<u>IPRO 335 – Architectural Capstone Design Final Report</u>

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Introduction

This project concerns design of a two-story building plus a basement to be constructed on a 60 feet wide by 120 feet long lot. The structure is located in Carbondale, Illinois subject to moderate-high seismic activities. The structure will serve as a museum of contemporary art. Our client is especially interested in having a design that would protect museum artifacts during a potential seismic activity. The suggested method is to use a base isolation system for the building. As a minimum, the following tasks are required: overall design layout for the building, architectural design of the building, structural design of the building, electrical and lighting, plumbing, fire protection and HVAC design, and addressing any serviceability issues.

Background

Many art museums, whether large or small, seem confusing, intimidating, and or inaccessible. Thus, visitors feel alienated to such buildings and don't experience what an art museum ought to provide: a sociable atmosphere. The goal of this design project is to provide that sociable atmosphere by incorporating spaces that involve daily activities.

Basic Organization and Tasks

<u>Architecture Group</u>

My research began by visiting museums (large and small). Such buildings included the Beverly Arts Center (a local neighborhood art museum located at 111th & Western, Chicago, IL), the Museum of Contemporary Art, the Art Institute of Chicago, and the Field Museum. During my visits, I received maps and walked around the museums to understand how my experiences there were affected by the layout of each building. I then read books and maps to create a program for our museum. Third, I designed the floor plans and elevations. Fifth, I worked with architectural, electrical and structural engineering students to modify plans and elevations as research evolved and questions arose.

<u>Structural Group (Base Isolation)</u>

Base isolation is an alternative approach when designing for seismic-prone areas. With seismic forces acting on a structure in mind, the goal of design is to protect the structure against lateral forces resulting from ground motion due to seismic activity. Base isolation is a relatively new technique that can be use to avoid seismic damage which can lead to collapse of structures.

There are two systems that can be used to isolate the structure from ground motion: 1) Elastomeric bearing systems; and 2) the Sliding system. Although both systems can be used to isolate a structure from the ground the elastomeric bearing system will be discussed in detail because this is the system that was chosen for the current project. The elastomer is made up of a flexible rubber with layers of stiffening plates. They are placed under each column, which is then connected to the foundation. Using this method, the building is decoupled from the lateral forces of the earthquake ground motion by imposing a layer of flexibility between the building and the foundation. The flexible layer will allow the structure a natural frequency that is much lower than that compared to the classical fixed-base frequency. The lowering of the natural frequency results in lower lateral forces acting on the structure. It also is a common misconception that the elastomer absorbs the energy applied by the earthquake; it deflects the energy through the dynamics of the structural system by allowing the structure to move as a whole as opposed to having it fixed at the base.

The project was divided into individual tasks and cooperative tasks. Dan Salabaj did load calculations. This involved calculating the distributed dead, love, and snow loads per floor, as well as point loads that were applied from the secondary beams. Since the live load is not on every floor at any given instant live load reduction factors were used. He also designed the main girders in the structure. This includes flexural reinforcement, compression reinforcement if needed, as well as shear reinforcement. Lastly he designed the slab and intermediate monolithic system. This also includes flexural reinforcement, compression reinforcement if needed, temperature reinforcement, and shear reinforcement.

Adam Witek had the task of doing SAP input and analysis. This included drawing the multiple frames in the computer program, assigning proper restraints for the frames and loading the frames. Analysis included three different cases for critical beam bending moments, as well as a single case for critical column bending. He had also had the responsibility of designing the columns; which includes flexural reinforcement, shear reinforcement, and confinement for seismic loads. This was done in two steps; 1) bending due to gravity loads, and 2) bending due to seismic loads. An interaction diagram was also drawn to aid in the selection of reinforcement. Adam also prepared all of the structural drawings of the frames and the floor plan, as well as the section drawings for the columns and beams.

Adam and Dan had collaborated on several parts as well. Preliminary sections-sizes were designed and determined to be the following; beams are 30” by 20”, columns are 20” by 20”. The decision to have an elastomeric bearing system as opposed to the sliding system was decided upon as well as type and manufacture of the elastomer. The foundation and retaining walls design was also a group effort. The midterm PowerPoint report, as well as the final report. We also collaborated for deciding what to include in the PowerPoint presentation for IPRO Day.

