Direct Force Paths in Buildings

Anna Bradley

Modern advances in construction methods and materials have now allowed buildings to become increasingly taller and more complex. As a result of this, there is a pressing need to ensure the structures have adequate stiffness so they can stand tall and resist all forces they are subjected to.

The stiffness of a structure and the deflection it experiences are related, such that,

$$K = \frac{P}{\Delta}$$

Where,

K *is the Stiffness*
P *is the Force*
Δ *is the Deflection*

Increasing the Stiffness of a structure will minimise the deflection it experiences.

The stiffness of a structure can be improved by various methods:

1. Uniformly distributing the internal forces.
2. Decreasing the magnitude of the internal forces.
3. Having a short or more direct force path from the load to the supports.

Direct force paths in buildings are usually implemented through the use of **Bracing Members**. Bracing is used to improve the structural performance of a building; it helps to evenly distribute loads and increase the stability of the structure. Bracing members act predominantly to resist the loads caused by wind, earthquakes and other lateral forces.

Bracing members can be arranged in a variety of forms either to carry solely tension or both tension and compression.

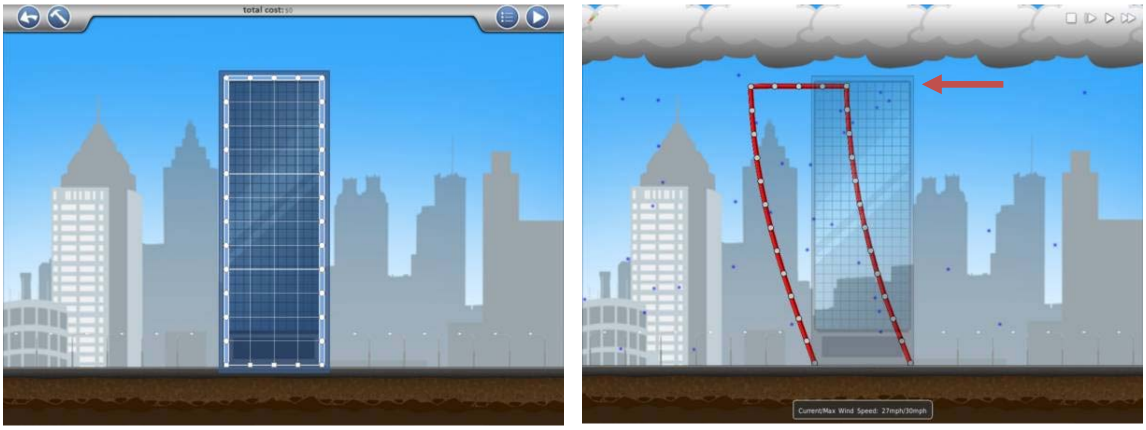
Bracing acts to transfer the force from its point of application, down through the building and to the ground. A shorter, or more direct, force path increases the stiffness of the structure, therefore bracing has to be placed tactfully to create effective direct force paths.

There are 4 different criteria which, if followed, will ensure successful bracing of the structure.

1. Bracing members should support the structure from the base to the top (i.e. they should be provided on each level)
2. Bracing members in adjacent storeys should be linked.
3. Bracing members should be linked in a straight line where this is possible.
4. Bracing members within the top storey and within adjacent bays should be directly linked where possible.

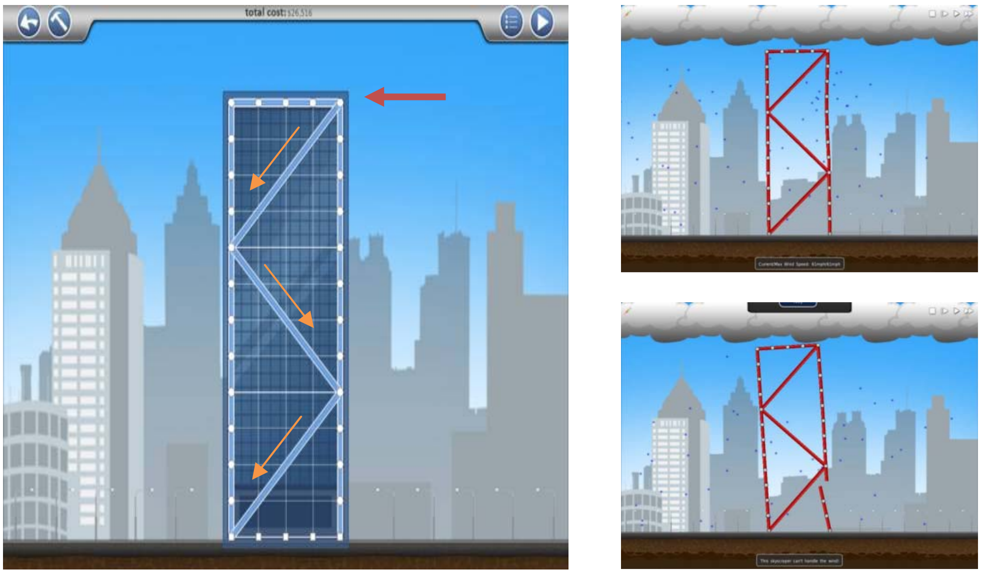
To test and prove these rules, the game ***'Simple Physics'*** will be used. Using this game, various types of bracing can be tested within a 24 storey building. The bracing needs to withstand gusts of wind reaching 300mph!

