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CONTROLLING THE DEMOLITION OF EXISTING STRUCTURES: AN APPROACH TO ANALYZE THE COLLAPSE OF THE WORLD TRADE CENTER NORTH TOWER WTC1

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ABSTRACT

Large buildings, tall chimneys, smokestacks, and increasingly some smaller structures may be destroyed by building implosion using explosives. Imploding a building is very fast and an expert can ensure that the building falls into its own footprint, so as not to damage neighboring structures. Implosion techniques can be applied on masonry structures, reinforced concrete structures, steel structures, and composite structures. On the contrary of the true implosion, building implosion techniques do not rely on the difference between internal and external pressure to collapse a structure. Instead, the technique weakens or removes critical supports so that the building can no longer withstand the force of gravity and falls under its own weight.

The mechanism of collapse of the towers of the World Trade Center WTC is of interesting matter and investigation that is more precise should be implemented to understand how those towers were collapsed. The present study provides an attempt to understand the mechanism of the collapse or demolition of the north tower WTC1from the structural point of view. Analytical modeling comprising the sound and damaged building was considered. Wind load, impact load, temperature effect, and combinations of different loads were taken into account. Digital Image Analysis DIA of documented video was very helpful when its results are related to the results of the analytical study. The results of the analytical study showed the structural safety of WTC1 against wind load, impact load and the combination of loads. The overall structural safety of the WTC1 was insignificantly affected due to hitting of aircraft. The average temperature rise due to the explosion of fuel tank was about 413ºC. Analysis of the documented video showed that the mode of collapse of WTC1 was identical to the collapse of buildings demolished using the controlled demolition technique.

Keywords: Controlled Demolition, Thermite, North Tower of World Trade Centre (WTC1), Digital Image Analysis (DIA), Sound Structure (SS), Damaged Structure (DS).

1. INTRODUCTION

1.1. Properties of a Controlled Demolition Collapse

Controlled demolition has distinguished characteristics related to the type of deformation (complete or partial deformation), production of large amounts of dust, safety of neighbor, structural failure, seismic minor effects, and the time and direction to fall. The time t required for an object to fall from a height h (in a vacuum) is given by the formula $\mathbf{t} = \sqrt{\frac{2\,x\,h}{g}}$, where g is the acceleration due to gravity. Thus, an object falling from the top of a structure is calculated assuming that the structure has become free in the space due to loosening of all restrains in the structure [1, 2]. it would usually take ten free floors to fall is about 1 to 2 seconds, so it would be noticeable for a controlled demolition collapse to appear as free falling. Controlled direction and shape of falling are monitored such as Pancake-type collapse, Zipper-type collapse, Domino-type collapse, Section-type collapse, Instability-type collapse, Mixed-type collapse [3, 4].

1.2. Prediction of Blast Pressure

Blast wave parameters for conventional high explosive materials have been the focus of a number of studies during the 1950's and 1960's. A full discussion and extensive charts for predicting blast pressures and blast durations are given [5, 6].

1.3. Velocity of Detonation

The velocity of detonation is defined as the velocity of propagation of reaction in the mass of the explosive. Most commercial mining explosives have detonation velocities ranging from 1800 m/s to 8000 m/s. Today, velocity of detonation can be measured with accuracy. Together with density it is an important element influencing the yield of the energy transmitted (for both, atmospheric overpressure and ground acceleration) [7, 8].

1.4. Thermite Reaction

The thermite is simply a mixture of metal, often called the "fuel" and an oxidizer. Some "fuels" that can be used include aluminum, magnesium, calcium, titanium, zinc, silicon, and boron and others. One commonly used fuel in thermite mixtures is aluminum, because of its high boiling point. The oxidizers can be boron(III) oxide, silicon(IV) oxide, chromium(III) oxide, manganese(IV) oxide, iron(III) oxide, iron(II,III) oxide, copper(II) oxide, and lead(II,III,IV) oxide and others.

$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$

The products are aluminum oxide, free elemental iron, and a large amount of heat. The reactants are commonly powdered and mixed with a binder to keep the material solid and prevent separation. A mixture of thermite and sulfur produces thermite, which lowers the melting point of the iron it contacts when reacting by forming a eutectic system. This is useful in cutting through steel. Nano-thermite, also called "super-thermite", is the common name for a subset of Meta-stable Intermolecular Composites (MICs) characterized by a highly exothermic reaction after ignition. Nano-thermites contain an oxidizer and a reducing agent, which are intimately mixed on the nanometer scale [3, 9].

1.5. Key Elements of Performing Controlled Demolition

The strategy of performing controlled demolition of a building comprised five key elements, which are inspection of the considered structure and the surrounding buildings, cad drawing of the structural system, evaluation of structure, analytical modeling, and selection of technique of demolition, decision-making and implementation.

2. CASE STUDY: THE WORLD TRADE CENTRE NORH TOWER WTC1

2.1. Building Description

The World Trade Center was a complex of seven buildings on 16-acres, constructed and operated by the Port Authority of New York and New Jersey (PANYNJ. Faced with the difficulties of building to unprecedented heights, the engineers employed an innovative structural model: a rigid "hollow tube" of closely spaced steel columns with floor trusses extended across to a central core. The columns, finished with a silver-colored aluminum alloy. The height of WTC1 was 417m. the architect is Minoru Yamasaki, Emery Roth and Sons consulting and the engineering was carried out by John Skilling and Leslie Robertson of Worthington, Skilling, Helle and Jackson [6].

2.2. Structural System of WTC-1

2.2.1. The Perimeter Walls

Figure (1) showed that the towers' perimeter walls comprised dense grids of vertical steel columns and horizontal spandrel plates. These, along with the core structures, supported the towers. In addition to supporting gravity loads, the perimeter walls stiffened the towers against lateral loads, particularly those due to winds. Richard Roth, speaking on behalf of the architectural firm that designed the towers, described each of the perimeter walls as essentially "a steel beam 209' deep." Regardless, it is clear that the core structures were designed to support several times the weight of each tower by themselves. As the diagram and photograph illustrate, the perimeter wall structures were assembled from pre-fabricated units consisting of three column sections and three spandrel plate sections welded together. Adjacent units were bolted together: column sections were bolted to adjacent columns above and below, and spandrel plate sections were mated with adjacent sections on either side with numerous bolts. There were 59 perimeter columns on each face of the towers, and 1 column on each corner bevel, making 240 perimeter columns in each tower. Figure (2) showed that like the core columns, the thickness of the perimeter columns tapered from the bottom to the top of the towers. The illustrated cross-sections represent columns near the top, and near the mid-section of the towers. The outside of the tower was covered by a frame of 14-inch-wide steel columns; the centers of the steel columns were 40 inches apart [6].

