Reply to Dr. Greening

Author:
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General Overview

Let us assume for a moment that Dr. Greening is correct. What would be the result of an analysis which allows all of Dr.Greening's assumptions to be held valid, all his figures to be utilised and all his reasoning to be used, but then simply allow the clock to tick over for a few more tenths of a second? Dr. Greening shows an energy excess at a point in time some 13 milliseconds into the collision. This is shown in more detail below.

Energy sources
Kinetic energy from initial freefall 2105MJ
58Ktonnes * g moving through 3.7m
Potential energy from additional downward movement
58Ktonnes * g *[16.5/16] moving through 111mm deflection of impacted storey 65MJ
58Ktonnes * g *[15.5/16] moving through 111mm deflection of impacting storey 61MJ
Compression of remainder of impacting section allowing an effective mass of 58Ktonnes * g * [11+[4/2]/16] moving through half of 4 affected storeys elastic deflection of 7.4mm 7MJ
Compression of remainder of impacted section effective mass of 58Ktonnes * g * [17+[4/2]/16] moving through half of 4 affected storeys elastic deflection of 7.4mm 10MJ
Total energy available 2248MJ

Energy demands
Pulverisation of impacting floor concrete [from Dr. Greening's article] 128MJ
Pulverisation of impacted floor concrete 128MJ
Energy consumed by inertial changes in collision [from Dr. Greening's article] 525 MJ
Strain energy in impacting storey 122MJ
58Ktonnes * g * [Dr. Greening's safety factor of 2] moving through 111mm deflection of impacted storey * [29/30]
Strain energy in impacted storey 122MJ
58Ktonnes * g * [Dr. Greening's safety factor of 2] moving through 111mm deflection of impacted storey * [29/30]
Elastic strain energy in remainder of impacting section 14MJ
effective mass of 58Ktonnes * g * 2 * [11+(4/2)/16] moving through half of 4 affected storeys full elastic deflection of 7.4mm
Elastic strain energy in remainder of impacted section 20MJ
effective mass of half of 58Ktonnes * g * 2 * [17+(4/2)/16] moving through half of 4 affected storeys full elastic deflection of 7.4mm

Total Energy demands 1059MJ
Energy excess 2248 - 1059 = 1189MJ

The falling upper section, according to Dr. Greening's analysis, remains able and equipped to continue to progress the collapse, and it will do so by continuing to accelerate the tower downwards and deforming the support columns. The most immediate task that it will face in doing so will be to continue the acceleration of those floors identified by Dr. Greening as being first affected by the collapse as it attempts to reconcile and satisfy the laws of conservation of momentum and energy. The upper section will also continue to act on the first impacted and impacting column sections by moving these through the remainder of their elastic strain phase and into the plastic phase range. This will consume energy and take time. Again assuming a continued constant velocity of 8.5m/sec the further movement through the plastic deflection of four storeys 444mm will take another 50 milliseconds.

Using the velocity of force propagation proposed by Dr. Greening which saw the force being felt at five storeys from the collision in the first 13 milliseconds, then we can deduce that in the next 50 milliseconds the influence of the force exerted by the falling mass will be felt over a further 20 storeys. The falling section will now tend towards a velocity given by the formula v1[m1 / [m1 + m2]] = 8.52 * [16 / (16 + 5 + {20/2})] = 4.4 m/second. The kinetic energy will now be embodied in the original 16 storeys, plus the five storeys under plastic loading, and the twenty storeys under elastic loading. This total kinetic energy, should, according to Dr. Greening, now be regarded as being available at the collapse front, and is calculated as now being only some 52% of its original energy input from the freefall initiation. Thus all of the kinetic energy, even that in the lowermost stories is regarded as being available to progress the collapse front, and the energy balance can now be examined for this point in time of the collapse.

Energy sources
Kinetic energy from initial freefall 2105MJ
58Ktonnes * g moving through 3.7m
Potential energy from additional downward movement
58Ktonnes * g *[16.5/16] moving through 555mm deflection of impacted storey 325MJ
58Ktonnes * g *[15.5/16] moving through 555mm deflection of impacting storey 305MJ
Compression of remainder of impacting section allowing an effective mass of 58Ktonnes * g * [[11/2]/16] moving through a proportion of 11 affected storeys elastic deflections of 7.4mm 13MJ
Compression of remainder of impacted section effective mass of 58Ktonnes * g * [17+[5/2]/16] moving through half of 20 affected storeys elastic deflection of 7.4mm 52MJ
Total energy available 2700MJ

Energy demands
Pulverisation of impacting floor concrete 128MJ
Pulverisation of impacted floor concrete 128MJ
Energy consumed by inertial changes in collision 1010MJ
Strain energy in impacting storey 710MJ
58Ktonnes * g * [Dr. Greening's safety factor of 2] moving through 555mm deflection of impacted storey * [29/30]
Strain energy in impacted storey 710MJ

