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## Introduction and Background

IPRO 335 consists of the design of an all purpose arena, located where the current United Center in Chicago, IL sets. This arena is to accommodate twenty thousand people along with having an underground parking structure. Specific main goals that needed to be accomplished were the architectural design, roof structure, underground parking structure, HVAC calculations, and plumbing calculations. The IPRO team members divided into four main groups: Architects, Civil Structural, Civil Non-Structural, and M/E/P groups. The individuals in each group are as such:

***Architects*** (IPRO Leaders): Blanca Pedrola, Amanda Hallberg

***Structural:*** Jeffery Grajewski (Group Leader), Elyes Boundaoui, Erum Imam, Kallinikos Kechagias, Valerie Roustan, Dennis Sanz

***Civil:*** Jinit Patel (Group Leader), Jorge Medina, Cyril Tay

***M/E/P:*** Donald McDougal (Group Leader), Adon Austin, Nicholas Jahnke, Syed Kazimi, Robert Rivera, Myung-eun Suk

## Purpose

The Purpose of this IPRO was to design an all purpose arena. The tasks were broken up into four parts.

### *Architectural:*

This project involves design of a multipurpose sporting arena to be located within the city of Chicago. The arena should seat a capacity of about 20,000 spectators and will house such sports as pro and college basketball, ice hockey, arena football, and also will be used for musical events. Assume the arena is to be located at the current location of United Center with the same amount of above ground area available for parking.

## *Structural:*

As a structural team of this project, our main goal was to design an efficient assembly of structural elements of the Arena so as to bring to practical reality the concept and form desired by the architect team. Also, guarantee satisfactory service life of the structure by ensuring that it conforms to accepted standards of strength, deflection, and maintenance characteristics.

In addition to that, our goal was to design the structure without appreciable change in form while meeting the prescribed performance criteria.

Our team and after we had looked into what the architect team developed in terms of the drawing of the structure, we were assigned the following tasks:

- The Roof ,
- The Foundations,
- The Seating Area, and
- The Shear Wall.

In order to best handle this project within the limited time, we agreed on sharing the tasks and splitting the team into two subgroups. Team one tackled the first two design objectives while Team two dealt with the last two design objectives.

## *Civil:*

The objectives given to the group were to create an underground parking structure and an above ground VIP parking structure. It was also necessary to make it safe for people to park their cars.

The way this was tackled was by research, program analysis, and asking professors for help. The research seemed to help the most. Every time a problem arose, we first researched it and to verify we asked a professor for help. A majority of the time he told us the same thing.

As an overall team we wanted to get the parking structures completed and have everything in functional working order.

## *M/E/P*:

The mechanical group had three major tasks of designing the HVAC system, plumbing system, and lighting system.

In order to design the HVAC design of the multi-purpose sports arena, the arena's dimensions were used to calculate the peak loads of the heating and cooling. The software used for calculating the loads was HVAC Explorer. The mission of the design was to have an efficient HVAC system for the multi-purpose arena to operate at different conditions based upon the event taking place, maintaining the temperature of the arena at 72˚ year round, and maintaining the air quality under city code.

The plumbing design purpose was to supply a water system to handle the maximum seated capacity of the arena. Supplying fresh water for restaurants and concessions was also a major factor as well as showers for the locker room. Hopefully, the design below suits the need of the owner. This was done using the applicable building codes and consulting plumbing design professionals.

The lighting system was designed with the help of lighting professionals and product manufacturers. Simple analysis for generic rooms were calculated, however due to the complexity of lighting an arena this size, is was determined that the design consist of a set of guidelines which could be provided to a product manufacturer. The manufacturer, working closely with the design engineer, would provide the equipment and layout required to meet the design illumination levels. The mission of a sports lighting installation is the control the brightness of the object and the background to the extent that the object will be visible regardless of its size, location, path and velocity, for any normal viewing position of spectator or player.

## Research Methodology

### *Architectural:*

The architectural design phase of the project began with research on both current and precedent methods of designing and constructing various types of arenas for various sporting events in addition to several case studies.

<u>Historic Stadiums</u>: The architectural typology of the modern stadium derives from the classical prototype of the Greek stadium, even if the link between ancient and modern stadiums is not always clearly visible. Today's stadiums mostly resemble the Greek theatres, and the Roman circuses and Amphitheatres.

The word 'stadium' is the Latin form of the Greek word that describes a standard of length (1 stadium = 600 Greek feet; or 606 feet and 9 inches; or 185 meters). Originally it refers to the measured length of the course in the ancient Greek stadiums.