Figure (1): The perimeter wall

2.2.2. Core Columns

The core columns were steel box-columns that were continuous for their entire height, going from their bedrock anchors in the sub-basements to near the towers' tops, where they transitioned to H-beams. The sections were fabricated by mills in Japan that were uniquely equipped to produce the large pieces. Some of the core columns apparently had outside dimensions of 36 inches by 16 inches. Others had larger dimensions, measuring 52 inches by 22 inches. The core columns were oriented so that their longer dimensions were perpendicular to the core structures' longer 133foot -wide sides. Like the perimeter columns and like steel columns in all tall buildings the thickness of the steel in the core columns tapered from bottom to top. Near the bottoms of the towers, the steel was four inches thick, whereas near the tops it may have been as little as 1/4th inch thick. Figure (2) showed a cross-section of one of the smaller core columns from about halfway up a tower, where the steel was about two inches thick. Figure (3) showed the base of one of the larger core columns, where the steel was five inches thick. The bases of the columns also had slabs of steel running through their centers, making them almost solid [6].

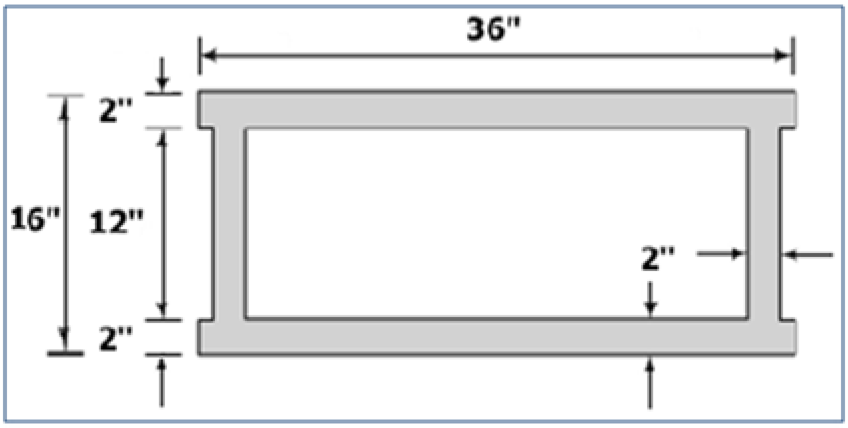

Figure (2): The dimensions of the smaller columns at half way up to the lower

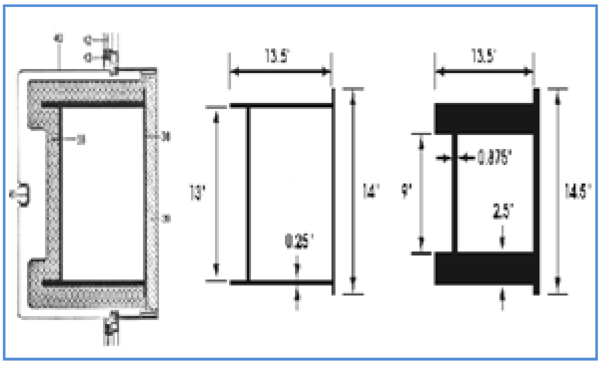

Figure (3): The base of the one of the larger columns

2.2.3. Floors System

Figure (4) showed that the floor diaphragms consisted of lightweight concrete slabs of 10cm thickness poured onto corrugated steel pans, which were supported by trusses. Primary double trusses were interwoven with transverse secondary trusses. The primary trusses were 900 mm deep, and spaced on 2.04 m centers. The floors were the only major part of these mostly steel buildings that contained concrete. There is evidence, however, that certain floors had solid steel-frame support structures rather than light open trusses, such as the following passage from the Engineering News-Record: On the 41st and 42nd floors, both towers will house mechanical equipment. To accommodate the heavy loads, the floors are designed as structural steel frame slabs. All other floors from the ninth to the top (except for 75 and 76, which will also carry mechanical equipment) have typical truss floor joists and steel decking. The truss ends rested on steel plates that were both welded and bolted to the top chords of the trusses and attached via bolted damping units to their lower bottom chords. Every floor has a network of steel trusses, horizontal and vertical trusses crossing each other forming a rectangular grid. Corrugated steel pans were attached to the top of the trusses including concrete to form strong and fireproof floors. These trusses repeated every 3,66m. For the exterior columns, there was a column each 1m all through the building. Steel plates were used to support exterior columns forming a shape of steel straps, where these steel straps repeated every 3,66m [6].

