Analysis of the Mass and Potential Energy of World Trade Center Tower 1

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1 Abstract

The mass and potential energy of one of the Twin Towers is calculated based on available data. The mass for each floor is established based on floor types, documented design loads, and estimated in-service live loads. The calculated mass of 288,100 metric tons (317,500 short tons) is found to correspond with two other comparable structures in terms of mass per unit floor area, NIST's SAP2000 model, and the reported amount of recovered debris. The calculated mass refutes the popular notion that the building weighed 500,000 tons.

2 Table of Contents

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3 Introduction

In the aftermath of the World Trade Center Disaster, the Federal Emergency Management Agency (FEMA) and the National Institute of Standards and Technology (NIST) conducted investigations of considerable scope regarding building performance and the collapse of the World Trade Center Towers. The FEMA report described a pancake-type progressive floor collapse scenario causing the removal of lateral support on several floors leading to buckling in unshored columns which were weakened by fire and partially damaged by aircraft impact.[3] The FEMA report was not rigorous and the conclusions regarding collapse initiation and progressive collapse can only be considered to be an educated guess by the investigators. The more rigorous NIST reports described aircraft impact damage and collapse initiation based on forensic evidence and computer simulations. Unlike scientific articles, the NIST investigation reports do not provide enough information to be able to reproduce the models or any results derived from the models.

Analyses from independent researchers regarding aircraft impact damage and collapse scenarios have appeared during and after the official investigations. Earlier analyses were severely limited by a lack of information and were overly simplified. Later analyses have been more substantial, but as seen in Bazant et al. (2007)[10], the mass and potential energy are probably grossly overestimated.

Due to these limitations, many have questioned both the government's specific account of collapse initiation and the general theory of gravity-driven, progressive collapse. These questions can only be answered by better modeling and a truly scientific approach. To be valid, further analyses and models must be based on the correct mass and mass distribution throughout the building.

The purpose of this paper is to establish a substantiated mass, mass distribution and potential energy in World Trade Center Tower 1 (north tower) within a reasonable margin of error. Here, the NIST "Federal Building and Fire Safety Investigation of the World Trade Center Disaster" (called NCSTAR) documents provide a wealth of information regarding the structural design, dimensions, building materials, contemporaneous building codes and an approach to modeling.

3.1 Popular numbers

Many references can be found with different values for the mass of and the amount of potential energy stored in the WTC twin towers. A number of references are shown in Table 1 below. None of these references provide any data or calculation method on which the mass and potential energy are based.

Note: Throughout this paper the term "ton" is used to designate the short or U.S. ton, which is equal to 2000 lbs, and the term "metric ton" is used to designate 1000 kg.

Table 1: Different values for mass and potential energy

Source	Mass	Potential Energy
Ashley [5]	500,000 tons	
Bazant et al. [10]	576,000 tons *	
Eagar and Musso [12]	500,000 tons	
Hamburger, et al. (FEMA) [4]		> 4 E+11 J
Sunder et al. (NIST NCSTAR1) [8]	> 250,000 tons	
Tyson [2]	500,000 tons	

* The Bazant et al. number is calculated here based on the following:

> *"Near the top, the specific mass (mass per unit height) $\mu = 1.02 \times 10^6$ kg/m. In view of proportionality to the cross section area of columns, $\mu = 1.05 \times 10^6$ kg/m at the impact level (81st floor) of South Tower. Generally, we assume that $\mu(z) = k_0 e^{k_2 z} + k_1$ (where k_0, k_1, k_2 = constants), with a smooth transition at the 81st floor to a linear variation all the way down (precise data on $\mu(z)$ are unavailable). The condition that $\int_0^H \mu(z)dz$ be equal to the total mass of tower (known to be almost 500,000 tons) gives $\mu = 1.46 \times 10^6$ kg/m at the base."* [10]

Since μ(z) is unknown we can approximate the value for floors 82-110 using a linear variation from the value at floor 81 to the value at floor 110 (29 floors) and the proportion of the height for those floors. The height of WTC1 from the base to the roof is 437.69 m. The total number of floors is 116. $\mu(z)avg_{81\text{-}110} = 1.035 \times 10^6$ kg/m. $\mu(z)avg_{B6\text{-}81} = 1.2475 \times 10^6$ kg/m.

$$Mass_{82\text{-}110} = \mu(z)avg_{81\text{-}110} \times (29/116) \times h = 113.3 \times 10^6 \text{ kg}$$

$$Mass_{B6\text{-}81} = \mu(z)avg_{B6\text{-}81} \times (87/116) \times h = 409.5 \times 10^6 \text{ kg}$$

The total mass is then 522.8×10^6 kg or, converting to short tons, 576,000 tons. Bazant et al. most likely assumed metric tons for the popular 500,000 ton number but that doesn't explain why we get 522.8×10^6 kg. The maximum error of using the linear approximation instead of the exponential equation is less than 2×10^6 kg. If Bazant et al. used the nominal height of the building (414.63 m from the concourse level to the roof) the result would be 493.9×10^6 kg which corresponds better to the statement "known to be almost 500,000 tons" assuming metric tons.

3.2 General overview of design and construction

A general description of the design and construction of World Trade Center Tower 1 is beyond the scope of this paper. An excellent overview is given in NIST NCSTAR 1-1, "Design, Construction, and Maintenance of Structural and Life Safety Systems."

3.3 Original design

A number of original design documents are provided in NCSTAR1-1 and NCSTAR1-1A. NIST NCSTAR1-1A (p. 5)[9] presents definitions from the original design as follows:

1. "Floor inside of core". That part of the floor bounded by the outside faces of columns 501, 508, 1001 and 1008.
2. "Floor outside of core". That part of the floor between the outside walls and the "Floor inside of core".
3. "Code live load". The load specified in the New York Building Code for a given occupancy.
4. "Live load for floor design". The actual live load used for the design of the parts of the floor which load may not be less than the "Code live load", and may be reduced for tributary areas as defined in "Live load reduction".
5. "Live load for column design". The code live load, reduced as defined in "Live load reduction" for columns.
6. "Construction dead load". The weight of the bare structure (i.e. the slab and beam) used in design of unshored composite beams.
7. "Construction live load". The allowance for the weight of any equipment and/or forms which is not permanent and does not form part of the total load summation.
8. "Superimposed dead load". The weight of ceilings, floor finish, walls or partitions of known location, mechanical and electrical equipment and similar items not included in the "Super imposed live load" or "Construction dead load".
9. "Dead load". The sum of items 6 and 8 above.
10. "Superimposed live load". The weight of the design live load, based on occupancy, plus the weight of partitions if their location is subject to change.

Essentially, the construction dead load (CDL), superimposed dead load (SDL) and superimposed live load (SLL) together comprise all mass or weight in the building. Values for CDL, SDL and SLL are also given in the design documents presented in NCSTAR1-1A for some of the different types of floors within the building, inside and outside the core. CDLs include steel used in floors such as beams, trusses, deck and concrete reinforcement.

3.4 Amount of steel

NIST gives the total weight of structural steel in the two WTC towers as 200,000 tons.[11] NIST describes steel contracts in NCSTAR1-3 (p.16), and the values are shown in Table 2 below.[3] These contracts do not include trusses outside the core, steel deck, concrete reinforcements or grillages.

Table 2: 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**

3.5 NIST reference models

In the NCSTAR1-2 series, NIST presents the methods used for developing the reference structural models of the WTC towers. These models were used to assess the towers' ability to withstand gravity and wind loads and to establish the reserve capacity in the structures to withstand unanticipated events. According to NIST:

> *"The reference models included the following: Two global models of the primary structural components and systems for each of the two towers (and) two models, one of a typical truss-framed floor (tenant floor) and one of a typical beam-framed floor (mechanical floor), within the impact and fire regions. All reference models were linearly elastic and three-dimensional, and were developed using the Computers and Structures, Inc. SAP2000 software. SAP2000 is a commercial finite-element software package that is customarily used for the analysis and design of structures."* [7]

The databases for the reference models were developed based on original structural drawings. The databases were reviewed and checked against the original drawing books. According to NIST:

> *"The original structural drawings of the WTC Towers were issued in two main formats: (1) Large-size drawing sheets containing plan and elevation information, and (2) Smaller book-sized drawings containing details and tabulated information of cross-sectional dimensions and material properties. The larger-sized drawings referred to the structural drawing books in their notes, section and details. The structural databases, developed in Microsoft Excel file format, were generated from these drawing books and included modifications made after construction. The databases were generated for use in the development of reference global models of the towers."* [7]

None of the original structural drawings were released by NIST. However, the larger drawing sheets for WTC-1 (north tower) were leaked subsequently to the general public and are generally available.[17] The smaller drawing books still have not been made public.

3.6 NIST's "Tower and Aircraft Impact Models"

NIST describes the "Tower and Aircraft Impact Models" in NIST NCSTAR 1-2. These models were developed using the LS-DYNA 2003 software package.

> *"The WTC models for the impact analysis required considerably greater sophistication and detail than was required for the reference models described in Chapter 2. The reference models provided a basis for the more detailed models required for the impact simulations. The impact models of the towers, which utilized the structural databases described in Chapter 2 (see also NIST NCSTAR 1-2A), included the following refinements…"* [7 (p. 93)]

The loading of the structure for the analysis was determined by NIST as follows:

> *"The densities of the tower components (workstations and gypsum walls) were scaled by the appropriate ratios to obtain the desired distribution of live loads in the core and truss floor areas. The densities of all the remaining tower structural components were scaled proportionately to obtain the desired superimposed dead loads. These additional loads were important for obtaining an accurate mass distribution in the towers and inertial effects in the impact response. The in-service live load used was assumed to be 25% of the design live load on the floors inside and outside the core. The in-service live load was selected based on a survey of live loads in office buildings (Culver 1976) and on engineering judgment."* [7 (p. 106)]

NIST NCSTAR 1-2B (p. 53) gives an SDL (36.2 psf) which is in fact applied to the structural components (columns).[13] The SDL mass being applied to columns, is not a problem when calculating the mass. However, the impact analysis must be significantly affected by reducing the probability of debris coming into contact with core contents. The effect is that impacting debris has a free shot at core structural members and is more likely to pass all the way through the core. It is unclear if the partitions are included in the SDL, SLL or both.

NIST NCSTAR 1-2B (p. 53) gives a summary of superimposed dead loads and live loads and floor areas to which they are applied.[13] The values are shown in table 3 below.

Table 3: Summary of superimposed dead loads and live loads

	Area (sq ft)	**Weighting (psf)**
Core Dead Load (SDL)	8,694	36.2
Outer Dead Load (SDL)	31,257	11.5
Core Live Load	8,694	19.7
Outer Live Load	31,257	16.2

4 Method

The mass for the building is calculated on a floor by floor basis based on information in the NIST reports and the architectural drawings. In some cases there are deviations from NIST values and motivations for alternative values are described. In cases where there is not enough information in the NIST reports, dimensions or materials are used from similar areas of the building. As described in the introduction above, the design documentation for WTC1 has the structural loads divided into construction dead loads, superimposed dead loads, and superimposed live loads. These divisions are also used here.