Many assumptions had to be made before taking on the task of analysis and design. The general assumptions that were made are that the structure will use normal weight concrete (150 lb/ft^3). The steel used for all reinforcement is A992 (yield strength of 60000 psi), and concrete compressive strength shall be used as specified in the ACI Code (no less than 6000 psi, we have used 4000 psi). The moments of inertia shall be computed using cracked moments for beams and columns, advised by the ACI Code. This is done to account for the effects of cracking and reinforcement (35% for beams, 70% for columns).

Frames were assumed to be two dimensional in form as to easily be able to load them into the SAP (Structural Analysis Program) computer program. The critical moments for beams will be calculated using the frame loading conditions in the Design of Concrete Structures textbook (figure 12.3, page 380). Critical moments for the columns will be calculated by determining applied moments by gravity loads only and then by seismic loads only. These design moments will then be added together by use of amplification factors if deemed necessary.

Structural Group (Seismic Design)

Initially the focus of our group was the selection of columns and beams. This was done on a preliminary basis as actual selection could not be done until final dimensions were decided on by the Architect. From the preliminary design we decided on a floor plan that would best work for our seismic load requirements. After we had our initial beam layout for the entire building we began our column design. It was decided early on that the building would be as symmetrical as possible, with the same size beams and columns throughout. To load the building we used the International Building Code recommendations for live load and basically used the concrete's own self weight for the dead load. However it was assumed the roof would be a green roof and thus the live load used was 125psf. From our architectural drawings we designed the controlling column and arrived at a column size of 16" x 16". Later, after a reevaluation of the loading, the column size was changed to 20” x 20”. This size seemed to match our advisors expectations and was used. We then moved on to design the main girders from our moment frames which would be in the north-south direction. To design these girders ACI provisions were used. Using these provisions we arrived at a beam size that was 20" x 30". The base was kept similar to that of the columns for symmetry. This same process was repeated for the interior beams that would span in the east-west direction. These interior beams were designed as monolithic one-way slab beams with dimensions 20" x 30" with an 8" slab thickness.

Once all of the preliminary selections were made the seismic loading of the building was determined. The International Building Code was heavily used for research into how a seismic design is done. Actual soil information for the site was needed to determine the site classification of this building. Information of this type was very limited for Carbondale, IL. Once this information was gathered, the equivalent lateral force procedure was used to find the lateral force per floor on the building. Using this information along with the predetermined live load and dead load the reinforcement for our beams, columns, and girders were able to be determined. With the above values we were able to load them into SAP2000. A typical moment frame with the member sizes and dimensions previously determined was created in SAP2000 and it was loaded using both the dead and live loads. This frame was analyzed with these loads and the moment and shear forces acting on the beams and columns were found. The frame was also loaded with point loads that were equivalent to the self weight of the interior beams and they were placed on the moment frame at positions were the interior beams would intersect the frame. Finally, the frame was loaded with the lateral seismic loading. Using different load combinations of the above, in accordance with ACI the max moments and shear forces were able to be determined. This procedure was repeated for the other moment resistance frames and their corresponding load cases. After the ultimate values were determined from SAP2000 we were able to design our member reinforcement.

Now that the values had been determined, the design of the steel reinforcement for the beams, columns, girders and slab could commence. Both IBC and ACI provisions for designing a reinforced concrete structure within a seismic zone were utilized. Basically this means that the design procedures had to be such that in the event of an earthquake, the building would deflect and deform, but not fail immediately. This “grace period” of time would allow the occupants of the building to safely evacuate before the building would collapse. The primary goal of the design is to completely prevent the building from failing, but such things are not guaranteed.

In order to properly design the structural members of the building we had to first make ourselves familiar with the seismic design provisions for steel reinforced concrete that are listed in both the ACI (American Concrete Association) and IBC (International Building Code). Once familiar with these codes we could properly design the steel reinforcement for the beams, columns, monolithic floor slab/beam system, and girders. After the design was complete we had to check the members to insure that they meet all these requirements in the ACI and IBC codes.