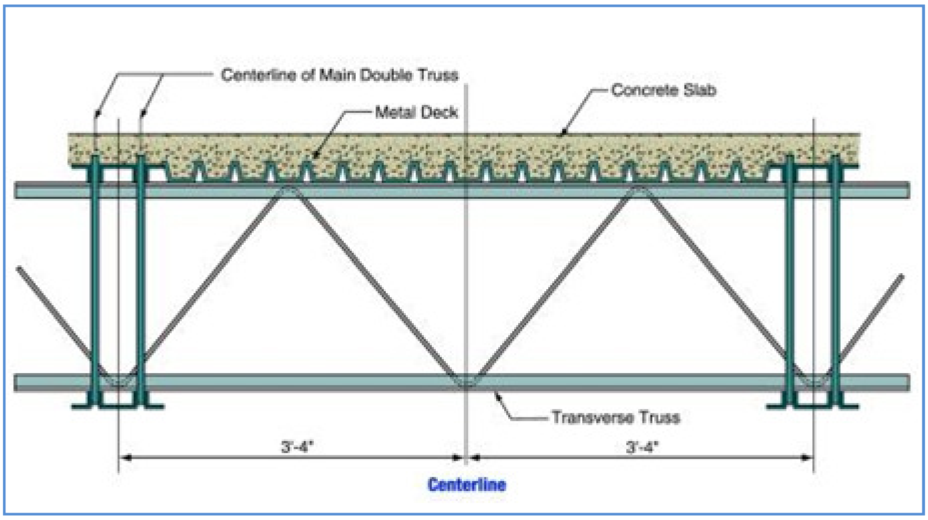

Figure (4): The floor system

2.2.4. The Bathtub (Foundation)

The World Trade Center contained a deep basement, the so-called bathtub. It was a skewed rectangle with sides about 980 and 520 feet, and a depth of about 7 stories. The bathtub is the 9-block area of the World Trade Center site that is excavated down to bedrock and hard soils and ringed by the slurry wall. The bathtub was created to enable the building of the Twin Towers' foundations, and was ultimately filled with seven stories of basements housing the parking garage, mall, and building services. Since the ground water level at the World Trade Center site was just a few feet below the surface, while bedrock was about 70 feet below the surface, creating the bathtub required first building a 7-story dam below the water level of the adjacent Hudson River. Ground excavated to make the bathtub was deposited west of West. The subbasement structures, once constructed, provided additional bracing of the walls [11].

2.2.5. The Hat Trusses

The fourth primary structural subsystem in each tower was the hat truss, a lattice of large diagonal I-beams that connected the perimeter walls to the core structure between the 107th floor and roof. This structure was also known as the "outrigger truss system." The hat truss structure strengthened the core structure, unified the core and perimeter structures, and helped to support the large antenna mounted atop the North Tower. The hat truss, which contained both horizontal and sloping I-beams, connected core columns to each other, and connected the core to the perimeter walls. Most the beams connected core columns to each other, while between a set of sixteen horizontal and sloping beams spanned the distance the core and perimeter walls. Eight of these, the outrigger trusses, connected the corners of the core to the perimeter walls, while another eight connected the centers of the core's periphery to the perimeter walls [6].

3. THE COLLAPSE CATASTROPHE

3.1. The Time and Place Intervals of the Accident

A Boeing 767-200ER series aircraft hit between the 94th and 98th floors roughly at the center of the north face at 08:46. The plane crashes caused considerable damage to principal structural components and multiple floor fired above the impacted floors. A fireball observed due to the explosion of the fuel tank, and then the north tower collapsed around 10:30 am. Figure (5) and (6) showed the details of Boing 767-200ER series that hit two towers as well as the locations of hitting.

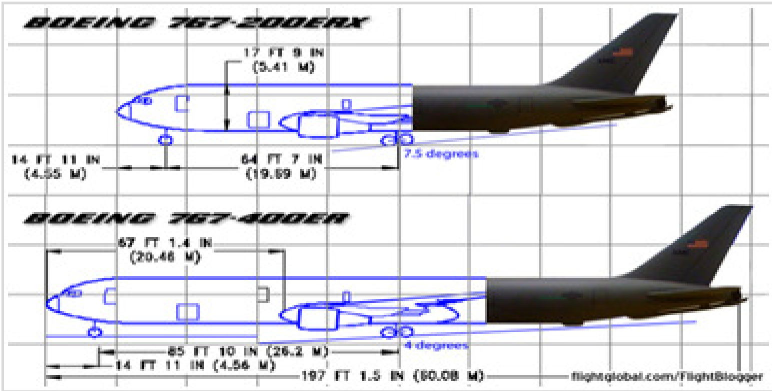

Figure (5): The Boeing 767-200ER

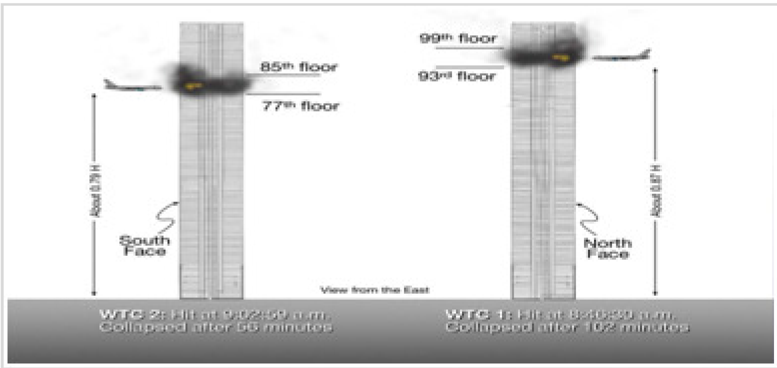

Figure (6): The Location of hitting towers WTC1 and WTC2

3.2. The Collapsing Airplane Details

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 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 traveling 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. Information about flight description was given in Table (1) [10].

Table (1): Flight description

Flight Description	American airlines Flight 11
Departure Airport	Logan International Airport in Boston, Massachusetts
Arrival Airport	Los Angeles International Airport in Los Angeles, California
Airplane Model	Boeing 767-223ER
The tower crashed	The North tower (WTC 1)
Time of departure	08:14 am September 11, 2001
Time of crash	08:46 Am
Time of collapse	10:29 Am

3.3. 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 has been seen is a motionless building rigidly retaining its shape, and then suddenly goes into catastrophic 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, upper building floors did not buckle. There was no significant pause in collapse when the upper floors impacted floor 97, then floor 96.

4. DESIGN CRITERIA

4.1 Dead load and Live Load

Table (2) showed the considered loads that were taken in back calculations. The total weight of steel structure in the two WTC towers was estimated to be 200,000 tons. NIST (National Institute of Standards and Technology) calculated the values shown in the Table (2) where these amounts do not include trusses outside the core, steel deck, concrete reinforcements or grillages. The following table shows the Summary of dead loads and live loads used in the structural analysis of WTC-1. Materials characteristics that were taken in the analysis were shown in Table (3).

