School of Engineering and Applied Science Building

Miami University, Oxford, OH

Thesis Proposal

December 18, 2007

Jonathan Kirk

AE 481W – Senior Thesis

The Pennsylvania State University

Faculty Advisor: Dr. Andres Lepage

Table of Contents

Executive Summary

Miami (OH) University's School of Engineering and Applied Science Building consists of four stories above grade, three of which are designated for classrooms and labs for students, as well as faculty offices. The fourth floor is a mechanical penthouse floor under a mansard roof which houses the building's main HVAC equipment. The building also has three levels of below-grade parking. The new building connects to the existing Benton Hall by way of a skywalk at the 2nd through 4th floor. The architectural voice of the new building is largely based upon the aesthetic concepts of Benton Hall.

The structure's gravity load system uses a steel frame with composite concrete floor slabs on steel columns. Lateral loads are resisted with steel moment frames in the longitudinal (east-west) direction and concentrically braced steel frames in the transverse (north-south) direction.

Based on previous research, it was found that the composite floor system may not be the best possible floor system for economic and scheduling reasons. The structural depth of this thesis will propose to redesign the building's floor system to be a precast hollowcore plank floor bearing on steel angles that are welded to supporting steel beams. The structure's basic lateral resisting system will remained unchanged in design, but members will need to be resized based on new seismic loads. Moving to a totally prefabricated structure where both the steel beams and hollowcore floor planks are fabricated and manufactured at plants, shipped in, and are quickly and easily erected on site. This can lead to a shorter construction schedule and decreased field labor costs.

As the first breadth topic, a precast architectural insulated wall panel system will be designed to replace the building's current enclosure system that uses steel stud walls with a face brick façade. This will also shorten the construction schedule by enclosing the building faster, allowing other trades to begin their work sooner. The second breadth topic will investigate the proposed changes' impact on various construction management issues. Detailed cost and schedule comparisons will be made between the proposed precast/prefabricated systems against the building's current structure and building enclosures.

Existing Structural System

- ## Foundation

The lower level of the parking garage is a 5" slab on grade with a minimum 28-day compressive strength of 4500 psi, over 6" of granular subbase. It is reinforced with WWF 6x6 – W4.0xW4.0 wire mesh. The concrete columns, which carry the load from the main building above are supported by spread footings which range in size from 4'-0"x4'-0"x24" reinforced with (7)#5 bars each way to 9'-0"x9'-0"x42" reinforced with (15)#8 bars each way. The garage walls around the exterior are supported by 2'-0"x2'0" footings reinforced with (3)#9 top and bottom steel, while the wall footing running through the center of the garage is only 1'6" deep and reinforced with (2)#7 bottom bars. The School of Engineering and Applied Science Building's entrance plaza is a slab on grade with a minimum 28 day compressive strength of 4000 psi which varies by location from 5" thick reinforced with WWF 6x6 W4.0xW4.0 to 9" thick reinforced with #5 bottom bars at 12" O.C. and top WWF 6x6 W4.0xW4.0. The plaza is supported by drilled piers that range in size from 36" diameter, 12'-8" deep, to 60" diameter, 17'-4" deep. Grade beams run between the drilled piers and are typically 2'-0"x2'0". All footings, piers, and grade beams have a minimum concrete strength of 5000 psi.

- ## Floor System
  - ### Upper Floors

The first, second and mechanical floor of the School of Engineering and Applied Science Building utilizes a composite floor system with a typical concrete slab of 3½" on 3" 18 gage composite metal deck with normal weight concrete of minimum 28-day strength of 4000 psi, and is reinforced with WWF 6x6 W2.9xW2.9. A framing plan can be found in the appendix of this proposal. The most typical bay is 30'-0"x30'-0" where the deck spans over (3) 10' spans on W16x26 beams with (26) ¾" diameter, 5" headed shear studs, and are cambered 1½". The beams frame into W21x83 girders at third-points, which have (40) shear studs of equal dimensions, and are not typically cambered. Girders in areas with larger tributary areas, in the north side of the building are W24x84's. These girders are also part of the lateral resisting system in the East-West direction and are supported with partially restrained moment connections at the columns. The roof is a mansard roof around the perimeter, sloping at a 12-12 pitch until it flattens off through the central part of the building. The roof does not have a concrete slab, and is built of 4" rigid insulation on 1½" 20 gage wide rib roof deck, which spans on wide flange beams which are typically W8x10 on the pitched part of the roof, and are W10x12 or W12x16 in the central, flat area. The beams frame into girders which are generally W18x55.

