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Pro-Con Structural Study for Alternative Floor Systems  
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Executive Summary

This report studies four alternative floor systems for the Agricultural Hall and Annex. Two-way flat plate and two-way flat slabs are eliminated from the start of the design due to the result of heavy systems. Each possible system is evaluated individually in details comparing mentioning both the advantages and disadvantages. Non-composite steel with composite metal deck, composite steel with composite metal deck, and prestress hollow-core are possible options for the current system, one-way joist. However, the waffle slab system is not a viable system.

Original system: One-way joist
- Good for long spans
- Good vibration resistance
- No fire-Protection needed
- Space for electrical and mechanical utilities
- Reduced dead load

Alternative #1 Waffle Flat Slab 30”x30” with voids: 6” Ribs @ 36”
- Expensive
- Slow in erection
- Complicated reinforcement steel
- Low shear capacity
- Heavy system
- More labor

Alternative #2 Non-composite Steel with composite metal deck
- Quick Erection process
- Long spans
- Plenum space
- Economical
Alternative #3 Composite steel with composite metal deck
- Light system
- Economical
- Plenum Space
- Good vibration resistance

Alternative #4 Prestress Hollow-Core
- Long spans
- Short floor depth
- Quick erection
- Space for electrical and mechanical utilities
- Heavy loads
- Fire-Protection
Building Description

The owner of Agricultural building and Annex (Michigan State University) preferred a concrete building. It is about 100’ x 100’ concrete building. It has been designed to be five-story building above grade, but only three floors have been built, a future expansion of two floors with a penthouse will be added. This building is an expansion to an existing building, Agricultural Building which looks like an early 1900’s building. The primary use of the building is for office space.

The use of concrete material was the preference of the owner. This is primary to match the existing building. The flooring system used is cast-in-place one way joist. Also, all other systems such as electrical and mechanical can be placed between the voids.

National Codes and Requirements Used

- BOCA- 1993 for gravity and lateral loads.
- AISC 318-95 for concrete structure and partitions.
- ASD 9th for partitions.
- BOCA 1996 for wind with wind speed = 75 mph and vertical drift = 0.05”.
- ASTM A615 for reinforcing steel, Grade 60
- ASTM A185 for welded wire fabric with minimum of fy = 65 ksi

Overall Structural System

Agricultural building and Annex has cast-in-place flooring system. The flooring system is a one way reinforced concrete joist which has a material strength of 4000 psi. Two types of joists are used for the framing. For the second floor, joists of 30 inches clear span are used. For the rest of the floor, joist of 20 inches clear span is used. The slab thickness varies from floor to another. Slab on grade has slab of 5-6 inches. A slab of 4.5 inches is used for the rest of the floors. Again, the concrete slab strength is 4000 psi. The maximum span form center of column to the next is about 31’. For wind/seismic load distribution, rigid diaphragms, concrete moment frames at each column line in each direction so the force is distributed by reactive stiffness.
Typical Framing Plan

TYPICAL FLOOR

TYPICAL JOIST 1

TYPICAL JOIST 2
Floor Systems

The main purpose of this report is to design four other possible flooring systems in addition to the existing system. Some of the systems such as two-way flat plate and two-way flat slabs with drop panels were eliminated at the beginning due to some factors such as long spans, and two much difference between live load and dead load. An attempt was made to design both systems; however, the absence of beams in the systems resulted in big slab thickness due to the control of shear in design.

All systems will be designed either using the CRSI design hand book (2002) ,RAM software using LRFD, and PCI design handbook. The same dead load (15 psf for superimposed and live load (100 psf) are used for every alternative system to make it possible to compare all flooring systems with each other, and see whether it is possible to use such a system or not. Some of the factors that were taking into account are cost, vibration, loads, spans, fire protection, space of electrical and mechanical utilities, and the weight of the system.
One Way Joist System (Existing System)

The system was believed to be the best flooring system. Using such a system can reduced the total dead load due to the voids and reinforcement. Also, electrical and mechanical utilities can be placed between the voids. Sometimes, vibration is a concern during design; therefore, one-way joist system has a good vibration resistance. When it comes to heavy loads, one-way joist slab can take heavy loads. The only concern with this slab system is that it requires expensive formwork which requires more labor. This might cause slowness in construction. The overall structure cost might be thought of as the formwork and construction time versus material cost. The cost can be reduced by reusing the same formwork thought out the project.

