# *COURTYARD INFILL STRUCTURE DESIGN*

## *Executive Summary*

The existing design for the courtyard within the G wing is for a cast-in-place concrete structure. The design being proposed within this analysis is a structural steel with slab on metal deck system. All beams, columns, and footers to support the columns are design. The new steel system does have several implications to the design and construction of the hospital. The steel system results in a floor thickness 8" greater than the existing design. However, the steel system eliminates the need for columns within the courtyard infill, instead placing them on the exterior of the floor plan. The steel system is less expensive than the cast-in-place system due in part to less labor hours, as well as general conditions time saved. The implications to the schedule are all positive, as the steel system takes less time to construct than the cast-in-place system. Weighing the advantages and the disadvantages, the proposed structural steel design is the superior system when compared to the existing cast-in-place concrete design.

## *Existing Structural Design*

The courtyard infill is a 42' (east-west) x 40' (north-south) cast-in-place concrete structure with four 22" x 22" columns. At the floor slabs, each column has a 10' x 10' 3 ½"-thick drop panel. The floor slabs are 9" thick concrete reinforced with #5's at 9" o.c. in the top of the slab and #4's at 8" o.c. in the bottom of the slab. Four columns support the 40' x 40' floor area. The columns are situated in a square at 20' o.c. in the middle of the infill, with the slabs cantilevering out 10' on each side.

## *Proposed Structural Design*

The proposed structural redesign consists of a structural steel system with concrete slabs on metal deck. The design intent is to eliminate the need for columns in the middle of the infill without altering the floor plan too much. The new design places the columns at the exterior of the floor area minimizing the need for cantilevers. Constraining the design is the fact that the floor area is surrounded by corridors, making it impossible to simply place columns at the four corners of area. The design consists of 2 columns spaced 21' apart along the north and south side of the area, and 1 column in the middle of the 40' span in each the east and west sides. Three main girders span the 40' in the north-south direction. The only complexity in the design is at the corners of the floor area where beams do not have columns to bear on. A schematic of the design is shown below in figure 1.

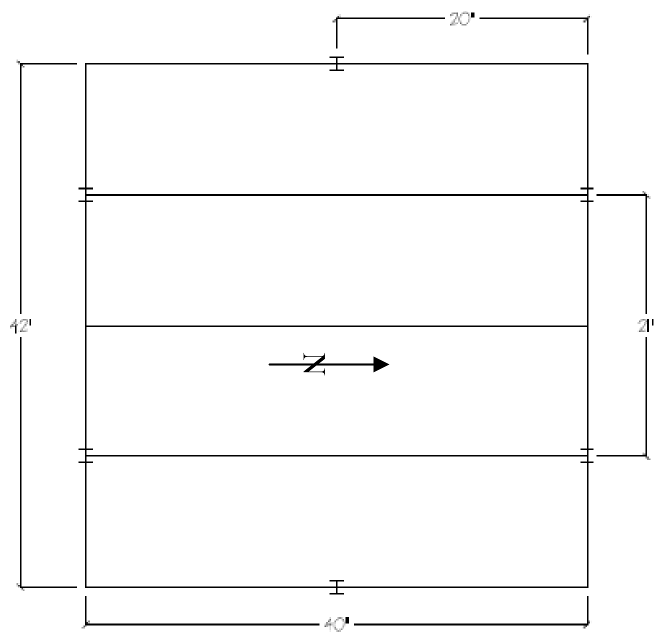



Figure 1: Schematic Layout

## *Design Calculations using RAM Structural System*

The original design requirements for the courtyard infill were used for the RAM calculations. The following loads were used: 30 psf dead load, and 80 psf live load. The slab was designed as a 5" concrete slab on USD 2" Lok-floor with 6x6 W1.4/W1.4 Mesh. After the schematic geometry was inputted into the program, the beam and column sizes, the number of shear studs, as well as the footer sizes were calculated. The structure consists of the W10x33 columns with the following girder and beam sizes: W8x10, W16x26, and W16x31. Figure 2 below shows the members and sizes. Each column on the north and south side has a 5' x 5' x 1'6" thick footer that is reinforced on the bottom with 10 #4 bars each way. The columns on the east and west side have 3' x 3' x 1'6" thick footers that are reinforced on the bottom with 6 #4 bars each way. Figure three below shows the structure in three dimensions. All of the connections are simple shear connections except for the column to cantilever beam interfaces, which require moment connections to counteract the cantilevering action. Because the structure is in the interior of the building, lateral loads did not need to be taken into consideration, as the existing building resists the any lateral load. Output from RAM can be found in Appendix B.