Garage

The middle and the upper levels of the garage, as well as the ground floor of the main building are comprised of a 2-way reinforced concrete slab with a minimum 28-day compressive strength of 5000 psi. The bay layout generally follows that of the columns above, typically 30’-0”x30’-0”, from the main building to avoid the need for transfer slabs and girders. The middle and upper levels of the garage use a 9” flat slab with 10’-0”x10’-0”x8” drop panels at the columns. At the east end of the upper level, the slab turns into a 10” flat slab, and continues to turn into a 12” flat slab at ground floor, particularly on the northern half of the building. This is due to the fact that the live load on the ground floor is higher than anywhere else throughout the main building or garage. There are (3) transfer beams in this northern section of the main floor spanning north to south where the garage column layout doesn’t exactly match that of the upper floors, which are 50” deep and are 36” or 48” wide. At the easternmost end of the building, there is a small section of slab where it is thickened to 14” to carry the some masonry walls.

Columns

Upper Floors

Columns supporting the first floor through the roof are rolled W12 shapes with a yield strength of 50 ksi. Most of the columns contribute to the moment frame in the East-West direction, which range in size from W12x40 to W12x136. Where the columns continue all the way to the main roof through the mechanical floor, they are spliced just above the mechanical floor level. The base plates of gravity columns typically 1¼” – 1½” thick on 2” of non-shrink grout, with (4) anchor bolts embedded 16” into the ground floor concrete, and are assumed to act as pin connections. Columns acting as part of the moment frames or the vertical braces have heavier 2” – 2¼” thick, much larger in area so that the anchor bolts can be placed outside of the columns’ projected area, unlike the gravity columns, and are assumed to act as fixed connections.

Garage

The concrete columns in the garage are typically 24”x24”, and have specified concrete strengths of either 4500 psi or 5000 psi depending on the location, and hence load, on the column. Reinforcement in the columns varies from (4)#11 bars to (12)#11 bars and splice at the middle level of the garage. The number of dowels at the base of the columns follows the number of reinforcement bars in the column, and are embedded to the bottom of the spread footing and hooked, creating a fixed connection.

- ## Lateral Resistance System
  - ### North-South Direction

The lateral system in the transverse (short) direction of the building consists of four (4) single bay concentrically braced steel frames from the ground floor to the mechanical floor, of roughly the same size. There is only one cross brace at each of the three levels of the brace, sloping up from south-to-north, and are made of steel tubing, ranging in size from HSS8x8x¼ to HSS10x10x½. Elevations of each braced frame and their locations on plan can be found in the appendix of this report. Additionally, there are two (2) single-span moment frames that support the skywalk that connects the west end of the School of Engineering and Applied Science Building to Benton Hall. At the eastern end of the building, there is also a moment frame with wide flange columns and HSS20x12x5/8 steel tube beams beside the stairwell. For lateral resistance from the mechanical floor to the roof, the mansard roof around the perimeter braces the roof, but is helped by four (4) single-span moment frames, which frame into the columns' weak bending axes.

  - ### East-West Direction

The longitudinal (long) direction of the building utilizes an ordinary moment frame system, comprised of a total of eight (8) frames. There are four (4) full height moment frames that run from the ground floor all the way to the roof in the southern half of the building. The remaining four (4) frames in the northern half of the building are only two (2) stories tall, and stop at the low roof where the building steps back at the second floor level. Refer to the framing plans in the appendix for the locations of each frame. The moment frames use a partially restrained moment connection that has plates bolted to the flanges, which then are welded with full-penetration welds into the columns supporting the beams.

  - ### Garage

There are three levels of below grade parking, mostly of which is directly beneath the main building. However, the northern end of the garage is below the exterior terrace in the rear of the building, where the grading drops down to approximately one level below the ground floor. This causes the weight of the ground floor to induce seismic forces, which are then transferred to the foundation through the exterior walls of the garage, which all act as shear walls. The walls range in thickness from 8" to 14" depending on their location. This report is focused primarily on the lateral resisting system above ground level, so the shear walls will have to be analyzed more carefully in upcoming reports.

