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Courtesy of Bernard Tschumi Architects

Thesis Proposal
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Executive Summary

The largest, most visible structural component of the University of Cincinnati Athletic Center is its perimeter diagrid system. Though the diagrid was certainly a sound and acceptable choice, there are three main issues which are potential drawbacks to the current design. They are:

1) The diagrid system is much heavier than typical gravity-only systems. Material costs are high.
2) Welded connections at each diagrid node are time and labor intensive. Labor costs are high.
3) Temperature differentials due to an exposed structure create additional stresses on the building.

These three issues warrant further investigation into alternative solutions to the perimeter lateral system. As a result, the proposed thesis for the upcoming semester will concentrate on proposing viable options to the possible weaknesses and ultimately determining which option, if any, is most appropriate.

Due to the unusual lateral structural system, it is unlikely that any one option will perform optimally in all performance considerations. Therefore, three distinct solution areas labeled I, II, and III will be investigated and evaluated.

I) Keep the system in the diagrid configuration while changing member material and/or detailing
II) Keep the perimeter lateral system while modifying its architectural (and hence structural) geometry
III) Move the lateral system from the perimeter to within the building

The first two solution areas concurrently address issues 1 and 2 while the third solution area addresses all three issues. The basic procedure for obtaining the solution is threefold. First, the available options will be researched. Second, those options will be designed to find size, cost, efficiency, etc. Finally, one option will be selected above the others in each solution area. Solutions will be evaluated on the criteria of material cost, labor cost, constructability, and schedule. A Construction Management cost-feasibility-site study and a Lighting/ Electrical daylighting study will tie in with the structural research as breadth work. A summarized schedule of work is below.

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Solution Area I																
Solution Area II									B							
Solution Area III									R							
Breadth Studies									E							
Preparation									A							
Presentation									K							
Review																

Background

General Building Description

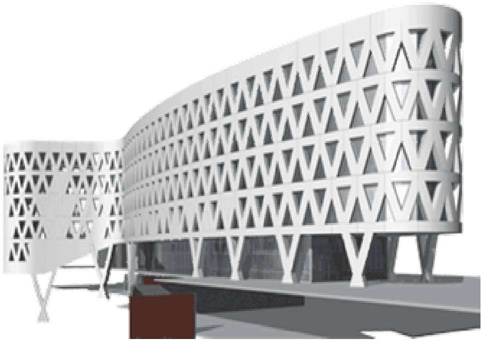
Figure 1

The University of Cincinnati Athletic Center (Figure 1) is an 8 story, 220,000 ft^2 multi-use facility to be located in the heart of UC's "Varsity Village" athletic complex. The building is designed to accommodate various sports-related activities all under one roof and to function as the social link and architectural centerpiece of a multi-stage athletic expansion plan. As such, it will be situated between two main sports facilities, the Nippert Football Stadium and the Shoemaker Center, with easy access to other sports fields and areas. The structure consists of 3 below-grade stories (levels 100-300) and 5 above-grade stories (levels 400-800), accommodating offices, public meeting areas, computer labs, locker rooms, treatment areas, and other related athletic spaces.

Gravity Framing System

The floor framing system consists of typical steel composite wide flange beams with composite metal decking supporting one-way slab diaphragms. Most connections carry shear only, though some elements framing into full height columns near the atrium are designed with moment connections to support atrium walkways. The layout is irregular due to the highly curved shape of the building, however, the N-S direction spacing is typically 9' o.c. within 27' bays. A representative above-grade framing plan is show in Figure 2.