With the structural design of an entire building given to just us few we knew we would have to split up the work to get it all done on time. In the beginning of the design process we all sat down and figured out a few things together. After calculation tributary areas, we came up with a trial section for our columns. With this out of the way, together we determined the loading values to load into sap2000. This step is where we got hung up for a few weeks. Fred and Alex did some calculations for the loading of our moment frames and sent them to Pedro who was busy tabulating everything into excel. Pedro also calculated the estimated seismic loads for the building. After Pedro conferred with the other structural group felt that our loading calculations needed calculated again. This happened a couple of times before we decided that our loading would be different than the other groups and to go with what we had. After Pedro had received loading from Alex and Fred he finalized them in excel so that it would be easy to read out the values to be used in sap2000. Pedro calculated the live load reduction factors and applied them to appropriate loads. Fred and Alex were sent a copy of the excel sheet so that they could run the simulated analysis. One last tweak was given to the loading values to make a small correction and then sap2000 was run. Fred ran the analysis for the three different moment frames in the N-S direction utilizing the three load cases that would give us the max +/- moments and max shear for reinforcement design. Alex went through the same procedure for the two different E-W moment frames. After the analysis was ran, Fred and Alex had to compare the results from each case and choose the max positive moment, max negative moment, and max shear value for each floor. After all the values for each case were determined for each frame, they were all compared to each other to get the max overall +/- bending moments and shear for girders as well as the max +/- bending moments and shear values for columns. All of us gathered to review the results to make sure that the values all made sense. Next, the columns, girders, and intermediate beams, and the slab had to be designed for reinforcement. Pedro took on the task of designing reinforcement of the columns, Fred designed the girder reinforcement, and Alex designed the intermediate beams and slabs. When the design was finished, we all made cross-section views of our respective sections in autoCAD. Pedro pieced together most of the slides for our power point presentation then Alex and Fred contributed a few extra points to add along with a slide to compare traditional seismic design with the base isolation design.

HVAC/Envelope design/Acoustics

HVAC: When designing the Heat Ventilating and Air-Conditioning, there was a lot to consider. Goals of the HVAC design were efficiency, little to no noise, and no roof air-handling unit. Also, a museum has strict environmental conditions that have to be met. Temperature should be between 68-72 degrees Fahrenheit and humidity should be between 50-60%. The first step to HVAC design is the load calculations. This designer decided to do load calculations by hand because computing programs were difficult to use and time was lacking to learn to use them. The system chosen for the HVAC was a radiant heat and cooling system using a water-to-water heat pump with supplementary air-to-air heat pump for additional cooling and air circulation for humidity and air quality control. Radiant heat/cooling is a very efficient and quiet system. Using the load calculations sizes for the heat pump, well pump, air-to-air heat pump, humidifiers and water pumps for the radiant coils were chosen. Diffusers and return ducts were also chosen for the air supply with noise control being a high priority in selection. The NC for all diffusers and return ducts was kept under 25 dB, which is very quiet. Unfortunately, there was not to time decide on the sizing for all the air ducts.

Envelope: The exterior wall design was primarily the work of the architect. After consulting an architectural Design major, it was agreed that a simple cement wall with insulation and an interior gypsum wall was sufficient for the building and no special treatment was needed. However, it was decided to use an innovated green roof design for the roof. This worked well with the architect’s design as well as added many advantages to the building and community. An Extensive green roof was designed for the building. An Extensive green roof has only small plants and only a 3-6 inch soil base oppose to an Intensive green roof, which could support large plants such as trees and bushes and could have up to a 24-inch soil base. The most noticeable benefit of the green roof is it’s high heat resistively, which is twice that of most standard roof constructions. The green roof would require that no air-handling unit would be on the roof, which affected HVAC design. However, since this was already a requirement of the architect this did not pose any new problems. The additional weight was also easily compensated in the structural plans.

Acoustic Design: since the same student was responsible for the HVAC, envelope, and acoustics of the building, many considerations were taken in the design of the HVAC and envelope to improve the acoustic ambience of the museum. A quiet HVAC design chosen and a green roof helps block a great deal of out-door noise. HVAC and out-door noise are the greatest contributors to noise within a building. Also, it was decided to use cork-flooring tiles in order to reduce the noise of footfalls and add absorption. Since acoustics was the last thing to be considered in the design, there was not enough time for detailed calculations. However, an evaluation of the second story museum galleries was made. It was found that with standard acoustic paneling, there was too much of a difference in reverberation time between sound frequencies. By adding plywood resonator panels to the ceiling and walls, the reverberation time of the lower frequency were lowered within 60% of 1000Hz. Because the average reverberation time was below 1 second (standard for public spaces is 2 seconds) the 60% difference was accepted. No additional acoustic treatment was needed for the walls.