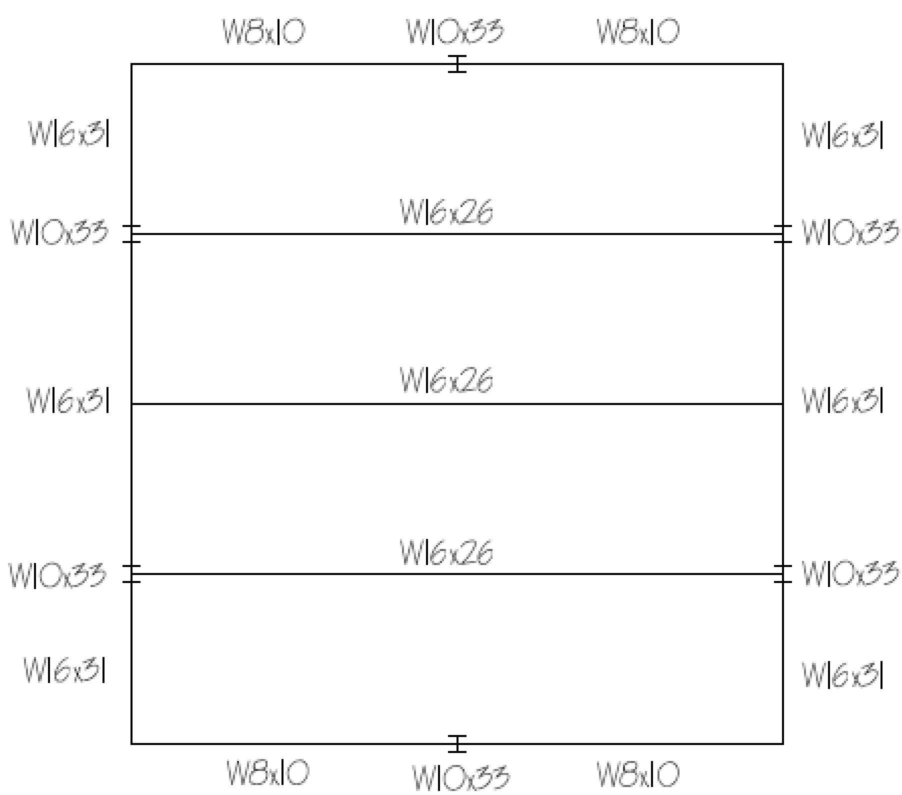



Figure 2: Designed Members

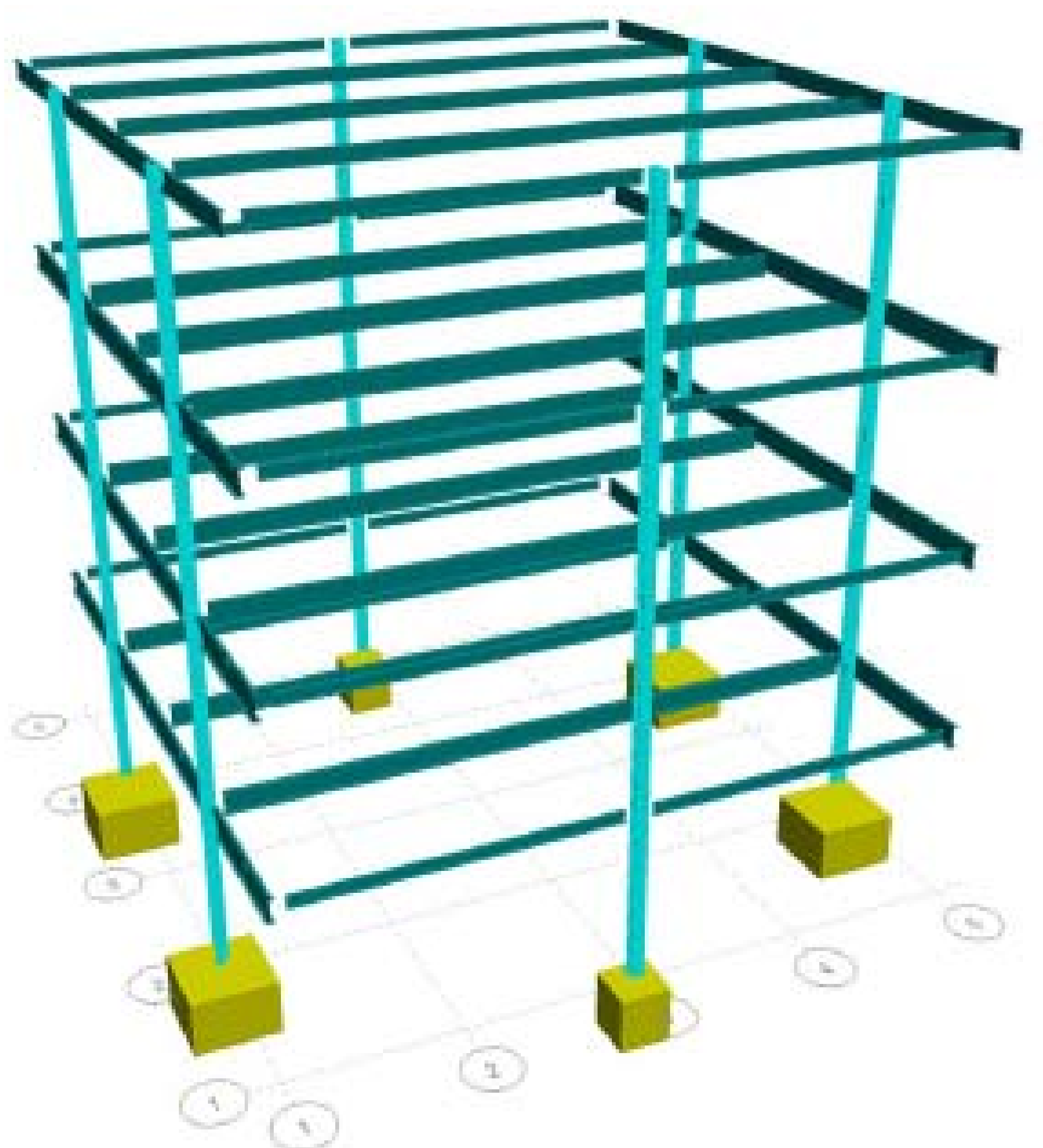


Figure 3: 3D Schematic of Design

## *Impact of Design*

There are several impacts of the new steel structure design. One disadvantage of steel construction versus cast-in-place concrete is that the floor to floor height is reduced. In this case the steel structure results in a floor cross section of 8” thicker than with a concrete structure. This is not an issue for the G wing because there is not a complex HVAC or piping system because the majority of the spaces are offices. The height of the duct in the area is 10”, and the largest pipes are 1-1/2”. At the very worst, the ceiling can be lowered 8” to accommodate the increased thickness of the structure. Figure 4 shows the comparison between the proposed and existing design.

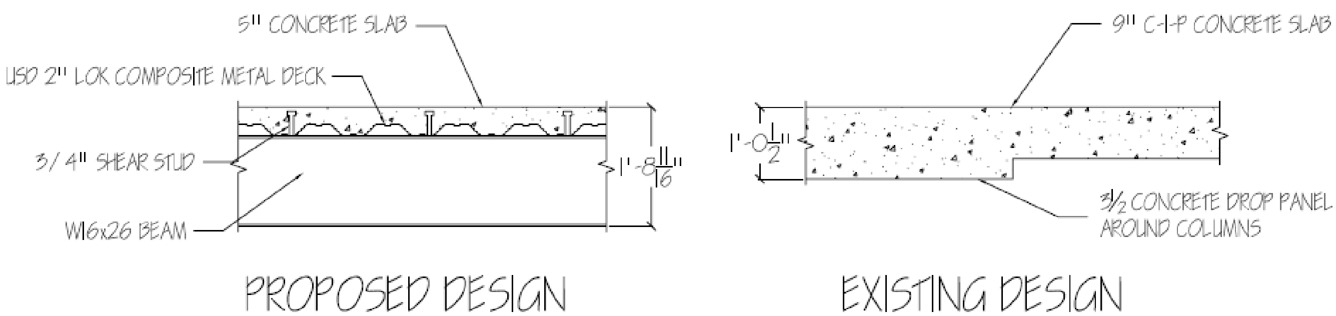



Figure 4: Proposed v. Existing Cross-Sections

Another impact of the design is in the architectural floor plan. Without the interior columns there is more flexibility allowed in the floor plan for the area. However, compromises must be made at the edges of the area where the proposed columns are to be placed. Figures 5 though 8 show the floor plans of the basement through the third floor respectively, with the locations of the proposed columns highlighted in red. In the basement floor plan the proposed design results in a completely open floor plan for the future employee gym (seen in figure 5). In the first floor plan, space can be saved where columns are no longer in the interior of the floor plan, however with the proposed columns situated at the edge of the infill area they now fall within the corridor, decreasing the corridor width at a few locations (seen in figures 6, 7 and 8). According to IBC 2003 section 1016.2 the minimum width must be at least 72” (6’) “in corridors serving surgical Group I, health care centers for ambulatory patients receiving outpatient medical care, which causes the patient to be not capable of self-preservation.” Despite having the proposed columns at the edge of the corridor, the hallway width still meets the minimum requirements. On the second floor the only other impact is a column that falls within the countertop of a kitchenette (figure 7). This would be easily remedied by moving the kitchenette over 2' or reducing the size of the countertop. On the fourth floor there are no other adverse impacts; the new layout eliminates the need for the columns in the center of the physical therapy room.