The Greek Stadium was the open space where footraces and other athletic contests took place in ancient Greece. The stadiums were usually U-shaped, the curve being opposite to the starting point. The courses were generally 600 Greek feet long (1 stadium), although the length varied according to local variations of the measuring unit. Natural slopes where used where possible to support the seats.

The Greek Theatres were the first constructions in open air where dances and ritual choirs of the Dyonysian cults were held. The first theatres were built in the fourth century B.C. They were characterized by a carefully laid down cavea in a natural declivity. The stands consisted of stones placed in a semicircular way. The lowest part of the theatre hosted the orchestra that had a circular form and that was enclosed with stands. At the opposite side of the cavea, one could see the scene that had a higher position in respect of the orchestra and that was open towards the environment.

The Equestrian Circus developed during the Roman Empire was a big structure with an elliptical and elongated form. It was used for two-wheeled chariots races, gladiator fights, and other shows. Its basin was almost completely interred: it could arrive at a length of 600 meters and a capacity of 250 000 spectators. Three sides of this structure had tiers, whereas the fourth one served for the depot of the chariots. The main entrance was at the centre of the fourth side.

The Roman Amphitheatre was constructed in elevation (as opposed to the Greek theatre) and contained an elliptical cavea. It had continuous tiers and arches that represent the typical architectural composition of overlying orders. The orchestra didn't exist anymore (the Roman theatre did not have choirs) and the central space of the construction was called the arena. The shows where held in the arena and were very close to the tiers. The first amphitheatres resembled much the Greek ones and many times they were completely interred.

Stadium Principles: Contemporary stadium construction involves a thought process far beyond thinking only about sports. With countless incentives and important limitations, there are many motives that stimulate architectural imagination. This section describes seven general principles pertaining to stadium construction. It will help you understand how to perceive a stadium from an architectural point of view.

Contents and functions: First, it is important to develop a relationship between a stadium, sport, and the expectations of the audience. In order to achieve this, several critical aspects must be well thought out and properly integrated in planning phases. These include the steel or reinforced concrete frames, tiers, galleries, staircases, roofs (whether opaque or transparent), tracks, gyms, locker rooms, press services (radio and television), conference rooms, etc. A loosely-knit structure that lacks "strength" will not stand up to today's standards and will show irreparable poverty.

Symmetry and differences: Second, the stadium is generally symmetrical with the conscious aim to repeat a similar representation of both horizontal and vertical views. That said, the architect may take some implicit risks in such harmonization by introducing subtle breaks or imbalances such as supporting pillars, walk ways, or even the choice of random colored seats which causes an optical illusion of not being in balance. Conscious symmetry is often seen as a shelter for the fearful and the lazy, and is widely disputed by the most creative architects.

Three-dimensional perspective: Third, a stadium is an inherently large structure - one which is often difficult to determine the start from the end, simply because each of its exterior sides are mirror images of each other. A real challenge for the designer or architect is to either accentuate the similarities from side to side or conversly create "breakes" in the stadium structure in order to defeat an anachronic view.

Syntax of the stadium: Fourth, the overall desired style and look of the stadium is important to consider. Understanding each of the separate critical aspects identified in the first guideline and deciding how they will be placed together is instrumental in determining the overall style of the stadium.

Structural Expressionism: Fifth, one thinks of the range between the Soviet constructions to the captivating sketches of Erich Mendelsohn: from a rather stade historical style to exciting experimental designs. Frames, pillars, roofs, lattices, curved surfaces and above all refractions and defractions of bright rays, and well-balanced proportions of clear and shaded spaces, are all aspects that contribute to many different results.

Creative use of space: Sixth, aside from the framework and parts of the stadium that will remain constant, the center of the stadium must be considered as it will be a focal point for those who perform, employees and the audience alike. Much detail is required to make this space impressive, creative, and very much alive.

Integrating stadium, city, and landscape: Seventh, an architect should pay attention to the relationship between the stadium and its natural and urban surroundings. There may be particular aspects or concepts of the city that the stadium construction must conform to create harmonization.

## *Structural:*

As a structural group, our research was done in accordance to a methodology. First, and since we decided that the main structure of the building is going to be primarily constructed by steel, we started gathering information that were given in the American Society of Civil Engineers (ASCE 7-02) building Code, the American Institute of Steel Construction (AISC) such as Manual of Steel Construction (Load and Resistance Factor Design (LRFD)).

Since there are sections that are made out of concrete such as seating area, walkway (slabs) and foundations, we referred to The Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02).

Also, the group members browsed through some magazines and web sites to get more ideas such as how the roof, seating area are constructed. In addition to that, we relied on some related topic books and class notes.