Problem Statement

A floor structure must be designed for the School of Engineering and Applied Science building to resist all dead loads, equipment loads, and a live load of 100 psf for the laboratories, classrooms, and office spaces. The current composite floor slab performs well given the design criteria, but may not be the most economical solution given the labor intensive process of pouring concrete floor slabs. Based on research from the second technical assignment, it was determined that precast hollowcore floor planks provide a number of advantages with few disadvantages over the current system. The thesis research performed in the upcoming semester will further investigate the feasibility and various impacts on the rest of the project that using a precast floor system will have on the redesigned building.

Proposed Solution

As an alternative to the composite floor slab system currently used in the School of Engineering and Applied Science building, a precast concrete hollowcore floor system will be designed. The planks will be supported by steel beams spanning the east-west (longitudinal) direction of the building. When hollowcore plank is used in steel framed buildings, the plank typically bears on the top flange of the beam, which creates a very thick floor sandwich. In an effort to minimize the depth of the floor system, the plank will bear on steel angles which are welded to the web of the supporting beam, so that the top of the plank is flush with the top of the supporting beam, as shown in the figure on the following page. A 2" concrete topping is then poured on top of the plank, which can be made thinner at midspan of the planks, so that the inherent camber to the plank can be hidden, effectively leveling the floor.

Based on preliminary research, the hollowcore floor plank will need to be 10" deep to resist the 100 psf live load over the typical 30' spans. The layout of steel framing elements will remain unchanged from the current layout, so that there are no architectural space planning changes. This includes maintaining the floor to floor height of the main floors at 14'-8". The new floor system will add additional dead weight to the building, which will require that seismic forces be recalculated based on the new building weight. The additional weight and seismic forces will require that steel beam and column sizes are redesigned, but overall depth of most steel beams should not change drastically.

Solution Method

Building dead loads will be calculated based on existing project specifications, while live and lateral loads will be determined using ASCE 7-05. Since the cross section of hollowcore floor planks vary from one precast plant to another, an arbitrary manufacturer's section properties will be used to design the plank, in accordance with ACI 318-05 and the 4th edition of the PCI Design Handbook.

An ETABS computer model will be developed to find loads and stresses in individual framing elements. Wind and seismic loads can manually input into the model to evaluate distribution to lateral framing elements, as well as to compute accurate story drifts. Once the load in all beams, columns, and lateral braces are determined, hand calculations will be done to size the applicable members.

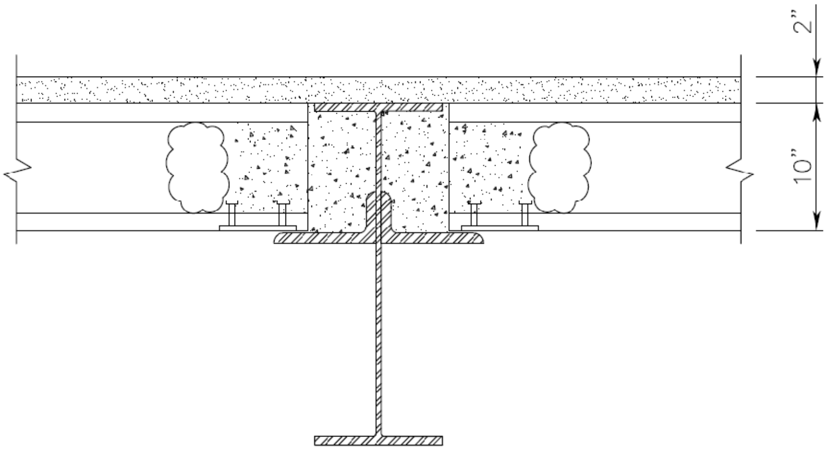
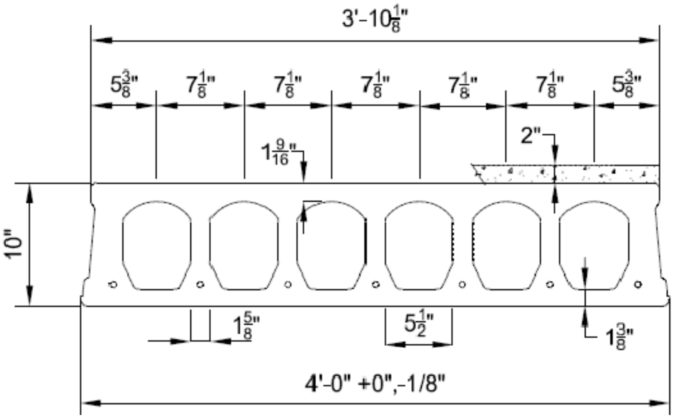


Diagram of proposed hollowcore plank bearing on steel angles



Cross section of 10" ECHO hollowcore plank system produced by Nitterhouse Concrete Products, Inc.

