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WTC ten years on: Learning from the unthinkable

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The 9/11 terrorist attacks on the World Trade Center in New York have forced engineers to rethink tall building design.

The 2001 terrorist attacks on the World Trade Center's (WTC's) Twin Towers in New York sent shockwaves through the structural engineering community.

In the immediate aftermath of the 11 September attacks many even questioned whether tall buildings on the scale of the Twin Towers would ever be built again.

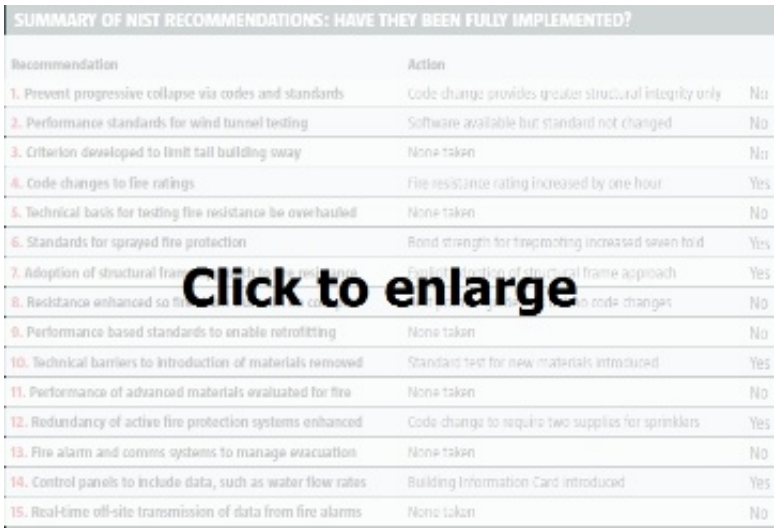
Terrorists flew Boeing passenger jets into the Twin Towers striking one just above the 80th storey and the other just above the 60th storey.

Thousands died in the resulting progressive collapses of the 415m and 418m tall towers (NCE 13 September 2001).

Four years after the attacks, the US National Institute of Standards and Technology (Nist) released damning findings from its building and fire safety investigation of the disaster.

Its 30 recommendations identified key areas of current US building and fire codes, standards, and practices that warranted revision. Many have yet to be acted on.

Summary of Nist recommendations — have they been fully implemented?



Yet 10 years on from the disaster, the industry is as busy as ever, with skyscrapers flying up all over the globe. The question is, have the designers learned the lessons?

Many structures experts say yes. Consultant WSP director Bill Price, who is designer of the 310m tall Shard in London, believes the more technical Nist recommendations have been embraced.

Improving active and passive fire protection, recognising the importance of structural redundancy and providing sufficient means to escape buildings are the three key areas of change, he says.

"I think of the changes in these terms, and they are all relatively technical things."

Fire protection was a major failing

Fire protection was a major failing in the WTC towers, with the explosive shock of the impact of the fuel-laden planes damaging much of the brittle fire resistance attached to the steel columns.

Many changes have been implemented here with nine Nist recommendations focusing on structural fi re response. Most have been adopted, with US codes notably demanding a seven-fold increase in fireproofing bond strength.

There has also been an upping of standards worldwide. For example, non-shattering intumescent paint is bonded firmly to the steel members on the Shard.

A lot of work has also gone into understanding better how buildings respond to fire. The US has adopted the

"structural frame" approach to fire resistance ratings that requires all members of the primary structural frame to have the higher fire resistance rating commonly required only for columns.

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> Professor Barbara Lane, Arup

Professor Barbara Lane, leader of Arup's fire engineering practice says this approach is being applied globally. "An enormous amount of work has been done with computational analysis to model what's likely to happen in a fire," she says, adding that things are totally different from 10 years ago.

"A lot of work was done to understand the collapse, and the knowledge gained from that analysis is being fed into tools that allow engineers to look at a new building or new structural concepts and say 'this is what will happen' and 'this is the chance to improve your structural response'.

"Traditionally what happened was that you applied fire protection to a certain fire rating and hoped for the best — that's oversimplifying it a bit. Now we have the tools down to the detail of what joints are being produced to look at how heat would affect those details". That's been done on structures that are being built now in London.

Slow progress on progressive collapse?

The progressive collapse of the towers after the fire had weakened the aircraft impact areas was a shock that reverberated around the world — and is something in that has still be to be tackled in the US.

Recommendation 1 of the Nist report was clear: "Nist recommends that progressive collapse be prevented in buildings through the development and nationwide adoption of consensus standards and code provisions, along with the tools and guidelines needed for their use in practice."

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>
> Pierre Desautels, Halcrow Yolles

Codes have changed — with a requirement for minimum structural integrity for framed and bearing wall structures through continuity and tie-force requirements.

But this code change is intended only to enhance overall structural integrity — and is not intended to prevent progressive collapse.

Price says that, nonetheless, much work has been done. "Before 9/11 the Americans didn't even have the concept of progressive collapse. Now it is very much in the vocabulary," he says.

"Codes have changed and clients have become much more attuned to the need to incorporate to some degree a certain amount of robustness," adds Halcrow Yolles principal Pierre Desautels. "It is no longer seen as a luxury. The last 10 years have seen a lot of analysis and intellect applied to create redundancy, so that other parts of the structure can take loads if a section was removed."