## *Civil:*

Most of the research started on the web, although, not much was found. We then started to hit the books to get more information on loads, and lengths and widths of the parking structure. We then decided to visit already existing parking structure to get a better feel for what we were doing. The visits helped us get a better understanding of we were trying accomplish. Help from the professors was our next resource. We asked them to assist us, without doing the work of us, and to direct us to better sources. They also helped with equations that would give us results.

The three members tackled on problem at a time. Each of us took a task and did what we had to do to get the correct information. During each scheduled meeting, we would consolidate our information and research. Then figure out a way to apply it to our project.

## *M/E/P:*

The M/E/P group started it research by reading through magazines related to the industry in order to get more familiar with modern and innovative systems. This seemed to be very knowledgeable but more advanced than the scope of the project. Notes from classes, class books, topic related websites, and communications with professionals were also referenced.

Extensive research was done with different soft wares concerning HVAC loads and finals loads for the arena. To name a few they are HVAC explorer, E-Quest and COMcheck EZ 3.0.

Furthermore, we used American Society of Heating, Refrigeration, Air-Conditioning Engineers (ASHRAE) Handbook and building codes, such as, International Plumbing Code (IPC) 2006, International Building Code (IBC) 2006, and 2003 Chicago Plumbing Code (CPC), to verify certain specifications needed to accomplish our goals.

The objective of the lighting research was to develop a project design guideline and technical specification which could be used to determine the actual lighting design. Research was conducted via the technical magazines, publications of professional societies / organizations such as The Illumination Engineering Society of North America and the internet. However, the best source was actual Manufacture Representatives and Professional Consultants and who work on designing and installing arena lighting projects similar to the United Center.

# Assignments

## *Architectural:*

The architects were to design a multipurpose sporting arena to be located within the city of Chicago. The arena should seat a capacity of about 20,000 spectators and will house such sports as pro and college basketball, ice hockey, arena football, and also will be used for musical events.

## *Structural:*

Due to the complexity of design, we split the tasks among two subgroups:

- Team One: and was assigned the following tasks:
  - Load Calculation,
  - Roof Design,
  - Foundations Design, and
  - Analysis and Final Design.

- Team Two: and was assigned the following tasks:
  - Load Calculations,
  - Seating Area Design,
  - Analysis and Final Design, and
  - Slab Design

<u>Load Calculation:</u> The forces and loads that are likely to act on the structure were determined by the structural team. In calculating the loads such as live loads on floors,

snow loads on roofs, or wind load on structure as a whole, we relied on the ASCE 7-02 building codes.

Roof Design: The roof system consists of eleven trusses that span about 374 ft across the field and seating area. Inside, the roof rises about 140 ft above the playing field. The main components of these trusses consist of three W-beams shapes, two of these making the base of the truss at distance of 6 ft from each other and one beam at the top at a distance of 10 ft from the base. These beams are connected by HSS circular sections diagonally in all three faces of the truss resulting in one three dimensional braced truss. The width of the truss (6 ft) was selected intentionally for the trusses to be supported on steel columns which were made a pair of two steel columns 6 ft apart all around the perimeter of the arena.

To achieve the oval shape of the arena roof, arched trusses with a desirable slope are selected to best fit this design feature. 30 ft spacing between trusses is used according to the distance between two adjacent columns which is also 30ft. To add more stiffness to the roof and have more rigidity for lateral displacement, steel joists are added to the roof design. These joists are made of steel which are 30 in deep, and span of 30 ft. in the north-south direction, and are spaced 3.75 ft on center. The joists have straight and parallel top and bottom chords.

These 3-D triangular arched trusses are designed to carry the loads (live and dead) within an acceptable deflection. The roof load, which is primarily the snow load, is transmitted to the trusses at the joints by means of a series of joists. At the perimeter of the arena, all these arched trusses are supported on heavy steel columns which are designed to carry the load transmitted from trusses. In the design phase of these trusses, forces were developed in each member when the truss is subjected to a given loading with the assumption that all loadings are applied at the joints. The main elements of the roof were analyzed and design checks were made using the SAP2000 computer program, in accordance with the AISC Load and Resistance Factor Design (LRFD) specifications.

Foundation Design: Despite we did not have a foundation engineer, the structural team was strong-willed to take a chance and apply some of the knowledge we got from a foundation class. After calculation all axial load and moment carried by the columns using SAP2000, we decided to design a spread footing for all the columns. Following foundation design books, the arena's foundation were designed accordingly with the appropriate reinforcements. For the soil conditions we assumed that the soil is good and approximate the soil bearing capacity to be 4000 psf.