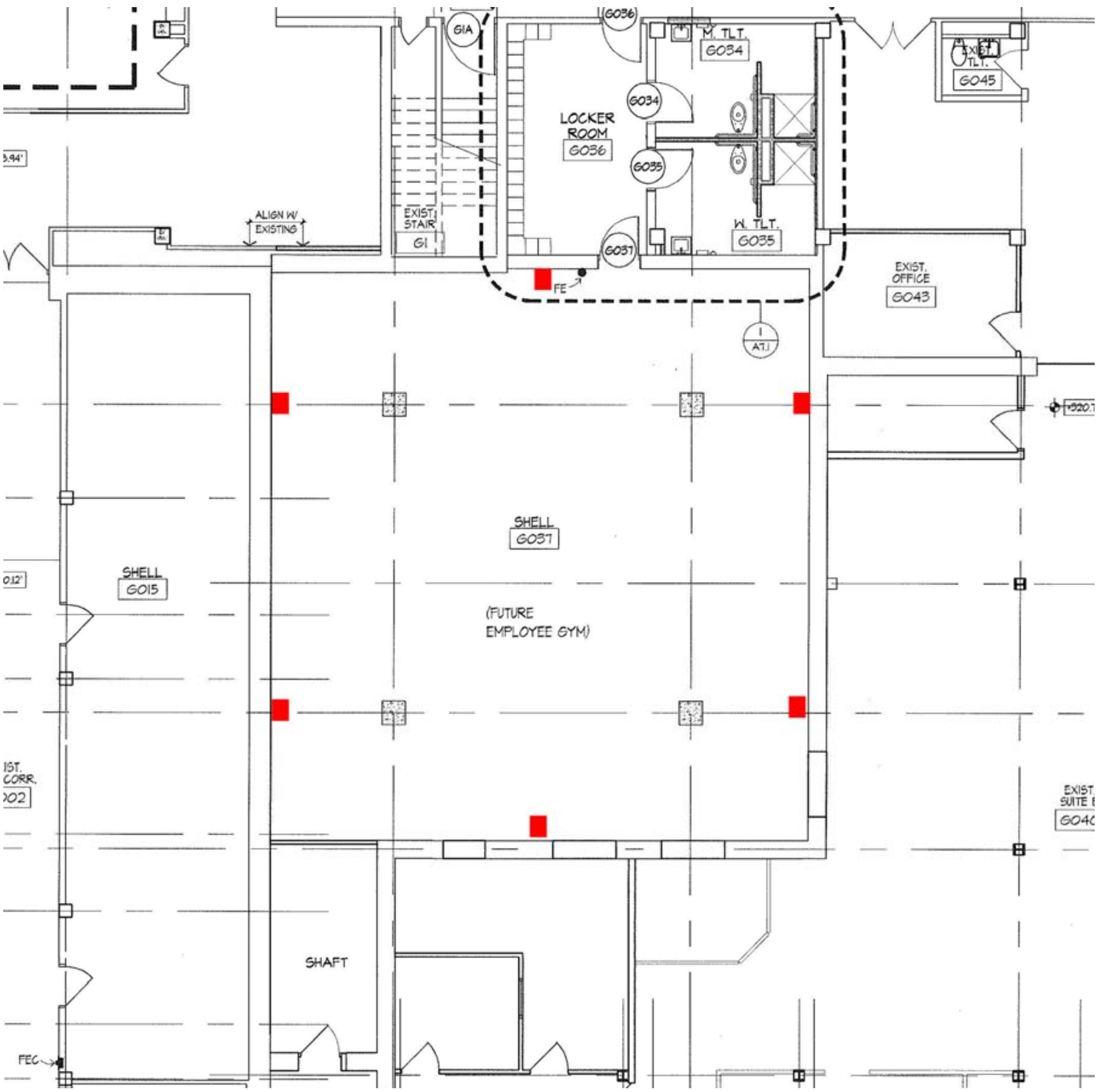



Figure 5: Basement

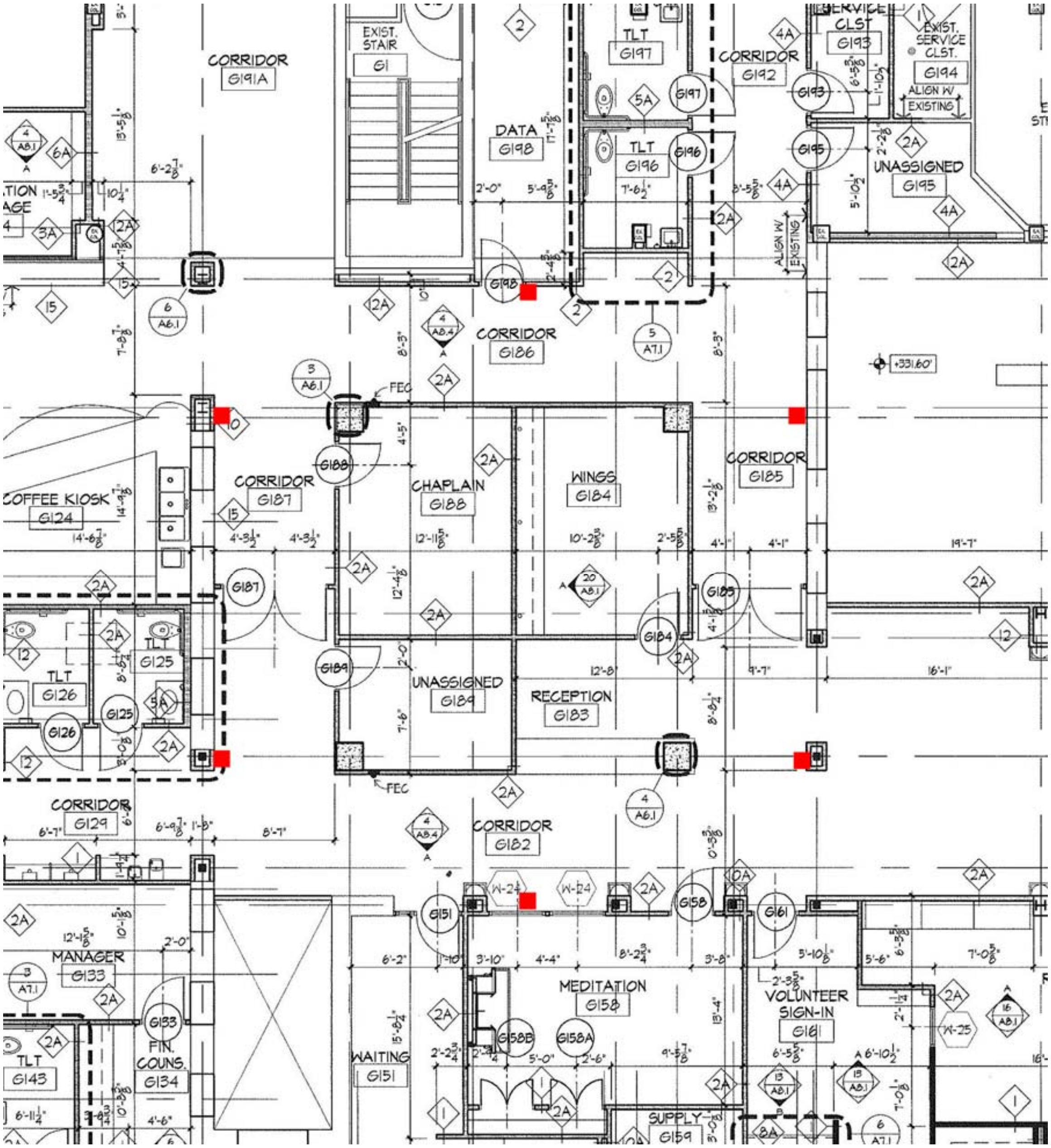



Figure 6: First Floor

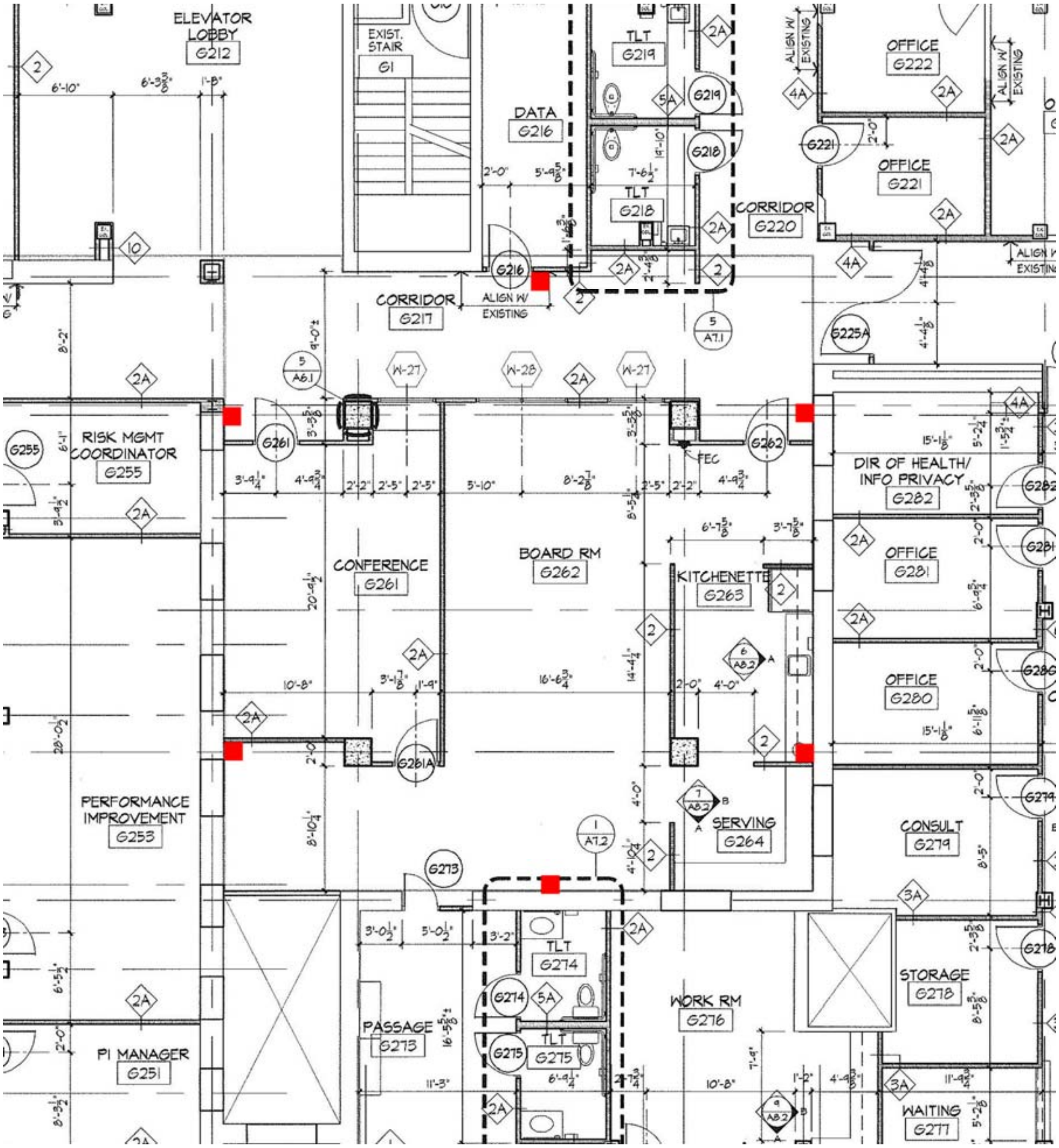



Figure 7: Second Floor

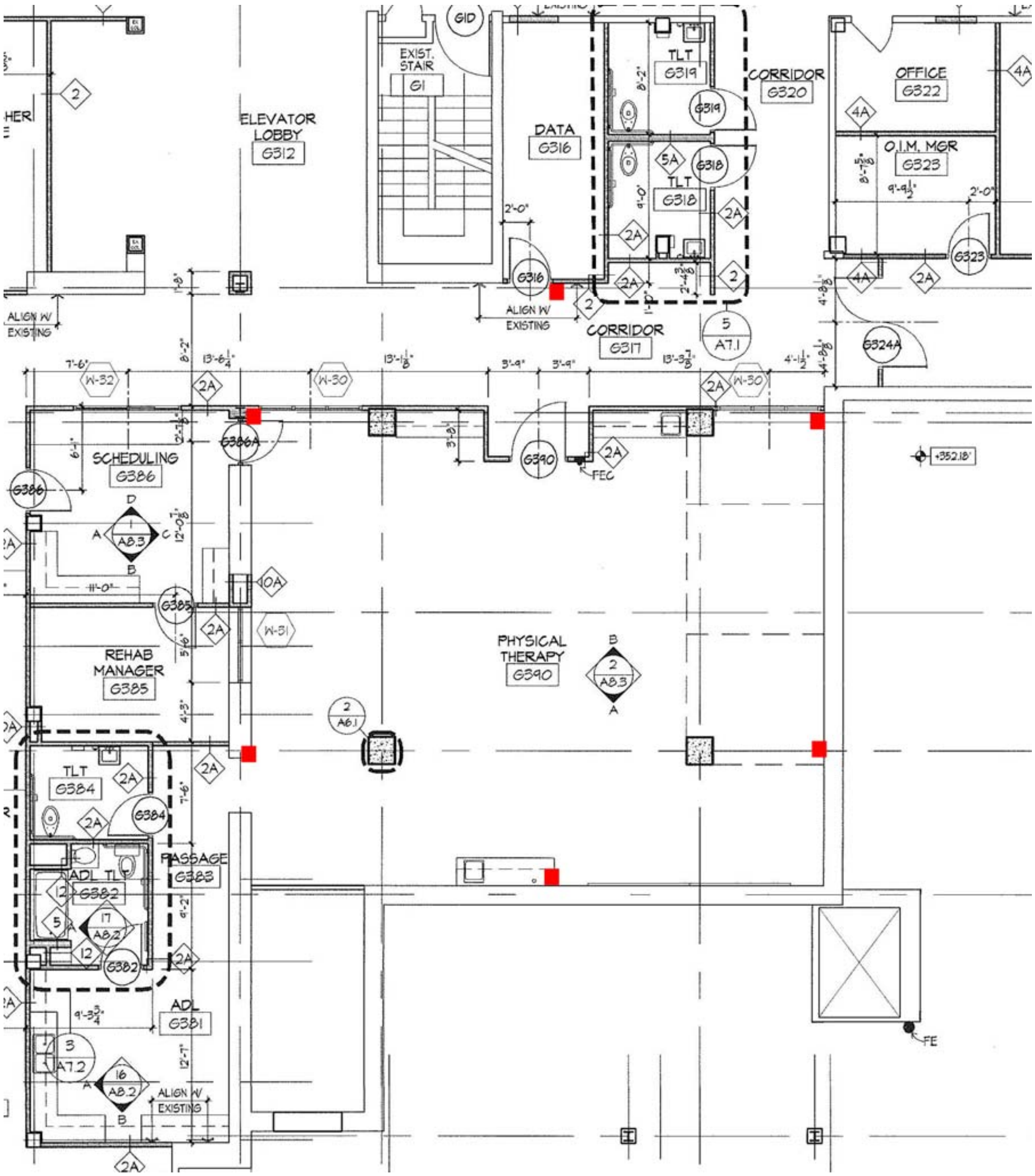



Figure 8: Third Floor Plan

## *Cost Implications*

The cost of the proposed design is significantly different from the existing design. The proposed structural steel design is roughly half as much as the existing cast-in-place concrete design. There are various factors that contribute to this difference. Cast-in-place concrete is a very labor intensive form of construction, requiring a lot of man hours. Whereas, steel does not require as many workers so there is less labor cost. Additionally, a steel structure can be erected faster, resulting in savings from less crane time, as well as savings from less general conditions time. General conditions savings are based of the general conditions estimate and can be found in appendix C. There is the possibility that the steel structure will cost more because of the need for some moment connections, which cost more than simple shear connections. Table 1 below shows the cost breakdown for the cast-in-place concrete structure, derived from the initial structural estimate. Table 2 below shows the cost breakdown for the steel and concrete slab on metal deck, derived from the MC$^2$ estimate of the structural steel system found in appendix D.

