One Liberty Center

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Executive Summary:

The proposed thesis will include analysis of a new structural system consisting of composite decks, composite beams, and braced frames and removing interior columns. The current system is a two-way slab system that works well to minimize the height of the building while maximizing plenum space. One problem with the two-way system is that columns are required spaced at 30 feet, 30 feet in from the exterior wall. The new composite steel system to be examined can eliminate this set of interior columns while also speeding up the construction process.

The proposal explains how the composite system will be looked at in depth by redesigning the entire structure and examining the results. Trial members will be chosen based on research already completed dealing with the loads. The loads will be updated, using the most recent codes, to create a final design for the gravity and lateral systems. The typical floors will be modeled and tested in RAM modeler and the results will be spot checked by hand calculations. The braced frames will also all be modeled in RAM for examination and the results will be spot checked by hand. A similar redesign will also take place with the garage that is the bottom five floors that are all below grade. The garage design is not as critical, but is necessary for estimating and scheduling purposes that will be used as a breadth option.

After the final redesign for the building is completed, with final sizes considering the plenum space and overall height of the building, the designs can be compared to see if the redesign is superior to the initial design. To judge the new system against the two-way slab, the size of the members and the effect they have on the plenum space will be examined, taking into account the interior columns have been removed. A new schedule will also be created to see what time advantages the steel construction could yield. An estimate for the redesigned project will also be made to see if the steel creates too much extra expense to outweigh the benefits of time gained.

The layout of the mechanical system will also be redesigned to accommodate for the deep beams that will now be spanning the full depth of the available plenum. A new layout for distribution must be created, and that will in turn have an effect on the type of cooling and heating system used.

The thesis will solve the problem of the interior columns taking up very valuable functional office space in the building. The change to steel will also have beneficial outcomes regarding an accelerated schedule, but adverse consequences regarding costs, and these will have to be weighed and measured along with the profits of the more flexible open office space.
Existing Structural System Background:

One Liberty Center is a 13-story cast in place concrete office building with open floor plans and five levels of underground parking. The 138 feet by 186 feet typical floor system used is a two-way flat slab system supported by integrally poured columns. For lateral resistance the building relies on the ability of concrete frames, created by the regular placement of columns, to resist moment. The lack of beams provides plenum space above the ceiling tiles, for electrical and mechanical systems, without making the building any taller than it has to be.

Floors and Columns: In the office building’s columns and floor slabs 60,000 psi reinforcing steel is cast in 6,000 psi concrete below the third floor to keep the columns, which have accumulated load from the stories above, a couple inches smaller on the lower floors. The third floor and above is 5,000 psi concrete. All floors above grade, are supported, typically by two feet square columns, and are eight inches thick with six inches deep by varying greater than ten feet square drop panels on the interior columns and a continuous nine inch deep by five foot drop connecting all of the exterior columns (as seen at right).

At ground level there is a plaza slab that extends beyond the walls of the building and overtop of the parking garage. The slab is 12 inches thick to accommodate the soil and fire-truck load. In the garage slabs are eight inches thick with four-inch thick drop panels at the columns. There are 14 by 24 inch columns in the garage to support the beams at the edge of the parking ramps.

Around the outside of the parking levels there is a 12 inch cast in place wall resisting the soil’s pressure assumed 48 psf/ft of depth. Each column has an individual spread footing resting on bedrock or disintegrated rock with a safe bearing pressure of 30,000 psf or 10,000 psf for wall footings. LRFD design methods were used to design the beams and columns, while the unfactored loads were maintained to the tops of the footings to size them using a table for rectangular footings derived from a book using LRFD methods.
From the exterior columns to the first set of interior columns the spans are from 29 to 31.5 feet. This first set of interior columns has the greatest amount of area contributing to their load, with about 30 foot spans on three sides and 22 to 23 foot spans to the core of the building. Illustration provided at left.

**Lateral Resisting System:** The lateral systems used in One Liberty Center are the rigid concrete moment frames. In this type of moment frame system the building relies on the ability of the concrete two-way slab to transfer moments to the columns in order to resist the forces imparted on the structure laterally. Following is the way the system is assumed to accumulate and transfer load.

*Wind:* In wind loading cases, winds act on the façade of the building creating a force pushing on the windward side and pulling on the leeward side of the building. The façade can be thought of as spanning vertically from floor to floor, and shear forces are created where the floors react upon the façade. The shears are transferred directly into the slab pushed on the windward side and pulled on the leeward side. The slab sliding in any direction is resisted by the connection of column to slab, which in this case is monolithically poured creating a stiff resistance to the couple created (seen in the figure below). Using all the columns in this manner creates many systems of frames in both directions to resist wind (see figure next page). The forces distribute themselves by the stiffness of the frames and columns. The stiffer the frame or column the more moment it absorbs from the forces.

*Seismic:* Seismic forces are accumulated due to the tendency of the slab to want to stay in the same place while the earth moves below it; its moment of inertia. This makes the forces dependent on the speed and type of ground the building is on, the height
and weight of the floor being considered and the period of the overall building. However, after the forces are found they are distributed into the same frames the same way as the wind forces.

The figure below, illustrating the typical floor plan, shows the major frame systems that are acting to resist lateral loads.
Problem Statement and Proposed Solution:

**Problem:** The buildings two-way slab system keeps the floor-to-floor height down to a small 11 foot 6 inches with a ceiling to floor envelope, due to structure, of one foot-six inches, but columns are required 30 feet in from the exterior that places them right in the middle of usable workspace. This may not be a major problem looking at the overall building, but after tenants start to move into the building the columns may be troublesome and restrictive as to how the floor space could be used.

Apart from the interior columns any concrete system takes considerable time to construct because of forming, shoring, pouring, stripping, and reshoring. The shoring and reshoring makes it more difficult or impossible for the other trades to start jobs while the structure is going up.