Analysis of elements: Knowing the loads acting on the structure, we analyzed the structure under different load combinations to evaluate the behavior of the structure and to determine the load effects such as bending moments, axial forces, and shears on the various components. SAP2000 computer program, in accordance with the AISC Load and Resistance Factor Design (LRFD) specifications were used in this project.

Seating area: In designing the seating area the shape of the structure was an important factor in dividing the length of the frame supporting the seating area. Characteristics such as slope and dimensions were strictly based on architectural design. The structure is made out of steel. It is a combination of moment frame and braced frame to control the relative lateral displacements of the structure. For the seating area it was decided to employ 12"x48" precast hollow-core plats which were going to be supported by horizontal plates welded to I-Beams (rakers). To load the structure ASCE 7-02 recommendations were used for the live loads. The live load applied on the precast plats was 100psf (live load for stadiums and arenas). In addition the design included horizontal swaying forces applied to each row of the seats as follows: 24lbs/linear ft of seat applied in a direction parallel to each row of seats and 10lbs/ linear ft of seat applied in a direction perpendicular to each row of seats. The dead load for the plates was 79psf (grouted weight of structural unit). When it came to analysis of the structure SAP 2000 was one of the main programming tools used. Using different load combinations, in accordance with AISC the max moments and shear forces were able to be determined and sections were obtained for the design and the critical sections for the hand calculations. The last column was used to support the truss roof system, reason why the section of the column had to be stronger. The same column and beam sections were used in order to achieve construction efficiency and lower the cost.

Slab: The structural slab designed for the arena was a 6 inches slab-on-grade with a reinforcement of # 4 bars 12 in C.C in both directions. The slab was checked for worst case loading scenario and calculations were done accordingly.

Connections: A typical moment connection was designed for the roof truss. The same type of connection repeats on every truss member used for the roof system. Other type of connections used on the project include pin and fix connections. The moment connection was designed for being considered to be critical on the structure.

## *Civil:*

As mentioned earlier, all the work was done as a distributed task. Everyone took a task and worked on it. If a problem arose with a task, and the individual couldn't figure it out, the team would throw a helping hand to get the problem resolved.

The project plan and mid-term reports were put together as a rough estimate of what needed to get done. All that was tasks were accomplished, although sometimes with delays.

Each member contributed by getting their tasks done, and asking for help when needed. Often times the group went above and beyond the requirements to make sure the project was done properly.

Some pictures are attached to see how much work was done, each member helped in putting this drawing together. Also each member was involved with the Auto Cad drawing as well.

## *M/E/P:*

The M/E/P group sub-divided into four groups: HVAC, Plumbing, Lighting, and Acoustics.

HVAC Design: Critical loads for the arena and individual rooms within every floor is to be calculated accompanied by the CFM calculations and the selection of HVAC systems based on the final results.

Plumbing Design: Calculate the water supply loads to each restroom; Size for booster pumps, piping material, and water heaters; calculate the drain, waste, and vent piping along with sizing the pipe.

Lighting Design: The design, based on minimum required horizontal and vertical illumination levels, of the arena bowl lighting, specialty rooms consisting of skyboxes or suites, bathrooms / player locker rooms, concession stands and public access was considered. The primary design considerations to the arena bowl lighting design included the event lighting system and the house lighting which includes aisle and emergency exit lighting.

Acoustic Design: The design of the acoustical performance within the main corridors of the structure was considered. The reverberation time had to be calculated using the acoustical properties of materials. Reduction of reverberation time is needed in order for the people to clearly hear and understand each other in the public corridors.

## Obstacles

The main obstacle for all to over come was time constraints. The scope of this project enormous and the amount of time allowed for us to complete it in, one semester was not enough. This type of project takes years to complete in the industry today. The second problem that all groups faced was the unknowns with in the project itself.

The third obstacle, and often times the most important, was that of communication between the different groups.

### *Architectural:*

The clearest obstacle for this project was how to design a building that would take typical team years, in just the span of a few months. We approached the project with optimism and quickly laid out a project plan that helped us define the goals and areas of importance so that we might efficiently focus our efforts.

### *Structural:*

The main obstacle we faced in the design of the arena was the constant changes incorporated in the design. The design has changed slightly a few times now and each time it does it makes us have to start over on our preliminary beam selection. Revisions were made accordingly to meet the architects' proposed design. Although these problems were easily overcome it did take a lot of time to keep redesigning the members. Thus, the main problem faced in this project was the time constraint. Structural design of such a huge project requires enormous time. Each of the members tried hard to come up with an efficient structural design but we are well aware that much has to be done in terms of complete structural design of the project.