Foundation of the building is always affected by weight of the buildings. In general, concrete buildings require bigger foundation systems than that of steel. Due to the heavy weight of concrete compared to steel, seismic design for most low-rise concrete buildings controls the design. Finally, a one-way joist system satisfies the fire-protection codes for two-hour rating. In other words, there is no need to add additional material to meet the 2-hour fire rating requirements.

**Design Results**

- Slab: 4-1/2” thick with 6x6w5.5xw5.5
- Joist: 36” wide , and 16” deep
  - Width = 6”
  - Rib = 4”
- Girder: 48” wide and 16” + 4.5” deep
- Girder reinforcement:
  - Top bars → 6#10 bars
  - Bottom bars → 4#10 bars + 2
- Joist Reinforcement:
  - Bottom Steel → 1#5 & 1#6
  - Top each end → #5 @ 9”
  - Top Distance end → #5@ 13”
Alternative #1 Waffle Flat Slab 30”x30” with voids: 6” Ribs @ 36”

Waffle flat slab is another option as a floor system having attractive exposed ceiling. The construction of this system allows a great reduction of dead load when compared to other flat slab system. Waffle slab is used for long spans or heavy loads. This eliminates sometimes the use of drop panels or beams. Also, all electrical and mechanical utilities can be accommodated within the system. Waffle slab might be costly if not design the right way.

To obtain maximum cheapest cost, a uniform depth and same size of domes must be used thought the flooring system. Reduction of cost might be obtained by selecting a system that can support the desired loads without using stirrups. The main concern of waffle slab systems is that it requires time to construct. This might lead to the need of more labor which results in more cost.

Also, the reinforcement of waffle slab is kind of complicated. Waffle slab is a heavy system, this leads to a control of seismic load as it is the case of the existing system. Most concrete buildings resist seismic and lateral loads via concrete moment frame. This is mainly via the stiffness created by the columns. Lateral system will not be changed much since concrete moment frame can be obtained in this system. As mentioned above, there is no need to add additional material to meet the 2-hour fire rating protection for concrete systems.

- Design Results
  - Slab: 3”
  - Rib depth = 12”
  - Min. Column = 18” x 18”
  - Reinforcement
    - Column strip (Exterior Panel)
      - Top edge → 25#5 + 2
      - Bottom bars
        - No. of Ribs = 6
        - Bars per Rib → 1#8 + 1#9
        - Top Interior → 28#6
    - Middle strip (Exterior Panel)
      - Top edge → 25#5 + 2
      - Bottom bars
        - No. of Ribs = 6
- Long bars → #6
- Short bars → #7
- Top Interior → 12#6

- Column strip (Interior Panel)
  - Bottom bars
    - No. of Ribs = 6
    - Bars per Rib → 2#7
    - Top Interior → 26#6

- Middle strip (Interior Panel)
  - Bottom bars
    - No. of Ribs = 6
    - Long bars → #6
    - Short bars → #6
  - Top Interior → 11#6
**Alternative #2 Non-composite Steel with composite metal deck**

Another system might be used in designing the floor system is non-composite steel system with composite steel metal deck. Ram software was used to analyze the typical floor system shown above. The metal deck was chosen to be 2 USD 2” Lok-floor, 20 gage. The concrete above the deck is 3 in with studs, which are 4” high having ¾ in diameter. The beam and girders sizes are shown below as a result from the RAM analysis. The lack of non-composite action in the system resulted in heavier members, which might add to the total cost of the building. Also, this might result in unwanted vibration. Adding to the total cost of the building, the beam might need extra cementitious spray to meet 2-hour rating protection code. The erection of steel in general is quick. However, the installation of shear studs might make the process slower since they require installation on site. This might add to the cost of construction. Another good advantage of Steel system is that it allows for longer spans. Due to complete different system, another lateral system must be designed to resist the lateral loads such as shear walls.