58Ktonnes * g * [Dr. Greening's safety factor of 2] moving through 555mm deflection of impacted storey * [29/30]
Elastic strain energy in remainder of impacting section 26MJ effective mass of 58Ktonnes * g * 2 * [(11/2)/16] moving through a proportion of 11 affected storeys' full elastic deflection of 7.4mm
Elastic strain energy in remainder of impacted section 104MJ effective mass of half of 58Ktonnes * g * 2 * [17+(4/2)/16] moving through half of 4 affected storeys' full elastic deflection of 7.4mm

Total Energy demands 2816MJ
Energy deficit 2816 - 2700 = 116MJ

This shows that by using the same reasoning and analysis as Dr. Greening and by adopting the figures proposed by him, the upper section can be shown to have been exhausted at a point in time prior to completion of the shortening phase of the buckle failures induced in only those columns identified by Dr.Greening as being the first affected by the collapse. This analysis shows that the collapse would progress for a further 50 milliseconds, beyond the point that was predicted in my article, before suffering arrest. Should the collapse be somehow enabled to continue, the *energy demands* will continue to present themselves. The 20 storeys now identified as feeling the effects of the collision will require energy to facilitate their downward movement and acceleration and the 3% plastic shortening of the columns will continue to present a demand until the minimum buckle length is reached. Other demands begin to become apparent such as disconnection of the floor connections and importantly, the disconnection of two vertical failure lines within the spandrel plates and core bracing at and about each corner to allow perpendicular buckle movements. The energy demands will offer no respite to the falling section especially as the order of the collapse is lost with the advancement of time and continually growing assymetry.

Kinetic Energy

If we take Dr. Greening's ratio of 1.77 derived from the ratio of velocities and multiply by the number of storeys in the impacting section, 16, we find that this gives 28.5 which is exactly the same as the mass which I did use. This is not surprising since it was from this figure that the velocity ratio was worked out in the first place. This is a circular argument evidently arising from Dr. Greening's misunderstanding. Dr. Greening seems to be concerned that the collapse will continue due to the kinetic energy already transferred from the upper section to the first impacted storeys. The energy being considered is originally embodied throughout the upper impacting section and on impact it will be partly transferred from that section and consumed by acceleration of the impacted masses involved and in elastic and plastic strain energy within the support columns. The strain energies have been separately accounted. The kinetic energy, after collision, of the columns undergoing plastic deformation has already been included in the analysis as being available to the collision.

Only the kinetic energy of those columns undergoing partial elastic deformation has been regarded as being unavailable at the collapse front. Since this energy has already passed below and beyond the area of plastic deformation and is now embodied in kinetic energy in a mass moving away from the collapse front it cannot be regarded as being able to act in a compressive manner at the collapse front. It does not cause predamage as Dr. Greening points out, the strain energies of any damage are separately accounted. Being a kinetic energy it has the ability to cause damage only upon deceleration.

As energy consumption at the collapse front begins to exhaust the energy available to the crushing mass, it will decelerate to such an extent as to then allow the elastic strain in the columns to act upwards against the kinetic energy in the floors and columns. The inertia of these columns would continue the elastic deflection of lower storeys, the kinetic energy will thus continue to spread downwards as the columns search for new equilibrium positions, and there would undoubtedly be a bounce and vibrations set up but with the opposing force now being reduced to only the static mass of the upper section, any possible return of kinetic energy from the lower storeys back to the collision front will not result in continued compression but rather as a lifting of the upper section, an increase in potential energy.

Concrete Pulverisation

Concrete pulverisation was immaterial to the initial argument of whether the collapse would be arrested or continue. It was included as indicative of the energies required and showed the early arrest of the collapse, but if considered as zero the collapse would have been arrested within the next few tenths of a second as the strain energy requirements instead drained the energy supply of the impacting mass. I specifically chose the analysis by Dr. Greening so as to avoid unnecessary debate on this important but not directly considered aspect.

However, regarding Dr. Greening's new analysis there are one or two points which are worth examining. The analysis using 5MPa and 8.5m/sec would use up 128 MJ for one floor, but an average collision would have 20 MPa and 35m/sec, so this would roughly give a total consumption for the pulverisation of concrete throughout the tower of 220GJ.
We know that the potential energy of the tower was roughly 1000GJ. We also know that a momentum only analysis of a tower of equal storey mass would give the collapse front progressing from initiation level to the ground level in just under 12 seconds and reaching a velocity of 52m/sec. This would give a remaining kinetic energy of 690 GJ using a mass of 510 ktonnes. A similar analysis of a tower whose mass more emulates the tower would show 13.5 seconds, reaching 46m/sec and having kinetic energy of 540GJ. To remove 220GJ from this figure in order to pulverise the concrete would leave only 320GJ and this would indicate a collapse front of 17.5 seconds taking into regard only the energies consumed in momentum changes and in pulverisation of concrete. None of the energies required to distort any of the steel structure, nor to pulverise the remainder of the tower construction materials or contents, nor to disperse the debris and dust, nor any of the other energy demands and sinks associated with the collapse, are included in this figure of 17.5 seconds, only the inherent momentum demands and the pulverisation of the concrete.