Another obstacle we faced within the structural group was the drawing of truss for the analysis purposes. Truss member being complex required efficiency in auto cad drawings. This major barrier was overcome with the help of one of our classmate Julio Ramerez. Due to the lack of soil conditions data in the project site, soil condition was assumed to be good with a bearing capacity of 3000 psf . In addition, we assumed metal decking will be used for the calculation of roof joist due to the fact that complete specifications were not known.

## *Civil:*

The problems the group faced were fixable. To get started we had to design and accommodate for a certain number of cars. We got our design from the Architectural group a later than expected. The time crunch made it difficult to accomplish all of our goals. Once we got the design, it was easier to determine how many cars would fit, and how many levels were needed. We also used the arena sitting as a reference to determine the number of cars we needed to accommodate the public.

A second major problem was the ramps with in the structures. It took us a while to figure out where and how to build them. The one way streets caused a problem when considering the squeeze for space and fitting the in and out service ramps from the ground level straight into the VIP parking. Due to the limited space, we had to come up with a circular exit ramp, which was hard to design. This design also caused a problem to accommodate larger vehicles, such as limousines.

We did not have enough time to do a cost analysis on this project.

Obstacles that we faced were again time constrains. We needed about a month to do traffic analysis on out parking structure. Since we did not have that kind of time, numbers were taken from previously done traffic analysis. The professor that helped us out with this told us to keep adding more cars to what we have. The values that we got from 2004 traffic analysis of around the United Center are located in Table C1 of the appendix. Since this data is old, we decided to add a multiplier of 1.5. Meaning if you take the cars that are on Madison, which are estimated at 4000 just multiply 1.5 and you get a total of 6000 cars per day.

## *M/E/P:*

HVAC: One of the problems the HVAC team faced was getting started on our given tasks. The team members where not experienced with HVAC systems. Added time was used to research on HVAC systems. The second problem the team faced was the software to calculate the HVAC calculations. All the software we were given had installation errors, until we received the HVAC Explorer. This software became our main software to calculate the heating and cooling loads. The third problem the team faced was lack of communication between the groups; a lot of assumptions were made during the calculations since most of the building design was not finished. And the fourth problem the team faced was picking a HVAC system for the multi-purpose sports arena. The team had little time to pick a system because the design team finally gave us the dimensions of the arena late in the semester.

Plumbing: All mechanical systems inherit the potential for many problems. One problem we faced early was coordinating the location of the public restrooms with the architectural and structural components of the building. We wanted to be sure we met the standards set forth in the plumbing codes for the number of restrooms in a sports arena while making the water pipes located at the correct place for the architects and engineers. The solution we came up with was having two main water taps come in on each side of the sports arena, thus allowing us to place our risers at the middle point of the arena. This ensures adequate water pressure as well as satisfying the requests of the architects and engineers for space locations.

Another issue that surfaced involved actual demand of the water system. It seemed evident that the designed demand would not take place until the stadium was full to capacity with people. We tossed around the idea of having two separate water supply systems, one for an active period (capacity seating met) & one for idle periods. However, this idea was abandoned due to lack of information on such a design, as well as time constraints.

Lighting: The size of the project created the largest potential for problems. In order to achieve results, simplify the analysis and based upon the recommendation of design professionals, the arena design was split into multiple sub-sections. Additionally, the bridge between achieving analytical results and project management created constraints. It was found that for typical projects of this size, the design engineer and product manufacturer would work closely together. Without the experience of a product manufacturer, the design was just too vast a task. We contacted and worked with GE Electronics, who provided assistance thru similar project design guidelines and product technical sheets. However, the amount of assistance is limited, as the professionals realized that this is an educational experience rather that a commercially viable project. Finally, a firm understanding of the scope was never provided from the architects. This is due to a parallel design philosophy instead of working in series. Most of the design inputs to the lighting analysis are based on the results of the architects.

Acoustics: With most of the walls, flooring, and ceiling non-absorbing of sound pressure waves, the sound reflects off surfaces causing it to "bounce" around the corridor and causing a person to hear delays or echoes in sound. In order to reduce the this problem an acoustical drop ceiling was set in place.

# Results

## *Architectural*

**Final Design**: A large portion of the site is given back to green space by incorporating an extensive underground parking garage with a park at ground level. Additional parking is handled with a few remaining surface lots and new above ground garages north of the site. This approach gives the land around the arena back to the community and provides a tremendous park to be used at any time as opposed to the previous approach of surface parking lots only in use during events. The green roof over the underground parking garage also provides better thermal performance, keeping the garages cool in the summer and warm in the winter.

The stadium itself incorporates an outdoor seating area and carefully considers the connection between 'inside' and 'outside.' The addition of the outdoor arena allows for the potential of a larger variety of activities to be held at the United Center as well as dual events bringing in more revenue for the arena. The indoor arena would house the typical hockey and basketball games while concerts and other venues might take advantage of the warm summer weather and hold their gatherings in the outdoor arena.