| Phase | CSI | Description | Quantity | | Unit Price | | Cost |
|---|---|---|---|---|---|---|---|
| Foundation | 3110 | Formwork for Spread Footings | 623 | SF | 7.15 | /SF | $4,454 |
| | 3210 | Rebar for Spread Footings | 2 | Tons | 1800 | /Tons | $3,600 |
| | 3310 | Concrete for Spread Footings, 5000 PSI | 87 | CY | 123.5 | /CY | $10,745 |
| Superstructure | 3110 | Plywood Forming System for Columns | 1330 | SF | 7.7 | /SF | $10,241 |
| | 3110 | Plywood Forming System for 2-Way Flat Plate with Drops | 8712 | SF | 10.45 | /SF | $91,040 |
| | 3150 | Shoring System for 2-Way Flat Plate with Drops | 7480 | SF | 1.02 | /SF | $7,630 |
| | 3210 | Reinforcing Steel for 2-Way Flat Plate with Drops | 25 | Tons | 1625 | /Tons | $40,625 |
| | 3210 | Reinforcing Steel for Columns | 4 | Tons | 2200 | /Tons | $8,800 |
| | 3310 | 5000 PSI Placed with Crane, for Flat Plates and Columns | 252 | CY | 137.5 | /CY | $34,650 |
| | 3350 | Machine Trowel Finish 2-Way Flat Plates | 7480 | SF | 0.7 | /SF | $5,236 |
| | | Location Modifier - Hagerstown | | | 0.89 | | -$23,872 |
| | | Estimate Total | | | | | $193,149 |

Table 1: C-I-P Cost Breakdown

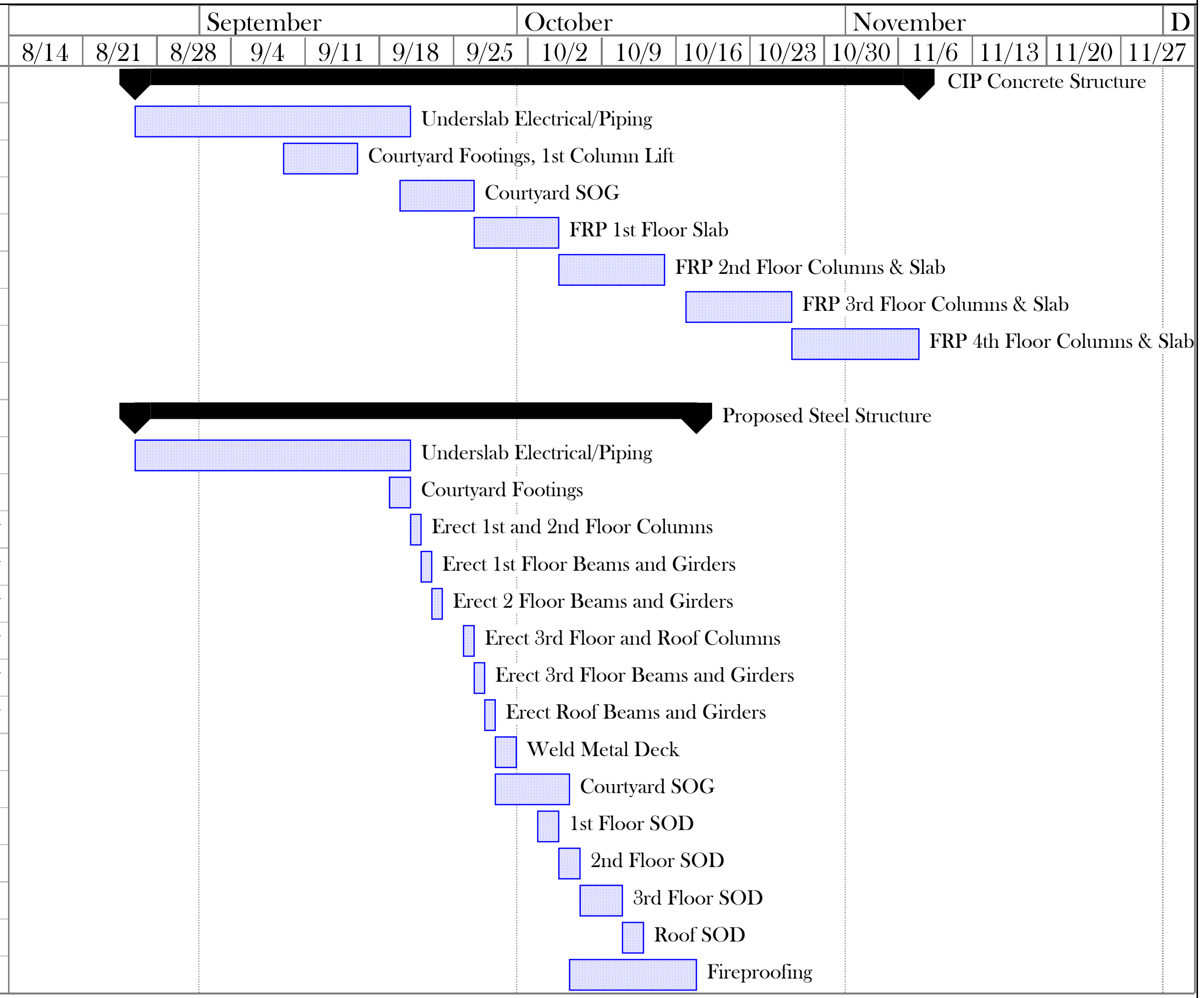
| Phase | CSI | Description | Quantity | | Unit Price | | Cost |
|---|---|---|---|---|---|---|---|
| Foundation | 3210 | Rebar for Column Footings | 4.14 | CWT | 58.5 | /CWT | $242 |
| | 3310 | Concrete for Column Footings, 3000 PSI | 8.33 | CY | 68.1 | /CY | $568 |
| Superstructure | 3320 | 6x6 W1.4/W1.4 Mesh in SOD | 73.92 | SQS | 27.1 | /SQS | $2,001 |
| | 3311 | Concrete for SOD | 82.96 | CY | 72.9 | /CY | $6,046 |
| | 3350 | Machine Trowel Finish | 6720 | SF | 0.33 | /SF | $2,220 |
| | 5129 | 3/4" Shear Studs | 522 | EA | 1.56 | /EA | $814 |
| | 5129 | Steel I Beams | 140 | CWT | 68.73 | /CWT | $9,622 |
| | 5129 | Steel I Girders | 94.1 | CWT | 68.73 | /CWT | $6,466 |
| | 5129 | Steel I Columns | 87.1 | CWT | 68.73 | /CWT | $5,988 |
| | 5310 | 2" USD Lok Floor Deck | 6720 | SF | 1.3 | /SF | $8,836 |
| | 7810 | Cementitious Fireproofing | 2606 | BDFT | 45 | /BDFT | $118,143 |
| | | Decrease in Crane Time (15 days per schedule) | 15 | DAY | 1513 | /DAY | -$22,695 |
| | | Less General Conditions | 2 | WK | 12837 | /WK | -$25,674 |
| | | Location Modifier - Hagerstown | | | 0.89 | | -$15,208 |
| | | Estimate Total | | | | | $97,369 |