As a structural system the two-way slab will work fine, but taking time of construction and usable space into consideration another floor system may be a more efficient use of resources. Other options for the floor system must be considered to find what is the most economical choice. By changing the floor system there will be repercussions that will also need to be addressed. The immediate variation caused by changing the floor system will be a new lateral system must also be devised, because the concrete frame system will change as a result. Another adjustment will be an enlarged ceiling to floor envelope due to the size of the structure, if interior columns are to be eliminated. Other changes may include fire protection issues and cost, if steel is to be used.

**Solution:** A composite beam composite deck steel system with braced frames at the core of the building.

Preliminary sizes:
- Slab: 4” deep 1.5”x12” composite deck; f’c: 3ksi; fy: 60ksi
- Beams: W16x26; fy=50ksi; @ 10’ O.C.; laterally supported by deck
- Girders: (Long Spans) W24x104; @ 30’ O.C.; laterally supported by beams

This system will need to be fire proofed and the braced frames will need to be designed. An advantage to steel systems is the speed by which the structure can be built. New columns and girders can be placed while the beams and deck on lower floors are installed on other sections of the building. The slabs also can be poured while the floors above are being framed due to no need of shoring for the composite deck. This may make up for some of the extra cost of the steel. The procurement time would not make a difference if the plans were known far enough in advance to order the shapes.

The steel beams and girders take up more space in the ceiling to floor envelope, about two foot six inches, about one foot more than the flat slab, but the interior columns can be
removed, making this system an option worth investigating. One foot more in the plenum is a fair increase, but MEP systems would have nevertheless increased the envelope size in the two-way system.

The floor to ceiling height would be nine feet without increasing the height of the building, but if ten foot ceilings were required then the building’s overall height would increase by 13 feet.

**Solution Method:** The design of the new structural system will be based on LRFD 1998 Second Edition. The computer program RAM modeler will be employed to check member sizes shown in the previous section along with analyze frames for the lateral system of the building. Hand calculations will also be supplied in certain cases to provide a check to the program.

The trial sizes will serve as a starting point for the new design. The sizes will be input into RAM and tested using applicable load cases. The members will be evaluated in their response to the loading and kept or resized accordingly. After a typical floor is designed moment-resisting braced frames can be designed and checked using the appropriate wind and seismic loads. The wind loads will remain the same as in the calculations for the existing building if the size stays the same, but new seismic calculations must be made due to the change in building weight.

After all the new sizes and the configuration of the braced frames are finalized a new schedule and estimate should be made to see if there are any advantages besides getting rid of the interior columns.
Tasks:

1. Establish trial member sizes
   A. Review calculations from technical report number one for starting point for beams and girders
   B. Slab thickness and deck should be chosen out of deck tables
   C. Identify areas where columns and braced frames could be located (original columns not found on a good grid system)

2. Calculate loads
   A. Find applicable floor loads from BOCA, dead loads from trial sizes, and superimposed dead loads from plans
   B. New lateral loads must be calculated, but the wind loads will remain the same if the building height doesn’t change; as a result seismic is not likely to control because the building will be significantly lighter due to the new steel system

3. Analysis
   A. Check floor system and make necessary adjustments to members
   B. Check braced frames and adjust locations of frames as required
   C. If braced frames do not offer significant support where they can be placed moment connections may be required in some locations of the building
   D. Determine most economical balance based on member sizes and allowable depth for ceiling to floor envelope
   E. Complete frame system analysis and design

4. Garage design
   A. Design new steel beams and columns for floor system (space is not as critical, so not as much in-depth analysis is required, layout can remain the same, and composite members may not be required)
   B. Complete design

5. Check
   A. Investigate the time savings on the schedule
   B. Find the new cost and compare with the cost of the existing building
   C. Do the costs, schedule, and less columns balance to make this a feasible option

6. Mechanical Breadth (construction management breadth will be taken care of with task #5)
Calendar:

Tasks denoted by number and letter when they should be completed.

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Breadth Issues:

Construction Management: The new steel design will have considerable impact on both the schedule and the cost of the building. The proposed thesis must include information detailing the effects of the new framing system on these construction management aspects of the building.

Two-way concrete slabs are time consuming to construct. The new steel system may be able to save time in the schedule allowing earlier move in dates for the tenants, permitting the owners to start collecting revenue from the building earlier, offsetting the cost of the steel. The lead-time for the steel is long if it is not ordered until the design is completely done and work is ready to begin. However, if the structural design is finished far enough in advance, about a year before steel is required on site, then the procurement time will not need to be a major consideration. The time saved by constructing the structure with steel instead of the two-way concrete slab system will be investigated and weighed against the extra cost of the steel and the construction.

After the structure is redesigned in steel the new cost will be contrasted against the cost of the concrete structure. If significant savings can be made in the construction timeline it will cancel out the extra cost of the steel, making the composite beam composite deck system a realistic option that will also add rentable interior spaces that used to be occupied by concrete columns.

Mechanical: The new structural system adds deeper beams that span all over the building instead of just taking plenum space near columns, as did the concrete drops. A new mechanical layout would be very beneficial to make use of the plenum space available.

The current layout has few restrictions, because there are no paths that it must follow. In the steel system beams will be deep and span from the exterior to the core of the building and there is not enough room for ducts to cross over the beams to maintain a floor to ceiling height of just nine feet. A new layout may consist of a forced air system with 14 main trunks going to each large bay to be split into smaller ducts for distributions into the offices, eliminating the need for ducts to cross over girders that are too deep.

After a new layout for the ductwork is found another mechanical system would probably lend itself better to service the new type of distribution. An investigation of main mechanical systems will be made to find a better-suited system.