Force Propagation

It is noted that Dr. Greening accepts that the force will propagate ahead of the movement of the collapse front.

The first question which must be asked is, if the force could not be transferred further than five storeys away from the collapse front in the time allowed, as Dr. Greening argues, how was it possible for the force from the hat truss and upper ten storeys to be transferred further than five storeys in the same time allowed, in order to act at the collapse front? If the velocity of the force propagation was as low as to only affect five storeys to a proportion of their elastic limit, then the same strictures must be applied to the force arising from those masses which are being applied by the collapse front. The effective mass under these circumstances would only be that arising from about 3/16 of the 58 ktonnes of the upper section. <u>Logic should dictate that the velocity of propagation would be such as to ensure that by the time the effect of the mass of the top storey, some sixteen storeys from the collapse front was fully engaged in the collision then the effects of the first impacting storey would be also felt at sixteen storeys from the collapse front.</u>

Dr. Greening suggests that the tilting of the upper section gave rise to lateral forces which aided the collapse and there are undoubtedly many aspects of the collapse which do require further analysis. I intend to address some of these points in a further article dealing with the mechanics of the collapse, and the strange behaviour of the upper section demands attention among several other aspects. With regard to this analysis the tilting of this tower was small and reached only about 2 degrees in the first second. This would give a horizontal reaction to applied vertical forces but this would be in the relation of the sine of the angle and at 2 degrees, this would give a maximum of only 3% of the applied force after about one second. It is safe to exclude the effects of this small lateral force in these early stages especially when it is remembered that the analysis excludes all other lateral strains. Were these to be included then the largest lateral strains would be those within the vertical columns occasioned by the vertical forces. If a vertical force is applied to a column it will set up stresses in the axis through which it is applied but also in the two perpendicular directions. These stresses will be proportional to the applied stresses and can be calculated using Poisson's ratio. With a typical value of 0.28 for Poisson's ratio of steel we can very easily see that these lateral strains would amount to almost 60% of all the elastic and plastic strains identified by the analysis, some 360MJ added to the energy deficit in my analysis. <u>If these lateral strains were included in the analysis the energy balance would reach exhaustion at an earlier stage.</u>

We know that the column end connection were able to propagate loads efficiently because they were already pre-loaded with the static load of the structure above, thus demonstrating the previous integrity and viability of the connections.

In my article I used only a second iteration to show the number of floors taking part in the momentum and velocity changes of the collision. A full iteration would give about 30 storeys, and allowing that the falling mass was decelerated to half of its original velocity would allow time for the propagation to extend loading to more than 40 storeys below the impact. My assumptions have the affect of reducing the number of storeys which take part. This together with the assumption that only a portion of the elastic deflection will apply underestimates the energy requirements of this task and makes abundant compensation for any possible losses in the velocity of propagation.

<u>Conclusion</u>

Dr Greening states, "Certainly, if Ross' suggestion that 24 floors below about the 95th floor moved downward after the impact of the upper section, the videos and photographs of the collapse of WTC should show a noticeable downward displacement of floors between the 70th and 94th levels immediately after the impact. In fact, no such movement was observed. "

My analysis showed that a gravity only collapse would produce a "noticeable downward displacement" and an arrest. I would argue that the absence of a noticeable downward displacement is less significant than the very noticeable absence of arrest. Since neither was observed then logic would dictate that either the analysis is wrong or it was not a gravity-only collapse.

By adopting Dr. Greening's own arguments, corrections, contentions, figures and reasoning, the analysis once again shows that the collapse would be arrested at an early stage. Dr. Greening has not disproved the logic and conclusions of my article, but has in fact reinforced the most important conclusion: that collapse would have been arrested at an early stage.

Further doubt has been cast on a gravity-driven collapse using the analysis Dr. Greening has provided in reference to the pulverisation of the concrete. Combining this with our knowledge of the theoretical minimum collapse time having regard only to momentum transfer, it is shown that a collapse time of 17.5seconds, is the theoretical minimum collapse time having regard only to the momentum transfers and the concrete pulverisation. This timing contrarily does not take regard of the loss of effective mass that would be present due to the pulverisation and the ejection of the concrete pieces outside the area where they play a role in promulgating the collapse. Having regard to this and the other energies involved, the theoretical minimum collapse time can be seen to be approaching double that of the figures given for the collapse timing in official reports, even with no account taken of the energy demand from the distortion and destruction wrought to the steel superstructures.