Breadth Options

Since the main focus of this thesis will be redesigning the floor to a precast solution to speed the construction process, it lends itself well to a couple breadth topics with similar goals. A precast wall panel option will be considered as a building enclosure breadth, and the impact of the precast floor and wall systems will be covered as a construction management breadth.

Precast architectural wall panels offer a number of advantages over the current face brick on steel stud wall system. Construction time will be decreased significantly, offering the benefit of decreased labor cost and faster enclosure of the building. Other trades will be able to begin their work on the project much sooner, and hence allow faster completion of the building. The overall look of the façade will not need to be altered significantly, since wall panels with a “thin brick” face are easily produced in a precast plant. These insulated wall panels are sometimes referred to as sandwich panels, since they are essentially made with a layer of rigid insulation sandwiched between two concrete wythes.

A construction management breadth is a necessity for this thesis, since the main goal of switching to precast building element is for faster erection and increased economy. An in depth study of the new construction timeline and erection sequence will be performed to analyze the impact of the proposed changes. Also, detailed cost estimation takeoffs will need to be calculated to evaluate the cost savings or increase of the new systems.

Tasks and Tools

Structural

1A: Determine superimposed loads

  a) Determine dead loads based on construction documents
  b) Determine live loads based on ASCE 7-05

1B: Determine trial member sizes

  a) Size hollowcore floor plank based on ACI 318-05 and 4th edition of the PCI Design Manual
  b) Size trial steel beams and columns for gravity loading based on the 13th edition of AISC's Manual for Steel Construction
  c) Design steel angles and welds that plank bear on based on the 13th edition of AISC's Manual for Steel Construction

1C: Analyze lateral system

  a) Calculate wind and seismic loads based on ASCE 7-05
  b) Create ETABS model of building to analyze distribution of lateral load to individual framing elements

1D: Design lateral system

  a) Use results from ETABS model to determine controlling load combinations for design of lateral resisting elements
  b) Size beams, columns, and lateral braces used to resist lateral loads
  c) Check lateral deflections for compliance against code limitations and redesign members if necessary

1E: Refine structural design

  a) Recheck loads on individual members and redesign if necessary
  b) Design both shear and moment connections of steel beams against gravity and lateral loads based on the 13th edition of AISC's Manual for Steel Construction

Building Enclosures Breadth

2A: Perform preliminary research

  a) Investigate current system and analyze its thermal and durability performance, as well as constructability issues

- b) Research precast insulated wall panels and compare their performance to existing system

2B: Design wall panels

- a) Determine trial sizes based on building and window layout
- b) Design panel reinforcing and prestressing to withstand both handling/shipping and in-service loading conditions based on the 4th edition of the PCI Design Handbook

2C: Design details

- a) Design connections of wall panels to each floor and to each other
- b) Determine impact on supporting foundations and garage shear walls

Construction Management Breadth

3A: Compare construction schedule of existing and proposed systems

- a) Research construction sequencing of existing system and construct a schedule of trades relating to the structure and building façade work
- b) Perform a similar analysis of proposed precast systems and compare time saved against existing systems

3B: Compare costs of existing and proposed systems using RS Means Building Construction Cost Data

- a) Perform detailed takeoff of existing composite floor slab system and the face brick façade backed by steel studs
- b) Perform detailed takeoff of proposed precast hollowcore floor system and precast architectural wall panels and compare results to existing system

Miscellaneous

4A: Prepare final report

- a) Bring together all final calculations and write analyses and conclusions
- b) Prepare PowerPoint presentation

