underground tanks, or underground vaults;

(8) The presence of exposed bracing or possible presence of covered bracing;

(9) The nature of walls, whether it is blocked walls, reinforced concrete walls, loads bearing walls, or partition walls

(10) Cantilevered structures such as canopies, balconies, and other forms of architectural features;

(11) Any fixtures to the building such as signboard, and sun-shading devices.

5.3.3 Special Structures

The Structural Survey shall review the following:

(1) The correctness of structural information available;

(2) The presence of any unconventional structural elements which may require special attention and well-defined modification procedures;

(3) The possibilities of structural modification to enable efficient demolition traffic during demolition; and

(4) Any limitation on shoring and other temporary supports.

5.3.4 Investigation and Testing

In the case when no structural details are available, the Structural Survey shall include on-site measurement and retrieve any structural framing as much as practicable, performing the tests and exposing some key structural elements to facilitate check on the existing structure. This will allow the development of procedures that ensure the stability of the building at all stages during demolition.

5.4 Analytical Modelling

The analytical modeling of collapse considers the following factors: direction of the fall of the structure, types of falling, and back calculations.

5.4.1 Types of falling:

- Pancake-type collapse.
- Zipper-type collapse.
- Domino-type collapse.
- Section-type collapse.
- Instability-type collapse.
- Mixed-type collapse.

5.5 Design Drawings

5.5.1 Location of Explosives:

Drawings are made and copied for blasters and workmanship implanting the explosives in the sections (beams and columns) including all the critical sections and intended members to be demolished. Also, the depths of charges are specified with the types of wires and electric connection connected to the blasting caps and the charger or the blasting starter. Timing can be mentioned or displayed in the drawings for safety and accuracy.

5.5.2 Quantity of Explosives:

The number of explosives can be determined according to the blasting code and regulations, but the main factors affecting the number of explosives put are

- Type of explosive material
- Height of the structure

- Type of the structure (steel-concrete-masonry)
- Thickness of the sections
- number of critical sections
- safety of the around structures
- Amount of pressure produced by each force
- Velocity of the collapse of the intended demolishing structure
- The size of the production of the collapse
- Cost of the explosives

5.5.3 Time Sequence of Implosion:

The time sequence of the implosion can be coordinated through:

- The velocity of the collapse
- Type of the collapse
- Direction of falling
- Neighboring structures

5.6 Implementation

Putting the charges in the structure and connecting the wires, into the intended demolish members, then giving the warning signal, and blast

6 Case Study: The World Trade Centre 1 (WTC 1)

The collapsing airplane details are as shown in Figure 1:

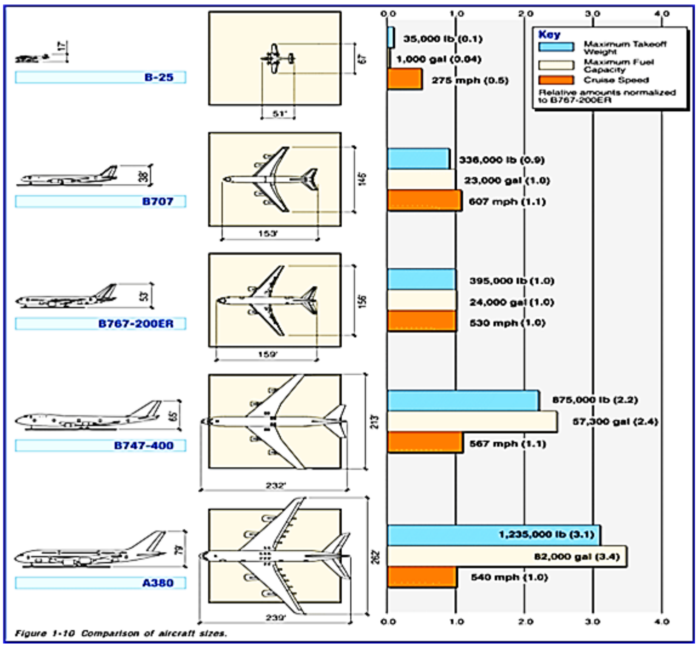

Figure 1-10 Comparison of aircraft sizes.

