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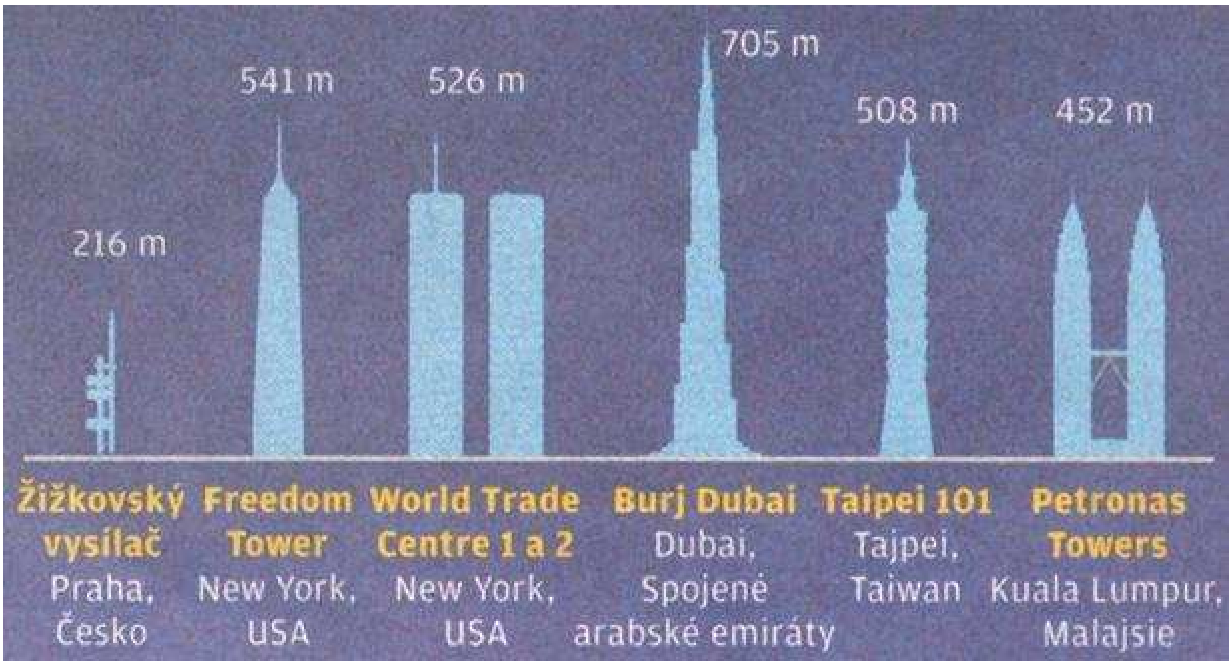
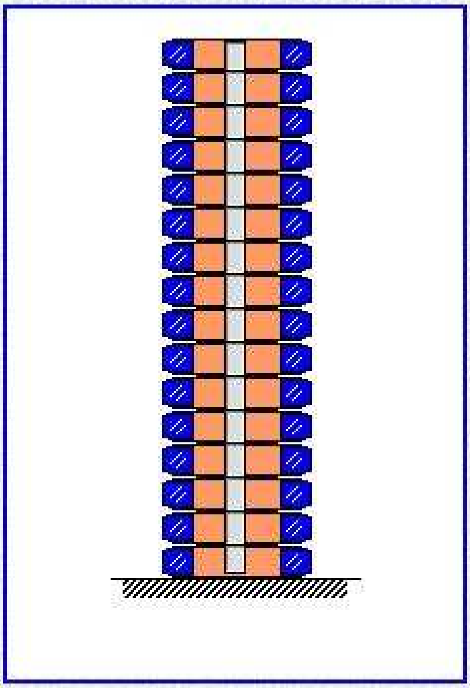
Tall buildings

Fundamental principles of design



Fundamental requirements

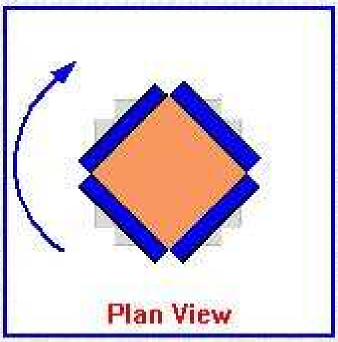


Tall buildings are extremely good ways of maximising the space available. When the purchase of land is expensive i.e. in major cities like London or New York, tall buildings provide a solution to the lack of space. Two factors limit the height of buildings.