Table (2): Weight of steel from supplier contracts

Structural component	Weight used for the two towers (short tons)	Weight per tower (short tons)
External Columns W/ Spandrels	55800	27900
Rolled Core Columns And Beams	25900	12950
Bifurcation Columns	6800	3400
External Box Columns	13600	6800
Core Box Below Floor 9	13000	6500
Core Box Above Floor 9	31000	15500
Slab Supports Below Grade	12000	6000
Total	158100	79050

Table (3): The characteristics of used materials in the back calculation

PROPERTY	SYMBOL	VALUE
Density	γ	2.5 t/ m^3
Modulus of elasticity	E	2200000 t/m^3
Poisson's ratio	μ	0.2
Coefficient of thermal expansion	£	$9.9x10^{-6}$
Shear modulus	G	1054604.44 t/ m^3
Compressive strength	f_c	2812.3 t/ m^2
Steel yield strength	f_y	42184.18 t/ m^2

4.2. Wind Load

For High Rise Buildings, it's preferably to use ASCE 7-02 for calculating the main wind force resisted by the system of the building. From this point, it was started to calculate the wind loads acting on WTC-1 with the help of wind contour maps of the building's zone. Wind Direction = Normal, Wind Speed V = 160 Km/hr, 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 = Monoslope, Topo. Factor Kzt = 1.00, Direct. Factor Kd = 0.85,Damping Ratio = 0.030, (Suggested Range = 0.010-0.070, Period Coef. Ct = 0.0200 (Suggested Range = 0.020-0.035).

4.3. Air Craft 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. The designers would have assumed that the aircraft was operated normally that the aircraft was traveling at its cruise speed and not at the break neck speed of some kamikaze. Accordingly, energy of the impact force could be calculated as follows:

F=mass*acceleration, taking the time of impact 1 sec for getting the worst condition, then:
Force of the impact (Boeing 707) =60727.99704 KN.
Force of the impact (Boeing 767) =59850.46376 KN.

4.4. Thermal Effect of Heat Induced Due To Impact

Expecting the maximum flight duration is 5.0 hours, the rate of consumed fuel per hour is 7000Kg, the mass of fuel consumed for Takeoff and flight up to Impact is 5000 Kg, the margin of safety is 10000 kg, and steel calorific is 450, then the expected mass of fuel is 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 Inside 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

4.5. Modeling of the Problem

The concrete slab was treated as isotropic material and modeled using shell element. The columns and beams were modeled using frame element. Dimensions of the steel section are as given in the text. Two cases were considered in the analysis, sound structure SS, and damaged structure DS. Figures (7) and (8) explain the considered loads and cases of loading that were taken in the redesign procedure.