The following picture shows the building frame. When the wind blows and no bracing has been provided within the building, the building sways to the side and the structure fails.



Due to the size and shape of the building, there are various ways in which to brace it. Several methods of bracing will be shown here to determine the necessity of each of the bracing criteria listed above.

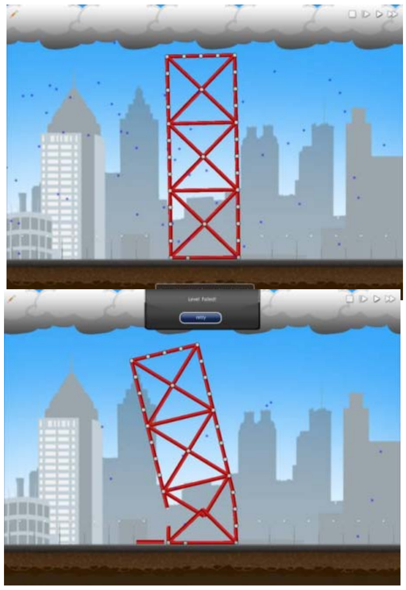
The first is a very simple bracing layout which fulfils the first and second criteria. The bracing runs from the top to bottom of the building however this level of bracing is not sufficient to support the structure and the structure fails when a strong gust of wind blows. Bracing the structure like this only provides a direct force path from the top of the structure; however the force of the wind which blows along the height of the building has to be withstood by the building wall, which simply is not strong enough.



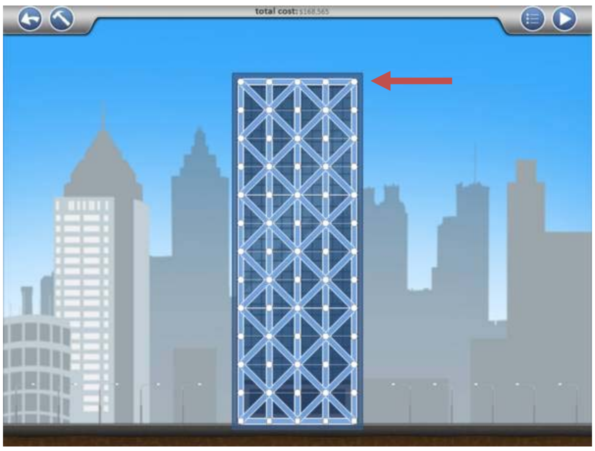
To improve the structure it is necessary to add more bracing members to improve the force path. Using a cross bracing layout, you will see that the bracing criteria are still being followed however there is now an additional point along the height of the structure which can carry the force of the wind down to the ground.

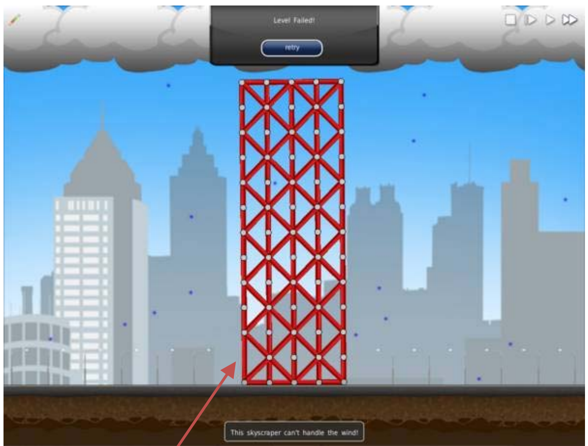
When the bracing members are arranged like this they are designed to resist tension. Depending on the direction of the force, one bracing member will be in tension while the other one remains inactive.