Permanent arena uses include the various program elements established in the first phase including, but not limited to: offices, conference rooms, ticketing, concessions, press boxes, VIP rooms, and the like. In addition to the current programmatic elements required by the United Center facility, a new museum is also allocated within the proposed structure.

The design intent behind this stadium is to provide an industrial expression of steel and lightness of materials. The building is intended to appear as a light form floating above a plane. To accomplish this the structure is brought to the ground within the building envelope and a reveal of glass is left between the "floating" roof and the ground. The structural trusses themselves are also kept as light as possible, using a triangulated form, to heighten the lightness of the overall form.

The roof material is composed of light aluminum with a sandwiched layer of rigid insulation; the aluminum is used for its lightness. On the interior of the arena the skin is allowed to continue beyond the seating areas to create the illusion of a skin that is uninterrupted by structure. The structure is integrate at floor levels utilizing carefully planned reveals.

## *Structural:*

Triangular roof trusses were designed in order to meets the aesthetics needs of the structure. Roof truss span approximately 380 ft and is composed of 3-dimensional triangular truss made of structural steel that includes W-sections and HSS pipes. For the sitting area W-sections 12" x 48" were employed. The 56000 lb Jumbotron is supported by different trusses.

Moment resisting frame in the radial direction and braced frame in the tangential directions was used to resist the lateral load. The roof system is supported by outer seating area columns. Seats are supported on prestressed, prefabricated, hollow core concrete slabs.

Concrete slabs are supported on rakers belonging to the supporting girder. Wind loads are transferred to shear walls which the house the elevators and the stairs. The main connection used in the roof truss was designed according to AISC standards, it consists of a moment connection that makes use of a gusset plate to hold in place the HSS sections and attach them to a W section. Required minimum welding thickness was designed, shear limit capacity was checked.

The floors for the walking area are reinforced concrete on metal decking making a composite beam effect with the W-sections.

The foundation will be a series of isolated spread footings. Soil bearing capacity was estimated to be 4000 psf since we did not have a bearing soil data. After checking the maximum soil pressures, we did design for the two extreme cases.

First case is at the perimeter of the arena, which take the largest axial load. Footing for this column was designed accordingly and the result was a square shallow footing of 12.5 ft with 11# 4 bars evenly spaced both directions. The other extreme was the last column from the seating area which carries the smallest load. After all calculation, the design was a square shallow footing of 6.25 ft each side. One a square footing of 6.25

ft on each side with 7 # 6 bars evenly spaced both directions. The deflections of the all of the members were within the code limits and meet all the specified requirements.

## Civil:

There were major findings as to where the loads by each car on certain areas were distributed. There were also very good findings on the height clearance of each floor and the length and width of parking spaces for handicap and regular parking. Also if there are beams between parking the space has to be bigger.

Based on the research the team was happy with what they found and we even used it in our design for this project. Critical learning was dimensions of the parking structure, such as heights, lengths and widths. As for parking structure, we wanted to get as much done as possible. Since we got the plans a later than expected, I thought we would run short of time. This was proven wrong when my team and I started to contribute a lot of time to get this project back on time and get everything that needed to be done safely and efficiently.

## M/E/P:

**HVAC:** For the skybox & other individual room locations, we would employ an all-water system. Cooling and dehumidification are provided by circulating chilled water through a finned coil in the unit. Heating is provided by supplying hot water through the same or a separate coil using water distribution from central equipment. Although humidification is not practical in an all-water system, installing a separate package humidifier is cost feasible and easily accommodated. The greatest advantage of the all-water system is its flexibility for adaptation to many building module requirements. All-water systems have individual room control with quick response to thermostat settings and freedom from recirculation of air from other conditioned spaces.

**Plumbing**: The first step in the design process is to determine the water load on the building. This involves calculating the water supply fixture units, which is a probability of usage, and then determining the flow rate in gallons per minute (GPM).

Based on the total WSFU calculated, the number of taps from the city main will be two, one on each side of the arena. This will allow two different risers to supply the bathrooms without causing too much congestion in the wall and ceiling space. The total flow rate of each riser will be 1581.2 GPM. The results are shown in Table M1.

Next, using the IPC, IBC, and CPC books as a reference, the correct number of bathrooms was determined. Table M3 in the index depicts the results to meet the forty-eight bathroom requirement, with a breakdown of the fixture units per bathroom. Also included in the table is a general estimate of the types of fixtures which will be applied to other areas of the arena. Each bathroom will be spaced at a distance of approximately 106' with 12 bathrooms on each level.