Figure 4

In planning a new building, an owner may request enhanced requirements in its design for events that are not anticipated by the building codes. In some cases, where unusual hazards such as explosive or toxic materials exist, the building codes prescribe special life safety and fire protection features. In most nonhazardous occupancies, these are not required.

Only a very small percentage of buildings have extraordinary provisions for unusual circumstances and there is a limit to the events that can be handled and the strength capacities that can be provided. Defense facilities, nuclear power plants, and overseas embassies are just a few examples where special strengthening features are requested by building owners in the design and engineering of their facilities.

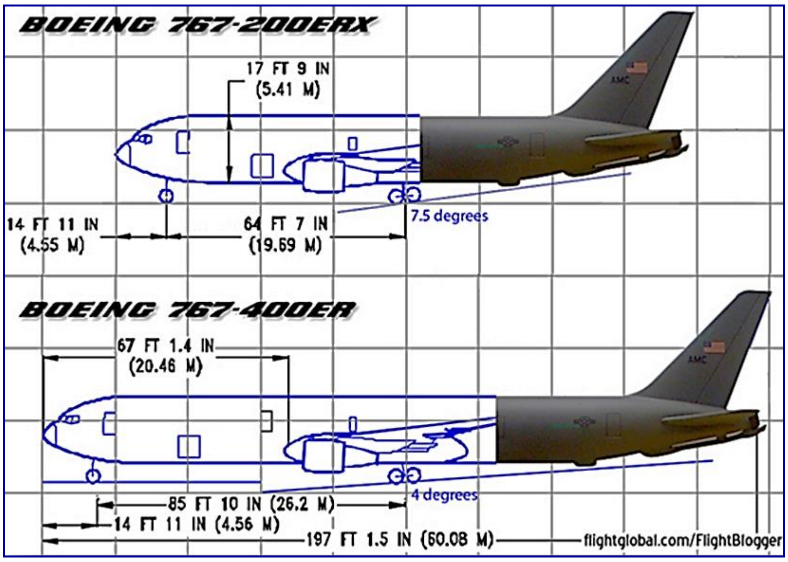

Figure 5

The WTC towers were the first structures outside of the military and the nuclear industries whose design considered the impact of a jet airliner, the Boeing 707. It was assumed in the 1960s design analysis for the WTC towers that an aircraft, lost in the fog and seeking to land at a nearby airport, like the B-25 Mitchell bomber that struck the Empire State Building on July 28, 1945, might strike a WTC tower while low on fuel and at landing speeds. However, in the September 11 events, the Boeing 767-200ER aircraft that hit both towers were considerably larger with significantly higher weight, or mass and traveled at substantially higher speeds.

The Boeing 707 that was considered in the design of the towers was estimated to have a gross weight of 263,000 pounds and a flight speed of 180 mph as it approached an airport; the Boeing 767-200ER aircraft that were used to attack the towers had an estimated gross weight of 274,000 pounds and flight speeds of 470 to 590 mph upon impact.

6.1 The Accident Sequence:

6.1.1 Collapse Analysis

Below is a summary of the WTC 1 collapse sequence by time instance. Keep in mind that each instant during the collapse occurred for only a fraction of a second. It would be helpful for you to review available videos of WTC 1 before continuing as it will allow you to visualize the descriptions in this paper. You can find these on the Internet for free. See the References section at the end of this paper for internet links.

6.1.2 Collapse Sequence

- Building is motionless with smoky fires.
- Collapse sequence begins.
- Tower antenna moves slightly east and south.
- First Row of explosions at floor 97 is seen.
- Upper building above floor 97 moves downward, second row of a dual set of explosions at Floor 97 are seen.
- Upper building moves downward, clouds expanding.
- Floor 98 impact floor 97, clouds expanding.
- More explosions, upper building moves downward in unison, clouds expanding.
- Floor 97 impacts floor 96, the expulsion of clouds, clouds expanding.
- Floor 96 impacts floor 95, the expulsion of clouds, clouds expanding.
- Collapse continues...