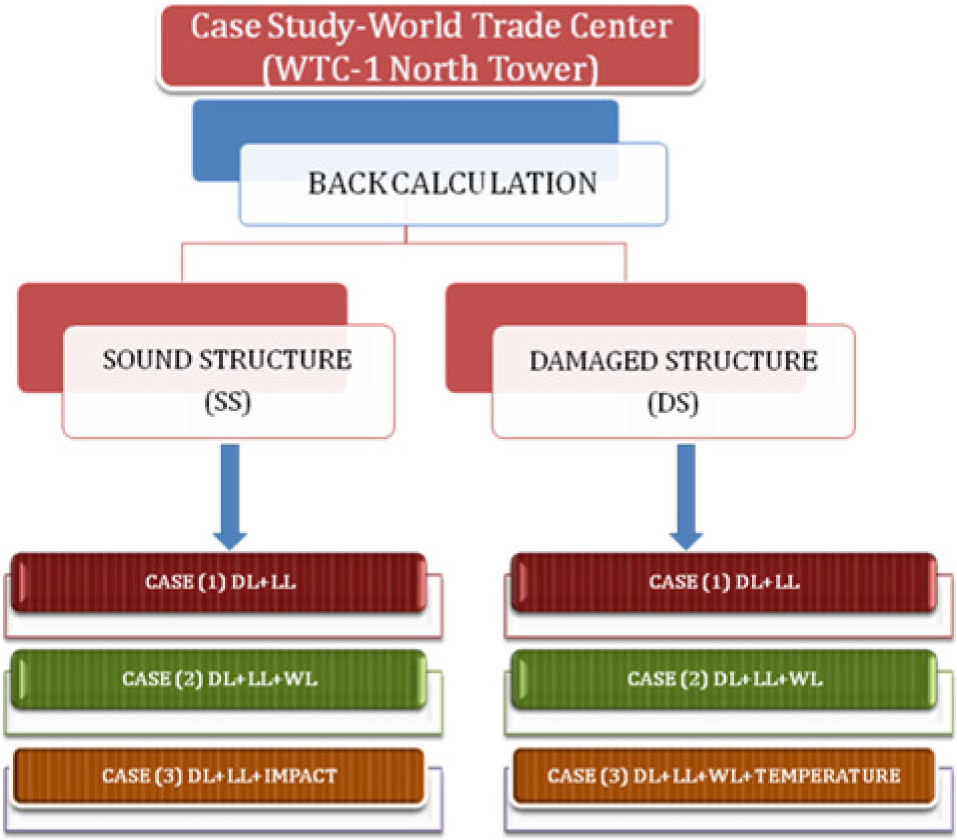

Figure (7): Cases of loading of sound and damaged structures

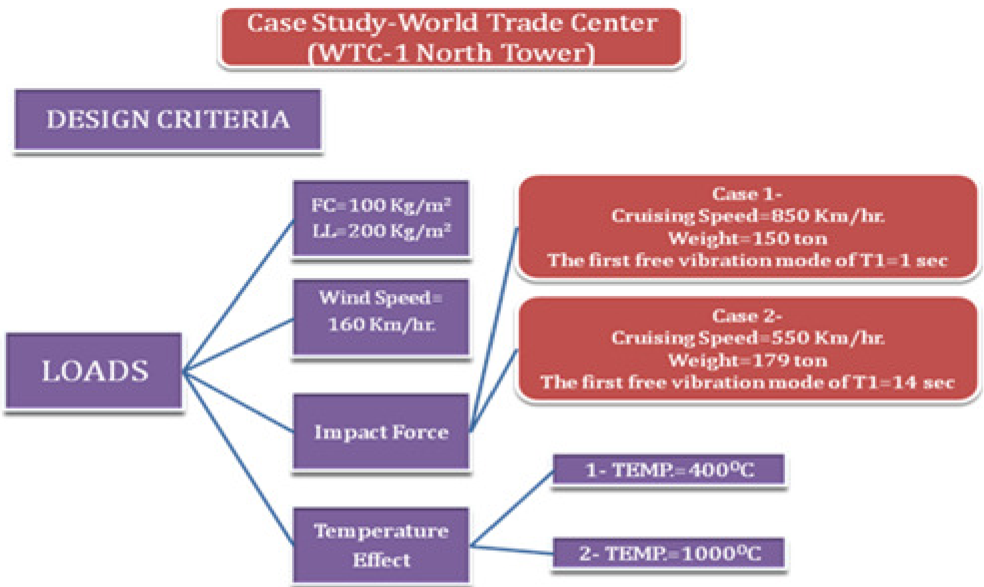

Figure (8): The considered loads and temperatures in the redesign procedure

4.5.1. Case (1) Sound Structure SS:

Table (4) and Figure (9) showed the computed maximum horizontal displacement for the case of sound structure (SS).Three cases of loading were considered and the straining actions were computed. The wind speed considered in calculation was 160Km/hr. Back calculation of SS for impact effect was based on air craft of total weight 150t and speed 850Km/hr. The impact effect on SS was verified by Bazant [11, 12], where the equivalent mass was taken141x10^6 Kg with equivalent speed 0.7km/hr. (0.19 m/sec). The response was assumed to be dominated by the first free vibration mode of period T_1= 14 sec based on estimating very roughly the bending stiffness of the tower and approximating it as a vibrating cantilever of a uniform mass distribution. This gives maximum defective ($V_0T/2\pi$) of 0.4 m, which is well within the range of the elastic behavior of the tower.

Table (4): The computed maximum horizontal displacement of the cases of loading

CASE	MAX Δ (m)	ALLOWABLE Δ (m)
DL-SS	0.180	1.00
DLW-SS	0.608	
DLC-1	1.296	
DLC-2	0.264	
DL-DS	0.189	
DLW-DS	0.589	
DLWT-DS(400)	0.589	
DLTW-DS(1000)	0.3022	

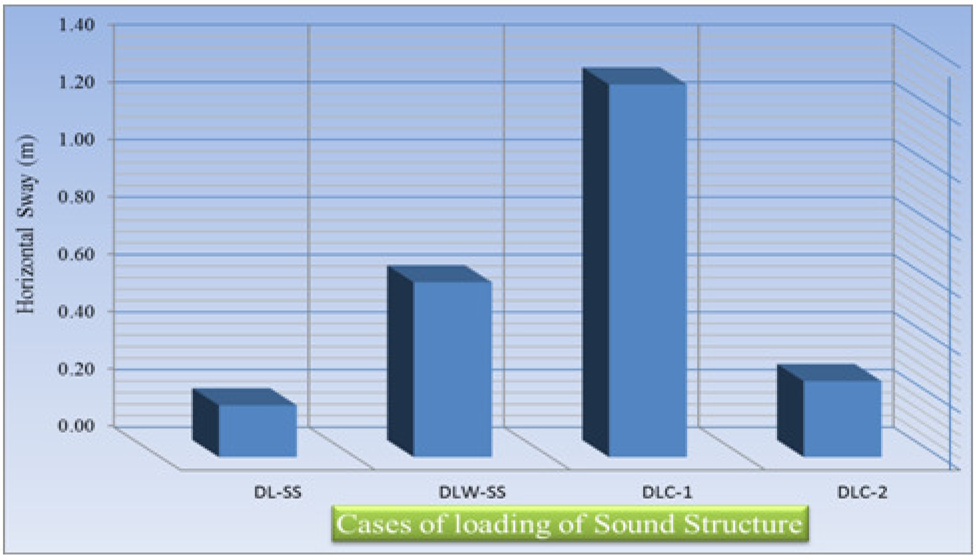

Figure (9): Maximum horizontal displacement for the case of sound structure (SS)

4.5.2. CASE (2) Damaged Structure DS:

Table (4) and Figure (10) showed the computed maximum horizontal displacement for the case of damaged structure (DS). The hitting of the aircraft caused locally damaged area between floor No.92 and floor No.98 the columns and beams were modeled using frame element. Documented videos were used to model the damaged area. The defected steel columns and beams where removed from the original model. The straining actions induced due to dead and live loads, wind loads, and temperature due to the explosion of the fuel tank of the aircraft were calculated. In all studied cases, the maximum sway at top of the tower WTC-1 as well as the strength ratio $(\frac{M(3-3)}{M(3-3)D})$ at different vertical sections at the corner and the center were considered.

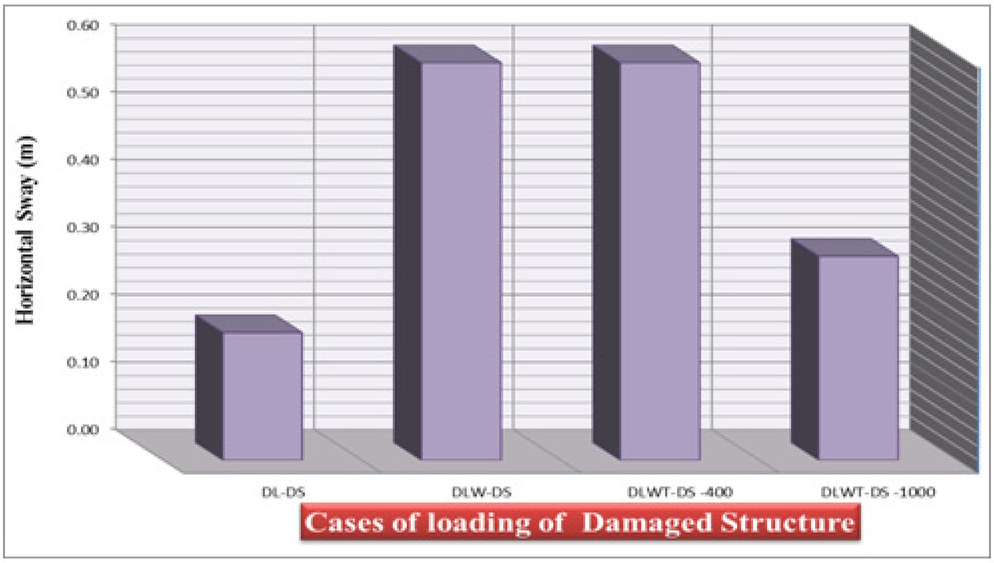

Figure (10): Maximum Horizontal Displacement for the Case of Damaged Structure (DS)

5. RESULTS AND ANALYSIS

The results in Table (4) and Figures (9) and (10) showed the computed maximum horizontal displacement due to the different loading conditions and their combinations for both sound and damaged structures. For sound structures, subjecting the tower to dead and live loads led to the lowest horizontal displacement, which is 0.180m. Contrary, the case of subjecting the tower to dead, live, and impact loads induced horizontal displacement of maximum value 1.296m. It should be noted that, this value was the extreme expectation of displacement as it based on time of hitting of one second. The reasonable value of horizontal displacement was as calculated based on Bazant assumption, which resulted in horizontal displacement value 0.264m.