- Firstly, the lower floors must support the weight of the building. As the height increases so does the load at the base.
- Secondly, the greater the height the larger the effect of wind is.

Unfortunately wind can act in any direction, and so the building must be able to withstand bending and shear forces in any direction.

Certain wind contions can cause a building to twist. Designers must remember this when considering torsional resistance.



A structure must be strong enough and stiff enough to resist the forces without significant deformation.

Cantilever principle

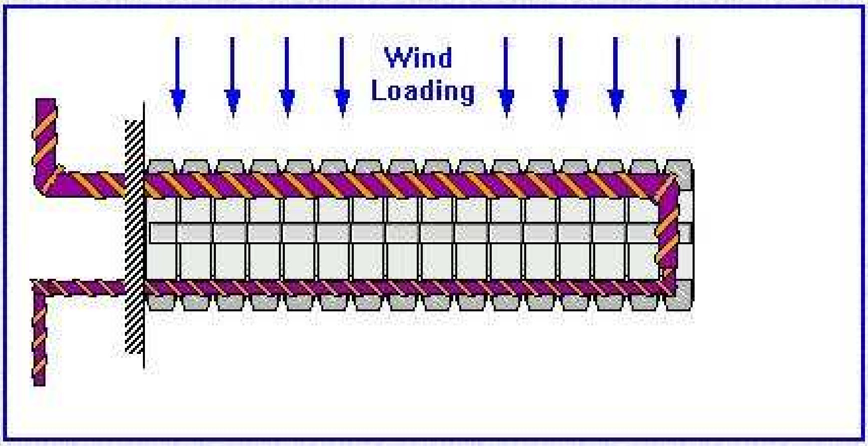
In many ways a tall building can be analagous to a cantilever. As we have seen, a cantilever undergoes bending and shear forces when subjected to a load (Topic 4). A similar effect occurs in tall buildings.

If this building were a cantilever, how would we design against bending and shear deflection?

With cantilevers, designers generally have to contend with downward point or UDL loads. WInd loading on a building is rarely uniform but can be likened to a UDL load.

This scenario would cause the formation of tension and compression zones.

With a cantilever, this problem is resolved using reinforcement bars.

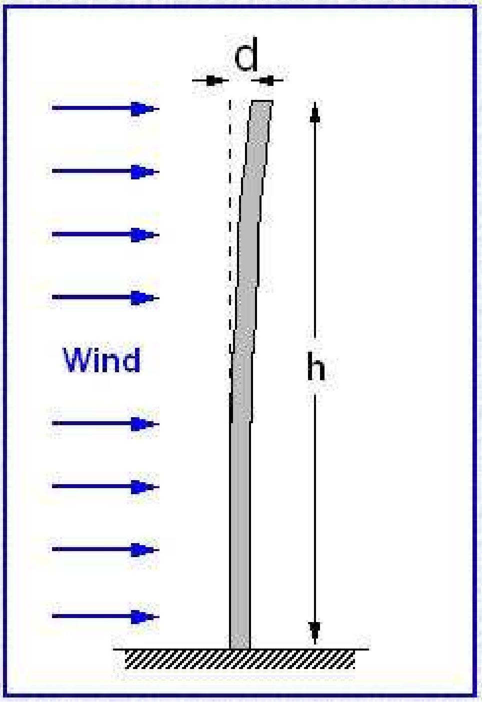


The large bars at the top will help to reduce the tensional forces, and the smaller bars at the bottom aid shear resistance.

With cantilevers however you know where the loading will occur and consequently design it appropriately. A tall building is different in that the wind load must be designed for in all directions.

Deflection of a cantilever

The taller a building is, the greater the problem of lateral and torsional stiffness becomes.



The deflection of a Cantilever is a function of the loading, the properties of the structure and the height.