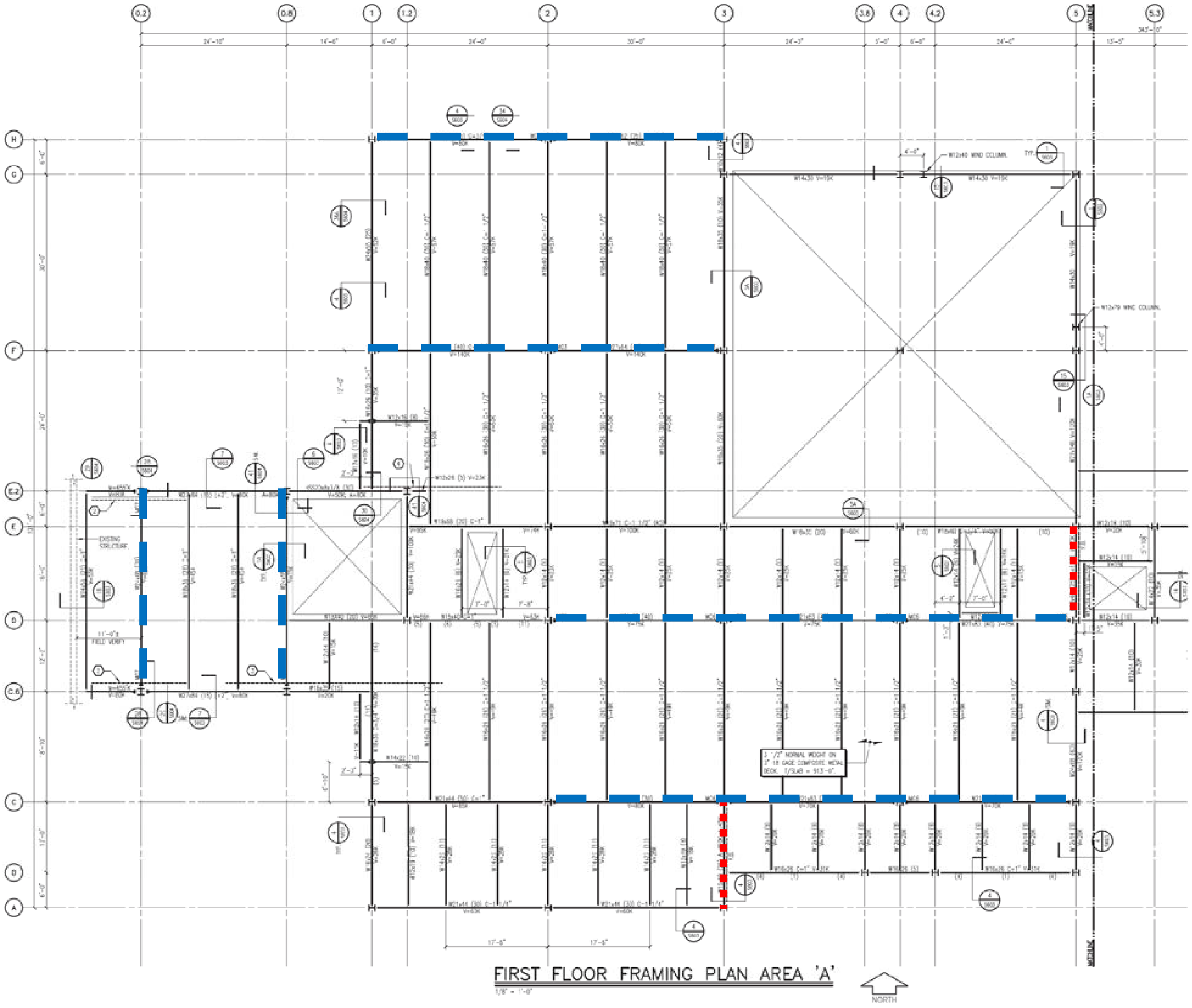
4B: Final preparations

- a) Review and revise final reports and update CPEP website
- b) Practice presentation

Schedule Timeline

Week	Date	Tasks
1	Jan 14 - Jan 18	1A, 1B
2	Jan 21 - Jan 25	1B, 1C
3	Jan 28 - Feb 1	1C
4	Feb 4 - Feb 8	1C, 1D
5	Feb 11 - Feb 15	1D
6	Feb 18 - Feb 22	1E
7	Feb 25 - Feb 29	2A, 2B
8	Mar 3 - Mar 7	2B, 2C
9	Mar 10 - Mar 14	Spring Break
10	Mar 17 - Mar 21	3A, 3B
11	Mar 24 - Mar 28	3A, 3B
12	Mar 31 - Apr 4	4A
13	Apr 7 - Apr 11	4A, 4B
14	Apr 14 - Apr 18	Presentation Week

First Floor Framing Plan – Area 'A' (West half of building)