Plumbing/ Fire Protection/Security/Lighting Group

Building security and lighting design are two very important features of museum construction. Such a place that houses rare and valuable pieces of art is one that must be well protected and also well-lit to be seen by the public. For both of these designs, the architect is a key figure to consult with. Since the fire protection, security, and lighting systems all contribute to the museum's aesthetics, conferring with the architect is a polite and necessary thing to do. The electrical engineers are essential to completing a well designed lighting system. Finally, the structural engineers need to be aware of any loading on the frame from any equipment so that their design accounts for all practical dead loads. Teamwork and communication are vital to the completion of any building project and security and lighting are no exception.

Included in the design of the fire protection systems are security, fire suppression, fire alarm and detection, and signage/lighting systems. The requirements of each of these sections consist of system/product selection, calculations, plan layouts, and code checks. Because of the high value of artifacts to be contained in the museum, a good security system is important to protecting the assets. The Visonic PowerMax security system was chosen to provide the museum a protection from theft. It includes a main control panel, door alarms, window breakage detectors, fire and heat detectors, and a remote access key. All of these separate components are wireless; the only thing needing hard wiring is the main control panel. Layouts for security on all the floors are provided.

Another area of security entails the prevention of fires in the building. Since conventional water sprinklers would damage the art work in the gallery spaces, an alternative approach is required; after searching online, a clean agent was found to be the answer. Calculations were made and a clean agent product has been chosen for the suppression system; Ecaro-25 made by the Fike Corporation was the choice. A layout was designed with help from the specifications listed in the company website. This included quantity of clean agent required, nozzle selection and placement, pipe sizing, and container selection. Seven - 1000lb containers will be stored in the mechanical room to hold the necessary amount of clean agent to be released. Using Ecaro-25 will remove the danger to the artifacts on display and will not harm the people being evacuated like carbon dioxide would. To facilitate the speedy exit of persons from the building, exit signs and emergency lights were added to help direct traffic to the egress exits. Both the fire suppression system and emergency equipment is laid out on the plans which include the security system. I notified the structural engineers that seven heavy containers were going to be needed in the mechanical so that they could plan for the foundation design.

In many commercial buildings, lighting does not take special consideration to design. In a museum however, certain requirements are needed to properly display artwork and paintings that are common to gallery spaces. Both vertical and horizontal surfaces demand illuminance. Track lighting was used to cover most of the wall spaces and can lights made up the difference on the floors throughout the galleries. Can lights were also used in the rest of the main floor and also in the storage and restoration rooms in the basement. All of these fixtures use incandescent bulbs which do not cause deterioration to artwork unlike the UV light in fluorescent bulbs. For the rest of the spaces in the basement, fluorescent lights were used which included the offices, loading, and mechanical rooms. I checked with the architect about the light levels and fixtures before my final designs were in place to make sure she was getting the look she wanted.

Since the south side of the museum includes many windows and an atrium is set in the middle of the structure, daylight becomes a huge factor to consider. To save energy during the day, daylight sensors and dimming controls were added to the lighting plans. Lutron's Radio touch wireless control system allowed us to integrate a remote control of all the lights on the main floor which lie in areas of daylight. The sensors keep track of how much light is entering the building and adjusts the interior light fixtures accordingly to sustain a constant level of brightness. The wireless controls allow for personnel to adjust the lights themselves for certain events. This technology promotes energy efficiency and personal comfort for guests. It also allows for differing functions to be provided for in the main gathering room where lights can be adjusted for whatever occasion.

Most of the lighting design was done with the help of the electrical engineers. We both worked together on picking out fixtures, determining light levels, and designing the number of lights needed. Using the data we gathered from the lighting design, they were able to make an estimate of how much power was required to run all these lights. I had to make sure to get the necessary specifications for the fixtures so I could give them the correct wattage information. I then gave them my lighting plan layout so that they could make the wiring diagram needed for their electrical drawings.

The plumbing pipes were sized using Table 6-2 from ANSI-A40 code and the pumps were sized using Appendix E of the International Plumbing code. There are 2 pumps, one for the cold water and one for the hot water. They are 60HP and 5 HP respectively. We have a 65 kW, 5000 gallon water heater and are using a hot water return system to ensure always hot water at each fixture. The plumbing pipes are located mainly in the drop ceilings and the risers are located in the wall of the women's restroom. There are two floor drains, one in each of the ground floor restrooms. The drainage system is a roof system, with 8" gutters and 8" leaders on the exterior of the building, with 8” diameter drains in the four main corners around the building. This will give our roof a 2% minimum slope to ensure positive drainage without standing water or ponding.