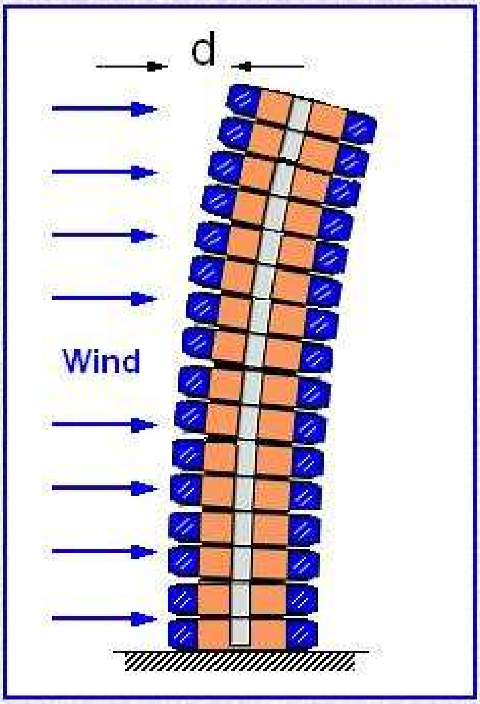
Deflection of a Cantilever

$$d = \frac{w h^4}{8 E I}$$

Deflection is proportional to height to the 4th power.

Deformations

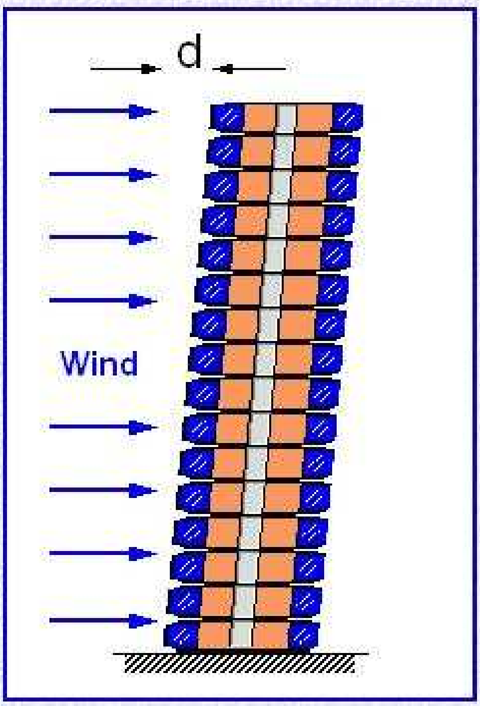
As with the cantilever there are two modes of deformation...



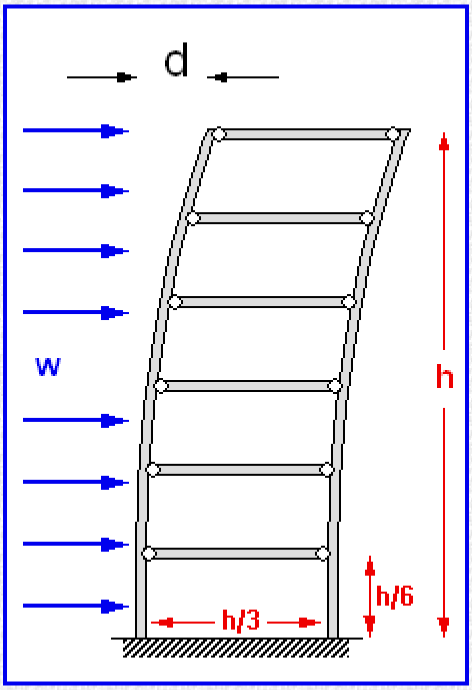
Bending

&

Shear



Deflection of a structure



Firstly, let us take a simple two-dimensional structure.

Two columns, six floors, and pin joints connecting them.

If we now apply a wind load, we can see that the loading is shared equally between the two columns.

On page three of this topic we saw that the deflection of a cantilever was...

Deflection of a Cantilever

$$d = \frac{w h^4}{8 E I}$$

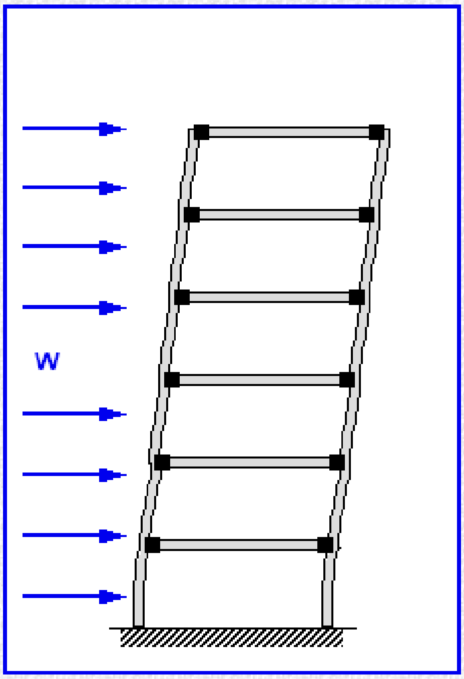
So the deflection here will be...