6.1.3 Observations

Individual floors collapsed in a demolition-like manner. All columns collapsed in near-unison and all four corners of the building fell in near-unison. There was no detectable fatiguing or bending of perimeter columns prior to collapse. What one sees is a motionless building rigidly retaining its shape, and then suddenly going into catastrophic, out-of-control collapse. There is no in-between state that would be typical of steel in fire.

The building's first point of collapse appears to be from the south side of the building. Columns on floor 97 did not bend prior to the observed explosions. Only floor 97 collapsed in the first moments. Floor 97 has dual rows of explosions around its perimeter at the top and bottom of its columns. When the upper building impacted and collapsed lower floors, the upper building floors did not buckle. There was no significant pause in collapse when the upper floors impacted floor 97, then floor 96.

6.2 Design Criteria

6.2.1 Dead load and Live Load

The total weight of structural steel in the two WTC towers is estimated to be 200,000 tons. NIST (National Institute of Standards and Technology) calculated the values shown in Table 2 below where these amounts do not include trusses outside the core, steel deck, concrete reinforcements, or grillages.

Weight of steel from supplier contracts		
Structural Component	Weight (short tons)	Weight per tower (short tons)
External Columns W/ Spandrels	**55 800**	**27 900**
Rolled Core Columns And Beams	**25 900**	**12 950**
Bifurcation Columns	**6 800**	**3 400**
External Box Columns	**13 600**	**6 800**
Core Box Below Floor 9	**13 000**	**6 500**
Core Box Above Floor 9	**31 000**	**15 500**
Slab Supports Below Grade	**12 000**	**6 000**
Total	**158 100**	**79 050**

Table (2)

Table 3 shows the summary of dead loads and live loads used in the structural analysis of WTC-1:

Type of Load	Loads (Kg/m2)
Core Dead Load	**100**
Outer Dead Load	**100**
Core Live Load	**200**
Outer Live Load	**200**

Table (3)

6.2.2 Wind Load

For High Rise Buildings, it's preferable to use ASCE 7-02 for calculating the main wind force resisting system of the building, from this point w started to calculate the Wind loads acting on WTC-1 with the Help of wind Contour Maps of the Building's Zone.

6.2.2.1 Design Data Terminologies

Wind Direction: The actual values of B and L Depend on the Wind Direction, and are defined as follows:

- B= horizontal dimension of building measured normal to wind direction.
- L=horizontal dimension of building measured parallel to wind direction.

Wind Speed: The Basic Design wind speed, v (mph) according to the Wind Speed Maps of the city. Building Classification: Classification of buildings and other structures for Flood, Wind, Snow, Earthquake …etc.

Exposure Category: Surface Roughness categories for the purpose of assigning Exposure Category.

Ridge Height, (hr):Total Height of Building including inclined Surface of Roof.

Eave Height, (he) :Clear Height of Building Excluding the height of the inclined surface of the roof.

Building Width & Building Length

Roof TYPE: Inclined of Mono slope (roof angle = 0o).

Topo. Factor, (Kzt) : The topographic Factor (Kzt) accounts for the effect of wind speed-up over isolated hills and escarpments (Kzt = 1.0 when H/Lh< 0.2).

Direct. Factor, (Kd): Wind Directionality factor (Kd) for Main wind-force resisting System = 0.85.

Enclosure: The building is Enclosed or opened.

Damping Ratio: The Damping Ratio (β) is the Percent of Critical damping. *Welded Steel β=0.01-0.02, * Reinforced Concrete β= 0.03-0.05, *Wood β=0.05-0.0.7.

Period Coefficient. (Ct): The building Period Coefficient (Ct) ranges from 0.02-0.035, it's used in the equation (T=Ct*h^3/4) for the assumed period of the building, where the natural frequency of the building (f) is determined by: (f=1/t).

