A

Seminar report

On

DIAGRID

Submitted in partial fulfillment of the requirement for the award of degree
Of Civil

SUBMITTED TO: **SUBMITTED   BY:**

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Next, I would thank Microsoft for developing such a wonderful tool like MS Word. It helped my work a lot to remain error-free.

Last but clearly not the least, I would thank The Almighty for giving me strength to complete my report on time.

Preface

I have made this report file on the topic **DIAGRID;** I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to …………..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

CONTENTS

INTRODUCTION

The Diagrids are perimeter structural configurations characterized by a narrow grid of diagonal members which are involved both in gravity and in lateral load resistance. Diagonalized applications of structural steel members for providing efficient solutions both in terms of strength and stiffness are not new ,however nowadays a renewed interest in and a widespread application of diagrid is registered with reference to large span and high rise buildings, particularly when they are characterized by complex geometries and curved shapes, sometimes by completely free forms.

Among the large-span buildings some examples are represented by the Seatlle Library, the London City Hall, the One Shelley Street in Sydney, and more recently by several outstanding Pavilions realized at the Shanghai 2010 Expo, (e.g. France, UAE) as well as by some dazzling projects like the Astana National library. Among tall buildings, noteworthy examples are the Swiss Re building in London, the Hearst tower in New York, the CCTV headquarters building in Beijing, the Mode Gakuen Spiral Tower in Aichi, the Cyclone Tower in Asan, the West tower in Guangzhou, the Lotte super tower in Seoul, the Capital Gate in Abu Dhabi, the Bow project in Calgary, the Building of Qatar Ministry of Foreign Affairs in Doha.

. The diagrid systems are the evolution of braced tube structures, since the perimeter configuration still holds for preserving the maximum bending resistance and rigidity, while, with respect to the braced tube, the mega-diagonal members are diffusely spread over the façade, giving rise to closely spaced diagonal elements and allowing for the complete elimination of the conventional vertical columns. Therefore the diagonal members in diagrid structures act both as inclined columns and as bracing elements, and carry gravity loads as well as lateral forces; due to their triangulated configuration, mainly internal axial forces arise in the members, thus minimizing shear racking effects. To begin with the behavior of basic Diagrid module is discussed, followed by construction process. Then the merits and demerits of Diagrids are listed.

THE TRIANGULAR DIAGRID MODULE

INTRODUCTION

Diagrid structure is modeled as a beam, and subdivided longitudinally into modules according to this repetitive diagonal pattern. Each Diagrid module is defined by a single level of diagonals that extend over 'n' stories.
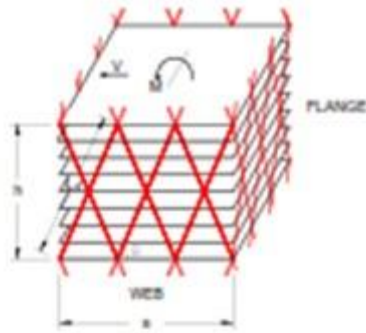

Figure 1: 8 storey Diagrid with 60 degree diagonal angle

MODULE GEOMETRY

Diagrid structures, like all the tubular configurations, utilize the overall building plan dimension for counteracting overturning moment and providing flexural rigidity through axial action in the diagonals, which acts as inclined columns; however, this potential bending efficiency of tubular configuration is never fully achievable, due to shear deformations that arise in the building "webs"; with this regard, diagrid systems, which provide shear resistance and rigidity by means of axial action in the diagonal members, rather than bending moment in beams and columns, allows for a nearly full exploitation of the theoretical bending resistance. Being the diagrid a triangulated configuration of structural members, the geometry of the single module plays a major role in the internal axial force distribution, as well as in conferring global shear and bending rigidity to the building structure. While a module angle equal to 35° ensures the maximum shear rigidity to the diagrid system, the maximum engagement of diagonal members for bending stiffness corresponds to an angle value of 90°, i.e. vertical columns. Thus in diagrid systems, where vertical columns are completely eliminated and both shear and bending stiffness must be provided by diagonals, a balance between this two conflicting requirements should be

searched for defining the optimal angle of the diagrid module. Usually Isosceles triangular geometry is used.