Deflection of structure

$$d = \frac{w h^4}{8 E I_{01}}$$

Note: where I_{01} equals the combined value of I for both columns

Rigid joints



If we take the same original frame, and replace the pin joints with rigid joints...

...the resultant structure is significantly more resistant to bending.

We can see this by once again applying a wind load and seeing how it deflects.

The rigid joints allow the floors to act as a brace for the columns.

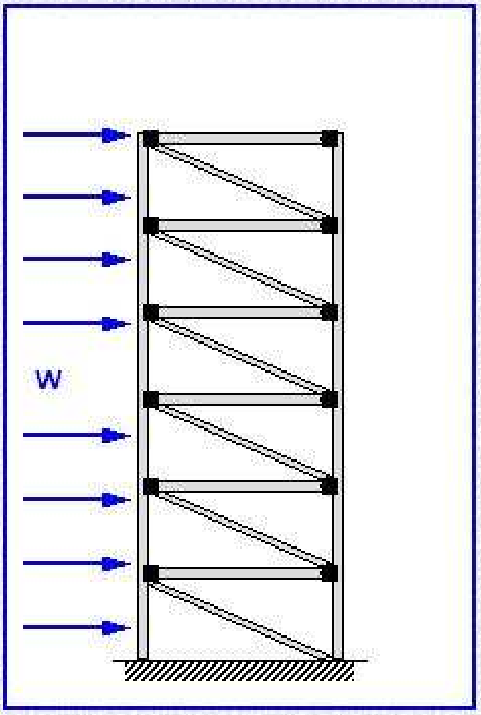
With the pin joints most of the displacement was due to bending. By introducing the rigid floor system , this has been vastly reduced. Deflection now is mostly due to shear.

It can be shown from first principals that the deflection for such a structure is:

Deflection of rigid floor structure

$$d = \frac{w\,h^4}{1728\,E\,I_{01}}$$

Bracing



One way to reduce the deflection due to shear is to include cross members within the structure.

If we now apply the wind load once more...

We can see that the rigid floor system reduces displacement due to bending, and the cross-members reduce displacement due to shear.

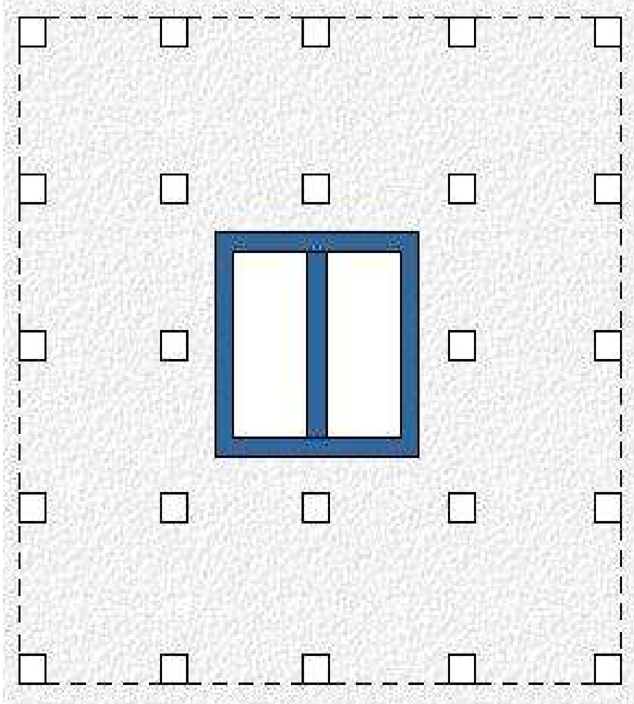
It can be shown from first principals that the deflection for such a structure is:

Deflection of rigid floor structure

$$d = \frac{w\,h^4}{48000\,E\,I_{01}}$$

Or to put it in simpler terms, the deflection of this structure is 1/6000 th that of the structure with no bracing and pinned joints.