- **Design Results**
  - Slab: 3” above deck
  - Deck: USD 2” Lok-floor, 20 gage
  - Stud: 4” with ¾ diameter
  - Beams and girders: noted on drawing
Floor Map

Floor Type: floortyp
**Alternative #3 Composite steel with composite metal deck**

Composite steel with composite metal deck is another viable option as a floor system. The system is designed using RAM software. The metal deck that was chosen for this system was USD 2” Lok-floor, 20 gage, with 3” concrete above it. ¾” studs were chosen for the system with 4 inches high. One of the best things about this system is minimizing the floor depth.

The composite reaction between steel and concrete resulted in lighter members compared to non-composite steel (Alternate#1). The using of light steel results in reduction in steel used in building which might result in reduction in cost. Since the system has a composite behavior, the live load deflection is reduced due to the increase in stiffness.

In general, installing the studs on site reduces the process of steel erection. Other than that, steel can be relatively quick. However, steel projects have greater leading time than that of concrete. Also, cementitious spray will be required to meet the 2-hour rating, with might lead to extra cost. As mentioned above; the lateral system should be changed from the original design due to complete different design of the system.

- **Design Results**
  - Slab: 3” above deck
  - Deck: USD 2” Lok-floor
  - Stud: 4” with ¾ diameter
  - Beams and girders: noted on drawing
Floor Type: typicalflor
Alternative # 4 Prestress Hollow-Core

Due to the long span between columns, prestress hollow-core system is another option for the floor system. The hollow-core section that is shown below is designed based on the PCI Design Handbook, 5th edition. The table in the manual is designed based on the service load instead of the ultimate load. The total load (topped sections) includes 15 psf for superimposed dead load, the rest is live load. The selected section is 58-S which means that the each section has 5 strands with a diameter 8 in 16ths, 1/2”. The S means that the strands are straight. Each section is 4’-0” x 10” with 2” topping (4HC10+2). The concrete that is being used is normal weight concrete having $f'_{c} = 5000$ psi and $f'_{ci} = 3500$ psi.

One of the great advantages of hollow-core is that electrical and mechanical utilities can be place in the hollow space available. In addition, the erection of this system is quick. Due to use the prestress steel, the total depth of floor is reduced, 12” for this system. The lateral system might not be changed much as long as the moment frames are capable in resisting the lateral loads.

There is no need to add spray to meet the 2-hour fire rating, and thus reducing the total cost. However, this system might be the far most expensive especially if it is not available in the area. Also, these sections must be designed with so much careful because corrosion is one of the main problems in the prestress concrete if not installed properly.

Design Results

- Topping: 2”
- Self weight = 93 psf
- $W = 115$ psf
- Depth: 10”
- Load = 115 psf (service load)
- Strands: 5 (Straight)
- Strand Diameter: 8 in 16ths = ½”
- G3 (see typical floor above) = 34” by 20”

Calculations for girder are upon request.
## Systems Comparison:

<table>
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<tr>
<th>Floor System</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Viable Option?</th>
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<tbody>
<tr>
<td>One-way Joist</td>
<td>Reduce dead load</td>
<td>Heavy</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Good for long spans</td>
<td>Slow in erection</td>
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<td></td>
<td>Meet fire protection</td>
<td>Need more labor</td>
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<td></td>
<td>Provides space for utilities</td>
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<td></td>
<td>Good vibration resistance</td>
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<tr>
<td>Waffle Slab</td>
<td>Good for long spans</td>
<td>Expensive formwork</td>
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<tr>
<td></td>
<td>Heavy loads</td>
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<td>Slow erection</td>
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<td>Heavy Members</td>
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<td>with composite metal deck</td>
<td>Long spans</td>
<td>Fire-Protection</td>
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<td>Plenum Space</td>
<td>Stud installation</td>
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<td></td>
<td>Relatively good with vibration</td>
<td>Floor depth</td>
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