Despite this, the structure is still not strong enough to withstand the force of the wind and the structure fails.

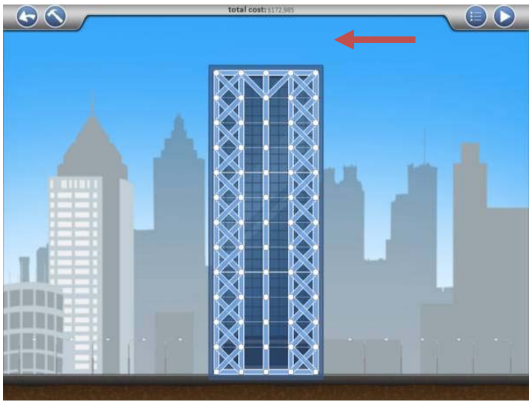


The third bracing layout fulfills all of the above criteria. The bracing flows from the top of the building to the bottom and the bracing in each adjacent level and bay are joined where possible. This is a very effecting bracing pattern, however due to the extreme force of the wind in this simulation; the building eventually fails albeit at a very high wind speed.



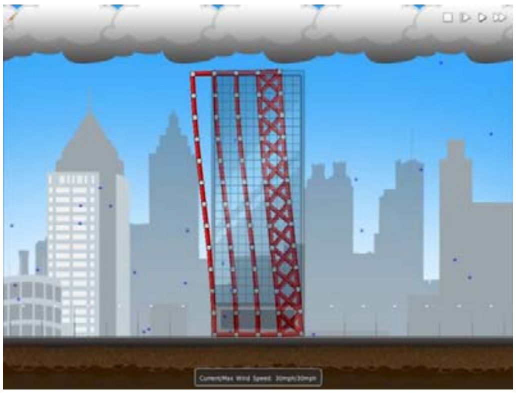


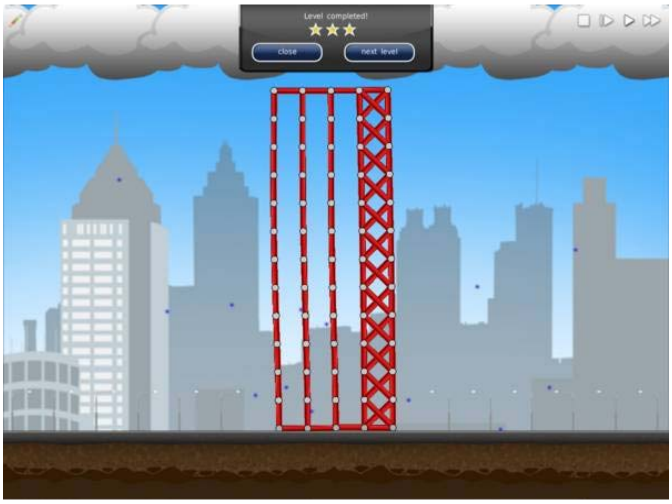
The next bracing layout shows the structure being fully braced down both sides, with adjoining bracing across the top. The cross bracing down each side provides a good direct force path to transfer the force of the wind down to the ground. The bracing layout allows the building to sway slightly but ultimately it keeps the building stiff enough to resist failure.



This bracing layout works well and withstands the force of the wind excellently. However, this is only one effective design; there will be various other bracing layouts which also work well. A more effective bracing pattern is shown below.

This bracing layout allows the force of the wind to be absorbed by the building and carried down to the ground, it also allows the building to sway but withstand fracture. This bracing layout is the most effective and it uses the least amount of material, making it the most economic solution also.





Examples of direct force paths in real life

References:

Tata Steel Construction (February 2012). Vertical Bracing Systems. URL: http://www.tatasteelconstruction.com/en/reference/teaching_resources/architectural_studio_reference/design/choice_of_structural_systems_for_multi/vertical_bracing_systems/

Tianjian Ji (2003). Concepts for Designing Stiffer Structures. The Structural engineer (4th November 2003) (pp. 36 – 42).

Wired New York (October 2003) Chicago – John Hancock Centre. URL: http://wirednewyork.com/forum/showthread.php?t=3784&page=2