DiaGrid: Structural Efficiency & Increasing Popularity

Ian McCain
• Diagrid:

- "Diagrid (a portmanteau of diagonal grid) is a design for constructing large buildings with steel that creates triangular structures with diagonal support beams"

- Is a system of triangulated beams, straight or curved, and horizontal rings that together make up a structural system for a skyscraper

- Similar in idea and execution to a typical moment frame - just more evolved
Completed in May 2004, the Swiss Re, or the Gherkin, is one of the first, iconic, executed large scale diagrid structures. Foster and Partners, an extensive user of the system, was architect on the project; the engineer was Arup. The DiaGrid structure is clearly visible in this construct on a clear day, and the undeniably unique form makes this building a good candidate for DiaGrid discussion.
Swiss Re by Foster as an Example

• Temporarily ignoring the curvature of the Gherkin, French for young cucumber, one can simplify the structure shown here into a series of triangles - connected at ‘nodes’ - and rings - that intersect the triangles at the ‘nodes.’
  – What can be seen then is a triangulated, curved perimeter framed system - the DiaGrid
  – In this image the DiaGrid is rendered in white (the glazing system is the blue imposed upon the building)
  – “it acts as a rigid shell, and for structural purposes can be considered a very thin, deep beam”
  – both the triangles and the rings are here formed from wide flanged rolled sections that are welded or bolted for full restraint (they can be constructed from other materials as well)

* The name ‘Gherkin’ may also be a reference to a popular children’s show in Britain called ‘Stoppit and Tidyup.’ The show, featured on the BBC and worked on by such luminaries as Steve Box of ‘Wallace and Grommit’ fame, featured two main characters, one of which was obsessed with gherkins. Tidyup lived in a giant gherkin and had a rather large and expansive field of planted gherkins just outside of his door. The reference to ‘Gherkin’ however may refer to something yet altogether different than the building’s cucumber like appearance. Many do not simply refer to the building as the Gherkin, some add the clarifier “erotic” before the term Gherkin…
• Clearly visible in this image are the triangles, rings, and nodes employed in the Swiss Re

• Once again, considering the DiaGrid to be a very thin, deep beam we can begin to understand the structural system in action
  - it is a self reliant structure - the core of the typical office building has little effect on a DiaGrid
  - similar to a typical moment frame, the diagrid effectively spreads its mass from its center and thus develops strength and resistance ability to forces from multiple sources and directions
  - the main departure then from a moment frame is the ability of a diagrid to resist lateral forces due to the stiffness inherent in its simplicity and shape
Swiss Re by Foster as an Example

- Diagrids are redundant and load path following

- The Diagrid combines the benefits of a hollow tube with those of a truss and its chords
  - The angled setting of the columnar elements allows for a natural flow of forces through the structure
  - In this manner, both gravity loads and lateral loads are transferred through the diagrid to the ground below
  - Loads are able to follow the diagonals through the structure as it naturally resists vectors of forces through its triangulation
Swiss Re by Foster as an Example

- Load paths are continuous and uninterrupted
- Vertical gravity loads follow the structure of the tube from top to base along the diagonal members of said tube
- The same vertical gravity loads are able to transfer from one columnar element to another in the rare or designed case of an interruption

- each diagonal can be viewed as continuous from top of tube to the bottom of the tube – this is one option for a load to follow to meet the ground

- lateral loads are introduced directly to the diagrid structure and immediately transferred into the triangulation system – these loads are then handled a similar manner to vertical gravity loads
Swiss Re by Foster as an Example

- The simple shape and redundancy already discussed are capable of withstanding great loading.

- The triangulation, however, does not resist buckling all that well on its own.
  - This is where the horizontal rings come into place.
  - The rings tie all of the triangulated pieces together into one solid tube.
  - By connecting one triangulated node to another, the rings instill a second degree of stiffness.
  - The rings resist buckling or, as is the case in the Gherkin, expansion of the buildings skin outward.
Diagrads employ configurations of members such as to take full advantage of said members’ inherent ability to resist compression and tension. Due to this reason, most diagrids employed today are constructed of steel, as is the Swiss Re, or Gherkin. The exploitation of steel's compressive and tensile abilities creates a need for less steel in a building using the diagrid system (for instance, in the Hearst Tower in NYC, it has been estimated that the diagrid employed there required 20% less steel than would have been needed if the building were a typical moment frame).
Nodes + Load Path Transference

Diagrid Node after assembly construction for use on the Swiss Re.
(Note that the Node is here seen on its side - the ring connections facing the top and bottom of the image)
Shown here are typical connection nodes – a good visual for an explanation of loading and requirements of individual building elements.

Notice the size of the connection slots for the slanted columnar elements (top L & R and bottom L & R) and the large scale of the connection slots for the rings (middle L & R). This is an obvious indication of the importance of these elements in the ‘tube’ – the stand alone tube of a diagrid.