The standpipe will be located in the wall of the main staircase. It is a Class I (can only be used by professionals) 4” black steel pipe standpipe going by ASTM Standard A0120. The Hose connections are 2.5” and we will have a 2-way Siamese, 2-port check valve connection on the ground floor. It is a one-zone system with the only water supply is simply the public waterworks system. We need a 500-1,000 GPM capacity fire pump, which at effective operating pressure performs at 50% of rated capacity delivering 250-psi net pump pressure. It is a 210 hp, 20,000 GVWR double suction impeller pump.

Electrical Group

Our primary task was to calculate the total electrical load for the museum and then design the electrical system to supply that load. Emergency and special electric needs must also be covered. The load consisted of the lighting design; the power needs of all the major motors; and the total number of receptacles in the museum. Distributing the power to each load was the other major element of design. We also considered efficiency and sustainability issues; however, with more time we would research this area much further.

The Carbondale Contemporary Art Museum lighting design was especially difficult because of the specialized lighting areas and the sensitivity of the artwork to light. The electrical motor needs of the building were standard. Often the difficulty here arises from the lack of timely information from the other engineers regarding the power needs for their systems. The receptacle load was also standard. Special emergency precautions included protecting the art from heat and humidity and protection from electrical fires due to earthquakes. Time constraints kept us from designing a data network; however, this application did not have a demand for an elaborate network. We began sustainability and efficiency considerations, but with more time we would like to explore this area much further—including alternative energy sources and further efficiency design.

The method we used for the electrical design consisted of guidance from professors and our own research from books and the Internet. We had to initiate our own strategy for design because Professor Mohammadi is a civil engineering professor and there was precedent set for electrical design. As an example, for lighting design we began by meeting with Professor Gentry in Architecture. He explained lighting design and its many steps. We then visited the Museum of Contemporary Art in Chicago to research their lighting design. We followed up with Professor Gentry many times to complete our design. The same steps were followed for the power and distribution design and the emergency design elements. Once the basic design was complete, we researched specialized applications for the museum. This included the natural gas cutoff switch and the variable speed motor drive for the HVAC system.

Elevator Group

When I volunteered to work on the elevators for the museum, I did not know anything about how they worked. I spent the first two weeks researching different types of elevators and why we should use them for the museum. I found that there are two basic types of elevators, hydraulic and roped elevators. In general, roped elevators are better for taller buildings, and hydraulic elevators are better for smaller buildings. I decided to use a hydraulic elevator since the museum only has three floors. There will be two passenger elevators and one freight elevator. I felt we needed the freight elevator because some of the sculptures that could be in the museum could exceed the capacity of a normal passenger elevator. The freight elevator is equipped with a key entry, so no visitors can access it. The passenger elevators have a key lock for the basement level. I thought it would be wise to not let the visitors be able to go down to the basement where the employees will be working and the artwork is stored.

A main focus designing the entire museum was earthquake safety. In order to keep the occupants of the elevators safe, I did some research into safety features for elevators. I looked up the city code of San Diego and San Francisco for elevators. They both did not have much information, but they did say that elevators had to be equipped with a sensor to sense an earthquake and immediately shut the elevator down. The city code referenced ASME A17.1-1996 Part XXIV. I looked up the ASME code, but was unable to find anything relating to earthquake safety rules for elevators. I also included a backup battery with the elevators. This insures that if power is cut, the elevator car will still be able to get to the closest floor and no passengers will be trapped.

The elevator that I finally decided on is called a telescoping, holeless, hydraulic elevator. Normal hydraulic elevators have a deep pit that descends below the building to house the hydraulic cylinder to lift the elevator. However, because the museum was concerned with earthquake activity and environmental effect, I decided that it would be best if we could keep the elevator from having a hole. That way, the elevator would be able to sit on the base isolators the structural group was working on. The telescoping holeless elevator has two cylinders on each side of the elevator. They are attached to the elevator and the hydraulic fluid moves plungers up and down, thus raising and lowering the elevator. The motors required to run the passenger elevators were found to be 25kW. The motor for the freight elevator needed to be 40kW.

Results

Architecture Group

I designed a simple and symmetrical floor plan and realized that these circulation of spaces flowed better and are easy for the visitor to understand (rather than solely the designer). A multipurpose room is located at the core of the building as the atrium is located above at the second level. These two areas become the focal point of the social environment. School dances, guest speakers, mini films, eating and shopping are among a few of the activities that happen at the Carbondale Contemporary Art Museum. The façade of the museum consists of cast in place concrete walls so that the "contemporary" design of the building will survive throughout all periods of time (past, present and future).