OPTIMAL ANGLE:

As in the diagrids, diagonals carry both shear and moment. Thus, the optimal angle of diagonals is highly dependent upon the building height. Since the optimal angle of the columns for maximum bending rigidity is 90 degrees and that of the diagonals for maximum shear rigidity is about 35 degrees, it is expected that the optimal angle of diagonal members for diagrid structures will fall between these angles and as the building height increases, the optimal angle also increases. Usually adopted range is 60 -70 degree.

MODULE DIMENSIONS:

- **Height of the module:** It depends on the number of stories stacked per module. Usually 2 – 6 stories are stacked per diagrid with average floor height varying from 3.5 -4.15 m on an average.

- **Base of the module:** It depends on the height and optimal angle (apex angle) of the diagrid.

STRUCTURAL   ACTION OF A DIAGRID MODULE

EFFECT OF GRAVITY LOADING

The diagrid module under gravity loads G is subjected to a downward vertical force,
NG,mod, causes the two diagonals being both in compression and the horizontal chord in
tension.

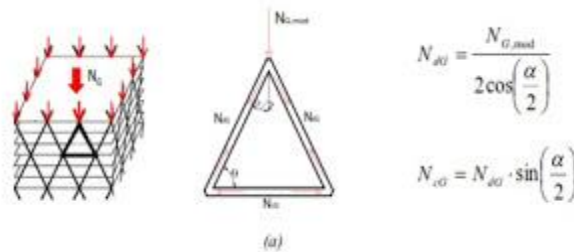$$N_{dG} = \frac{N_{G,mod}}{2\cos\left(\frac{\alpha}{2}\right)}$$

$$N_{cG} = N_{dG} \cdot \sin\left(\frac{\alpha}{2}\right)$$

Figure 2: Effect of Gravity Loading.

EFFECT OF LATERAL LOADING

Under horizontal load W, the overturning moment MW causes vertical forces in the apex joint of
The diagrid modules, NW,mod, with direction and intensity of this force depending on the
position of the Diagrid module, with upward / downward direction and maximum intensity in
modules located on the Windward / leeward façades, respectively, and gradually decreasing
values in modules located on the Web sides .
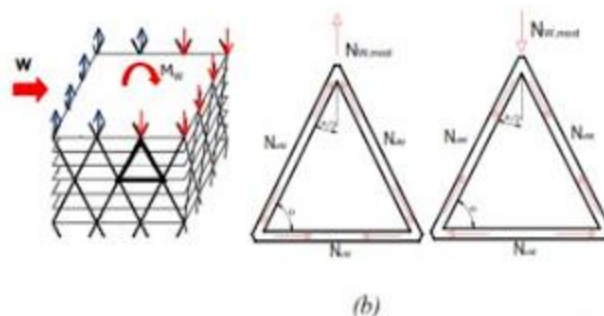
$$N_{dM} = \frac{N_{w,mod}}{2\cos\left(\frac{\alpha}{2}\right)} \qquad N_{cM} = N_{dM} \cdot \sin\left(\frac{\alpha}{2}\right)$$

Figure 3: Effect of Lateral Loading.

EFFECT OF SHEAR LOADING

The global shear VW causes a horizontal force in the apex joint of the diagrid modules, Vw,mod, which intensity depends on the position of the module with respect to the direction of wind load, i.e. the shear force VW is mainly absorbed by the modules located on the web façades, i.e. parallel to the load direction .
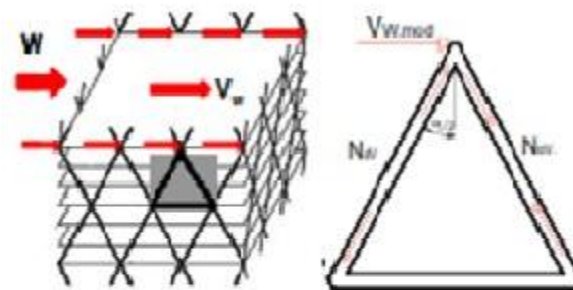
$$N_{dV} = \frac{V_{w,mod}}{2\sin\left(\frac{\alpha}{2}\right)}$$