For damaged structures, loads were considered and as expected, the case of dead and live loads resulted in horizontal displacement of 0.189m which was relatively close to that value of the case of sound structure. Similar result was noted for the case of dead, live, and wind loads where the horizontal displacements were 0.589m and 0.608m for damaged and sound towers respectively. Combining the temperature effect to the dead, live, and wind loads resulted in horizontal displacement values 0.589m and 0.302m for temperature rises 400ºCand 1000ºC.

Tables (5) to (8) showed the strength ratio $(\frac{M(3-3)}{M(3-3)D})$ at corner and central columns of the sound structure. Central columns showed relatively strength values less than one. Similar trend was observed for corner columns with the exception of the columns at the hit area. Table (9) to (12) showed the relative strength values for the case of damaged structure. For the first three cases where the damaged structure was exposed to dead loads, live loads, wind load, and temperature rise of 400ºC, the relative strength values were less one. For the purpose of comparison, the relative strength was computed with changing the temperature rise from 400ºC to 1000ºC. The results showed significant decrease in the strength where the relative strength ranged from 54.89 at the eightieth floor to 133.09 at the thirtieth floor. In fact this comparison suggested that high rise in temperature approaching the melting point of the steel is needed to cause the mechanism of collapse of the steel structure. This hypothesis is impossible to occur as hitting the tower made the inside space exposed to outside air temperature.

As indicated in item 4.4, the expected average temperature rise was 413.1ºC. It is clear that such rise in temperature of steel structure caused strength loss but it would not lead to the mechanism of collapse of the steel structure, especially if it was known that the WTC was exposed to fire before and it was repaired.

Table (5): STRENGTH RATIO OF CASE (1) OF CORNER AND CENTER COLUMNS

CASE 1 (DL-SS)				
DEAD+LIVE (SOUND STRUCTURE)				
CORNER COLUMNS				
NUMBER	**COLUMN**	**STORY**	**RATIO** $(\frac{M(3-3)}{M(3-3)\ D})$	**CHECK**
1	C166	110	0.743	PASS
2	C166	100	0.701	PASS
3	C166	90	0.686	PASS
4	C166	80	0.525	PASS
5	C166	70	0.880	PASS
6	C166	60	0.799	PASS
7	C166	50	0.769	PASS
8	C166	40	0.784	PASS
9	C166	30	0.878	PASS
10	C166	20	0.096	PASS
11	C166	10	0.032	PASS
12	C166	2	0.004	PASS
CASE 1 (DL-SS)				
DEAD+LIVE (SOUND STRUCTURE)				
CENTER COLUMNS				
NUMBER	**COLUMN**	**STORY**	**RATIO** $(\frac{M(3-3)}{M(3-3)\ D})$	**CHECK**
1	C138	110	0.919	PASS
2	C138	100	0.799	PASS
3	C138	90	0.251	PASS
4	C138	80	0.178	PASS
5	C138	70	0.262	PASS
6	C138	60	0.267	PASS
7	C138	50	0.271	PASS
8	C138	40	0.272	PASS
9	C138	30	0.266	PASS
10	C138	20	0.071	PASS
11	C138	10	0.054	PASS
12	C138	2	0.002	PASS

Table (6): STRENGTH RATIO OF CASE (2) OF CORNER AND CENTER COLUMNS

CASE 2 (DLW-SS)				
DEAD+LIVE+WIND (SOUND STRUCTURE)				
CORNER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\,D})$	CHECK
1	C166	110	0.935	PASS
2	C166	100	0.924	PASS
3	C166	90	0.914	PASS
4	C166	80	0.889	PASS
5	C166	70	0.824	PASS
6	C166	60	0.733	PASS
7	C166	50	0.691	PASS
8	C166	40	0.691	PASS
9	C166	30	0.758	PASS
10	C166	20	0.120	PASS
11	C166	10	0.016	PASS
12	C166	2	0.002	PASS
CASE 2 (DLW-SS)				
DEAD+LIVE+WIND (SOUND STRUCTURE)				
CENTER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\,D})$	CHECK
1	C138	110	0.915	PASS
2	C138	100	0.786	PASS
3	C138	90	0.243	PASS
4	C138	80	0.170	PASS
5	C138	70	0.149	PASS
6	C138	60	0.240	PASS
7	C138	50	0.241	PASS
8	C138	40	0.239	PASS
9	C138	30	0.232	PASS
10	C138	20	0.099	PASS
11	C138	10	0.011	PASS
12	C138	2	0.002	PASS

Table (7): STRENGTH RATIO OF CASE (3) OF CORNER AND CENTER COLUMNS

CASE 3 (DLCEAFT IMPACT-1-SS)				
DEAD+LIVE+ CEAFT IMPACT-1 (SOUND STRUCTURE)				
CORNER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C166	110	2.694	FAIL
2	C166	100	12.385	FAIL
3	C166	90	1.250	FAIL
4	C166	80	0.835	PASS
5	C166	70	0.667	PASS
6	C166	60	0.584	PASS
7	C166	50	0.549	PASS
8	C166	40	0.551	PASS
9	C166	30	0.609	PASS
10	C166	20	0.129	PASS
11	C166	10	0.014	PASS
12	C166	2	0.003	PASS
CASE 3 (DLCEAFT IMPACT-1-SS)				
DEAD+LIVE+ CEAFT IMPACT-1 (SOUND STRUCTURE)				
CENTER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C138	110	0.915	PASS
2	C138	100	0.786	PASS
3	C138	90	0.243	PASS
4	C138	80	0.170	PASS
5	C138	70	0.149	PASS
6	C138	60	0.240	PASS
7	C138	50	0.241	PASS
8	C138	40	0.239	PASS
9	C138	30	0.232	PASS
10	C138	20	0.099	PASS
11	C138	10	0.011	PASS
12	C138	2	0.002	PASS