Structural Group (Base Isolation)

Despite the problems in our group, we were able to compare the final results of our two designs. As expected, the base isolation system reduced the stresses and reinforcement needed for the structure. On average, the stresses in the frames were reduced by 60% and steel reinforcement was reduced by 40%. The most important difference, however, was in the overall displacement of the structure – a difference of a factor of five. Due to lack of time, we did not get a chance to perform an in-depth cost analysis on the two systems. However, from our research we found that the base isolation system would be 5-10% more expensive to implement than the traditional design. Those are only the initial construction costs. In the long-term, the base isolation is a much better investment, as the structure it supports will preserve its functionality. Therefore, the costs of repair after an earthquake will be greatly reduced. Another benefit is that the elastomeric bearings are maintenance free and last the lifetime of the structure. Clearly, base isolation is a technology worth investing in.

Structural Group (Seismic Design)

Our part of this IPRO was to use traditional methods to design effective concrete members, for this museum, under seismic conditions. This traditional design incorporates using significant amounts of steel reinforcement throughout the building. Our final member sizes were similar to those of base isolation design, but our design incorporated a significantly larger amount of steel reinforcement and Moment Resisting Frames.

HVAC/Envelope design/Acoustics

The envelope design of the general building was simple. It was decided to incorporate a Greenroof to the building increase thermal resistance and aesthetics and decreasing noise pollution and maintenance. The HVAC system chosen is a highly efficient and quiet hybrid system of radiant heat through the floors and air circulation. Acoustics was a consideration in the design process of the envelope and the HVAC. General calculations of the public spaces found the noise control to be adequate for the building.

Plumbing/ Fire Protection Group

Part of the design reserved for the architectural engineers was the plumbing, fire protection, security, and lighting systems. The job at hand was to analyze and research into what ways work best to provide for the plumbing fixtures, in the building, protect a museum from fire and theft as well as the proper way to light the interior. An independent clean agent system was used for the fire suppression in the building since it is non-toxic and will not damage the artwork like water would. The system works off of its own pressure and requires no outside power. For security, a wireless system was installed to protect the artwork and includes a range of detectors including fire and door sensors. Three different kinds of lights were used to illuminate the interior: fluorescent, can, and track lighting. Only incandescent bulbs were designed for the gallery spaces to prevent deterioration of the art. Smart lighting and dimmers were also installed to adjust inside level with the amount of sunlight received from the windows on the south side.

The plumbing was designed and sized using the ANSI A-40 and International Plumbing code. Drawings and isometrics were used to properly show the placement and size of the pipes and fixtures.

The whole design process was a good experience overall. The teamwork and communication between team members was a good experience. Times appeared when conflicts between designs came up but were all handled well and I was able to see each person's point of view through effective conferring. I believe with help from my partner and others in the group, the building is now designed to adequately handle fire and theft. Its lighting system will also be effective at allowing patrons to see visually stunning pieces of art properly and be efficient as well. Through hard work and communication, this IPRO has been a success at coming up with an innovative design and garnering a great experience to myself and the other members.

Electrical Group

The total electrical load is 841 kVA. We choose 3-phase, 480/277 Voltage because the higher voltage used, the lower the current losses. Egyptian Electric in Carbondale was used to supply the service voltage. The company was contacted for its supply voltage: 12.5 kV. We sized a main transformer at 13.8 kV – 480/277 V, 3-phase, 1000 kVA. This is a pad-mounted, oil-filled transformer that provides underground service to the museum. All light fixtures were fed from 480/277 V panels (all fixtures could take 277 V supply). A step down transformer was used to supply receptacles at 120/208V. An emergency generator was sized for emergency lighting, air conditioning and fire pump loads. We chose a natural gas cutoff valve for the museum to reduce the chance of fires if an earthquake occurred. Most fires result from electrical faults in the presence of natural gas leaks. To reduce energy use we proposed a variable speed motor for the air handler system of the HVAC system. This provides better control of air temperature and reduces energy use by matching the output of the system to the cooling load.

Elevator Group

The elevators needed to be both environmentally friendly and conscientious of the design of the building. A glass enclosed elevator was selected in order to match the building design. A special telescoping hydraulic elevator was chosen to be both practical and environmentally friendly. In order to protect against earthquakes, the elevator is equipped with sensors that cut the power during an earthquake. A backup battery lowers the cab to the nearest floor when the power is cut.