Figure 4: Effect of Shear Loading

EFFECT OF NON-APEX LOADING

For deriving internal forces in the diagrid elements, it has been implicitly assumed that the external load is transferred to the diagrid module only at the apex node of the module itself. However, since the triangle module usually expands over a certain number of stories, transfer of loads to the module occurs at every floor level, thus also concentrated loads along the diagonal length are present ; as a consequence, bending moment and shear force are expected due to this load condition. However the introduction of a horizontal member at each floor girder to diagonal intersection allows for the absorption of the force component orthogonal to the diagonal direction, thus preserving the prevailing axial force condition.
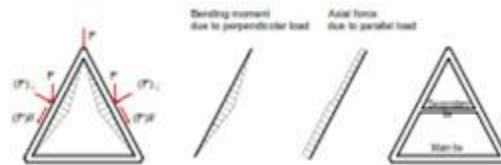
Figure 5: Effect of non-apex loading.

EFFECT OF HORIZONTAL AND VERTICAL CURVATURE UNDER VERTICAL LOADING

The above simplified analysis of the diagrid module has been carried out implicitly assuming that the plane of the triangular module coincides with the vertical plane; however, recent Applications often concern buildings characterized by curvilinear, non prismatic forms, which require the study of the diagrid curvature effect on the internal force distribution. In particular, by considering that the single module may be inclined of an angle with respect to the vertical direction, the effect of both gravity loads and overturning moment gives rise to an additional horizontal force, in the direction Orthogonal to the module plane. Therefore the chords of the diagrid modules, continuously connected Each other along the building perimeter at the diagonal intersections, also act as hopping elements or Ring beams, for absorbing these horizontal forces.
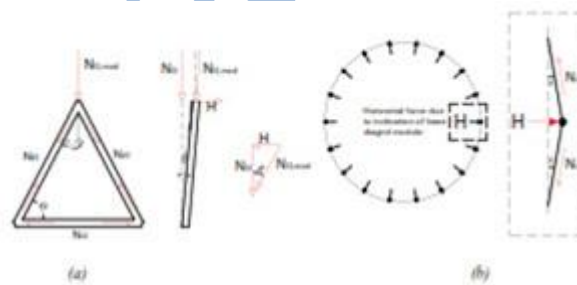
$$N_{d,mod} = \frac{N_d}{\cos\beta} \quad H = N_d \cdot tg\beta \quad N_{rb,m} = N_{db} \cdot \sin\left(\frac{\alpha}{2}\right) + \frac{H}{2\sin\varepsilon}$$

Figure 6: Effect of vertical and horizontal curvature.

EFFECT OF HORIZONTAL CURVATURE UNDER HORIZONTAL LOADING

When the building has a nonrectangular, rounded plans, similar effects due to this horizontal curvature develop under the action of Lateral shear, and the ring beams also collect these outward forces arising in the horizontal plane.
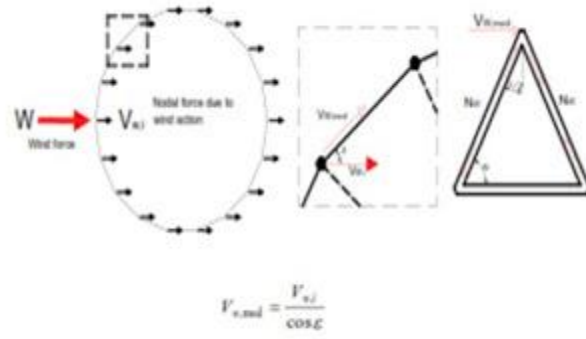
$$V_{e,md} = \frac{V_{e,j}}{\cos \varepsilon}$$

Figure 7: Effect of horizontal curvature.

DESIGN AND CONSTRUCTION OF DIAGRID NODES

MATERIALS USED FOR DIAGRIDDS:

Material selection for a Diagrid construction is based on the following factors .

They are:

a) Unit weight of the material.

b) Availability of the material.

c) Lead Time.

d) Erection Time.

e) Flexibility.

f) Durability.

g) Labor cost.

h) Fire resistance.

The basic materials used in Diagrid construction are Steel, Concrete and Wood. The relative merits and demerits of using them are discussed below.

STEEL:
Steel is by far the most popular material for Diagrid constructions. The typical steel sections used are Wide flanges, Rectangular HSS and Round HSS.
 Steel Wide Flanges:
Advantages- The weight and Size of wide flanges are optimized to resist the high bending loads many of the members experience. Thus use of wide flanges results in reduced structure weight and flexibility of size. The sections can be prefabricated in multi-panel sections, allowing quick erection by crane, reducing labor costs in the field.