4.1 Floor Areas

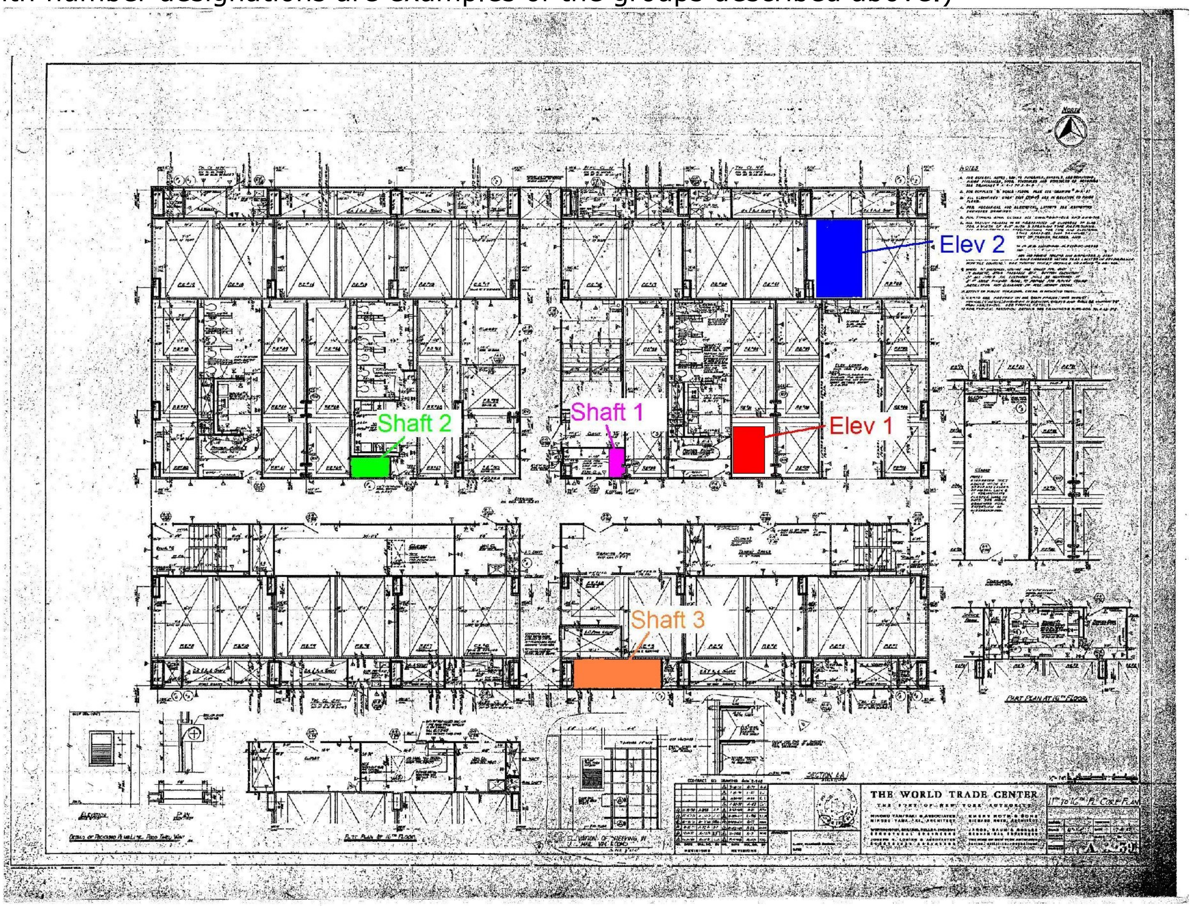
According to NIST, the floor areas inside the core and outside the core are 8,694 sq ft and 31,257 sq ft respectively (see Table 3). However, the architectural drawings give the distance between the center of the external columns on one side to the center of the external columns on the other side as 207′-8″.[17] NIST gives the width of the external column flanges as 13.5″ and the spandrel thickness as 5/8″. Together these are roughly 14″ contributing approximately 7″ on each side to the 207′-8″ dimension. Thus the overall floor dimensions must be 206′-6″ x 206′-6″ with a gross floor area of 42,642 sq ft. The outer dimensions of the core were 137′ x 85′ giving a gross core area of 11,745 sq ft. Thus the floor area outside the core is 30,897 sq ft. It may be that NIST subtracted the areas taken up by core columns, elevator shafts and utility shafts in the core area, which would account for the difference of roughly 25%. Generally in this analysis, the floor areas used inside the core and outside the core are 11,745 sq ft and 30,897 sq ft respectively.

For the purposes of establishing CDLs in the core, the floor areas inside the core were adjusted to account for empty space due to elevator and utility shafts. The actual floor areas were approximated by sampling a number of representative floors using the architectural drawings.[17] Two sizes of elevators predominated and the other shafts were split into three groups: small, medium and large. The areas for the shafts in each group were established by taking the dimensions of all shafts on floors 11-16 from the architectural drawings (core plans), grouping them, and taking the average size for each group.[17] Elevators and shafts were then counted on the representative floors and grouped by size. Elevators and shafts on average take up 41% of the core floor area. The sampled floors, number of elevators and shafts, area with no floor, and the percentage of empty space in the core are shown in Table 4. See Diagram 1 for examples of elevators and shafts.

Table 4: Elevators and shafts on representative floors

floor	count elev. 1 89.5 sq ft	count elev. 2 203.8 sq ft	count shaft 1 10.5 sq ft	count shaft 2 27.3 sq ft	count shaft 3 48.1 sq ft	area w/ no floor sq ft	% core
6	27	23	12	16	0	7 231	62
14	27	23	9	8	10	7 462	64
26	15	23	10	10	10	6 456	55
33	15	23	10	10	10	6 456	55
41	3	23	10	10	10	5 385	46
50	26	14	11	7	6	5 508	47
66	14	12	12	8	7	4 153	35
77	3	14	11	5	6	3 401	29
83	24	2	8	5	5	2 974	25
94	19	2	11	5	5	2 559	22
105	7	2	8	4	5	1 429	12
average						**4 819**	**41**

Diagram 1: Example of architectural drawings - core plan floors 11-16. (Colored areas with number designations are examples of the groups described above.)



4.2 Floor Types

A table of floors and diagrams of 15 different floor framing types are given in NIST NCSTAR 1-2A, Appendix G (p192-196).[14] The table shows which type of floor framing was used for each particular floor. The diagrams show how the different types of framing (i.e. truss or beam) were used in different floor types. The approximate percentages of truss versus beam areas can easily be deduced from the diagrams. Unfortunately, there is no indication of concrete types or thicknesses. For the purposes of this analysis, floors are divided up into normal, mechanical, special and sublevel floors.

4.2.1 Normal Floors

All floors are considered normal unless they are mechanical floors, sublevels, or special floors as described below. The floor numbers for normal floors are 10-40, 44-74 and 78-106. These floors, which are predominantly offices and related areas, comprise eleven floor types (type 1-11) that are predominantly truss framed. Some of these types have sections of beam framed floor and two types have heavier angles or have reinforced trusses. All of these floor types are treated as type 1 (100% truss framed) to simplify the calculation of mass. The total error induced by this simplification is less than 1/1000 and can be calculated as follows:

$$Err\% = A_{Avg}\% \times S\% \times (B-T)/B\% = 0.073\%$$

Where A_{Avg} is the average proportion of beam area (1.45%), S = the floor frame steel proportion of the total mass of the building (approx. 10%), T is the truss design construction dead load (10 psf) [9] and B is the design construction dead load (20 psf) [9] for beam framed floors. See table 5 for calculation of $A_{Avg.}$

Table 5: Floor types, count and beam framed area for calculation of average beam area.

Floor type	Beam area/floor area	count
1	0	74
2	0	3
3	0.0338	4
4	0.2772	1
5	0.2017	1
6	0	1
7	0.1689	1
8	0.1014	1
9	0.0338	4
*10	0.5	1
11	0	0
total	**1.3168**	**91**
avg %	**0.0145**	

** Note: Floor 106 is type 10, which has reinforced trusses. The reinforced trusses are assumed to be heavier than normal trusses and lighter than beam frames. Thus the floor is given as being 50% beam framed to account for the extra weight for the purpose of calculating the error due to simplification.*

4.2.2 Mechanical floors

The mechanical floors are 7-9, 41-43, 75-77, and 108-110, which are all beam framed floors. In each group of three floors, the upper and lower floors are type 12 and the middle floor is type 13 (mechanical mezzanine). The mechanical mezzanines were 50% open (no floor) outside the core so the floor area is 15,448.5 sq ft.

4.2.3 Sublevels

Sublevel floors were beam framed floors, designated B1-B6, and are type 14. As seen in Table 2, 6000 tons of steel were used for slab support below grade. There is a minor discrepancy between the NIST documentation and the architectural drawings. In the architectural drawings, the floor below floor 1 is called the "Service Level" and the five floors below are named B1-B5.

4.2.4 Special floors

Special floors include the Concourse level (floor 1), Plaza level or mezzanine (floor 2), and the roof, which are beam framed floors. Floors 3-6 had no floors outside the core. The Concourse level which was a high pedestrian traffic area is type 14 and probably had stronger than normal floors. The Plaza level was type 15 and was partially open. Floor 107 was the restaurant "Windows on the World" and had beam-framed floors.

4.3 Gravity Loads

4.3.1 Foundation

The mass of the foundation provides no load on structural components other than itself and contributes a negligible amount to potential energy. The mass of the foundation is nonetheless approximated based on the film footage from the Port Authority of New York and New Jersey.[1] Dimensions are established by comparison to objects of known size, i.e. humans. The total mass of the foundation is shown in Table 7.

The foundation for the core columns was comprised of steel reinforced concrete footers and steel grillages built up out of I-beams. One steel grillage is made up of 17 I-beams, each with approximate dimensions 0.75m x 0.2m x 2m and a plate thickness of around 0.03m. Each grillage also had a base plate for the core column with average approximate dimensions 1m x 1m x 0.1m. It is assumed that there is one grillage per core column. Using a density of 7.784 metric tons per cubic meter for the density of A36 steel, the total mass for the grillages is approximately 484 metric tons. Each grillage was placed on a concrete footer with approximate dimensions 2.5m x 2.5m x 2m. Using a density of 2.4 metric tons per cubic meter, the total mass for the concrete footers was approximately 1410 metric tons.

The foundation for the external columns was comprised of a continuous, steel reinforced, concrete footer and base plates ranging from 7 to 9 sq ft (approx. 0.74 m2).[6] The thickness of the base plate is unknown but a thickness of 3 cm is assumed. Using a total number of 80 exterior columns (transition to 238 columns at 7th floor), the total mass of the base plates is approximately 14 metric tons. The concrete footer for the external columns had a perimeter of 252 m. The other dimensions of the footer are unknown but are approximated using 2 m for depth and 2 m for width. The total mass for the concrete footer was approximately 2420 metric tons.

Table 6: Mass of the foundation

Component	**Mass (short tons)**	**Mass (metric tons)**
Core steel grillage w/ base plate	513	466
Core concrete footer	1555	1410
External column steel base plates	15	14
External column concrete footer	2670	2420
Total mass foundation	**4753**	**4310**

4.3.2 Amount of Core Column Steel

As described in the introduction, the steel contracts included 6,500 tons for core box columns below the 9th floor, 15,500 tons for core box columns above the 9th floor and 12,950 short tons for rolled columns and beams. The amount of steel attributed to rolled columns (wide flange shapes) is calculated in Appendix 2 as 3,268 short tons. Thus the total core column steel is 25,268 short tons.

4.3.3 Variation of Core Column Steel

Core columns dimensions have been extracted from NIST's SAP2000 model, which was released based on a Freedom of Information Act (FOIA) request. These dimensions are currently available on the internet.[15] It can be seen in this data that the variation of core columns steel is non-linear in the areas from floor B6 to floor 7 and from floor 107 to the roof. There are also non-linear variations at the mechanical floors where the columns were somewhat heavier, but these are ignored. The variation of core column steel mass is shown in Table 7, which is based on calculations of core column steel per floor for selected floors (see Table 19 in Appendix 3).

Table 7: Variation of Core Column Steel

Floor range	Variation	Varies from (tons)	Varies to (tons)
B6-001	Linear	380.63	427.14
002-007	Individual floor	n.a.	427.14
008-053	Linear	427.14	181.57
054-106	Linear	181.57	30.91
107	Individual floor	n.a.	35.81
108	Individual floor	n.a.	41.42
109	Individual floor	n.a.	35.81
110	Individual floor	n.a.	35.81
111(roof)	Individual floor	n.a.	31.20

When the core column steel mass is varied in this manner, the total core column steel becomes 24,576 tons with 5,801 tons below floor 9. This amount of core column steel below floor 9 should be 6,500 tons according to the steel contracts. This discrepancy may be due to errors in the SAP2000 model, errors extracting data from the SAP2000 model or maybe the contract included cross bracing not seen in the model data. Regardless, an extra 699 tons is distributed evenly among the floors below floor 9 based on the assumption that the steel contracts were correct at least in terms of the amount of steel. The resulting total core column steel mass becomes 25,275 tons which correlates well with the amount of core column steel calculated in the previous section (25,268 tons, based on steel contracts and the calculation of rolled core columns in Appendix 2).

4.3.4 Amount of External Column Steel

As described in the introduction, the steel contracts included 6,800 tons for external box columns, 3,400 tons for bifurcation columns and 27,900 tons for external columns (prefabricated panels). The external box columns were used below floor 6. The bifurcation columns were used between floors 6 and 9. The prefabricated panels included spandrels. It is unclear if the other steel contract values for box and bifurcation columns included spandrels but it is assumed that they did.

4.3.5 Variation of External Column Steel

There is no information given by NIST regarding the external box column dimensions so the mass is distributed evenly between floor B6 and floor 5. The mass for the bifurcation columns is distributed evenly over floors 6-8.