Table 2: Structural Steel Cost Breakdown

## *Schedule Implications*

There is a significant difference in the schedule for the existing cast-in-place concrete structure design, and the proposed steel structure design. The courtyard infill structure takes 3 weeks (15 days) less to construct as structural steel with slab on metal deck rather than cast-in-place concrete. The main reason for this difference in construction times is because of the discrepancy in production rates between cast-in-place and structural steel. Steel can be erected very rapidly, whereas it takes a lot of time to erect formwork and shore concrete slabs. Because of the need for moment connections which take longer to construct, the schedule could possibly be increased with the steel structure. The schedule for the steel structure would be even faster if it were not for the need to fireproof the steel. This activity is very time consuming, and is not needed for a concrete structure. The schedule on the following page shows a schedule comparing the construction of the cast-in-place structure construction with the proposed structural steel courtyard infill.

| ID | Task Name | Duration |
|---|---|---|
| 1 | CIP Concrete Structure | 52 days |
| 2 | Underslab Electrical/Piping | 18 days |
| 3 | Courtyard Footings, 1st Column Lift | 5 days |
| 4 | Courtyard SOG | 5 days |
| 5 | FRP 1st Floor Slab | 6 days |
| 6 | FRP 2nd Floor Columns & Slab | 8 days |
| 7 | FRP 3rd Floor Columns & Slab | 8 days |
| 8 | FRP 4th Floor Columns & Slab | 8 days |
| 9 | | |
| 10 | Proposed Steel Structure | 37 days |
| 11 | Underslab Electrical/Piping | 18 days |
| 12 | Courtyard Footings | 2 days |
| 13 | Erect 1st and 2nd Floor Columns | 1 day |
| 14 | Erect 1st Floor Beams and Girders | 1 day |
| 15 | Erect 2 Floor Beams and Girders | 1 day |
| 16 | Erect 3rd Floor and Roof Columns | 1 day |
| 17 | Erect 3rd Floor Beams and Girders | 1 day |
| 18 | Erect Roof Beams and Girders | 1 day |
| 19 | Weld Metal Deck | 2 days |
| 20 | Courtyard SOG | 5 days |
| 21 | 1st Floor SOD | 2 days |
| 22 | 2nd Floor SOD | 2 days |
| 23 | 3rd Floor SOD | 2 days |
| 24 | Roof SOD | 2 days |
| 25 | Fireproofing | 8 days |



## *Conclusion*

The proposed structural steel courtyard infill construction provides a lot of advantages and disadvantages over the existing design of cast-in-place concrete. In terms of cost and schedule the structural steel is cheaper and faster than cast-in-place concrete. Unfortunately, the structural steel floor construction is 8" thicker than the existing floor design. Additionally the structural steel requires fireproofing whereas the concrete does not. A last advantage is that the structural steel design eliminates the need for columns in the interior of the courtyard infill, although some of the corridors are narrowed at spots. Weighing the advantages and the disadvantages, the proposed structural steel design is the superior system when compared to the existing cast-in-place concrete design.