Disadvantages- Pre-fabrication of the Diagrid sections takes a longer lead time.

 Rectangular and Round HSS:
Advantages- As with wide flanges, HSS sections can be prefabricated in multi-panel sections, allowing quick erection time, also reducing labor costs in the field.

Disadvantages- Use of HSS sections will need a change in floor layouts as the beams will need to frame into the node points. This reduces the floor flexibility and efficiency.

CONCRETE:

Concrete is another widespread material for Diagrid constructions. It is used both in Precast and Cast-in-situ forms.

 Precast concrete:

Advantages-The flexibility of precast sections allows them to fit to the complex building geometries. Concrete also offers extreme safety against structural fire damage.

Disadvantages- The use of Concrete increases the dead load on the foundations, deflections of long spans, etc. Creep in concrete is also an issue.

 Cast-in-situ Concrete:

Under an Efficient material management system, cast-in-situ concrete is the best material in terms of material cost. Lead time is virtually nothing as cast-in-situ is available on demand.

TIMBER:

Timber is the least popular material for Diagrid constructions.

Advantages- Multi-panel sections can reduce erection time and labor cost.

Disadvantages – Timber cost, both for material and connection, are much higher than the traditional structural materials of steel and concrete. Owing to its lesser material strength, the member sizes would be very large and hence is not preferred for major construction works. Durability and weathering of timber are other major issues.

DIAGRID NODE DESIGN

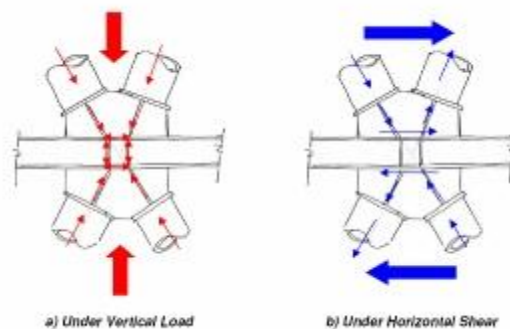a) Under Vertical Load   b) Under Horizontal Shear

Figure 8: Load path at Node

The diagrid segments are planned to minimize onsite butt welding and the welding locations illustrated in Figure 9. The load path can be divided into two main scenarios, vertical load and

horizontal shear their combination), as shown in Figure 8. The vertical load will be transferred in the form of an axial load from the diagrid members above the node to the gusset plate and stiffeners, then to the diagrid members below the nodes as shown. The horizontal shear will be in the form of axial loads in the diagrid members above the node with one in compression and one in tension to the gusset plate and stiffeners. The force will then be transferred as shear force in the gusset plate and then to the other pair of tensile and compressive forces on the diagrid members below the node. From this load path, the shear force at the location of bolt connections is high under lateral loads. Because this may create weak points at the node particularly during earthquakes, the strength of the bolts should be designed carefully.
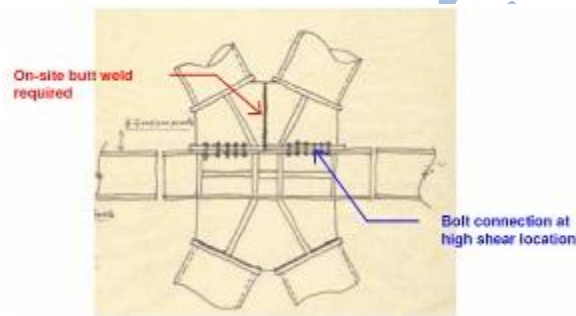

Figure 9: Node Design Plan

NODE CONSTRUCTION FOR DIAGRID STRUCTURES

Constructability is a serious issue in diagrid structures because the joints of diagrid structures are more complicated and tend to be more expensive than those of conventional orthogonal structures. In order to reduce jobsite work, prefabrication of nodal elements is essential. Due to the triangular configuration of the diagrid structural system, rigid connections are not necessary at the nodes, and pin connections using bolts can be made more conveniently at the jobsite. If considerately designed using appropriate prefabrication strategy, constructability will not be such a limiting factor of the diagrid structures. Prefabrication of diagrid nodes for conventional rectangular shape buildings can be done relatively easily and economically because many nodes of the same configuration are required in this case.