Core



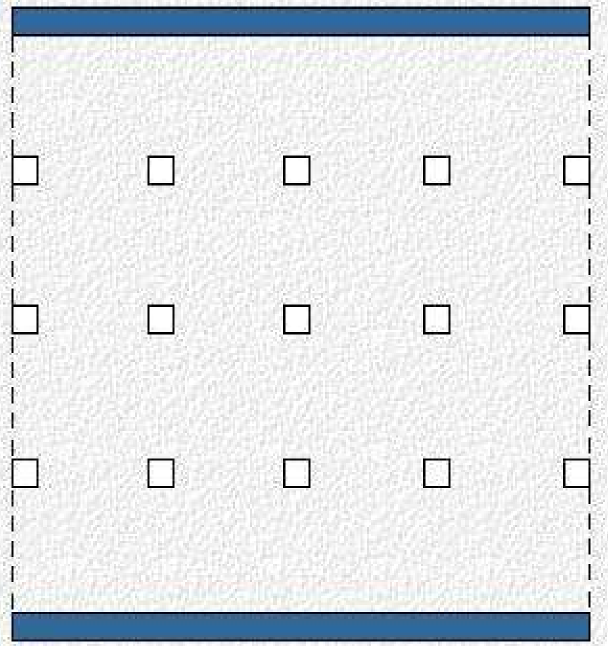
Opposite is an plan view of a 5x5 column building.

By constructing a central core the stiffness of the building is greatly increased.

A core of this type is used to house stairs, lifts and building services.

+ This method is it allows the building to keep an open facade.

Shear walls



5x5 column building - plan view

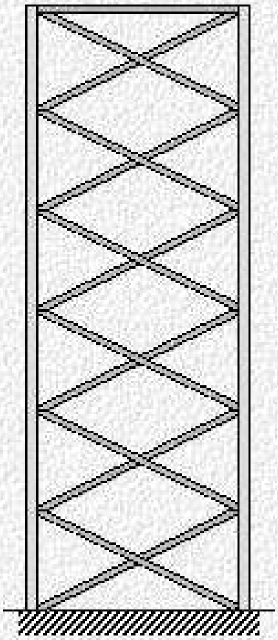
Shear Walls are constructed at opposite ends of a building to provide stiffness in a particular direction.

+ Shear Walls are particularly useful in non -square buildings, where the wind forces predominently come from one direction.

+ The interior of the building is kept clear.

– They only provide minimal torsional stiffness.

Braced frame



Six-storey building elevation view

This is the simple structure with bracing that we saw in the previous page.

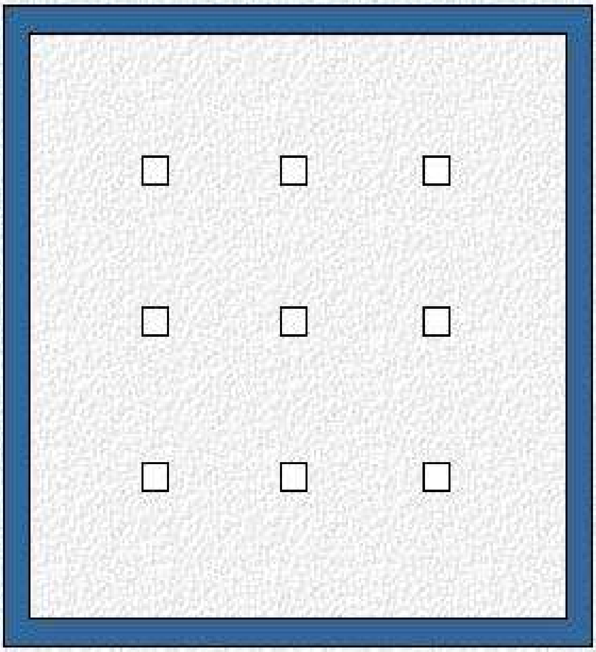
A Braced Frame is similar, but it does not depend on the stiffness provided by the floor system, rather on the addition of another diagonal cross member.

+ This system of bracing is lighter than it's counterpart with floor bracing.
+ The building has good stiffness.

– Compared to the system with floor bracing, this system is less easy to construct.

– The facade detailing can be interesting but also expensive.