It's the small things that count

Particular focus has gone on the way beams and columns are connected and the way they are then connected to the core, and on floor systems.

Arup principal David Scott, who leads its building practice in the Americas, says a key change is that the type of lightweight floor structure used in the WTC towers is not considered so robust anymore.

The WTC towers had "an incredible robustness", he says. "And the buildings performed well under the impact." On the other hand they had a vulnerability to them — and that was that they used lightweight floor trusses.

This problem, says Scott, was that the floor beams were constructed throughout with "millions of elements", damage to which would greatly weaken the structure. And it wouldn't necessarily have to be something as dramatic as the impact of a jet plane. Even something falling on it causing damage would mean that it would have to redistribute its load, he says.

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> Bob Smilowitz, Weidlinger Associates

"There is a much greater industry understanding of the impact of floor systems [on the resilience of a building]," he says.

Scott says that soon after the WTC disaster, he conducted a vulnerability assessment on a super tall building he

was working on in Hong Kong that was already a quarter built.

"We looked at the floors and we were surprised to find the floor didn't perform," he said. Specifically this was to do with how it connected to the building's core and its steel plates. It was thought the problem with theses connections in fires was to do with the elements heating up and losing strength.

Scott says that while heating and strength loss had an impact, this is not as significant as one as them heating up and then expanding. The solution was to make the connections ductile, which also had the benefit of being cheaper, he says.

Weidlinger Associates principal Bob Smilowitz, who chairs the American Society of Civil Engineers committee studying progressive collapse, agrees that the behaviour of the connections is key. "You can allow [building] systems to deform but not fail, but the connections have to be able to cope."

Even in the UK — which is much further ahead in terms of understanding progressive collapse after the 1968 Ronan Point collapse in East London — particular focus has gone on connections.

"In the UK that has definitely changed," says Price. "We look very closely at pulling out loads and large deflections."

Does super-tall equal super-cautious?

Confidential Reporting on Structural Safety director Alastair Soane adds that there have even been some changes to the Building Regulations as a result of 9/11. From December 2004, any designers of large and more complex Class 3 buildings have to undertake a "systematic risk assessment" that not only takes account of all normal events that should be expected during the lifetime of the building, but also abnormal events. The same approach has been adopted in Eurocodes.

It is not prescriptive — for example by specifying how many columns must be redundant — the idea is that each building is looked at in its own right and assessed for vulnerability.

What the Standing Committee on Structural Safety (Scoss) is advocating is that especially innovative, complex and unusual (ICU) buildings — those that are really striking buildings, or unusual shapes, or have a complex geometry — are special cases and would benefit from anindependent review and peer review.

"The more complicated, unusual or innovative, the higher the need for an independent review to manage that additional risk," says Scoss chairman and Jacobs vice president Gordon Masterton.

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> Bill Price, WSP

Another big change has been in emergency exit design — probably the most tragic cause of death in the WTC towers. "You had emergency responders coming in and up the stairs at the same time as occupants going down," says Price. "These stairs were only 800mm wide in places. That's incredibly narrow and it caused great confusion." And with the lifts not operational, essentially everybody above the impact levels had no way out.

Things are very different now. "There's been a holistic change in approach in how you get people out of a building in the event of a fire," says Mosen managing director Fathi Tarada.

"Lift evacuation is very common and very accepted now," says Price. "It's slightly amazing that people were expected to walk down 100 storeys in the WTC."

"If the lift has been fire protected, which is often the case if it is located in the core of the building, then it is a viable escape route," explains Tarada.

In the US, codes have been changed in response to Nist recommendation 17 that calls on tall buildings to be designed to accommodate "timely full building evacuation" of occupants and "counterflow due to emergency access by responders".

Specifically, tall buildings must now have an additional exit stairway; stairways must be 50% wider; and lifts with back-up power are to be used for evacuation.

Luminescent strips are on every step and every handrail, so in almost total darkness you can see where you are — even if a stairwell is almost full of smoke. Stair pressurisation requirements are looking at being enhanced. And a dedicated lift for emergency responders is mandatory.

In the new WTC1 at the Ground Zero site in Manhattan, the stair shafts are completely blast-proof and have reinforced concrete encasement. "To what extent is that an overreaction? I don't think it is — especially in a very tall building," says Desautels.

A change of economics

Pressure from owners and occupiers is also forcing a change in approach. "Americans were always famous for providing the most efficient and economic buildings. You can see, if you've only got staircases 800mm wide and small lifts, you can make the core smaller and hence increase the lettable area," explains Price.

"The Port Authority of New York was probably quite chuffed with the net lettable area of the WTC when it was built.

"But owners and occupiers are asking more and more how they are going to get out. The economics have changed."

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The UK, with its tendency towards mixed-use buildings, has it easier, says Price. "The Shard, for example, is a heavily mixed-use building, with a hotel, offices, shops, apartments and a viewing gallery. Because of that you need additional stairs and lifts and that adds to the bulk of the core, which means the job of making it stand up is less onerous."

But there have been changes in the UK. New legislation as a result of 9/11 in the form of the Regulatory Reform (Fire Safety) Order 2005 makes the client, such as the chief executive of the bank occupying the building, principally responsible for response to a fire.

"That means the appropriate entity must understand what their responses are to a fire, which in turn means a whole new level of plans — including for extreme events," says Lane.

"It now has to be very clear on what the chain of command is, who's doing what and how people should respond."