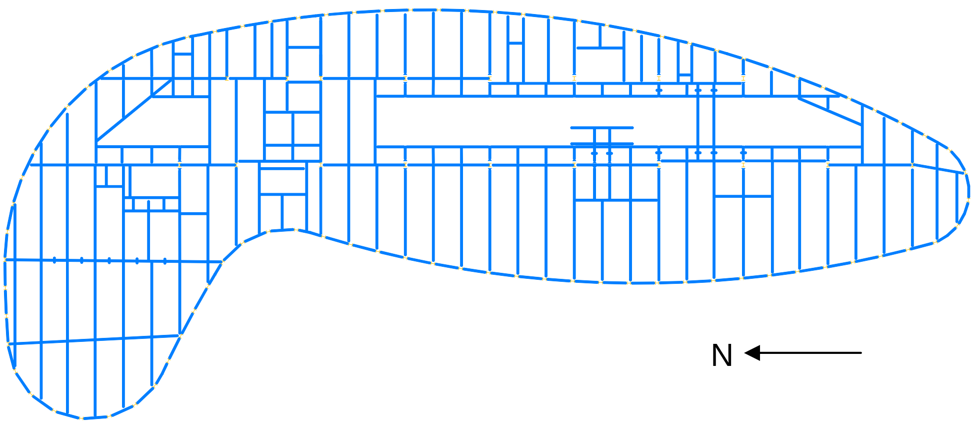

Figure 2: Main framing areas

Lateral System

Diagrid and Diaphragms

The above-grade enclosure of the UC Athletic Center is a triangulated, curved perimeter frame system called a diagrid. The diagrid acts as a rigid shell, and for structural purposes can be considered a very thin, deep beam. It is composed of wide flange rolled sections welded or bolted for full restraint. The steel will be covered with concrete or similar material to produce a monolithic appearance. Between the beams are triangular window glazings. A rendering of a typical diagrid connection is shown in Figure 3. The above-grade diaphragms are 6.5" reinforced concrete slabs on metal deck, supported by steel framing. There are numerous slab openings, including the main atrium, elevator and stair shafts.


Figure 3

Braced Frames

There are four types of braced frames. Two of them, labeled BF2 and BF3, are light braced frames around the atrium staircase. They both span from Level 100 to Level 400 (ground floor) and provide lateral support for the staircase only. The other two, labeled BF1 and BF4, are heavy braced frames to resist lateral movement for the entire building. Two BF1s brace against E-W deflection around an elevator shaft in the northern half of the building, while the lone BF4 braces against E-W deflection in the southern half.

Columns

There are two kinds of columns found in the UC Athletic Center. Within the perimeter of the building are two rows of full height vertical columns, supporting the floor and partition gravity loads of the interior bays. Between Levels 300 and 500 are large "V" columns which are rigidly connected to both the diagrid and the substructure. Though their primary function is to carry gravity load from the diagrid, they also play a significant role in the transfer of lateral forces from the bottom of the diagrid to ground level. They are made of either heavy wide flange rolled shapes or built-up boxes, and sit on single below-grade columns. A rendering of a V column is shown in Figure 4.


Figure 4

Foundation Shear Walls and Diaphragms

The foundation utilizes a combination of spread footings and drilled piers, set into sound gray shale. Reinforced concrete shear walls below grade serve as the retaining walls as well and are typically 1'6" thick. They are rectangular in plan and therefore do not carry the loading from the curved above-grade floors. They do, however, work with the below-grade diaphragms to resist shear forces. There are 16 threadbar anchor rods embedded in the foundation walls to resist shear. As in the upper floors, the foundation diaphragms are 6.5" reinforced concrete slabs on metal deck.

Problem Statement

The largest, most visible structural component of the Athletic Center is its perimeter diagrid system. It is arguably the most unique aspect of the building, and it presented quite a challenge to the structural engineer. Though the diagrid was certainly a sound and acceptable choice for the cost, schedule, architectural, and other constraints given to the structural team, it was not the only available solution to the design parameters of the project. In fact, three main issues were identified which are potential drawbacks to the current design. They are presented below:

1) The perimeter diagrid lateral system is much heavier than a typical gravity-only perimeter system. Material costs are high.
2) Welded connections at each diagrid node are time and labor intensive. Labor costs are high.
3) Temperature differentials due to an exposed structure create additional stresses around the perimeter of the building.

These three issues alone represent significant disadvantages to the Athletic Center's budget and performance. They warrant further investigation into alternative solutions to the perimeter lateral system. As a result, research for the upcoming semester will concentrate on identifying all potential weaknesses in the diagrid system, proposing viable options to those weaknesses, and ultimately determining which option, if any, is most appropriate.

Proposed Solutions

The Athletic Center's unusual perimeter lateral structural system does not lead to a standard, "cut and dry" solution to the design requirements. It is unlikely that any one option will perform optimally in all performance considerations. Therefore, three distinct solution areas labeled I, II, and III will be investigated and evaluated. Each area varies in its degree of deviation from the original design.

I) Keep the perimeter lateral system in the diagrid configuration while changing the material and/or detailing of its members
II) Keep the perimeter lateral system while modifying its architectural (and hence structural) geometry
III) Move the lateral system from the perimeter to within the building, changing the envelope to a curtain wall

The first two solution areas concurrently address issues 1 and 2 from the problem statement. Changing the material or detailing of the diagrid will have an immediate impact on both the material and labor costs associated with its construction. Modifying the geometry of the lateral system can increase the overall load carrying efficiency, reducing material and connection costs. The third solution area is the most drastic change to the structural design of the building, and has the potential to effect not only the temperature concerns of issue 3, but the cost concerns of issues 1 and 2 as well.

The intention of proposing three solution areas is to obtain a relatively complete picture of the available alternatives to the diagrid system. In the hope of discovering a truly better alternative, it is necessary not to restrict research to just one option. However, in the interest of keeping the scope of this project within manageable limits, focus will be given to the design of the above grade lateral system only. Any effects the proposed changes have on the rest of the structure will be considered, but research will not be as detailed as for the diagrid.