Tube



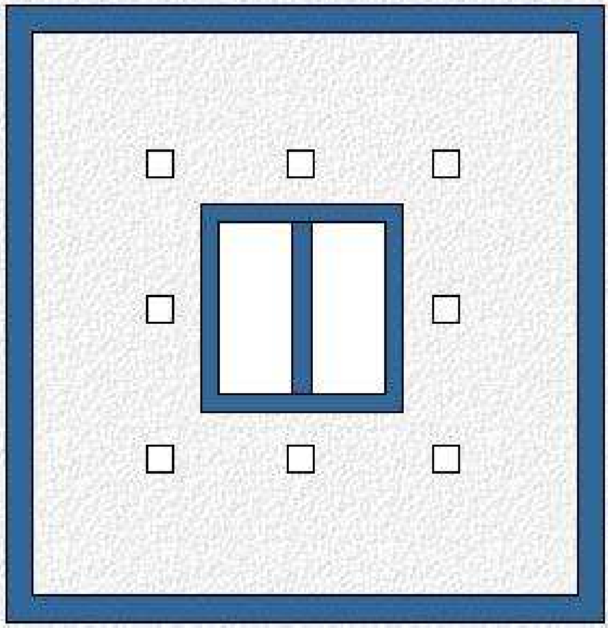
5x5 column building - plan view

A tube system is essentially two sets of shear walls.

+ The tube system allows the building to be stiff in all directions of loading. The building will also have a high torsional resistance.
+ The interior of the building is kept clear.

– The tube system must be pierced for windows. These openings, however, must be kept to a minimum.

Double tube



5x5 column building - plan view

A Double Tube system is a combination of the Core and Tube systems

\+ This combination of both systems allows the building to be extremely stiff.

\+ The building has high torsional resistance

– As with the tube system, apertures for windows must be kept to a minimum.

– The central core takes up valuable space.

This extremely rigid design is used for very tall buildings.

Kuala Lumpa

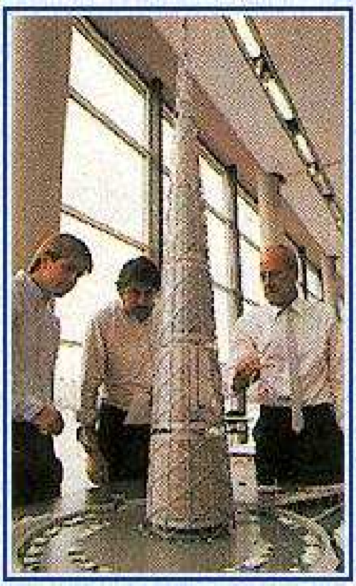
This is the worlds tallest building, the Petronis Twin Towers in Kuala Lumpa. Its design derives from geometric patterns common to Islamic traditions.

The twin towers each have 88-storeys and stand over 450 m high which is the equivalent to 30 average houses stacked up on top of one another

Connecting the twin towers is a sky bridge at the 41st and 42nd floors, which itself is 175 m above the ground.

The towers which will primarily be the Headquarters of a Malaysian Oil company, are so huge that each will have 29 high speed lifts and ten escalators

The Millennium Tower



This is a model of the building that is set to shatter the existing record for the tallest building. The Millennium Tower, Tokyo, will dwarf all other buildings. Due to be completed in 2009, the giant cone, will be 840m high (that's over half a mile), 130 m across at the base, and will have 50,000 people living and working there.

The load bearing structure will be on the outside, in the form of a complex steel tubular helix. The building has been designed with a natural resonance different from those associated with earthquakes, which is a very real threat given the buildings location.

Perhaps more of a threat to this building with be high winds. This is the reason for the tapered cone like structure which is far more aerodynamic than a box like skyscraper. The tapering shape which alters the natural resonance of the building along its height and protects the building from earthquakes should also prevent destructive vibrations from wind loading.

With the population of the world doubling approximately every 25 years, the need for space can only increase, which explains why the Millennium tower is to built in Tokyo where living space is already at a premium. Tomorrows generation of civil engineers can be expected to construct even taller buildings than the Millennium tower, and overcome the inherent problems with such a task.

The main topics

This has described the following:

1 **The inherent problems with designing a tall building**
This Topic has described the problems with wind loading, and the increased compressional forces

2 **Modes of deflection**
This Topic has described the analogy with a cantilever and the two modes of deflection, shear and bending

3 **Internal structure**
This has described how shear walls, cores, internal bracing and other methods can drastically reduce deflection under loading

4 **Present and future**
This has described the tallest building in the world and details of the new project that will be almost twice as tall