4.3.5.1 Above Floor 9

NIST NCSTAR1-3 describes the variation of spandrel thickness from 1.375 in. at floor 9 to 0.375 in. at floor 107. Also described is the external column flange thickness (above floor 9) varying from 3 in. to 0.25 in. at the top of the building. Since the exterior panels are given in the steel contracts as a single value the mass must be divided between the columns and the spandrels to give an accurate variation for both.
A rough distribution of the steel between the columns and spandrels can be done by calculating the spandrel mass based on a linear variation between floors 9 and 111 (roof). However, the problem arises that there is not enough steel left to do a similar linear variation for the external columns. This is most likely due to the fact that the variation is not linear and actually has more weight lower in the building, similar to the core columns. Thus a scale factor is used on the average column flange thickness and spandrel thickness to arrive at the amount of steel as given in the steel contracts as shown in Table 8.

Table 8: Distribution of mass between external columns and spandrels

	flange t	w	h	cnt	web t	w	h	cnt	volume cu ft	cnt/ floor	mass tons
exterior col											
min	0.250	13.5	144	2	0.25	13.500	144	2	1.1250	232	6 458
max	3.000	13.5	144	2	0.25	13.500	144	2	7.3125	233	42 161
avg (scaled)	1.467	13.5	144	2	0.25	11.065	144	2	3.7626	232	21 600
spandrel											
min	0.375	120	58	1					1.5104	80	2 990
max	1.375	120	58	1					5.5382	80	10 963
avg (scaled)	0.790	120	58	1					3.1824	80	6 300
									total		27 900
scale factor	0.9030										

Note: t = thickness, w = width and h = height (in inches), cnt = the number of plates and the number of columns or spandrels, mass = volume x cnt x 101 floors x 490 lbs/cu ft (converted to tons).

Thus, the steel mass allocated to the external columns and spandrels is 21,600 tons and 6,300 tons respectively. These masses are scaled linearly using proportions based on the minimum and maximum values from NIST which results in a slightly higher proportion of the mass higher in the building.

4.3.6 Gravity Loads for Normal Floors

In NIST NCSTAR1-2A, the baseline performance of the reference model is described under several loading cases corresponding to the full design loads from the original design, New York City Building Code (2001) and ASCE7-02 standard. It is not stated explicitly but it appears that all loading cases used live load reduction in accordance with the code.

4.3.6.1 CDLs inside the Core (normal floors)

Unit dead loads for concrete slabs inside the core are given in NIST NCSTAR1-1A (pp. 7-10). Both lightweight and normal concrete are specified as well as thicknesses ranging from 4.35 in. to 5.5 in. There is no information which type of concrete or thickness was used in any particular location. The design document on page 7 is for "unit dead load" and there is no indication of floors to which they apply. This may indicate that this was just a list of material unit dead loads. NIST NCSTAR1-2A (p.56) states that inside the core the normal floors slabs were normal concrete and had a thickness of 4.5 in. However, no source is given for this claim.

The design document on page 9 is for "unit design load" for floors 1-110 and indicates that both lightweight and normal concrete were, in fact, used in the dead load design. This document also gives an average slab thickness of 4.35 in. Unit design loads are given for different floor finishes, but there is no specification of where these were used.

For the purposes of this analysis, normal concrete with a thickness of 4.35 in. is used except on mechanical floors. As seen below, design SDLs and SLLs within the core are similar to outside the core for normal floors, which have lightweight concrete floors with a thickness of 4.35 in. Consequently, it would not be unrealistic to assume that lightweight concrete was used for some or all floors in the core. Due to the fact that normal concrete is 33% (18 psf) heavier and the difficulty in determining the locations of various floor toppings, the extra weight is assumed to account for some variation of concrete types and floor toppings, which range from 2-24 psf. The unit dead load for normal concrete with thickness 4.35 in. is 54.38 psf.

Original design dead loads for steel floor components in the core are not found in the NIST NCSTAR documentation. Nonetheless, reasonable values for steel CDLs can be deduced from the beam framed floors outside the core.

CDLs for beam floor framing outside the core are given for mechanical floors 41 and 75 in NIST NCSTAR1-1A (p.12) as slab reinforcement = 3 psf, steel deck = 2 psf, and steel beam = 20 psf. Since these beams include long spans of up to 60 ft., the beams are most likely heavier than beams within the core where the maximum span is approximately 20 ft, as seen in the architectural drawings.[17] Thus, the core beam unit dead load is assumed to be the average, of truss and beam framed floors outside the core, which is 15 psf. In fact, NIST NCSTAR1-2A (p.70) gives a value of 6 to 7 psf used in the reference model, but it is unclear if this was applied to the gross core area or just the area with floor slabs. If these values were applied to the gross area it would be roughly equivalent to applying 15 psf to the actual floor slab areas (avg. 59%). The mechanical floors had much higher combined SDLs and SLLs than the core on normal floors, so the slab reinforcement is assumed to be the same as truss framed floors, which is 1.5 psf.

Unit CDLs for normal floors in the core including concrete slab, beams, steel decking and reinforcement as well as the total unit CDL are shown in Table 9. The CDLs are only applied to the portion of the core that actually has a floor.

Table 9: Normal Floors - Core component unit CDLs and total unit CDL

Component	Unit dead load psf
concrete slab	54.38
beams	15.00
steel decking	2.00
reinforcement	1.50
total	**72.88**

4.3.6.2 SDLs Inside the Core (normal floors)

NIST provides design documents which give unit dead loads inside the core for different types of partitions, fireproofing, ceilings, and floor finishes, but no information is given as to where they are applied on normal floors. As seen below, example SDLs are provided for core areas on floor 96, but it is not clear if, or where, these apply to other floors. No information is given regarding specific core contents such as pipes, cables, ducts, etc. Nonetheless, NIST did calculate gravity loads for all floors inside the core based on architectural drawings [17] and the original design criteria. Relevant information for normal floors inside the core is as follows:

NIST NCSTAR1-1A

Partition loads are given in original design documents on p. 9 as "N.Y. code uniform equivalent" 6 psf and 12 psf. SDLs for fireproofing outside the core are given in NIST NCSTAR1-1A (p.12) for mechanical floors as 5 psf and 3 psf for the floors above. It is assumed that the mechanical floors required extra fireproofing to avoid a fire spreading to the mechanical area, so a unit dead load of 3 psf is assumed within the core. Unit SDLs for ceilings ranged from 2-10 psf but there is no information which ceiling types were used in specific areas. The ceiling unit SDL for the mechanical floors outside the core is 3 psf, but the ceiling is most likely the one hanging from the floor and hence the ceiling for an office area. The lighter types of ceiling are assumed to be more prevalent, so a weighted average unit dead load of 3 psf is assumed for ceilings.

NIST NCSTAR1-2A

Section 4.2.2 (pp. 70-72) gives SDLs for partition groups from 6 to 44 psf. This seems not to agree with the original design documents which give 6 and 12 psf as uniform code values. The actual values used in reference model (SAP2000) on particular floors are not provided except for floor 96. This section also describes floors B5, B3 to 9, 43 and 77 as mostly having concrete encasement for fireproofing on beams, so fireproofing on normal floors inside the core is assumed to be spray-applied fire resistant materials (SFRM). Section 6.2.1 (p. 137) gives SDLs for five core areas on floor 96 ranging from 29-49 psf.

NIST NCSTAR1-2B

Chapter 3 describes development of the Tower Impact Model. Unit SDL for impact floors is given on page 53 as 36.2 psf. This unit dead weight may be applied to an area of only 8,694 sq ft, so it is possible that the total SDL for the core is underestimated in that model.

The SDLs given in NIST NCSTAR1-2A for five core areas (29-49 psf) and the SDL given in NIST NCSTAR1-2B (36.2 psf) seem to indicate an average unit SDL for normal floors inside the core of around 40 psf. This value is assumed and is applied to the entire core area on all normal floors. A reasonable break-down of the SDLs as well as the total unit SDL are shown in Table 10.

Table 10: Normal Floors - Core component unit SDLs and total unit SDL

Component	Unit dead load psf
partitions	12.00
floor finish (avg.)	8.00
fireproofing	3.00
ceiling	3.00
other *	14.00
total	**40.00**

* Note: "Other" includes items such as pipes, electrical cables, ducts, mechanical equipment, etc.

4.3.6.3 SLLs inside the core (normal floors)

Unit live loads within the core are given in NIST NCSTAR1-1A for different occupancy types and usages ranging from 40-100 psf. Exceptions are floor 109 which had 150 psf throughout and areas occupied by equipment which had none. For the impact analysis, NIST NCSTAR1-2 (p.106) states:

> "The in-service live load used was assumed to be 25% of the design load on the floors inside and outside the core. The in-service live load was selected based on a survey of live loads in office buildings (Culver 1976) and engineering judgment." [7]

Another analysis based on a survey of live loads in Sydney, Australia (Choi 1989), gives the mode for sustained live loads as 0.05 kPa (1 psf) for floor areas 2.5-5.0 m^2 and 0.45 kPa (9.4 psf) for floor areas greater than 80 m^2.[16] A trend towards higher load intensity for larger notional bays was identified. The mean for sustained live loads was approximately 0.50 kPa (10.4 psf) for floor areas greater than 80 m^2. This survey included offices, parking and plants rooms (mechanical). It is unclear if partitions were included in the live loads.

NIST NCSTAR1-2B gives live loads, based on 25% of the design load, as 19.7 psf inside the core and 16.2 psf out side the core. This would imply an average design load of 80 psf inside the core and 65 psf outside the core. NIST applies these loads to the entire core area and the outer floors. It should be noted that the live load should only be applied to areas with actual floors in the core (average 59%). On the other hand, NIST uses a floor area inside the core of 8,694 sq ft, but it is unclear where this number comes from. There is no indication that live load reduction was applied within the core.

For the purposes of this analysis, the in-service live load inside the core is assumed to 19.7 psf for all normal floors, but this load is only applied to areas with actual floor.

4.3.6.4 CDLs outside the Core (normal truss-framed floors)

NIST NCSTAR1-1A (p.11) provides design documents for truss framed floors outside the core. A lightweight concrete slab with thickness 4.35 in. (36.5 psf) is specified along with slab reinforcement (1.5 psf), steel deck (2.0 psf) and structural steel (trusses, 10 psf). The total unit CDL is thus 50 psf.

4.3.6.5 SDLs outside the Core (normal truss-framed floors)

NIST NCSTAR1-1A (p.11) provides an original design document for truss framed floors outside the core. Components specified are ceiling (2.0 psf), mechanical and electrical (2.0 psf), floor finish (2.0 psf) and fireproofing (2.0 psf). SDLs for wall finish and windows are not provided. NIST NCSTAR1-2A (p.136) indicates that SDL allowances were 11.5-13.5 psf. If this includes wall finish and windows, the SDL for those components would be on average 160 lbs per linear foot of external wall, which seems reasonable. Thus the average unit SDL for normal truss framed floors is assumed to be 12.5 psf.

4.3.6.6 SLLs outside the Core (normal truss-framed floors)

NIST NCSTAR1-1A (p.19) provides an original design document for the floor slab which specifies 100 psf for live load. Column design is given on p. 20 which specifies 50 psf live load (to be reduced according to code) and a 6-12 psf partition allowance. NIST NCSTAR1-2B presents live loads, based on 25% of the design load, as 16.2 psf outside the core which implies an average design load of 65 psf outside the core. On page 136 there is a diagram of reduced live loads and how they are applied to long span, two-way and short span truss areas. Here partition allowances appear to be included in the reduced live loads and the average reduced live load is approximately 65 psf. This corresponds well with Choi (1989) if a 6 psf partition allowance is added to the survey's mean sustained live loads (10.4 psf) in that study. The average unit live load for normal truss-framed floors is thus assumed to be 16.2 psf including partition allowances.

4.3.7 Gravity Loads for Mechanical Floors

4.3.7.1 CDLs inside the Core (mechanical floors)

Unit dead loads for concrete slabs inside the core are given in NIST NCSTAR1-1A (pp. 7-10). Both lightweight and normal concrete are specified as well as thicknesses ranging from 4.35 in. to 5.5 in. There is no information which type of concrete or thickness was used in any particular location. The design document of page 7 is for "unit dead load" and there is no indication of floors to which they apply. This may suggest that this was just a list of material unit dead loads. NIST NCSTAR1-2A (p.57) states that inside the core the mechanical floor slabs were normal concrete and had a thickness of 6 in. as well as a 2 in. topping slab. However, no source is given for this claim. The design document on page 9 is for "unit design load" for floors 1-110, suggesting that both lightweight and normal concrete were in fact used in the dead load design. This document also gives an average slab thickness of 4.35 in. Unit design loads are given for different floor finishes, but there is no indication where these were used. For the purposes of this analysis, normal concrete with a thickness of 6 in. is used for mechanical floors.