Of note in these images, is the fact that the connection to the floor plate (visible in the image to the left) is small and diminutive. Floor plates in a Diagrid structure are not relied upon to relieve lateral loading (they do take some loading but are relied upon to do so). The next slide shows floor plates and their structures and the non-reliance of the diagrid towards the floor plates.
Shown here are connections of floor plates to the DiaGrid structures of the Hearst Tower (on the left) and the Swiss Re (on the right). Note the types of connections, the relative lack of substantiality and a seemingly random placement of the connections to the DiaGrid (where floor plates meet the structure anywhere other than a node). Ideally, the only transference of load from the floor plate to the DiaGrid is a gravity load. The Diagrid itself needs not transfer loads to the floor plate, its tubular structure resists any loads which would typically be transferred.
“The diagrid system offers several advantages in addition to eliminating perimeter columns. Most notably it optimizes each structural element. Typically, columns are used to provide vertical-load-carrying capacity, and diagonals or braces provide stability and resistance to large forces, such as wind and seismic loads. But Rahimian [structural engineer for the Hearst Tower] says that diagonals and braces ‘want’ to participate in the vertical load transfer, and the columns want to participate in the lateral load under ideal assumptions in a typical high-rise. In a diagrid system the two functions are married, he says. ‘The columns and diagonals and bracings are all one.’”

- “Landmark Reinvented” by Brian Fortner
DiaGrid - Not Necessarily a New Technology
DiaGrid - Not Necessarily a New Technology

- Diagrid technology may not have been a primarily building related concept to begin with

- The ideas and structural expressions inherent in a Diagrid can be found in early aviation as well as other locales

- In terms of building, DiaGrid is still not simply a recent idea
  - multiple examples of such structures can be found throughout Europe
  - for instance, many parking structures from the seventies and eighties used the Diagrid in London (No images could be found by me - It has been noted that these uses were colossal failures)
  - The first detailed structural analysis I found on DiaGrids was written in 1932
DiaGrid Implementation
DiaGrid Implementation

• Moving from the conventional to the DiaGrid

  - thorough use of material leads to ability to express organic form in a new(er) structural language

  - Most forms that can be created with a triangulated form (within reason) can be assumed possible

  - Note that floor plates must not be regular - they can change from one level to the next

  - as long as the structural skin employed in a DiaGrid is mostly continuous the structure can rather safely be assumed acceptable (this is not a firm rule or blessing to design a DiaGrid without further research and/or consultation.)
DiaGrid Implementation

- Materiality and the DiaGrid

- There are multiple choices of material for use when employing a DiaGrid
  - steel (the most common)
  - wood
  - concrete w/steel

- steel is the typical material of choice due to its high abilities to resist both tensile and compressive forces
DiaGrid Implementation

- the DiaGrid allows for freedom of the floor plan

- the exterior, or perimeter, of a floor plan which incorporates a DiaGrid, is relatively static (depending upon movement in floor plate placement)

- however, the floor plan is free from columns and structure everywhere the service core is not. Note that the service core, when used with a DiaGrid, needs not carry any load other than some vertical gravity load and can therefore be offset

- Thus, most of the area of any particular floor plate is free and open

- For example, this floor plan of City Hall, London shows an irregular core set within a DiaGrid
The use of the diagrid in skyscraper design is a relatively new idea. As such, a new or more explored language of the structural system has yet to appear.

Most cladding and enclosure types available on typical skyscrapers are available on a DiaGrid.

Typically, the diagrid has been one of the primary aesthetic cues in such a skyscraper.

Form can be derived from the diagrid or the diagrid can be derived out of necessity from the form.
- Either means of derivation brings up formal and aesthetic language issues.
- Exploration of DiaGrid expression may have hit its peak. The DiaGrid is now becoming eclipsed by similar structures that are more radical at their core.
- What is for sure is that the DiaGrid is here to stay.
DiaGrid Exemplar - Hearst Tower
DiaGrid Exemplar - UC Tschumi Building
DiaGrid Exemplar - CCTV, China
DiaGrid Exemplar - Foster Submission to WTC Competition
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A model of the proposed Freedom Tower shows the latticework effect of a structural diagrid.
Libeskind Freedom Tower executed in Legos
DiaGrid (Non)Exemplar - Royal Ontario Museum, Libeskind
DiaGrid (Non)Exemplar - Royal Ontario Museum, Libeskind
DiaGrid: Benefits of

- Some, but not all:
  - mostly column free exterior and interior
  - generous amounts of day lighting due to dearth of interior columns and structure
  - roughly 1/5th reduction in steel possible
  - simple construction techniques (although they need to be perfected yet)
  - full exploitation of the structural material
  - similar design/construction tolerances as a typical moment frame construct (for instance: a typ. columnar element would be created 1/8th of an inch longer than called for to allow for compression in the final product in a M.F. project. The same can be said for a DiaGrid project.)
  - Free and clear, unique floor plans are possible
  - aesthetically dominate and expressive
DiaGrid: Benefits of (Redundancy)

- Redundancy in the DiaGrid design is obvious

- It is this redundancy then that can transfer load from a failed portion of the structure to another

- Skyscraper structural failure, as it is such an important/prominent topic, can be minimized in a DiaGrid design

- A DiaGrid has better ability to redistribute load than a Moment Frame skyscraper. Therefore, there is deserved appeal for the DiaGrid in today's landscape of building.
Some, but not all:

- As of yet, not a thoroughly explored construct when applied to large scale high rises.
- Construction crews (especially here in the U.S.A) have little or no experience creating a DiaGrid skyscraper.
- the DiaGrid can dominate aesthetically, which can be an issue depending upon design intent
- it is hard to design windows that create a regular language from floor to floor (a similar issue to what was confronted in the top, curving windows in the Chrysler Building)
- the DiaGrid is heavy-handed if not executed properly
- can be brash, garish
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