Critical barriers and obstacles

Architecture Group

One of the major obstacles of this project was determining what an art museum consisted of and placing those spaces into a small site. Second, I designed a floor plan in less than two weeks time so that the entire group could begin their part of the project. This floor plan had to be close to its final design keeping in mind that it would determine the direction of the individual team projects. Finally, I learned that assumptions from members can create problems. For instance, I decided to remove the first row of columns at the south side of the building. I assumed that anything is possible when it came to designing a structural system and assumed that the window mullions with steel reinforcement could support the upper portion of the building. I discovered the concept was not feasible for such a small building. The load was too much for those mullions to handle and the other columns sizes would have been 50” x 50.”

Structural Group (Base Isolation)

We encountered our first obstacle at the planning stages of the project. Our structural group could not reach agreement with the architect as to the layout of the floor plans – more specifically the location of the columns. The architect was proposing a highly impractical design, especially unfit for a seismic prone region. After some debate we were able to agree on a final plan. It did, however, take quite a bit of time and took away three weeks that we could have used to start designing our beams and columns. The next major obstacle was within our structural group. Whereas our base isolation group was on task, the traditional design group kept falling behind. One of the members of that group tried hard to catch up, but the lack of support from the other two members was a big barrier to overcome. It seemed that they just did not care or expected that others will carry the entire load. Therefore throughout the project we had to deal with their lack of productivity. This compromised the thoroughness of the overall design.

Structural Group (Seismic Design)

Up to now the major problem we have faced is the constant redesign of the layout of the building. 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. Although this is a problem easily overcome it does take a lot of time to keep redesigning these members. A more significant problem in terms of actual doing work is the lack of information about the soil conditions in Carbondale, IL. As of now we have found an old experiment done by the University of Illinois in Carbondale the sheds some light on the soil conditions yet it is still very limited.

HVAC/Envelope design/Acoustics

This designer had little experience with HVAC design; therefore the learning process of designing the HVAC was difficult and long, which did cause things to fall behind schedule.

Plumbing/ Fire Protection/Security/Lighting Group

Because of the potential size of the project, work was limited to basic designs. With more time, green building design considerations and detailed cost estimates could be made.

Electrical Group

Our primary task was to calculate the total electrical load for the museum and then design the electrical system to supply that load. The load consisted of the lighting design, the power needs of all the major motors, and the total receptacles in the museum. The next step was choosing the main voltage, determining the local utility supply voltage, and sizing the transformers and panels to feed the voltage to all loads. We proposed a variable speed motor for the heating/air conditioning system; this uses less energy and, thereby, increases the efficiency of our design.

Elevator Group

The person designing the elevators should be able to start at the beginning of the semester. I was given the job when the semester was half over. When all the other groups had completed their background research and were starting calculations, I was just starting my background research. Since I had less time to work with, I was not able to calculate exactly what size of components the elevator would need.

Recommendations/ Next Steps

Architecture Group

As a whole I think we also would like to explore more ways to decrease energy consumption in the museum and, along with that, explore the possibility of using alternative energy sources, such as solar energy. More accurate and in-depth code checks, as well as considerations for green building design and a cost estimate. For electrical, a full data network would have been sized and placed, and a more comprehensive load calculation would be done. For structural, we would further refine our design – use smaller beam/column sections and perform in depth modal analysis of seismic loading on the structure. Concerning the elevators, it would be wise to complete detailed calculations of the stresses the elevator would undergo. Due to time constraints, not all the tasks could be accomplished. Also, more time should be used in research for understanding how an elevator reacts during an earthquake. If more time was available it would be desirable to do a thorough foundation design for this building.

Structural Group

Although, our group tried to go as in-depth as time permitted, we were only able to scratch the surface of the most economic final design. Using the created templates from our design, new, smaller sections for beams and columns could be chosen to create a more economical design. Most of the beams used in our design were over designed and even the minimum reinforcement could be drastically reduced if smaller sections were used. Performing more research on seismic ground motion could also be undertaken to have a better understanding how the structure would react to it. From that research a three dimensional model of the response to earthquake forces could be constructed. Once the two designs were finalized, a detailed cost estimate could be performed to provide a better picture as to the difference in cost. Those are just a few recommendations that could be carried out if time was not a restraint.