Dead loads for steel floor components in the core are not found in the NIST NCSTAR documentation. Nonetheless, reasonable values for steel CDLs can be deduced from the beam framed floors outside the core.

CDLs for beam floor framing outside the core are given for mechanical floors 41 and 75 in NIST NCSTAR1-1A (p.12) as slab reinforcement = 3 psf, steel deck = 2 psf, and steel beam = 20 psf. Since these beams include long spans of up to 60 ft., the beams are most likely heavier than beams within the core where the maximum span is approximately 20ft, as seen in the architectural drawings.[17] Thus, the core beam unit dead load is assumed to be the average of truss and beam framed floors outside the core which is 15 psf. In fact, NIST NCSTAR1-2A (p.70) gives a value of 6 to 7 psf used in the reference model, but it is unclear if this was applied to the gross core area or just the area with floor slabs. If these values were applied to the gross area it would be roughly equivalent to applying 15 psf to the actual floor slab areas (avg. 59%). Slab reinforcement is assumed to be the same as beam framed floors outside the core, which is 3 psf.

Unit CDLs for mechanical floors in the core including concrete slab, beams, steel decking and reinforcement as well as the total unit CDL are shown in Table 11. The topping slab is included in the SDL. The CDLs are only applied to the portion of the core that actually has a floor.

Table 11: Mechanical Floors - Core component unit CDLs and total unit CDL

Component	Unit dead load psf
concrete slab	75.00
beams	15.00
steel decking	2.00
reinforcement	3.00
total	**95.00**

4.3.7.2 SDLs inside the Core (mechanical)

NIST provides design documents which give unit dead loads inside the core for different types of partitions, fireproofing, ceilings and floor finishes, but there is no information regarding where they are applied on mechanical floors. As seen below, example SDLs are given for core areas on floor 96, but it is not clear if, or where, these apply to other floors. No information is given regarding specific core contents such as pipes, cables, ducts, etc. Nonetheless, NIST did calculate gravity loads for all floors inside the core based on architectural drawings and the original design criteria. Relevant information for mechanical floors inside the core is as follows:

> NIST NCSTAR1-1A
>
> Partition loads are given from original design documents on p. 9 as "N.Y. code uniform equivalent" 6 psf and 12 psf. SDLs for fireproofing outside the core are given in NIST NCSTAR1-1A (p.12) for mechanical floors as 5 psf and 3 psf for the floors above. It is assumed that the mechanical floors required extra fireproofing to avoid a fire spreading to the mechanical area, so a unit dead load of 5 psf is assumed. Unit SDLs for ceilings ranged from 2-10 psf but there is no indication which ceiling types were used in particular areas. The ceiling unit SDL for the mechanical floors outside the core is 3 psf, but the ceiling is most likely the one hanging from the floor and hence the ceiling for an office area.
>
> NIST NCSTAR1-2A
>
> Section 4.2.2 (pp. 70-72) gives SDLs for partition groups from 6 to 44 psf. This does not agree with the original design documents which give 6 and 12 psf as uniform code values. The actual values used in reference model (SAP2000) on particular floors are not given except for floor 96. This section also describes floors B5, B3 to 9, 43 and 77 as mostly having concrete encasement for fireproofing on beams with a unit dead load of 20 psf. Section 6.3.1 (p. 141) gives SDLs for ten core areas on floor 75 ranging from 25-141 psf. A topping slab is described with a thickness 2 in. and a unit dead load of 20 psf.

On floor 75, it can be seen in the architectural drawings that the heavier areas take up approximately 18% of the core area while elevator and service shafts take up approximately 30%.[17] Using 30 psf for shafts, 141 for heavy areas and 66 psf for other areas, a weighted average gives 70 psf over the entire core. Floor 76 is similar and is also assumed to have an average unit SDL of 70 psf. However, it can be seen from the architectural drawings that floors 7-8, 41-42, and 108-109 are more similar to normal floors inside the core so 40 psf is assumed for these floors.[17] Most floor areas inside the core above the mechanical floors (9, 43, 77) had occupancies and usages similar to normal floors (see above SDL=40 psf), but the concrete beam encasements add 20 psf giving 60 psf over the entire core for these floors.

A reasonable break-down of the SDLs for mechanical floors inside the core as well as the total unit SDL are shown in Table 12.

Table 12: Mechanical Floors - Core component average unit SDLs and average total unit SDL

Component	Unit dead load psf
partitions	12.00
floor finish	20.00
fireproofing	5.00
ceiling	2.00
other *	31.00
total	**70.00**

* Note: "Other" includes items such as pipes, electrical cables, ducts, mechanical equipment, etc.

4.3.7.3 SLLs inside the core (mechanical floors)

Unit live loads within the core are given in NIST NCSTAR1-1A for different occupancy types and usages ranging from 40-100 psf. Exceptions are floor 109 which had 150 psf throughout and areas on all floors occupied by equipment which had none. There is no indication that live load reduction was applied within the core. In NIST NCSTAR1-2A, the baseline performance is described under several loading cases corresponding to the original design, New York City Building Code (2001) and ASCE7-02 standard. It is not stated explicitly but it appears that all cases used live load reduction. For the impact analysis, NIST NCSTAR1-2 states:

> "The in-service live load used was assumed to be 25% of the design load on the floors inside and outside the core. The in-service live load was selected based on a survey of live loads in office buildings (Culver 1976) and engineering judgment."

NIST NCSTAR1-2B gives live loads inside the core, based on 25% of the design load, as 19.7 psf which is applied to the entire core area. This would imply an average design load of 80 psf inside the core. It should be noted that the live load should only be applied to areas with actual floors in the core (average 59%). On the other hand, NIST uses a floor area inside the core of 8,694 sq ft, but it is unclear where this number comes from.

For the purposes of this analysis, the in-service live load inside the core is assumed to be 19.7 psf for mechanical floors except floor 109, but this load is only applied to areas with actual floor. The in-service live load inside the core is assumed to be 37.5 psf for floor 109.

4.3.7.4 CDLs outside the Core (mechanical beam-framed floors)

NIST NCSTAR1-1A (p.12) provides original design documents for beam framed mechanical floors 41, 43, 75 and 77 outside the core. Floors 41 and 75 are lower mechanical floors and had one specification while floors 43 and 77 were floors above the mechanical areas which had another specification. The unit CDL given for floors 41 and 75 is 94 psf. All lower mechanical floors (floors 7, 41, 75 and 108) appear to be similar and are assumed to have the same specifications. All mechanical mezzanines (floors 8, 42, 76 and 109) are also assumed to have a unit CDL of 94 psf but with half the area. The unit CDL given for floors 43 and 77 is 125 psf. All floors above the mechanical areas (9, 43, 77 and 110) are assumed to have the same specifications.

4.3.7.5 SDLs outside the Core (mechanical beam-framed floors)

NIST NCSTAR1-1A (p.12) gives a unit SDL for floors 41 and 75 as 116 psf (including 75 psf of mechanical equipment). All lower mechanical floors (floors 7, 41, 75 and 108) appear to be similar and are assumed to have the same specifications. The unit SDL given to floors 43 and 77 is 55 psf. All floors above the mechanical areas (floors 9, 43, 77 and 110) are assumed to have the same specifications. No unit SDL is provided for the mechanical mezzanines. The mezzanines were most likely used for lighter equipment so the SDL is assumed to be the same as lower mechanical floors minus 25 psf. Thus the mechanical mezzanines (floors 8, 42, 76 and 109) are assumed to have a unit SDL of 91 psf.

4.3.7.6 SLLs outside the Core (mechanical beam-framed floors)

NIST NCSTAR1-1A (p.12) gives a design unit SLL of 75 psf for floors 41 and 75. All lower mechanical floors (floors 7, 41, 75 and 108) appear to be similar and are assumed to have the same specifications. The mechanical mezzanines (floors 8, 42, 76) are assumed to have the same unit SLL as mechanical floors. In accord with preceding motivations, the average unit SLL is assumed to be 25% of the design values or 19 psf. The design unit SLL is not given for floors 43 and 77. All floors above the mechanical areas (floors 9, 43, 77 and 110) were essentially tenant floors and assumed to have the same SLL as normal floors outside the core, which is 16.2 psf. NIST NCSTAR1-2A (p. 73) gives the unit SLL for floor 109 as 150 psf so 37.5 psf (25%) is assumed for that floor.

4.3.8 Gravity Loads for Sublevels

There is little information in the NIST documentation regarding the sublevel floors. It is assumed that these floors were similar to lower mechanical floors except that floors B1-B3 were primarily tenant storage areas. As mentioned above, 6,000 tons of steel were used for slab support below grade. It is unclear how this steel was applied, but floor 1 (Concourse level) did not have unusual load requirements. It is assumed therefore that this steel was applied to floors B1-B5. It can be seen in the architectural drawings that there are 24 columns supporting the floors outside the core. Nonetheless, for the sake of simplification, the entire 6,000 tons is included in the floor CDL evenly distributed over the gross floor area minus empty core space (41,467.5 sq ft.) both inside and outside the core. This results in a unit CDL of 57.88 psf for structural steel. Given the comparatively large amount of structural steel, it is assumed that the floor slabs are also somewhat heavier than mechanical floors. The floor thickness is assumed to be 8 in. with normal concrete which gives a unit CDL of 100 psf for the concrete slab. The steel deck and slab reinforcement are assumed to be the same as mechanical floors or 5 psf combined. The total unit CDL is then 162.88 psf.

For all sublevels, it is assumed that the CDLs, SDLs and SLLs are the same as lower mechanical floors (see above) except for B1-B3 for which the mechanical equipment (75 psf) is removed from the SDL.

4.3.9 Gravity Loads for Special Floors

The NIST documentation provides little information regarding loads on special floors.

- Floors 3-6 are assumed to have the same CDLs as lower mechanical floors inside the core and the same SDLs and SLLs as normal floors inside the core. Floors 3-6 had no floors outside the core.
- The Concourse level and Plaza level, which were high pedestrian traffic areas, are assumed to have the same CDLs and SDLs as lower mechanical floors without the mechanical equipment. Since the Plaza level was partially open (approx. 42%), the total CDL and SDL for that floor is reduced by this amount. The SLLs for these floors is assumed to 25% of the design load (100 psf), which is 25 psf throughout.
- Floor 107 is assumed to have the same CDL as lower mechanical floors and the same SDL as normal floors. This floor has a design live load of 100 psf so the SLL is assumed to be 25%, or 25 psf.
- The roof was a beam-framed, type 12 floor with a CDL equivalent to the lower mechanical floors (94 psf). The SDLs for the roof are not described, but there must have been some type of roof finish. 5 psf is assumed for the SDL (roof finish only) plus 375 tons for the antenna. The design SLL for the roof was 40 psf and is assumed to be 25% or 10 psf.

4.3.10 Hat Truss

According to NIST NCSTAR1-1:

> *"At the top of each tower (floor 107 to the roof), an assembly of hat trusses interconnected the core columns and the exterior wall panels. Diagonals of the hat truss were typically W12 or W14 wide flange members. In addition, four diagonal braces (18 in. by 26 in. box beams spanning the 35ft gap, and 18 in. by 30 in. box beams spanning the 60ft gap) and four horizontal floor beams connected the hat truss to each perimeter wall at the floor 108 spandrel. The hat truss was designed primarily to provide a base for antennae atop both towers…"* [6]

Little information is available for establishing the mass of the hat truss. A rough estimate of the mass of the hat truss is as follows:

NIST NCSTAR1-6D (p. 170) shows a diagram (figure 4-3) which shows the modeled portion of the hat truss.[25] The box and floor beams described above are seen in this diagram plus, what appears to be, 12 major members in the core with lengths of approximately 50-70 ft. Using column 902 at floor 108 (to which it appears the hat truss is connected) as a representative W14 shape, the cross sectional area would be 37.0 sq in.[15] For the 12 major members the steel volume would be around 185 cu ft which is the same as approximately 45 tons using 490 lbs/ft^2 for the density of steel. Assuming a similar plate thickness (0.8 in.) for the box beams the cross sections would be approximately 80 in^2. There were 8 long span (approx. 64 ft long) and 8 short span box beams (approx. 36 ft long). Together they account for 108 tons. It is unclear if the floor beams described above were normal beam-framed floor members of if they were added especially. Assuming they were added, that would account for another approximately 100 tons. So a rough estimate of the mass of the hat truss members gives 250 tons.

In NCSTAR1-2A (p.73), NIST describes using an additional uniform SDL of 20 psf to the gross area inside the core to account for hat truss steel which was not included in the model and concrete beam encasement on all floors 107-roof. For the purposes of this analysis, additional uniform SDL of 20 psf to the gross area inside the core on floors 107-roof. The mass of the hat truss (250 tons) is divided equally over floors 107-roof and applied as SDL to the core (50 tons/floor).