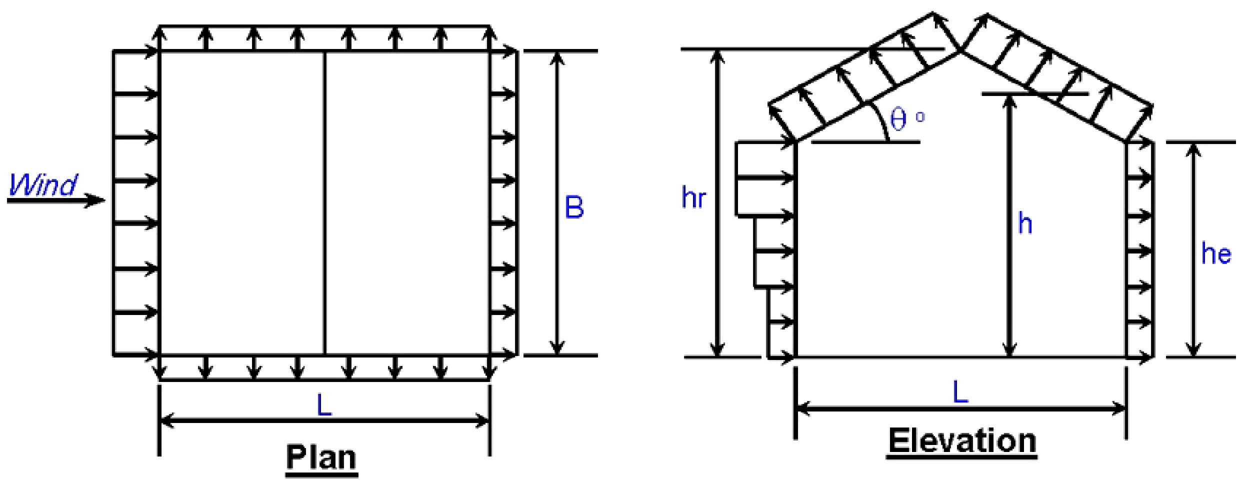

Figure 6

<u>Building Wind Load Calculations' Data:</u>

- Wind Direction = Normal.
- Wind Speed, V = 160 mph.
- Bldg. Classification = IV.
- Exposure Category = D.
- Ridge Height, hr = 1370.08 ft. (hr>= he).
- Eave Height, he = 1370.08 ft. (he <= hr).
- Building Width = 208.00 ft.
- Building Length = 208.00 ft.
- Roof Type = Mono slope.
- Topo. Factor, Kzt = 1.00.
- Direct. Factor, Kd = 0.85.
- Enclosed? (Y/N) Yes.
- Damping Ratio = 0.030
- (Suggested Range = 0.010-0.070).
- Period Coef. Ct = 0.0200
- (Suggested Range = 0.020-0.035).

6.2.3 Aircraft impact load

The twin towers WTC 1 & 2 were designed to withstand a collision with a Boeing 707, while the twin towers were hit by an airplane of model Boeing 767-200 ER. In designing the towers to withstand the impact of a Boeing 707, the designers would have assumed that the aircraft operated normally. So, they would have assumed that the aircraft was traveling at its cruise speed and not at the breakneck speed of some kamikaze. With this in mind, we can calculate the energy that the plane would impart to the towers in any accidental collision and also the Force of Impacting on the Members of the Tower.