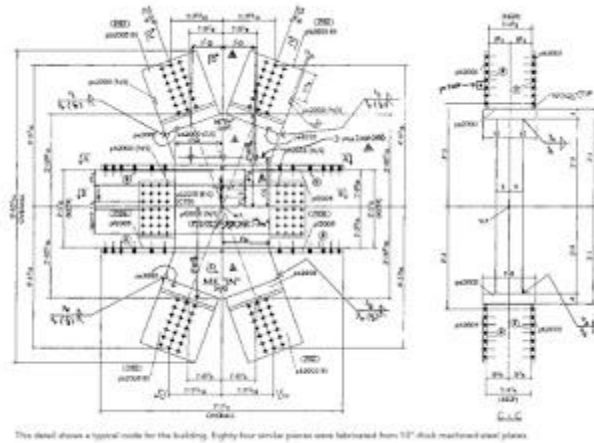The Hearst Headquarters in New York is the typical case.

Figure 10: Node detail for the Hearst Tower

The prefabricated nodes are connected to the large built-up diagonal members by bolts at the jobsite. As building form becomes more irregular, generating appropriate construction modules is critical for better constructability. Though it is possible to produce any complex shape construction module using today's CAD/CAM technology, it is not the most economical solution. Extracting regularity from an irregular building form, and then adjusting the building form following the extracted regularity could be one approach. Another approach could be to make the construction modules relatively regular and design universal connections so that they can accommodate any irregularity.

Figure 11: A Diagrid node after fabrication

ERECTION OF DIAGRID NODES

During construction, the stability in the in-plane direction can be provided by the modules themselves and in the out-of-plane direction can be provided by the tie beams at the node. The temporary restraint to the diagrid and the construction may be minimized. The various steps in the Diagrid erection process include :

☐ In-place steel shop welding

☐ Lifting up piece by piece.

    ☐ Trial shop assembly of parts with high strength bolts.

    ☐ In-place welding.

    ☐ High strength bolts assembly.
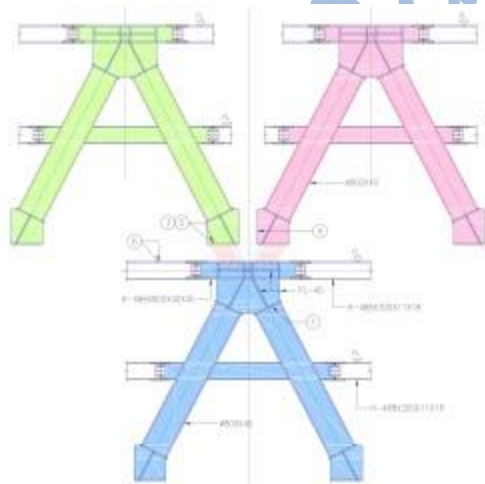
    ☐ Setting up perimeter girders

Figure 12: Construction Plan of Diagrid

Figure 13: Diagrid Erection Process

CASE STUDIES

SWISS RE BUILDING

Figure 14: Swiss Re Building, London

30 St. Mary Axe – also known as the Swiss Re Building – in London, is the first modern application and the most representative example of diagrid structure. Designed by Sir Norman Foster, with 40 stories and an inter-story height of 4.15 m, the tower is 180 meters tall. The building is circular in plan with diameter changing along elevation, equal to 56 m at its widest point, at the 20 story, reducing to 49 m at ground level, and to 30 m at the 38 level, where a steel and glass dome tops off the building. The diagrid structure is generated by a pattern of intersecting diagonals which follow the helical path of the so called light wells, created for enforcing natural light and air circulation. It is formed by a series of steel triangles, two-story high and 9 m wide, with an intermediate tie connecting the two diagonals, which gives to the module the aspect of a "A-shape frame". The diagonals are CHS members, with cross section between 508 x 40 mm at the lowest floors and 273 x 12.5 mm at the top, while the chord members have RHS, 250 x 300 mm with wall thickness of 25mm. The circular central core, which has constant diameter along elevation, does not contribute to the lateral resistance and rigidity, being a simple frame structure.