4.3.11 Aluminum cladding and elevators

There is no information in the NIST reports regarding loads attributed to aluminum cladding and elevators. These are assumed to be included in the design SDLs.

5 Results

5.1 Summary of Results

The in-service mass of Tower 1 (North Tower) of the World Trade is found to be 288,100 metric tons (317,500 short tons). The potential energy above the 1st floor is found to be 480,600 MJ.

5.2 Detailed Results

The calculation of mass and potential energy was done in an Excel spreadsheet. The spreadsheet is too large to fit in this document and is therefore linked as a separate document (pdf, xls, html). Sources and motivations for values used are found in the Method section above. An explanation of the columns in the spreadsheet is given in Table 13.

Table 13: Description of Spreadsheet Columns for Calculation

Column name	Description
Floor	Floor number from ground level. There are 110 floors plus the roof.
Floor + 6	This is the floor count from the bottom of the building upwards. Since there are six sublevels not counted in the usual "110 floors", there are actually 117 floors including the roof. This is used for distributing column steel over the height of the building.
Column steel	Includes external spandrels
Core column steel tons	Mass of steel for core columns above each floor in US tons.
Core column steel kg x 10^3	Mass of steel for core columns above each floor in metric tons.
Ext. column steel tons	Mass of steel for external columns above each floor in US tons.
Ext. column steel kg x 10^3	Mass of steel for external columns above each floor in metric tons.
Ext. spandrel steel tons	Mass of steel for spandrels at each floor in US tons.
Ext. spandrel steel kg x 10^3	Mass of steel for spandrels at each floor in metric tons.
Total column steel kg x 10^3	Combined mass for core columns, external columns and spandrels in metric tons. Exceptions: The grillage steel is also included in this column.
Floors inside of core	Core floor area is 11,745 sq ft
Area with floor %	The portion of the core area with concrete floor in percent.
Average unit CDL psf	Average unit CDL per floor inside the core in pounds per sq ft. Exceptions: The foundation concrete is also included in this column.
Core CDL kg x10^3	Total CDL per floor inside the core in metric tons. Calculated from the psf value and the actual area with floor.
Steel component of CDL psf	Portion of CDL per floor inside the core attributed to steel beams, deck and concrete reinforcement in pounds per sq ft.
Steel component of CDL kgx10^3	Total CDL per floor inside the core attributed to steel beams, deck and concrete reinforcement, in metric tons.
Average unit SDL psf	Average unit SDL per floor inside the core in pounds per sq ft. The average SDL is applied to the entire core. Exceptions: The antenna is included in the roof. The hat truss is added to floors 107-roof as 50 metric tons per floor and 20 psf over the entire core area on those floors.

Core SDL kgx10^3	Total CDL per floor inside the core in metric tons.
Average unit SLL psf	The average unit SLL per floor inside the core in pounds per sq ft.
Core SLL kgx10^3	Total SLL per floor inside the core in metric tons.
Floors outside of core	Area outside the core is 30,897 sq ft
Average unit CDL psf	Average unit CDL per floor outside the core in pounds per sq ft.
Outer CDL kgx10^3	Total CDL per floor outside the core in metric tons. Exceptions: Floors 3-6 have no floor outside the core and thus no CDL. Floors 8, 42, 76 and 109 have only half floors outside the core.
Steel component of CDL psf	Portion of CDL per floor outside the core attributed to steel beams, deck and concrete reinforcement in pounds per sq ft.
Steel component of CDL kgx10^3	Total CDL per floor outside the core attributed to steel beams, deck and concrete reinforcement, in metric tons. Exceptions: Floors 3-6 have no floor outside the core and thus no CDL. Floors 8, 42, 76 and 109 have only half floors outside the core.
Average unit SDL psf	Average unit SDL per floor outside the core in pounds per sq ft.
Outer SDL kgx10^3	Total SDL per floor outside the core in metric tons. Exceptions: Floors 3-6 have no floor outside the core and thus no SDL. Floors 8, 42, 76 and 109 have only half floors outside the core.
Average unit SLL psf	The average unit SLL per floor outside the core in pounds per sq ft.
Outer SLL kgx10^3	SLL for the floor outside the core in metric tons. Exceptions: Floors 3-6 have no floor outside the core and thus no SLL. Floors 8, 42, 76 and 109 have only half floors outside the core.
Total mass kgx10^3	Total mass for the floor and in the summary row, for the building in metric tons.
PE(MJ)	Potential energy for the floor relative to the 1st floor in MJ. In the summary row this is the total potential energy of the building relative to the 1st floor. Exceptions: The total mass of the antenna (340 metric tons) is taken halfway up the antenna at 469m above the 1st floor.

6 Discussion

6.1 Comparison with Other Buildings

In order to provide a "reality check" for the mass of World Trade Center Tower 1, it can be compared to other buildings in terms of mass per unit area. It can be seen in Table 14 that the much older Empire State Building and the "popular" mass of the World Trade Center Tower do not fit in with other buildings contemporaneous to The World Trade Center. The Twin Towers and other skyscrapers from the same time period ushered in a new era of highly efficient structures with new design techniques and building materials. Nonetheless, it is important to bear in mind that the values presented in Table 14 are from internet sources and that the values are based on definitions of "floor area" which are not always clear and may differ from one another. Further study might include validating the mass and floor area values for the other buildings.

Table 14: Comparison of mass per unit area with other buildings

Building	**Completed**	**Floor area m^2**	**Mass kg**	**Mass per unit area kg/m^2**
Empire State Building	1931	254 000 [21]	330 000 000 [21]	1299
World Trade Center (popular)	1970	459 500	500 000 000	1088
World Trade Center	1970	459 500	288 100 000	626
John Hancock Center	1969	260 128 [20]	174 180 000 [19]	670
Sears Tower	1973	423 624 [18]	201 852 000 [18]	476

6.2 Comparison to Values Extracted from SAP2000 model

Self-weight and load values extracted from the SAP2000 model have been posted by a blogger known only as "Shagster" on the James Randi Educational Foundation forum. These values are shown in Table 15. These are only preliminary values and have not been corroborated. Subsequent analyses could try to validate these values.

NIST modeled 3 different cases using SAP2000: "the original design case", "the state of the practice case" and the "refined NIST case". However, it is unclear which case is represented by the data released under the FOIA request. Two different live loads are given as LLA and LLW. The total mass is given in Table 15, including these live loads individually and together. The average loads for the building's gross floor area are given in psf. The load values calculated in this paper are given for comparison.

Table 15:

Loads	SAP2000 w/ LLA 10^6 kg	SAP2000 w/ LLW 10^6 kg	SAP2000 LLA+LLW 10^6 kg	SAP2000 avg psf	Calculated 10^6 kg	Calculated avg psf
self-weight + CDL	191.8	191.8	191.8		189.9	
SDL	44.6	44.6	44.6	19.9	62.1	27.7
SLL	50.1	59.9	110.0	49.0	36.2	16.1
total	286.5	296.3	346.4		288.1	

6.2.1 Comparison to CDL from SAP2000 Model

The calculated CDL matches the SAP2000 model value very closely. Since the hat truss (0.25 x 10^6 kg) is taken as SDL in the calculation but is considered to be CDL by NIST the difference becomes less than 1%.

6.2.2 Comparison to SDL from SAP2000 Model

The SDLs from the SAP2000 model and the calculated values are definitely not in agreement. One way of checking the NIST model is to asses the average value after excluding the mechanical floors. In accord with the original design SDLs, the mechanical floors account for 15.2 x 10^6 kg leaving 29.4 x 10^6 kg for the other 104 floors. The average SDL for these floors becomes 14.6 psf which seems low considering that no areas in the core are given by NIST as having less than 29 psf and the typical truss framed floor is described as having an SDL of 14-16.

The calculated SDL may be somewhat over-estimated due to the fact that tenant space in the core, which has a lower SDL, is not considered. A quick approximation of tenant space on floors 50-105 indicates that the tenant space ranged from 17-50% of the core. Using NIST's SDL from outside the core, (14 psf, which included a 6 psf partition allowance) the total SDL would be reduced by approximately 2.5 x 10^6 kg. Also, the hat truss (0.25 x 10^6 kg) is taken as SDL in the calculation, but it is considered as CDL by NIST.

It is interesting to note that the over-estimation described above, the hat truss and the SDL from the mechanical floors, taken together amount to 17.75 x 10^6 kg, which, if added to the total SDL from the model becomes 62.35 x 10^6 kg. Consequently, it may be that NIST missed applying the SDLs from the mechanical floors to the model.

6.2.3 Comparison to Live Loads from SAP2000 Model

In NIST NCSTAR1-2A (p. 69), the live loads for the three cases are described as identical for a typical truss floor being 50 psf. This section is contradictory as the original design load is also given as 100 psf. This section also states that live load reduction was applied.

Elsewhere in NIST NCSTAR1-2A (p. 137), live load reduction is described for the three loading cases where the original design case is based on 100 psf. The reduced live loads for the original design case range from 55-82.5 psf. The reduced live loads for the other two cases range from 25-47 psf to which a 6 psf partition allowance is added. Also given in this section of NCSTAR1-2A, are the live loads for various core occupancies, ranging from 40-100 psf. The large majority of these are greater than 50 psf.

If the SAP2000 data was from the original design case, the average live load would necessarily be greater than 50 psf, which indicates that the data must be from one of the other cases. If either the LLA value or the LLW value is taken individually, the average live load is less than 27 psf, which doesn't correspond with any of the loading cases.

When comparing the SAP model live load to the average live load calculated in this paper, it is important to remember that it is a comparison between live load permitted by code and in-service live loads which are usually equal to or less than 25% of code or design (as described in more detail above in the section "SLLs outside the Core (normal truss-framed floors"). Thus the calculated value of 16.1 psf is actually slightly higher than what would normally be expected.

6.3 Comparison to Total Column Loads in NIST Models

NIST NCSTAR1-6D (p. 176) presents total column loads for WTC1 and WTC2 models.[25] The NIST loads are shown along with calculated loads for a number of floors in Table 16. The percent difference is calculated relative to the NIST loads. It can be seen that the floor mass trend is toward higher mass lower in the building for both the calculated and NIST loads, as expected. Nonetheless, the floor mass variation is greater in the calculated loads. In fact if the difference trend is extrapolated to the lowest floor, the calculated total load would be 30% higher than the NIST total load at the base.

Table 16:

Floor	Calc Mass 1000 kg	NIST Mass 1000 kg	Difference
98-99	30,972	33,177	-6.64%
95-96	36,521	37,775	-3.32%
93-94	40,252	40,850	-1.46%
80-81	64,971	*61,563	5.54%
78-79	68,826	*64,749	6.30%

* NIST mass from WTC2 model

In the calculated loads, the primary contribution to increasing mass lower in the building is made by structural steel (columns and spandrels). Since this variation is based on the SAP2000 data and other data from NIST, it is very difficult to explain this discrepancy.

6.4 Comparison to Amount of Debris Removed from Ground Zero

6.4.1 The Amount of Debris

Martin Bellew, Director of the Bureau of Waste Disposal, New York Department of Sanitation states in an article on the AWPA website:

> "200,000 tons of steel were recycled directly from Ground Zero to various metal recyclers. The Fresh Kills Landfill received approximately 1.4 million tons of WTC debris of which 200,000 tons of steel were recycled by a recycling vendor (Hugo Neu Schnitzer)." [22]

Phillips & Jordan, Inc. reported:

> "The last debris was processed on July 26, 2002, day 321 of the project. At the close of the Staten Island Landfill mission: 1,462,000 tons of debris had been received and processed, 35,000 tons of steel had been removed (165,000 tons were removed directly at Ground Zero)." [23]

Thus the total amount of debris is 1,662,000 tons.

6.4.2 Calculation of Debris Amount

The calculated debris mass is 1.6 million tons. (See Appendix 1, Calculation of Debris Amount.)

6.4.3 Comparison of Calculated Mass to Recovered Mass

The calculated debris mass (1.6 million tons) seems to correspond well with the reported debris mass (1.66 million tons). Table 17 also includes a column for scaled mass assuming the mass of the two towers to be the commonly stated 500,000 tons. The other WTC Complex building masses are scaled in accord with the same proportions while the rest of the debris is not scaled. The proportional scaling is based on the assumption that if the WTC Towers were more massive, the rest of the buildings would also be more massive. The resulting scaled debris mass of 2.44 million tons is roughly 50% more than the reported amounts.