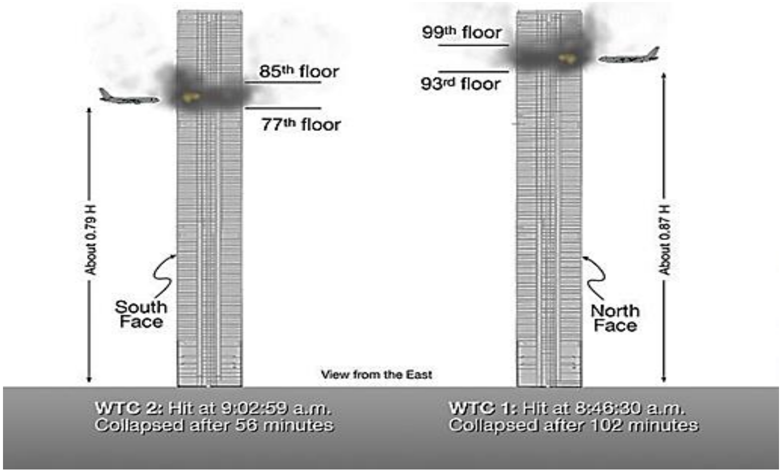

Figure 7

6.2.4 The Impact's Energy

- The maximum takeoff weight for a Boeing 707-320B is 152407 Kg.
- The maximum takeoff weight for a Boeing 767-200ER is 179168 Kg.
- The wingspan of a Boeing 707 is 44.50 m.
- The wingspan of a Boeing 767 is 47.54m.
- The length of a Boeing 707 is 46.63 m.
- The length of a Boeing 767 is 48.46 m.
- The Boeing 707 could carry 87.064 m3 of fuel.
- The Boeing 767 could carry 90.774 m3 of fuel.
- The cruise speed of a Boeing 707 is 607 mph = 976Km/hr.
- The cruise speed of a Boeing 767 is 530 mph =1250Km/hr.
- Jet fuel density=820kg/m3
- Boeing 707 fuel weight=density of fuel * volume of used fuel=820*87.064=71392.84kg
- Boeing 767 fuel weight= density of fuel *volume of used fuel=820*90.774=74434.68kg
- Total mass of Boeing 707=152407.036+71392.84=223799.51kg
- Total mass of Boeing 767=179168.98+74434.68=253603.66kg

So, the Boeing 707 and 767 are very similar aircraft, with the main differences being that the 767 is slightly heavier and the 707 is faster. In designing the towers to withstand the impact of a Boeing 707, the designers would have assumed that the aircraft was operated normally.

So, they would have assumed that the aircraft was traveling at its cruise speed and not at the breakneck speed of some kamikaze. With this in mind, we can calculate the energy that the plane would impart to the towers in any accidental collision.

The kinetic energy released by the impact of a Boeing-707 at cruise speed is =0.5x336, 000x (890) ^2/32.174 =4.136billion.ft.lbs.force (5,607,720Kilojoules).

The kinetic energy released by the impact of a Boeing-767 at cruise speed is=0.5x395, 000x (777) ^2/32. 174=3.706billion.ft.lbs.force (5,024,650 Kilojoules).

From this, we see that under normal flying conditions, a Boeing 707 would smash into the WTC with about 10 percent more energy than would the slightly heavier Boeing 767. That is, under normal flying conditions, a Boeing 707 would do more damage than a Boeing 767. In conclusion, we can say that if the towers were designed to survive the impact of a Boeing 707, then they were necessarily designed to survive the impact of a Boeing 767. So, what can be said about the actual impacts?

The kinetic energy released by the impact of AA Flight 11 was = 0.5 x 395,000 x (689)^2/32.174 = 2.914 billion ft-lbs. force (3,950,950 Kilojoules).

This is well within the limits that the towers were built to survive. So, the North tower fall because The kinetic energy released by the impact of UA Flight 175 was = 0.5 x 395,000 x (865) ^2/32.174 = 4.593 billion ft-lbs. Force (6,227,270 Kilojoules). This is within 10 percent of the energy released by the impact of a Boeing 707 at cruise speed. So, it is also a surprise that the 767 impact caused the South tower to fall.

6.2.5 The Impact's Force

- F=mass*acceleration=mass*(velocity/time) = (mass*velocity)/time=momentum/time
- Assume time of impact is minimum=1 second
- Assume final velocity= Zero (at the instance of impact)
- Force of the impact (Boeing 707) =60727997.04 N=60727.99704 Kn.
- Force of the impact (Boeing 767) =59850463.76 N=59850.46376 Kn.
- Overall, it comes as a great surprise that the impact of a Boeing 767 bought down either tower.