The IPC book was used in sizing the system. The table on the following page (Table 1) shows the results of the pipe sizing of the arena. The type of copper that will be used in the building of the arena will be of Type 'K', which has a thicker wall and thus more durability. Two cold water pumps, one for each riser, will be used to handle the demanded flow rate and also to make up for the pressure loss due to friction in the piping system. Since the flow rate is approximately 1200 GPM, the determined total combined power requirement for the water pressure booster system is 120-HP. The controller attached to the device will raise the pressure 10-psi at periods of low demand. This will allow the booster pumps to shut down until the high demand period (sporting events) resume, and reduce the risk of pump malfunction since the pumps are designed to work at maximum capacity.

The hot water for the sports arena was determined in a similar fashion. The diagram on the following page (Figure P1) shows the type and system function of each water heater supplying the showers. The water heaters that will be used for food service are shown in Figure P2.

The waste and vent system load and pipe sizing was done using the IPC & CPC books. The results are shown in Tables M3 and M4.

The waste and vent stacks were broken up by bathroom location. Essentially, each stack of bathrooms has its own vent and waste system, yielding 16 total vent and waste stacks. This will help minimize pipe exposure throughout the arena. Using the IPC book, it was estimated that 10 drains would be needed on each floor, spaced evenly, in order to comply with the codes. The results are shown in Table M5.

**Lighting:** The lighting analysis consisted of three phases. The first phase consisted of developing a workable design guideline which would be used in discussion with the product manufacturer. Second, the project management required for the communication of the guidelines to the manufacturer. The final phase was reviewing the recommendations of the manufacturer.

The research into the design guideline was done with the aid of the internet, design codes, and design professionals. The guideline considers required vertical and horizontal illumination levels, power requirements, and controls. The results from the research, the design guideline, are attached as appendix L1.

The project management considered the special considerations that go into specifying, installing and managing a lighting control system into a sporting facility. These considerations include the installation requirements, operation of the lighting system, lighting supports and location, and integration into the buildings management and maintenance systems. Additional information on what is included in the project management phase is included in appendix L2. The most important aspect of the lighting design within these facilities is that it is of utmost importance for the design team to build a good relationship with the equipment manufacturer. Sporting facility requirements are constantly changing and developing, leading to the observation that facilities that just duplicate features from previous installations are not seen as being competitive. Lighting is essential for proper functioning of the facility.

Proposed Lighting Design Description: Luminaire technical sheets for the event lighting are provided in appendix L3.

Event Lighting: The event lighting is a fixed system that provides illumination for regularly scheduled events, including sporting events, conventions and floor exhibits.

System Description: Quadrant system with 50 Metal Halide (5x10) per quadrant providing 200 total lamps. GE Ultra Sport Special Purpose Floodlights supported by structural steel truss lifted into place from the stadium floor. 2000 / 1000 Watt, providing 0%-50%-100% automatic controlled dimming lamps providing a minimum of 200-footcandles on the playing surface. Lamps can come with instant on / off application, however shutter controls are recommended by GE.

Retractable Twin Luminaries at 25-foot spacing instant on/off 400-Watt Metal Halide suspended from catwalk steel at 30-foot height above playing surface providing a uniform 75-footcandles on the playing surface.

House / Emergency Lighting: The house / emergency lighting system provides instant-on source of general illumination in the arena bowl and is used extensively during spectator arrival, departure, and event intermissions. Additionally, it is powered by the emergency power generator to full brightness to allow safe egress.

System Description: 500 Watt suspended Tungsten Halogen supported by catwalk above seating areas providing 25-foot candle minimum illumination. Additionally, emergency lighting includes LED displays at all stairways and emergency lamps at all exits.

Scoreboard: Retractable OMNI LED score cube suspended over the playing surface. (8-ton weight supported by structural roof steel).

Specialty Rooms (Skybox, Suites, Locker rooms): Halogen ceiling lights with additional task lighting providing a minimum illumination of 40-foot candles.

Public Room / Bathroom; Flourescent lighting which provides a minimum illumination of 30-foot candles.

Portable Spotlights: Four owned spotlights with 12 optional locations within the catwalk.

Acoustics: An estimated area for the longest corridor was calculated in order to estimate reverberation time. Taking into account the surface areas of the floors, walls, and ceiling, the total surface area of 47,350 feet was considered. Air attenuation and material properties were then used to look up the absorption coefficients. The reverberations times were calculated for each to the frequencies given in Table A1. This resulted in times ranging from 0.3 seconds to 1.38 seconds. These results are shown in Table M6.