6.4.4 Conclusions

The calculated mass of 288,100 metric tons (317,500 short tons) is found to correspond with two other comparable structures (in terms of mass per unit floor area), data from NIST's SAP2000 model, and the reported amount of recovered debris. The calculated mass refutes the popular notion that the building weighed 500,000 tons. Further study may be warranted to examine other contemporaneous structures, validate the SAP2000 model values, and establish a more reliable estimation of the distribution between sources of removed debris.

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8 Appendices

8.1 Appendix 1: Calculation of Debris Amount

While it is difficult to know exactly what was removed from ground zero, there are numerous articles describing damage to the WTC complex and the surrounding areas. There are also numerous photographs available on the internet of the damage as well as the progress of the cleanup at various stages. The calculation shown in Table 17 is a very rough estimate based on a wide range of sources. Sources are not cited as they are too numerous for the scope of this study. Photos are not included because of usage rights issues. Further study could include a detailed analysis of the debris as well as complete presentation of motivations for assumptions as well as detailed sourcing.

Table 17: Calculation of Debris Amount

desc	area sq ft	stories	CDL + SDL psf	total CDL + SDL kgx10^3	SLL psf	total SLL kgx10^3	mass total kgx10^3	mass total tons	scaled mass
WTC1	3 800 000	116					288 100	317 606	500 001
WTC2	3 800 000	116					288 100	317 606	500 001
WTC3 Marriott est. 25,000 sq ft x 22 stories	540 000	22	140.00	34 292	16.20	3 968.09	38 260	42 179	66 401
WTC4	950 000	9	140.00	60 329	16.20	6 980.90	67 310	74 203	116 817
WTC5	1 080 000	9	140.00	68 584	16.20	7 936.19	76 521	84 357	132 802
WTC6	537 693	7	140.00	34 146	16.20	3 951.14	38 097	41 998	66 117
WTC7	1 868 000	47	112.00	94 900	16.20	13 726.66	108 627	119 752	188 523
Plaza btw 4+5	100 000		220.00	9 979	16.20	734.83	10 714	11 811	18 594
Concourse btw 4+5 (part not included in 4+5)	100 000		220.00	9 979	16.20	734.83	10 714	11 811	18 594
Basement 2 level - WTC4, WTC5 and under concourse	250 000		220.00	24 948			24 948	27 503	43 298
Bathtub ground level	398 792		220.00	39 796	0.00	0.00	39 796	43 872	69 067
Bathtub Concourse	398 792		220.00	39 796	25.00	4 522.30	44 319	48 857	76 915
Bathtub sublevel B1	398 792		225.00	40 701	50.00	9 044.60	49 745	54 840	86 334
Bathtub sublevel B2	398 792		225.00	40 701	50.00	9 044.60	49 745	54 840	86 334
Bathtub sublevel B3	398 792		300.00	54 268	50.00	9 044.60	63 312	69 796	109 879
Bathtub sublevel B4	398 792		300.00	54 268	50.00	9 044.60	63 312	69 796	109 879
Bathtub sublevel B5	398 792		300.00	54 268	50.00	9 044.60	63 312	69 796	109 879
Con Edison substation	50 000	2	210.00	4 763	15.00	340.20	5 103	5 626	8 856
total area	**15 817 237**				**sq ft/cu ft**	**psf/pcf**	**lbs**		
Cortland St Station 1/9					5 000.00	245.00	1 225 000	613	613
Cortland St Station N/R					600.00	245.00	147 000	74	74
Subway 1/9 2500 ft double track									
• track					26.66	lb/ft	266 600	133	133
• concrete					210 000	150.00	31 500 000	15 750	15 750
1400 vehicles					4 000.00	per vehicle	5 600 000	2 800	2 800
debris from Winter Garden					45 000.00	200.00	9 000 000	4 500	4 500
debris from WFC3 American Express					30 000.00	150.00	4 500 000	2 250	2 250
debris from One WFC									
debris from Bankers Trust Building									
debris from 90 West St.									
debris from Verizon Building								1 800	1 800
debris from 130 Cedar St.					10 000.00	160.00	1 600 000	800	800
debris from 30 West Broadway					8 000.00	160.00	1 280 000	640	640
earth excavated in front of WFC buildings					180 000	90.00	16 200 000	8 100	8 100
Vesey Street collapsed (20x50 ft.)					1 000.00	245.00	245 000	123	123
a portion of the slurry wall was destroyed and removed on the south east side of the bathtub					12 000.00	150.00	1 800 000	900	900
Collapsed area in front of Bankers Trust					20 000.00	200.00	4 000 000	2 000	2 000
North bridge from Winter garden to WTC6					3 600.00	150.00	540 000	270	270
water								88 418	88 418
Total								**1 595 420**	**2 437 462**

8.1.1 Comments on Calculation of Debris Mass

The mass of destroyed buildings in Table 17 is calculated from assumed unit loads based on the loads from WTC1. The average unit load from WTC1 was 128 psf. WTC 7 which had a similar construction uses the same unit load. The other WTC complex buildings were somewhat heavier due to a more conventional post and beam construction and are assumed to have a unit load of 156 psf. WTC1 and WTC2 include sublevels, while the other buildings do not. It can be seen in the architectural drawings that the area of the sublevels within the bathtub, excluding WTC1 and WTC2 was close to 400,000 square feet. The sublevels within the bathtub are assumed to be much more heavily constructed, especially in the lowest levels due to very heavy mechanical areas such as electrical substations and the cooling plant. Also much of the sublevels were used for parking. The Con Edison substation is assumed to similar to the sublevels.

The calculated total floor area is roughly 16 million sq ft. FEMA gives the total office area for the World Trade Center Complex as 12 million sq ft.[24] There were no offices in the sublevels which accounts for 2.1 million sq ft. This leaves 1.9 million sq ft which is 14% of the remaining area. It is not unreasonable to assume that the rest of the areas had 14% of the space allocated for other uses such as service, utility, mechanical and transit. Thus 16 million sq ft seems to be a reasonable number.

Notes on other debris:

- The Cortland Street station for the 1/9 subway was completely destroyed.
- The Cortland Street station for the N/R subway was damaged where external columns from WTC1 penetrated Vesey St.
- 2500 ft of subway tunnel for the 1/9 were removed and replaced due to damage. This line ran along the outside of the eastern wall of the bathtub.
- 1400 destroyed vehicles were removed to the Staten Island Landfill.
- The Wintergarden, part of the World Financial Center (WFC) Complex was severely damaged and mostly removed.
- Eight floors with roughly 10 bays were removed from the southeast corner of the American express building (WFC3).
- The Verizon building had extensive facade damage and large portions of the facade the east and south side were replaced.
- 130 Cedar St. had extensive damage to the roof where external panels from WTC2 penetrated the structure.
- 30 West Broadway had extensive damage from the collapsing WTC7 building and roughly 25 bays were completely destroyed.
- Vesey Street collapsed where the debris from WTC7 landed.
- In photographs taken during cleanup, it appears that at least 3 ft of earth were excavated from in front of the WFC complex on the eastern side.
- A portion of the slurry wall was destroyed by the collapse of WTC2. The dimensions are approximately 3 ft x 100 ft x 20 ft.
- The entire area in front of the Bankers Trust building collapsed.
- The North Bridge from the Wintergarden to WTC6 was completely destroyed.

One easily overlooked factor is the amount of water that inundated nearly all debris areas. Broken water mains and fire-fighting must have made the larger portion of cementitious debris and earth heavier during removal. The value in Table 17 is based on the total amount of concrete having the additional weight based on the density of wet sand with stone aggregate.

Ignored factors:

- A small portion of the sublevels at the northern end of the bathtub remained intact.

- Facade damage to all buildings except the Verizon building were ignored.
- Large portions of the PATH train track were removed.
- Absorption of water by debris other than cementitous materials, such as pulverized gypsum wall board, fabric and wood based materials.
- The amount of earth removed outside the bathtub.
- The amount of material that was burned off in the fires.
- Temporary structure materials for shoring and bridging.
- Subway cars.
- Debris from One WFC, the Bankers Trust building, and the building at 90 West St.

8.2 Appendix 2: Calculation of Rolled Core Column Mass

The transition from box shapes to wide flange shapes was identified based on the shape images from the WTC Modeling and Simulation site for the transition floors.[15] Rolled core column dimensions (wide flange shapes) were taken from that site. The cross-sectional area is assumed to vary linearly between the transition floor and floor 106. The mass for all rolled core columns is 3,268 short tons.

In Table 18, the cross-sectional area for each column is calculated at the transition floor, based on the dimensions given. Volume is calculated assuming a height of 12 ft. The mass of the column on the transition floor is calculated using the density of steel (490 lbs/ft^3). The mass of the columns at floor 106 is taken from Appendix 3. The total for the column from the transition floor to floor 106 is calculated using the average between the transition floor and the 106th floor and the number of floors. Floors 107, 108, 110 and 111 (roof) are calculated individually (see Appendix 3). Floor 109 had the same dimensions as floor 110.

Table 18: Calculation of Mass from Core Column Wide Flange Data

col nr	transition floor	width in	depth in	cnt	width in	depth in	cnt	area sq ft	volume cu ft	t-floor short tons	fl. 106 short tons	t-106 short tons
501	83	12.58	3.07	1	17.9	4.91	2	1.4889	17.8666	4.3773	1.2610	76.12
502	83	12.58	2.02	1	16.8	3.21	2	0.9255	11.1056	2.7209	0.9425	49.46
503	83	12.58	2.02	1	16.8	3.21	2	0.9255	11.1056	2.7209	0.8938	48.80
504	86	12.624	1.655	1	16.475	2.658	2	0.7533	9.0395	2.2147	0.7080	35.07
505	66	12.624	1.545	1	16.365	2.468	2	0.6964	8.3568	2.0474	0.8151	61.54
506	83	12.6	2.19	1	17	3.5	2	1.0180	12.2162	2.9930	0.8938	50.53
507	83	12.624	1.875	1	16.695	3.033	2	0.8677	10.4118	2.5509	0.8151	43.76
508	83	12.58	3.07	1	17.9	4.91	2	1.4889	17.8666	4.3773	1.2610	73.30
601	86	10.908	1.08	1	12.67	1.736	2	0.3873	4.6476	1.1387	0.3838	17.51
602	80	12.624	1.205	1	16.025	1.936	2	0.5365	6.4384	1.5774	0.4304	29.11
603	80	12.624	1.205	1	16.025	1.936	2	0.5365	6.4384	1.5774	0.4982	30.10
604	80	10.908	1.08	1	12.67	1.736	2	0.3873	4.6476	1.1387	0.3120	21.03
605	86	10.908	1.08	1	12.67	1.736	2	0.3873	4.6476	1.1387	0.3838	17.51
606	80	12.624	1.31	1	16.13	2.093	2	0.5837	7.0048	1.7162	0.4982	32.11
607	80	12.624	1.125	1	15.945	1.813	2	0.5001	6.0015	1.4704	0.4982	28.54
608	86	10.908	1.08	1	12.67	1.736	2	0.3873	4.6476	1.1387	0.3838	17.51
701	95	10.908	0.905	1	12.515	1.486	2	0.3268	3.9222	0.9609	0.5876	10.84
702	36	12.58	3.07	1	17.9	4.91	2	1.4889	17.8666	4.3773	0.5641	180.36
703	75	12.624	1.545	1	16.365	2.468	2	0.6964	8.3568	2.0474	0.2813	39.59
704	0	12.6	2.19	1	17	3.5	2	1.0180	12.2162	2.9930	0.2512	176.81
705	7	12.624	1.31	1	16.13	2.093	2	0.5837	7.0048	1.7162	0.2512	100.34