HVAC/Envelope design/Acoustics

HVAC: There was essentially only one person working on the HVAC design. It is recommended that two architectural engineers should be assigned to work on the HVAC design. The work of a single person, who was also responsible for two other design elements of the building, envelope and acoustics, was not enough to finish the design. Air ducts were not designed, loading calculations could have been more precise, and overall, a more efficient and better design could have resulted. Most of the designer's time was taken by research in the HVAC design because their experience in the area was low.

Envelope: Overall, this designer was happy with the results of the envelope design. The use of an innovated technique, the green roof, was rewarding to use and is a key feature of the building. Perhaps, if there was more time, more research could have been done on green roofs and their use in urban planning, thermal efficiency, and integration with other "green" building design aspects.

Acoustics: This designer wishes more time and effort could have been put into the acoustic design of the building. There were good and bad results from having a single person responsible for envelope, HVAC, and acoustics. The positive influence of this was that all these systems could be designed with their integration in mind. The HVAC was designed with efficiency and quietness as a priority. The envelope was designed to help heating efficiency and noise reduction. As a result, acoustics was part of many of the design features. However, because so much time was put into HVAC and envelope designs, which are traditionally considered more important, detailed acoustic calculations could not be finished. Also, plans for Audio/Visual design of the first floor convention areas had to be discard due to lack of time. This designer wanted to spend much more time with acoustic design since this is were her career interest are.

Plumbing/ Fire Protection/Security/Lighting Group

Upon completion of the project, I am now able to think back on the work that was done and what, if anything would I have changed. The clean agent was a good choice for this building but it did have one downside: it was particularly expensive. Since money was not an issue here, it was not a problem but I think that CO_2 gas may have been used safely with the addition of a pre-alarm warning. Besides these differences, the two gases are similar in the way they handle fire. Had I been able to spend more time on the lighting, I could have come up with a layout that included more diversity in fixtures or complexity of layout designs. Given the short time and work in other areas, I was only able to focus for so long on the lighting. Time considerations were an important part of deciding what to do with the design tasks given to me.

Electrical Group

We were successful in designing the electrical system for the Carbondale Contemporary Art Museum, including the special lighting and cooling needs. The major obstacle was not being familiar with electrical design procedure for a building nor the specific elements that comprise it, such as the panels, circuiting, etc. We overcame this by contacting many professors outside class time who helped us by describing this procedure and giving us material that described the many steps involved. We highly recommend researching more options for alternative power sources and ways to increase the efficiency in the museum, along with cost comparisons for such systems.

Elevator Group

The major recommendation if anyone continues this project would be to calculate the size of the hydraulic cylinder and connections. Also, more studies could be done on elevator safety mechanisms.

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We would like to acknowledge the following people for assisting us throughout the length of the IPRO:

- Dr. Mohammadi was a major consultant with regard to frame design. He aided us with the preliminary section sizes. Helped us in the way that how our frames should be entered into SAP. Also pointed us in the direction of a one-way slab design for the structure. Also gave us information on the retaining walls and the foundation. We had contacted, talked, and reviewed our work with him on a weekly basis.
- Dr. Shen was a consultant with that regarding seismic design. He helped us with the Equivalent Lateral Force Procedure, as well as leaning us toward the use of the elastomeric bearing system. He provided us with much useful literature regarding the isolation system. We met with him on a weekly basis.
- Prof. Ralph Muehleisen for his assistance to the HVAC, envelope, and acoustic designer, also for his extensive help in lighting.
- Professor Gentry, in the school of Architecture. He helped us considerably with the lighting design process.
- Professor Pinnello, in Electrical Engineering. He helped us with the design and distribution of electrical power throughout the Museum.
- Beverly Arts Center
- Museum of Contemporary Art
- Art Institute of Chicago
- Field Museum

We used the following references:

- Clark, William H., *Electrical Design for Commercial Buildings*, McGraw-Hill 1998.
- Websites for elevator information
  http://web.mit.edu/2.972/www/reports/elevator/elevator.html
  http://science.howstuffworks.com/elevator1.htm
  http://www.amlegal.com/nxt/gateway.dll?f=templates&fn=default.htm&vid=alp:lamc_ca
  http://www.elevatorconcepts.com/sitemap.htm
- Websites for Radiant floor heat
  http://www.radiantec.com/440/index.html
  http://www.wirsbo.com/main.php?pm=1&mm=0&sm=0&pc=homeowner/ho_mm0sm0.php
  http://www.warmlyyours.com/

Documents Enclosed

Project Plan
Midterm Report
Abstract
Meeting Minutes