# Recommendations

## *Structural:*

Although, our group tried to go as in-depth as time permitted, we were able to design members that were considered to be critical on the structure. A general structure analysis was performed to determine the loading condition for each member of the structure. We strongly recommend that the project should be continued in order to perform in depth analysis of the structure so that more efficient design could be done. Also, different tests of the construction site should be completed in order to have better understanding of the soil capacity for loading conditions. Wind tunnel tests should be performed on a prototype of the structure to produce better serviceability on the design.

## *Civil:*

A cost analysis would be recommended to be performed on this project. From a cost analysis perspective we would be able to determine if we need to adjust materials or the structure itself. Although, as previously mentioned, to complete this more calculations and a finished structure would be necessary.

We tried to do a rough cost estimation using previous year's values. These values are located in Table C2 of the appendix.

The United Center was a $175million project so compare the values. The total area of the united center is 960000sf so multiplying it by 127 we get $122million and if we include a location multiplier which is around 1.5 considering it is downtown Chicago, it comes up to $183million so its in the same ball park. The same can be done for plumbing, electrical, and garage.

As for this project, I think more interaction with the professors would have helped to direct us on what should be getting done and have a better idea of what is required.

Also, if this project is going to be continued, I would suggest to do more traffic analysis and also to do more test using Structure Analysis Program (SAP).

## *M/E/P:*

**HVAC:** To get the HVAC system done, the initial layout for the building is to be well organized, which in this case was very poor as we had to make a lot of assumptions when it came to choose our materials. Also, mechanical engineers should be given a task related mainly towards their primary major rather then working on a load based system that requires industrial background. Our suggestions would be to have a well organized layout for the load calculations and introduce mechanical systems and designs, not industrial, for mechanical major students.

Coordination within the groups would be another great value for the success towards this project, as we only met once or maybe twice as a whole group.

However, we feel confident that our design of the water supply & DWV system could be put into a real-world stadium design. For this happen, many more issues would need to be addressed. These include the location of the mechanical room, the location of the water heaters, the types of valves and other piping materials to be used. We encourage any continuation of this project and hope our work was not in vain.

**Plumbing:** We feel confident that our design of the water supply & DWV system could be put into a real-world stadium design. For this happen, many more issues would need to be addressed. These include the location of the mechanical room, the location of the water heaters, the types of valves and other piping materials to be used. We encourage any continuation of this project and hope our work was not in vain.

**Lighting:** The project scope is too large for a completed research and development projects. The research provided within the appendices provides a preliminary analysis. A complete project specification could be developed using the design guidelines. Using the project specification and project management information and previous communications with product manufacturers, additional actual luminaries could be determined. Additionally, the locations for the lighting within the arena, requires secondary support steel and a catwalk.

**Acoustics:** The scope of the project was much too large to finish in one semester. In order to end up with more accurate results for acoustical properties there needs to be a more finished product. Starting with a project already in certain stages or given specs would be recommended.

# References


### *Architectural:*

- www.worldstadiums.com

### *Structural:*

- Manual of Steel Construction (Load and Resistance Factor Design LRFD), Third Edition.
- Steel Structures; Behavior and LRFD, Sriramulu Vinnakora, First Edition.
- Foundation Design; Principle and Practices, Donald P. Coduto, Second Edition.
- Principles of Foundation Engineering, Braja M. Das, Fifth Edition.
- Structural Analysis, R.C. Hibbeler, Fifth Edition.
- Vulcraft steel joists & joists girders, Vulcraft Steel decks.

### *Civil:*

- http://www.downtowndevelopment.com/pdf/dix021506docs.pdf
- http://www.sburl.com/docs/parkstruct.pdf
- http://www.skylinesteel.com/documents/apps/Economics.pdf
- http://www.qcode.us/codes/stanton/view.php?topic=20-20_28-20_28_050
- http://www.yurkevich.ru/pdf_publications/Rs_eng.pdf
- http://www.toronto.ca/zoning/parking.htm
- Chrest, Anthony. Smith, Mary. Bhuyan, Sam . Parking Structures: Planning, Design, Construction, Maintenance, and Repair. New York: Chapman & Hall, January 1996.

### *M/E/P:*

- International Plumbing Code (IPC) 2006
- International Building Code (IBC) 2006
- 2003 Chicago Plumbing Code (CPC)
- CAE 334 Notes, Professor Ralph Muehleisen, The Illinois Institute of Technology

- http://hyperphysics.phy-astr.gsu.edu/Hbase/acoustic/revtim.html#c5
- Illuminating Engineering Society, IES Lighting Handbook, 5th Edition
- Professional Consultant: http://www.lightingsystemsinc.com

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