706	45	12.624	1.875	1	16.695	3.033	2	0.8677	10.4118	2.5509	0.4013	94.47
707	7	12.624	1.205	1	16.025	1.936	2	0.5365	6.4384	1.5774	0.5409	108.04
708	89	10.908	1.08	1	12.67	1.736	2	0.3873	4.6476	1.1387	0.7922	19.31
801	95	10.908	0.905	1	12.515	1.486	2	0.3268	3.9222	0.9609	0.5898	10.86
802	33	12.58	3.07	1	17.9	4.91	2	1.4889	17.8666	4.3773	0.5641	187.77
803	95	10.908	0.755	1	12.365	1.236	2	0.2695	3.2335	0.7922	0.3838	8.23
804	9	12.58	2.02	1	16.8	3.21	2	0.9255	11.1056	2.7209	0.2315	147.62
805	36	12.624	1.875	1	16.695	3.033	2	0.8677	10.4118	2.5509	0.4380	109.10
806	27	12.58	3.07	1	17.9	4.91	2	1.4889	17.8666	4.3773	0.5409	201.65
807	89	12.624	0.98	1	15.8	1.563	2	0.4289	5.1469	1.2610	0.5641	18.25
808								0.0000	0.0000	0.0000	0.0000	0.00
901	86	10.908	1.08	1	12.67	1.736	2	0.3873	4.6476	1.1387	0.4256	17.99
902	48	12.6	2.19	1	17	3.5	2	1.0180	12.2162	2.9930	0.4982	106.48
903	80	12.624	1.415	1	16.235	2.283	2	0.6388	7.6660	1.8782	0.7080	37.50
904	77	10.908	1.08	1	12.67	1.736	2	0.3873	4.6476	1.1387	0.3675	24.10
905	86	10.908	0.905	1	12.515	1.486	2	0.3268	3.9222	0.9609	0.3120	14.64
906	48	12.58	2.02	1	16.8	3.21	2	0.9255	11.1056	2.7209	0.4982	98.18
907	48	12.56	2.38	1	17.2	3.62	2	1.0724	12.8684	3.1528	0.5641	113.36
908	48	12.624	1.875	1	16.695	3.033	2	0.8677	10.4118	2.5509	0.4256	90.78
1001	80	12.58	3.07	1	17.9	4.91	2	1.4889	17.8666	4.3773	1.6595	87.53
1002	77	12.56	2.83	1	17.7	4.52	2	1.3580	16.2961	3.9925	1.3978	86.25
1003	77	12.56	2.83	1	17.7	4.52	2	1.3580	16.2961	3.9925	1.1519	82.31
1004	86	12.624	1.545	1	16.365	2.468	2	0.6964	8.3568	2.0474	0.8151	32.92
1005	86	12.624	1.415	1	16.235	2.283	2	0.6388	7.6660	1.8782	0.7559	30.29
1006	77	12.58	2.6	1	17.4	4.16	2	1.2325	14.7897	3.6235	0.8151	71.02
1007	77	12.6	2.19	1	17	3.5	2	1.0180	12.2162	2.9930	0.8938	62.19
1008	80	12.58	3.07	1	17.9	4.91	2	1.4889	17.8666	4.3773	1.6595	87.53
											Subtotal: transition floor - 106	**3,088.28**
											floor 107	35.81
											floor 108	41.42
											floor 109	35.81
											floor 110	35.81
											roof (111)	31.20
											Total core columns (wide flange shapes)	**3,268.31**

8.3 Appendix 3: Core Column Data for Selected Floors

The data in Table 19 was collected from the WTC Modeling and Simulation site.[15]
For each column, the cross sectional area is given in sq ft and the volume for a 12-foot high floor is given in cu ft. The mass is given in short tons based on the density of steel (490 lbs/ft^3).

Table 19: Core column data for selected floors

floor B6-B3												
col	**w**	**d**	**cnt**	**w**	**d**	**cnt**	**w**	**d**	**cnt**	**sq ft**	**cu ft**	**tons**
501	52	5	2	12	5	2	39	6.5	1	6.20	74.46	18.24
502	52	4.75	2	12.5	4.75	2				4.26	51.06	12.51
503	52	4.375	2	13.25	4.375	2				3.96	47.58	11.66
504	52	2.9375	2	16.125	3	2				2.79	33.52	8.21
505	52	3.375	2	11.25	3.375	2				2.96	35.58	8.72
506	52	5	2	12	5	2				4.44	53.33	13.07
507	52	4.625	2	12.75	4.625	2				4.16	49.91	12.23
508	52	5	2	12	5	2	39	6.5	1	6.20	74.46	18.24
601	43	3.625	2	6.75	3.625	2				2.50	30.06	7.36
602	36	3.375	2	9.25	3.375	2				2.12	25.45	6.24
603	36	3.125	2	9.75	3.125	2				1.99	23.83	5.84
604	36	2.375	2	9.25	2.375	2				1.49	17.91	4.39
605	36	2.5625	2	8.875	2.5625	2				1.60	19.17	4.70
606	36	3.125	2	9.75	3.125	2				1.99	23.83	5.84
607	36	3.125	2	9.75	3.125	2				1.99	23.83	5.84
608	43	3.125	2	7.75	3.125	2				2.20	26.43	6.48
701	37	4.25	2	6.5	4.25	2				2.57	30.81	7.55
702	30	3.5	2	19	3.5	2				2.38	28.58	7.00
703	34	2.5	2	11	2.5625	2				1.57	18.86	4.62
704	12.6	2.19	1	17	3.5	2				1.02	12.22	2.99
705	28	1.25	2	14.5	1.25	2				0.74	8.85	2.17
706	30	3	2	11	3.125	2				1.73	20.73	5.08
707	30	3.375	2	19.25	3.5	2				2.34	28.10	6.89
708	37	4.125	2	6.75	4.25	2				2.52	30.22	7.40
801	34	4.5	2	6	4.5	2				2.50	30.00	7.35
802	30	3.375	2	19.25	3.5	2				2.34	28.10	6.89
803	34	2.6875	2	9.625	2.6875	2				1.63	19.54	4.79
804	28	1.75	1	13.5	1.8125	2				0.68	8.16	2.00
805	34	2.375	2	12.25	2.375	2				1.53	18.31	4.49
806	30	3.25	2	19.5	3.25	2				2.23	26.81	6.57
807	34	4.25	2	6.5	4.25	2				2.39	28.69	7.03
808										0.00	0.00	0.00
901	43	2.625	2	8.75	2.625	2				1.89	22.64	5.55
902	36	3.125	2	9.75	3.125	2				1.99	23.83	5.84
903	36	3	2	10	3.125	2				1.93	23.21	5.69
904	36	2	2	10	2	2				1.28	15.33	3.76
905	22	3.625	2	6.75	3.75	2				1.46	17.51	4.29
906	36	2.8125	2	10.375	2.8125	2				1.81	21.74	5.33
907	36	3.25	2	9.5	3.25	2				2.05	24.65	6.04
908	43	2.625	2	8.75	2.625	2				1.89	22.64	5.55
1001	52	5	2	12	5	2	39	6.25	1	6.14	73.65	18.04
1002	52	5	2	12	5	2	39	0.9375	1	4.70	56.38	13.81
1003	52	5	2	12	5	2	39	0.9375	1	4.70	56.38	13.81
1004	52	3.25	2	11.5	3.25	2				2.87	34.40	8.43
1005	52	3	2	16	3	2				2.83	34.00	8.33
1006	52	4.75	2	12.5	5	2	39	0.9375	1	4.55	54.63	13.38
1007	52	4.875	2	12.25	4.875	2				4.35	52.20	12.79
1008	52	5	2	12	5	2	39	5.75	1	6.00	72.02	17.65
total										129.47	1553.60	380.63

Table 19: (continued) Core column data for selected floors

floor 002-007												
col	w	d	cnt	w	d	cnt	w	d	cnt	sq ft	cu ft	tons
501	52	5	2	12	5	2	39	6.5	1	6.20	74.46	18.24
502	52	4.75	2	12.5	4.75	2				4.26	51.06	12.51
503	52	4.375	2	13.25	4.375	2				3.96	47.58	11.66
504	52	2.9375	2	16.125	2.9375	2				2.78	33.35	8.17
505	52	3.5	2	11	3.5	2				3.06	36.75	9.00
506	52	4.875	2	12.26	4.875	2				4.35	52.21	12.79
507	52	4.625	2	12.75	4.625	2				4.16	49.91	12.23
508	52	5	2	12	5	2	39	6.5	1	6.20	74.46	18.24
601	43	4.5	2	5	4.5	2				3.00	36.00	8.82
602	36	4.5	2	7	4.5	2				2.69	32.25	7.90
603	36	4.25	2	7.5	4.25	2				2.57	30.81	7.55
604	36	3.1875	2	7.625	3.1875	2				1.93	23.18	5.68
605	36	3.4375	2	7.125	3.4375	2				2.06	24.71	6.05
606	36	4.25	2	7.5	4.25	2				2.57	30.81	7.55
607	36	4.25	2	7.5	4.25	2				2.57	30.81	7.55
608	43	4	2	6	4	2				2.72	32.67	8.00
701	37	4.5	2	6	4.5	2				2.69	32.25	7.90
702	30	4.5	2	17	4.5	2				2.94	35.25	8.64
703	34	3.375	2	9.25	3.375	2				2.03	24.33	5.96
704	12.58	2.02	1	16.8	3.21	2				0.93	11.11	2.72
705	28	2.125	2	12.75	2.125	2				1.20	14.43	3.54
706	30	4.375	2	8.25	4.375	2				2.32	27.89	6.83
707	30	4.5	2	17	4.5	2				2.94	35.25	8.64
708	37	4.625	2	5.75	4.625	2				2.75	32.95	8.07
801	34	5	2	5	5	2				2.71	32.50	7.96
802	30	4.5	2	17	4.5	2				2.94	35.25	8.64
803	34	4	2	7	4	2				2.28	27.33	6.70
804	28	3	1	11	3	2				1.04	12.50	3.06
805	34	3.125	2	10.75	3.125	2				1.94	23.31	5.71
806	30	4.375	2	17.25	4.375	2				2.87	34.45	8.44
807	34	4.875	2	5.25	4.875	2				2.66	31.89	7.81
808										0.00	0.00	0.00
901	43	4	2	6	4	2				2.72	32.67	8.00
902	36	4.125	2	7.75	4.125	2				2.51	30.08	7.37
903	36	4.125	2	7.75	4.125	2				2.51	30.08	7.37
904	36	2.875	2	6.25	2.875	2				1.69	20.24	4.96
905	22	5	2	4	5	2				1.81	21.67	5.31
906	36	4.125	2	7.75	4.125	2				2.51	30.08	7.37
907	36	4.5	2	7	4.5	2				2.69	32.25	7.90
908	43	4	2	6	4	2				2.72	32.67	8.00
1001	52	5	2	12	5	2	39	6.5	1	6.20	74.46	18.24
1002	52	5	2	12	5	2	39	1.25	1	4.78	57.40	14.06
1003	52	5	2	12	5	2	39	1.25	1	4.78	57.40	14.06
1004	52	3.25	2	11.5	3.25	2				2.87	34.40	8.43
1005	52	3.125	2	15.75	3.125	2				2.94	35.29	8.65
1006	52	5	2	12	5	2	39	0.9375	1	4.70	56.38	13.81
1007	52	4.875	2	12.25	4.875	2				4.35	52.20	12.79
1008	52	5	2	12	5	2	39	6.5	1	6.20	74.46	18.24
total										145.28	1743.42	427.14

Table 19: (continued) Core column data for selected floors

				floor 51-53								
col	**w**	**d**	**cnt**	**w**	**d**	**cnt**	**w**	**d**	**cnt**	**sq ft**	**cu ft**	**tons**
501	52	3.25	2	15.5	3.25	2				3.05	36.56	8.96
502	52	2.0625	2	17.875	3.125	2				2.27	27.18	6.66
503	52	1.9375	2	18.175	2	2				1.90	22.85	5.60
504	52	1.4375	2	19.125	1.4375	2				1.42	17.04	4.17
505	52	1.5625	2	14.875	1.5625	2				1.45	17.42	4.27
506	52	2.125	2	17.75	2.1875	2				2.07	24.89	6.10
507	52	2	2	18	2.0525	2				1.96	23.49	5.76
508	52	3.25	2	15.5	3.25	2				3.05	36.56	8.96
601	43	1.4375	2	11.125	1.4375	2				1.08	12.97	3.18
602	36	1.5625	2	12.875	1.5625	2				1.06	12.73	3.12
603	36	1.4375	2	13.125	1.4375	2				0.98	11.77	2.88
604	36	1.1275	2	11.75	1.1275	2				0.75	8.97	2.20
605	36	1.1875	2	11.625	1.1875	2				0.79	9.43	2.31
606	36	1.625	2	12.75	1.6875	2				1.11	13.34	3.27
607	36	1.5	2	12	1.5	2				1.00	12.00	2.94
608	43	1.125	2	11.75	1.125	2				0.86	10.27	2.52
701	37	1.6875	2	11.625	1.6875	2				1.14	13.68	3.35
702	12.56	2.38	1	17.2	3.82	2				1.12	13.44	3.29
703	34	1.125	2	13.75	1.125	2				0.75	8.95	2.19
704	12.624	0.695	1	15.515	1.128	2				0.30	3.65	0.89
705	12.624	0.68	1	15.5	1.063	2				0.29	3.46	0.85
706	12.624	1.77	1	16.59	2.843	2				0.81	9.72	2.38
707	12.56	2.38	1	17.2	3.82	2				1.12	13.44	3.29
708	37	1.6875	2	11.625	1.6875	2				1.14	13.68	3.35
801	34	1.8125	2	11.375	1.8125	2				1.14	13.71	3.36
802	12.56	2.38	1	17.2	3.82	2				1.12	13.44	3.29
803	34	1.8125	2	11.375	1.8125	2				1.14	13.71	3.36
804	12.624	1.205	1	16.025	1.936	2				0.54	6.44	1.58
805	12.624	1.545	1	16.385	2.468	2				0.70	8.37	2.05
806	12.56	2.38	1	17.2	3.82	2				1.12	13.44	3.29
807	34	1.6875	2	11.625	1.6875	2				1.07	12.83	3.14
808										0.00	0.00	0.00
901	22	2.0325	2	8.875	2.0625	2				0.88	10.50	2.57
902	12.58	2.02	1	16.8	3.21	2				0.93	11.11	2.72
903	36	1.4375	2	13.125	1.4375	2				0.98	11.77	2.88
904	36	0.875	2	12.25	0.675	2				0.55	6.63	1.62
905	22	1.4375	2	11.125	1.4375	2				0.66	7.94	1.94
906	12.58	2.02	1	16.8	3.21	2				0.93	11.11	2.72
907	12.6	2.19	1	17	3.5	2				1.02	12.22	2.99
908	12.624	1.77	1	16.59	2.843	2				0.81	9.72	2.38
1001	52	3.125	2	15.55	3.125	2				2.93	35.18	8.62
1002	43	2.25	2	17.6	2.25	2				1.89	22.73	5.57
1003	43	2.8125	2	16.375	2.8125	2				2.32	27.83	6.82
1004	52	1.375	2	15.25	1.4375	2				1.30	15.57	3.81
1005	52	1.25	2	19.5	1.3125	2				1.26	15.10	3.70
1006	43	2.625	2	16.75	2.625	2				2.18	26.14	6.40
1007	43	2.25	2	17.5	2.3125	2				1.91	22.87	5.60
1008	52	3.125	2	15.75	3.125	2				2.94	35.29	8.65
total										61.76	741.11	181.57