6.2.6 Thermal Effect of heat-induced due to Craft's impact

- Max. Flight Duration = 5.0 Hours.
- Rate of Consumed Fuel per Hour = 7000Kg.
- Mass of Fuel consumed for Takeoff and Flight up to Impact = 5000 Kg.

- Margin of Safety = 10000kg.
- Expected Mass of Fuel = 5(7000) +10000- 5000 = 40000 Kg.
- Net Energy Content = 47000000 J/ kg.
- Heat Released = 47000000 X 40000 = 188x E+12 J.
- % of Fuel Consumed Out of the Building = 10%.
- % of Fuel Consumed Out of the Building = 90%.
- % of Building Affected (5 floors) = 0.0455%.
- Weight of Steel Affected = 0.0455 (2E+08) = 9100000 kg.
- Steel Calorific Value = 450.
- Expected Average Temperature Rise = (0.90*1.88E+12) / (450*9.1E+06) = 413.1 ºC

6.3 Analysis of Result:

Based on the above investigation phases and calculations, The most probable causes of the collapse of the WTC1 are design and construction causes, environmental causes, and/or accidental causes.

6.3.1 Case (1) Sound Structure:

Two cases were considered according to the sound of the structure of WTC1.

The first case where WTC 1 was considered structurally sound

In this case, the statical system of the building was facing the following straining action:

- Straining action imposed due to Dead loads +Live loads.
- Straining action imposed due to wind loads of speed of 160 Km/hr.
- Straining actions imposed to hitting of aircraft of total weight 150t and speed 850km/hr.

6.3.2 Case (2) Damaged Structure:

The hitting of the aircraft caused a locally damaged area between floor No.92 and floor No.98 Documented videos were used to model the damaged area the defective steel columns and beams were removed from the original modal.

The following cases of loading conditions were considered:

- The straining action induced due to Dead and Live loads.
- The straining action induced due to Wind Loads.
- The straining action induced due to Temperature due to the explosion of the fuel tank of the aircraft.

In all studied cases the maximum sway at top of the tower WTC1 as well as the strength ratio ($\frac{M3-3}{M3-3D}$) at different vertical sections at the edge and the center was considered.

7 Conclusions and Recommendations

Based on the above investigation phases and Analysis of Result, In general, the conclusions are as follows:

- Building implosion is considered one of the best techniques that should be widely used.
- The application of the implosion technique needs precise analytical modeling followed by an accurate implementation by highly skilled persons.
- The finite element analysis source code "ETABS" was used to examine the role of WIND LOAD and IMPACT LOAD on the soundness of the skeleton of WTC1 before and after being hit by the aircraft.
- The incorporation of analytical modeling, blast loading effects, and controlled demolition strategies has provided a comprehensive understanding of the critical factors influencing the effectiveness and safety of demolition activities. The case study on the World Trade Center WTC1 has offered valuable insights into the practicalities of implementing such techniques and the challenges faced in critical cases.
- The results of the finite element analysis indicated that the structure of the WTC1 was safe in terms of horizontal sway and relative strength when wind and impact loads are considered.
- The thermo-analysis showed that the explosion of the fuel tank of the aircraft resulted in increasing the temperature of the steel columns and beam by about 400Co.
- After analyzing the structure exposed to aircraft hitting, the damaged building was structurally safe under the combination of wind and temperature loads.
- Field Observations based on the analysis of the documentation, indicated that the collapse of WTC1 was mainly due to the implementation of the Controlled implosion Technique.

Overall, by embracing the lessons learned from this study and continuing to develop new approaches, the construction industry can expect to progress towards more efficient, environmentally responsible, and cost-effective demolition operations. The findings presented here make a significant contribution to the ongoing quest for excellence in the demolition and construction fields, ultimately driving the industry towards a safer, greener, and more sustainable future.

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