HEARST TOWER

The Hearst Tower in New York was designed by Sir Norman Foster; the building, 46 stories and 183 meters tall, has a prismatic form and a rectangular floor plan, 48 x 37m and is built on an existent 6 storey building. The diagrid structure, creating the characteristic "diamond effect" in the façade, rises from 12 composite columns, which reach the tenth floor starting from the ground level. The diagrid module is 12.25 m wide and 16.54 m high, and covers four stories. The diagonal cross section are I shape, with maximum size W14x370 at the base of the diagrid (tenth level), while the megacolumns between the tenth and the ground level are concrete filled box section 1100 x 1100 x 10m.

Figure 15: The Hearst Tower, New York.

GUANGZHOU WEST TOWER

The Guangzhou West Tower, designed by Wilkinson Eyre architects, London with 103 stories and a height of 440m, is the tallest building in China and one of the tallest in the world. The building has a curvilinear shape along elevation and the floor plate is an equilateral triangle with round-corners, with side 65 m at the base, increasing to a maximum value of 65 m at approximately 1/3 of the way up the building, at which point the side begins to reduce, up to 43.5 m at the top. It has a composite structure, made by a central concrete core and perimeter diagrid

structure, with the diagrid module expanding on six stories, 12.4 m wide and 24.8 m high. The diagonals are steel tubular members filled by concrete (CFST), with size ranging between 1080 x 55 mm at the first floor and 700 x 20mm at the top. The concrete core has a triangle shape with chamfered corners and fully participates to the lateral resistance up to the seventh floor, where it is eliminated, leaving place to a central giant atrium for the hotel which occupies the upper floors.

Figure 16: Guangzhou West Tower, China

Table 1 –Comparison among the three case studies – major data

MERITS AND DEMERITS OF DIAGRIDS

MERITS OF DIAGRIDS:

Some major benefits of using Diagrids in structures are discussed below.

1) The Diagrid structures have mostly column free exterior and interior, hence free and clear, unique floor plans are Possible.

2) The Glass facades and dearth of interior columns allow generous amounts of day lighting into the structure.

3) The use of Diagrids results in roughly 1/5th reduction in steel as compared to Braced frame structures.

4) The construction techniques involved are simple, yet they need to be perfect.

5) The Diagrids makes maximum exploitation of the structural Material.

6) The diagrid Structures are aesthetically dominant and expressive.

7) 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. Thus creating a deserved appeal for the DiaGrid in today's landscape of building.

DEMERITS OF DIAGRIDS:

Some demerits of using Diagrids are mentioned below:

1) As of yet, the Diagrid Construction techniques are not thoroughly explored.

2) Lack of availability of skilled workers . Construction crews have little or no experience creating a DiaGrid skyscraper.

3) The DiaGrid can dominate aesthetically, which can be an issue depending upon design intent.

4) It is hard to design windows that create a regular language from floor to floor.

5) The DiaGrid is heavy-handed if not executed properly.

CONCLUSION

We are at a time when the global population is inching the 7 billion mark. Around the globe we witness frequent recurrence of natural calamities, depletion and degradation of vital life supporting systems, all presumed to be the impacts of Global warming, making life miserable on earth. It is high time for humanity to switch to sustainable and eco-friendly lines of infrastructure development. The construction industry, the greatest contributor to green house emissions, has the moral obligation to play the lead. The most stable and sustainable of ecosystems is the natural ecosystems. Attainment of sustainability goals would require sound knowledge and understanding of nature's mechanisms and modeling of all artificial infrastructure in close resemblance to it. Owing to the complexity due to size and geometry of the natural systems, development of artificial infrastructure on the lines of biomimicking principles, is in fact the greatest challenge the modern day builder would have to confront with. Thus a modern day structural system should have extreme efficiency in terms of strength, expression, and geometric versatility. Most of the present structural systems are highly advanced in terms of structural efficiency and aesthetic quality, but lacks the much needed geometric versatility. As we have seen, the diagrids, the latest mutation of tubular structures, has in addition to strength and aesthetics, that extra quality of geometric versatility, making it the most suited structural system to this respect. Thus the diagrid, with an optimal combination of qualities of aesthetic expression, structural efficiency and geometric versatility is indeed the language of the modern day builder.

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