Table 19: (continued) Core column data for selected floors

floor 105-106												
col	w	d	cnt	w	d	cnt	w	d	cnt	sq ft	cu ft	tons
501	12.624	0.98	1	15.8	1.563	2				0.43	5.15	1.26
502	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
503	12.624	0.695	1	15.515	1.128	2				0.30	3.65	0.89
504	12.624	0.57	1	14.65	0.938	2				0.24	2.89	0.71
505	12.624	0.68	1	14.74	1.063	2				0.28	3.33	0.82
506	12.624	0.695	1	15.515	1.128	2				0.30	3.65	0.89
507	12.624	0.68	1	14.74	1.063	2				0.28	3.33	0.82
508	12.624	0.98	1	15.8	1.563	2				0.43	5.15	1.26
601	10.908	0.39	1	12	0.606	2				0.13	1.57	0.38
602	12.624	0.42	1	11.5	0.686	2				0.15	1.76	0.43
603	12.624	0.451	1	12.023	0.778	2				0.17	2.03	0.50
604	10.908	0.345	1	10	0.576	2				0.11	1.27	0.31
605	10.908	0.39	1	12	0.606	2				0.13	1.57	0.38
606	12.624	0.451	1	12.023	0.778	2				0.17	2.03	0.50
607	12.624	0.451	1	12.023	0.778	2				0.17	2.03	0.50
608	10.908	0.39	1	12	0.606	2				0.13	1.57	0.38
701	10.908	0.58	1	12.19	0.921	2				0.20	2.40	0.59
702	12.624	0.465	1	14.545	0.748	2				0.19	2.30	0.56
703	12.624	0.338	1	8.031	0.592	2				0.10	1.15	0.28
704	12.624	0.308	1	8	0.526	2				0.09	1.03	0.25
705	12.624	0.308	1	8	0.526	2				0.09	1.03	0.25
706	12.624	0.418	1	10.04	0.716	2				0.14	1.64	0.40
707	12.624	0.54	1	14.62	0.673	2				0.18	2.21	0.54
708	10.908	0.755	1	12.365	1.236	2				0.27	3.23	0.79
801	10.908	0.59	1	12.19	0.921	2				0.20	2.41	0.59
802	12.624	0.465	1	14.545	0.748	2				0.19	2.30	0.56
803	10.908	0.39	1	12	0.606	2				0.13	1.57	0.38
804	10.908	0.284	1	8	0.515	2				0.08	0.94	0.23
805	12.624	0.45	1	10.072	0.783	2				0.15	1.79	0.44
806	12.624	0.54	1	14.62	0.673	2				0.18	2.21	0.54
807	12.624	0.465	1	14.545	0.748	2				0.19	2.30	0.56
808										0.00	0.00	0.00
901	10.908	0.43	1	12.04	0.671	2				0.14	1.74	0.43
902	12.624	0.451	1	12.023	0.778	2				0.17	2.03	0.50
903	12.624	0.57	1	14.65	0.938	2				0.24	2.89	0.71
904	14	0.375	2	10	0.375	2				0.13	1.50	0.37
905	10.908	0.345	1	10	0.576	2				0.11	1.27	0.31
906	12.624	0.451	1	12.023	0.778	2				0.17	2.03	0.50
907	12.624	0.465	1	14.545	0.748	2				0.19	2.30	0.56
908	10.908	0.43	1	12.04	0.671	2				0.14	1.74	0.43
1001	12.624	1.09	1	16.13	2.093	2				0.56	6.77	1.66
1002	12.624	1.045	1	15.81	1.748	2				0.48	5.71	1.40
1003	12.624	0.89	1	15.71	1.438	2				0.39	4.70	1.15
1004	12.624	0.68	1	14.74	1.063	2				0.28	3.33	0.82
1005	12.624	0.61	1	14.69	0.998	2				0.26	3.09	0.76
1006	12.624	0.68	1	14.74	1.063	2				0.28	3.33	0.82
1007	12.624	0.695	1	15.515	1.128	2				0.30	3.65	0.89
1008	12.624	1.09	1	16.13	2.093	2				0.56	6.77	1.66
total										10.51	126.16	30.91

Table 19: (continued) Core column data for selected floors

floor 107												
col	w	d	cnt	w	d	cnt	w	d	cnt	sq ft	cu ft	tons
501	12.624	0.84	1	15.68	1.378	2				0.37	4.48	1.10
502	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
503	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
504	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
505	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
506	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
507	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
508	12.624	0.84	1	15.68	1.378	2				0.37	4.48	1.10
601	10.908	0.62	1	12.23	0.866	2				0.19	2.33	0.57
602	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
603	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
604	10.908	0.71	1	12.23	1.106	2				0.24	2.90	0.71
605	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
606	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
607	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
608	10.908	0.62	1	12.23	0.866	2				0.19	2.33	0.57
701	10.908	0.755	1	12.365	1.236	2				0.27	3.23	0.79
702	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
703	12.624	0.46	1	10.072	0.783	2				0.15	1.80	0.44
704	12.624	0.308	1	8	0.528	2				0.09	1.03	0.25
705	12.624	0.308	1	8	0.528	2				0.09	1.03	0.25
706	12.624	0.46	1	10.072	0.783	2				0.15	1.80	0.44
707	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
708	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
801	10.908	0.755	1	12.365	1.236	2				0.27	3.23	0.79
802	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
803	10.908	0.47	1	12.08	0.736	2				0.16	1.91	0.47
804	10.908	0.294	1	8	0.516	2				0.08	0.96	0.23
805	12.624	0.42	1	14.5	0.686	2				0.17	2.10	0.51
806	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
807	12.624	0.68	1	14.74	1.063	2				0.28	3.33	0.82
808										0.00	0.00	0.00
901	10.908	0.62	1	12.23	0.866	2				0.19	2.33	0.57
902	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
903	10.908	0.71	1	12.32	1.106	2				0.24	2.92	0.71
904	10.908	0.71	1	12.32	1.106	2				0.24	2.92	0.71
905	10.908	0.71	1	12.32	1.106	2				0.24	2.92	0.71
906	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
907	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
908	10.908	0.62	1	12.23	0.866	2				0.19	2.33	0.57
1001	12.624	0.84	1	15.68	1.378	2				0.37	4.48	1.10
1002	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1003	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1004	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1005	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1006	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1007	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1008	12.624	0.84	1	15.68	1.378	2				0.37	4.48	1.10
total										12.18	146.15	35.81

Table 19: (continued) Core column data for selected floors

floor 108												
col	w	d	cnt	w	d	cnt	w	d	cnt	sq ft	cu ft	tons
501	12.624	1.125	1	16.945	1.813	2				0.53	6.30	1.54
502	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
503	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
504	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
505	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
506	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
507	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
508	12.624	1.125	1	16.945	1.813	2				0.53	6.30	1.54
601	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
602	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
603	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
604	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
605	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
606	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
607	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
608	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
701	12.624	1.125	1	16.945	1.813	2				0.53	6.30	1.54
702	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
703	12.624	0.46	1	10.072	0.783	2				0.15	1.80	0.44
704	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
705	12.624	0.308	1	8	0.528	2				0.09	1.03	0.25
706	12.624	0.46	1	10.072	0.783	2				0.15	1.80	0.44
707	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
708	12.624	0.46	1	10.072	0.783	2				0.15	1.80	0.44
801	12.624	1.125	1	16.945	1.813	2				0.53	6.30	1.54
802	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
803	10.908	0.47	1	12.08	0.736	2				0.16	1.91	0.47
804										0.00	0.00	0.00
805	12.624	0.42	1	14.5	0.686	2				0.17	2.10	0.51
806	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
807	12.624	1.125	1	16.945	1.813	2				0.53	6.30	1.54
808										0.00	0.00	0.00
901	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
902	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
903	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
904	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
905	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
906	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
907	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
908	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
1001	12.624	1.125	1	16.945	1.813	2				0.53	6.30	1.54
1002	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1003	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1004	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1005	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1006	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1007	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1008	12.624	1.125	1	16.945	1.813	2				0.53	6.30	1.54
total										14.09	169.05	41.42

Table 19: (continued) Core column data for selected floors

floor 109-110												
col	w	d	cnt	w	d	cnt	w	d	cnt	sq ft	cu ft	tons
501	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
502	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
503	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
504	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
505	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
506	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
507	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
508	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
601	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
602	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
603	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
604	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
605	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
606	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
607	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
608	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
701	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
702	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
703	12.624	0.339	1	8.31	0.593	2				0.10	1.18	0.29
704	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
705	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
706	12.624	0.378	1	10	0.643	2				0.12	1.47	0.36
707	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
708										0.00	0.00	0.00
801	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
802	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
803	12.624	0.371	1	8.077	0.641	2				0.10	1.25	0.31
804										0.00	0.00	0.00
805	12.624	0.42	1	11.5	0.686	2				0.15	1.76	0.43
806	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
807	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
808										0.00	0.00	0.00
901	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
902	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
903	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
904	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
905	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
906	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
907	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
908	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
1001	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1002	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1003	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1004	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1005	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1006	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1007	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1008	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
total										12.18	146.15	35.81

Table 19: (continued) Core column data for selected floors

				floor 111 (roof)								
col	**w**	**d**	**cnt**	**w**	**d**	**cnt**	**w**	**d**	**cnt**	**sq ft**	**cu ft**	**tons**
501	10.908	0.45	1	10.072	0.783	2				0.14	1.72	0.42
502	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
503	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
504	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
505	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
506	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
507	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
508	10.908	0.45	1	10.072	0.783	2				0.14	1.72	0.42
601	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
602	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
603	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
604	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
605	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
606	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
607	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
608	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
701	10.908	0.45	1	10.072	0.783	2				0.14	1.72	0.42
702	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
703										0.00	0.00	0.00
704	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
705	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
706										0.00	0.00	0.00
707	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
708										0.00	0.00	0.00
801	10.908	0.45	1	10.072	0.783	2				0.14	1.72	0.42
802	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
803										0.00	0.00	0.00
804										0.00	0.00	0.00
805										0.00	0.00	0.00
806	10.908	0.45	1	10.072	0.783	2				0.14	1.72	0.42
807	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
808										0.00	0.00	0.00
901	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
902										0.00	0.00	0.00
903	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
904	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
905	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
906	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
907	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
908	12.624	0.61	1	14.59	0.998	2				0.26	3.07	0.75
1001	10.908	0.45	1	10.072	0.783	2				0.14	1.72	0.42
1002	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1003	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1004	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1005	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1006	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1007	12.624	0.73	1	15.55	1.188	2				0.32	3.85	0.94
1008	10.908	0.45	1	10.072	0.783	2				0.14	1.72	0.42
total										10.61	127.34	31.20