Table (8): STRENGTH RATIO OF CASE (4) OF CORNER AND CENTER COLUMNS

CASE 4 (DLCEAFT IMPACT-2-SS)				
DEAD+LIVE+ CEAFT IMPACT-2 (SOUND STRUCTURE)				
CORNER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C166	110	2.694	FAIL
2	C166	100	12.385	FAIL
3	C166	90	1.250	FAIL
4	C166	80	0.835	PASS
5	C166	70	0.667	PASS
6	C166	60	0.584	PASS
7	C166	50	0.549	PASS
8	C166	40	0.551	PASS
9	C166	30	0.609	PASS
10	C166	20	0.129	PASS
11	C166	10	0.014	PASS
12	C166	2	0.003	PASS
CASE 4 (DLCEAFT IMPACT-2-SS)				
DEAD+LIVE+ CEAFT IMPACT-2 (SOUND STRUCTURE)				
CENTER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C138	110	2.173	FAIL
2	C138	100	12.173	FAIL
3	C138	90	1.428	FAIL
4	C138	80	1.034	FAIL
5	C138	70	0.864	PASS
6	C138	60	0.783	PASS
7	C138	50	0.752	PASS
8	C138	40	0.767	PASS
9	C138	30	0.858	PASS
10	C138	20	0.098	PASS
11	C138	10	0.018	PASS
12	C138	2	0.002	PASS

Table (9): STRENGTH RATIO OF CASE (5) OF CORNER AND CENTER COLUMNS

CASE 5 (DL-DS)				
DEAD+LIVE (DAMAGED STRUCTURE)				
CORNER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C166	110	2.600	FAIL
2	C166	100	12.491	FAIL
3	C166	90	1.454	FAIL
4	C166	80	1.060	FAIL
5	C166	70	0.885	PASS
6	C166	60	0.796	PASS
7	C166	50	0.756	PASS
8	C166	40	0.755	PASS
9	C166	30	0.803	PASS
10	C166	20	1.001	FAIL
11	C166	10	0.026	PASS
12	C166	2	0.005	PASS
CASE 5 (DL-DS)				
DEAD+LIVE (DAMAGED STRUCTURE)				
CENTER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C138	110	0.967	PASS
2	C138	100	0.646	PASS
3	C138	90	0.196	PASS
4	C138	80	0.159	PASS
5	C138	70	0.153	PASS
6	C138	60	0.259	PASS
7	C138	50	0.270	PASS
8	C138	40	0.275	PASS
9	C138	30	0.275	PASS
10	C138	20	0.264	PASS
11	C138	10	0.017	PASS
12	C138	2	0.003	PASS

Table (10): STRENGTH RATIO OF CASE (6) OF CORNER AND CENTER COLUMNS

CASE 6 (DLW-DS)				
DEAD+LIVE+WIND (DAMAGED STRUCTURE)				
CORNER COLUMNS				
NUMBER	COLUMN	STORY	RATIO ($\frac{M(3-3)}{M(3-3)\ D}$)	CHECK
1	C166	110	2.595	FAIL
2	C166	100	1.525	FAIL
3	C166	90	1.377	FAIL
4	C166	80	1.005	FAIL
5	C166	70	0.836	PASS
6	C166	60	0.741	PASS
7	C166	50	0.697	PASS
8	C166	40	0.695	PASS
9	C166	30	0.762	PASS
10	C166	20	0.120	PASS
11	C166	10	0.017	PASS
12	C166	2	0.003	PASS
CASE 6 (DLW-DS)				
DEAD+LIVE+WIND (DAMAGED STRUCTURE)				
CENTER COLUMNS				
NUMBER	COLUMN	STORY	RATIO ($\frac{M(3-3)}{M(3-3)\ D}$)	CHECK
1	C138	110	0.953	PASS
2	C138	100	0.653	PASS
3	C138	90	0.176	PASS
4	C138	80	0.149	PASS
5	C138	70	0.141	PASS
6	C138	60	0.138	PASS
7	C138	50	0.234	PASS
8	C138	40	0.235	PASS
9	C138	30	0.228	PASS
10	C138	20	0.099	PASS
11	C138	10	0.011	PASS
12	C138	2	0.002	PASS

Table (11): STRENGTH RATIO OF CASE (7) OF CORNER AND CENTER COLUMNS

CASE 7 (DLWT-DS-400)				
DEAD+LIVE+WIND+TEMPERATURE ($400^{O}C$) (DAMAGED STRUCTURE)				
CORNER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C166	110	2.595	FAIL
2	C166	100	1.525	FAIL
3	C166	90	1.377	FAIL
4	C166	80	1.005	FAIL
5	C166	70	0.836	PASS
6	C166	60	0.741	PASS
7	C166	50	0.697	PASS
8	C166	40	0.695	PASS
9	C166	30	0.762	PASS
10	C166	20	0.120	PASS
11	C166	10	0.017	PASS
12	C166	2	0.003	PASS
CASE 7 (DLWT-DS-400)				
DEAD+LIVE+WIND+TEMPERATURE ($400^{O}C$) (DAMAGED STRUCTURE)				
CENTER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C138	110	0.953	PASS
2	C138	100	0.653	PASS
3	C138	90	0.176	PASS
4	C138	80	0.149	PASS
5	C138	70	0.141	PASS
6	C138	60	0.138	PASS
7	C138	50	0.234	PASS
8	C138	40	0.235	PASS
9	C138	30	0.228	PASS
10	C138	20	0.099	PASS
11	C138	10	0.011	PASS
12	C138	2	0.002	PASS