Solution Method

The basic procedure for obtaining the solution is threefold. First, the available options will be researched. Second, those options will be designed to find size, cost, efficiency, etc. Finally, one option will be selected above the others in each solution area. This will yield three possible alternatives to the original design. This procedure is laid out for each area below.

I) Keep the perimeter lateral system in the diagrid configuration while changing the material and/or detailing of its members

Research

- Propose different materials
- Propose different connection techniques
- Whittle down the selection to three alternatives, in addition to the original, using the qualitative criteria of cost, size, required labor, etc.

Design

- Determine representative member forces from ETABS output in Technical Report #3.
- Size members for strength using those forces, according to the applicable material codes, ACI 318, AISC LRFD 3rd edition, NDS 2000, etc.
- Check diagrid story drift using new stiffnesses of members. If serviceability fails resize members and try again.
- Detail joints and mid-member connections with proper reinforcement

Select

- Assess cost and efficiency of connection
- Choose the most appropriate material and connection combination

II) Keep the perimeter lateral system while modifying its architectural (and hence structural) geometry

Research

- Study theory behind efficient structural geometries in engineering literature
- Propose at least five alternative configurations to the perimeter lateral system

Design

- Input the alternative configurations into STAAD 2000 as 2D plane frames with steel wide flange members
- Apply representative loads
- Check strength and deflection characteristics

Select

- Analyze each option for connection intensity and member sizes
- Select the most efficient and aesthetically pleasing configuration

III) Move the lateral system from the perimeter to within the building, changing the envelope to a curtain wall

Research

- Brainstorm possible internal lateral force resisting systems
- Identify possible configurations of those systems
- Select the three most reasonable systems using qualitative criteria

Design

- Layout the placement of lateral stiffness elements, including adding resistance in the N-S direction as well as the E-W direction
- Use hand calculated methods or computer software to size the members
- Check other structural integrity issues such as floor slab transfer, perimeter gravity load columns, and foundation design.

Select

- Choose a system on the basis of cost, weight, reliability, and impact on other systems

It must be noted that the redesigns proposed in all three solution areas will undoubtedly impact more than what is specified above. When such an impact is found it will be dealt with accordingly.

Evaluation Criteria

Solutions will be evaluated on the following criteria:

1) Material cost – based on weight of material, unit cost of material, variability of member sizes
2) Labor cost – based on time of construction, connection intensity, labor rates
3) Constructability/Feasibility
4) Schedule

The criteria are set this way to make the final decision as objective as possible. Other minor factors will be a part of each major criterion as well. Ultimately, the three alternatives will be compared to the original design to determine the overall best solution.

Breadth Work

Construction Management

Naturally, changes to the structure of the perimeter lateral system will have a major impact on several CM-related issues. A construction management study of each change will be a crucial part in determining which proposed change is most economical and feasible. The CM factors which will be studied for each alternative are the same as the evaluation criteria above:

- Material cost
- Labor cost
- Constructability
- Schedule

In addition, sequencing and site constraints will also be considered, due to the relatively little room between the Athletic Center and surrounding buildings. Scheduling and estimating software such as Primavera and MC^2 will be used to evaluate each factor.

Lighting/Electrical

All of the proposed options for the perimeter lateral system will affect the building's enclosure properties, including the amount and position of glazing required. A daylighting study will be an appropriate extension of the structural depth work. Using AutoCAD models and computer rendering software such as 3D Studio VIZ and Luxicon, the amount and nature of daylight into the perimeter spaces of the Athletic Center will be modeled. The results can be integrated into the decision making process for the overall best solution by assessing each option's daylighting performance.

Timetable

The schedule for performing the tasks above is below. In the interest of keeping flexibility to the schedule, no specific dates are set as deadlines for each item. Instead, one week segments define the layout of the schedule. Solution areas are broken down into the research, design, and selection components.

	Jan 12	Jan 19	Jan 26	Feb 2	Feb 9	Feb 16	Feb 23	Mar 1
Solution Area I	Research	Design		Select				
Solution Area II			Research	Design		Select		
Solution Area III				Research		Design		
CM Study								
Daylighting Study								
Presentation Preparation								
Thesis Presentation								
Review and Assessment								

	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16
	Mar 8	**Mar 15**	**Mar 22**	**Mar 29**	**Apr 5**	**Apr 12**	**Apr 19**	**Apr 26**
Solution Area I								
Solution Area II	B							
Solution Area III	R	Select						
CM Study	E							
Daylighting Study	A							
Presentation Preparation	K							
Thesis Presentation								
Review and Assessment								