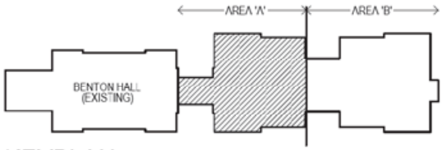
Legend

Braced Frame (red dotted line)

▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪

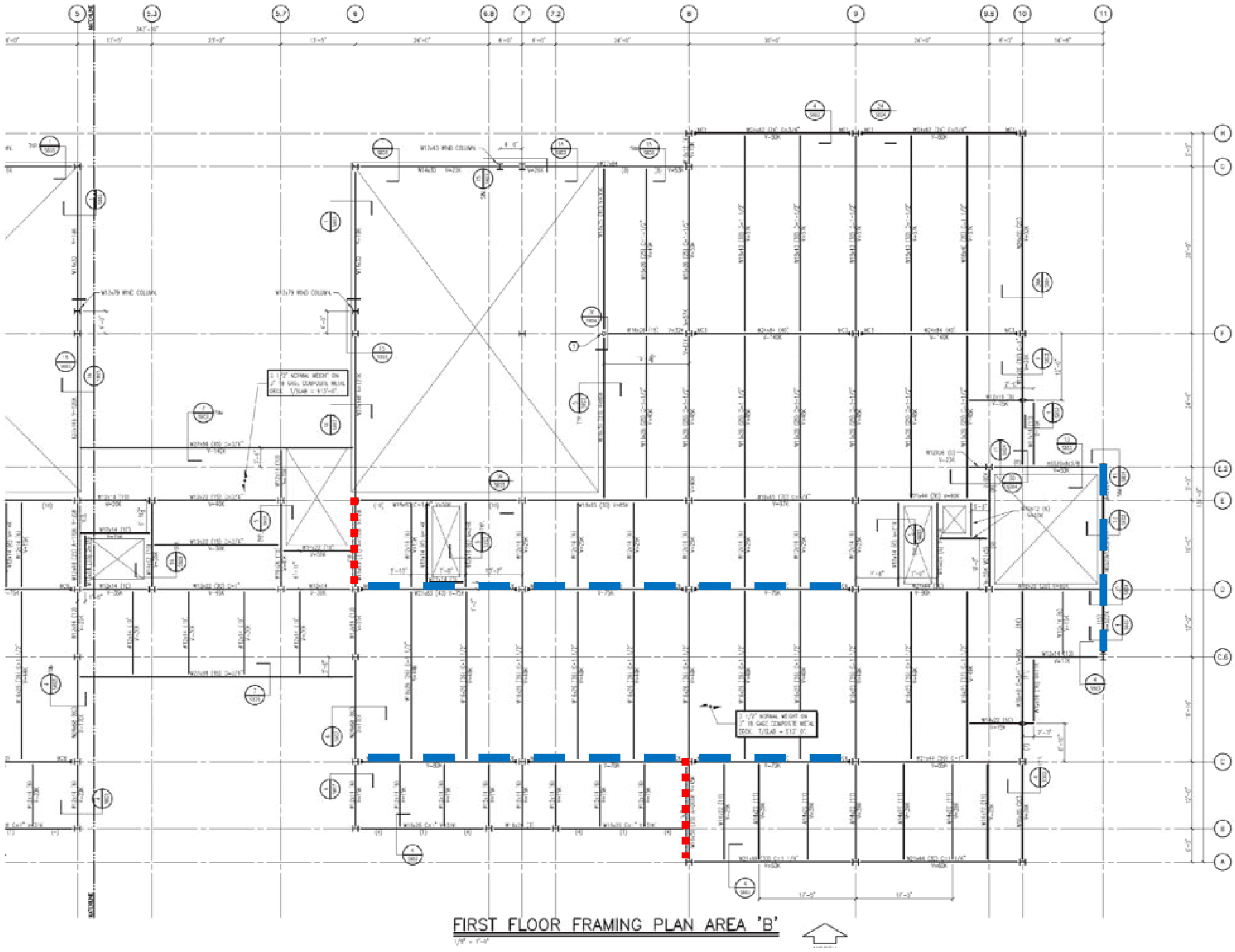
Moment Frame (blue dashed line)

▬ ▬ ▬ ▬ ▬



KEYPLAN

First Floor Framing Plan – Area 'B' (East half of building)



Legend

Braced Frame (red dotted line)

▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪

Moment Frame (blue dashed line)

▬ ▬ ▬ ▬ ▬