Table (12): STRENGTH RATIO OF CASE (8) OF CORNER AND CENTER COLUMNS

CASE 8 (DLWT-DS-1000)				
DEAD+LIVE+WIND+TEMPERATURE ($1000^{O}C$) (DAMAGED STRUCTURE)				
CORNER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C166	110	2.010	FAIL
2	C166	100	2.035	FAIL
3	C166	90	23.010	FAIL
4	C166	80	235.029	FAIL
5	C166	70	205.300	FAIL
6	C166	60	202.004	FAIL
7	C166	50	213.950	FAIL
8	C166	40	243.224	FAIL
9	C166	30	312.000	FAIL
10	C166	20	0.055	PASS
11	C166	10	0.018	PASS
12	C166	2	0.004	PASS
CASE 8 (DLWT-DS-1000)				
DEAD+LIVE+WIND+TEMPERATURE ($1000^{O}C$) (DAMAGED STRUCTURE)				
CENTER COLUMNS				
NUMBER	COLUMN	STORY	RATIO $(\frac{M(3-3)}{M(3-3)\ D})$	CHECK
1	C138	110	1.443	FAIL
2	C138	100	1.347	FAIL
3	C138	90	0.769	PASS
4	C138	80	54.890	FAIL
5	C138	70	81.801	FAIL
6	C138	60	100.542	FAIL
7	C138	50	114.672	FAIL
8	C138	40	125.379	FAIL
9	C138	30	133.091	FAIL
10	C138	20	0.039	PASS
11	C138	10	0.013	PASS
12	C138	2	0.002	PASS

6. FIELD OBSERVATIONS

Figures (11) and (12) showed important field observations that have been obtained from documented videos. The first observation was strongly related to the pattern of failure of the building. The pattern of failure is ideal model to controlled demolition collapse. The duration time of falling is about 10 sec for about 400m building height. The pancake shape was observed. Steel sections inside the dust were observed to move upward against gravitational acceleration. The second observation was related to the blonde woman that appeared in figures (11) which completely contradicted that the temperature rise was reached the melting point of the steel. Thirdly, hitting the building by the aircraft alternated the building from closed space to open air allowing cooled air to flow in causing the inside air temperature to reduce significantly.

The third observation was related to the falling of the 100m height antenna tower inside the building. The digital image analysis confirmed the gradual falling of the steel tower inside the building starting from the top of the building in spite of the fact that the hit floors were located between the 85th floor and the 77th floor.

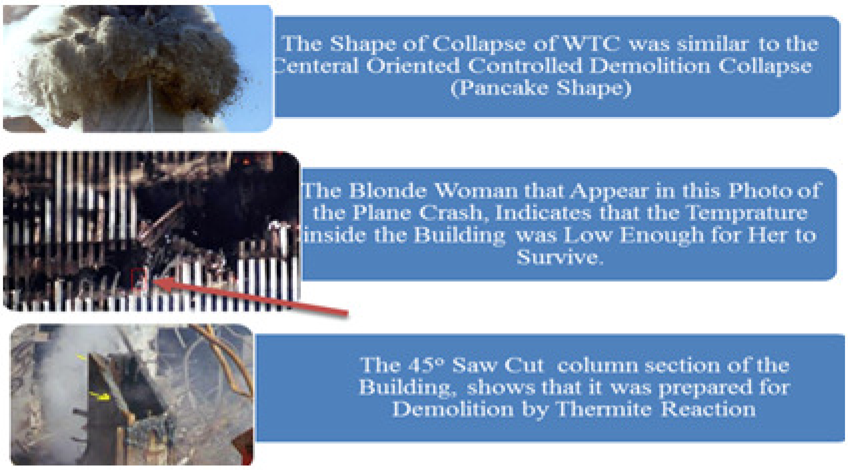

Figure (11): Observations about building collapse

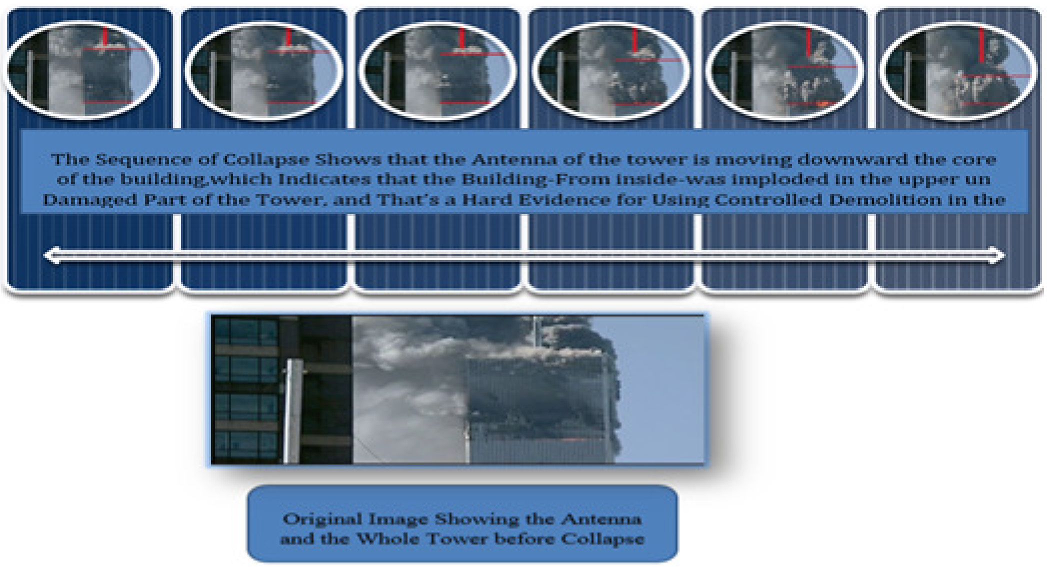

Figure (12): Digital image processing to analyze the falling of steel antenna tower

7. CONCLUSIONS AND RECOMMENDATIONS

The presented research work concluded the following remarks:

1- 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 dead, live, wind and impact loads are considered.
2- The thermo-analysis showed that the explosion of the fuel tank of the aircraft resulted in increasing the temperature of the steel columns and beams by about 413C^o.
3- The damaged structure hit by aircraft, was structurally safe under the combination of dead, live, wind and temperature loads.
4- Field Observations based on the analysis of the documented videos, indicated that the collapse of WTC1 was mainly due to the implementation of the controlled implosion technique.

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