Pro-Con Structural Study of Alternate Floor Systems (S-2)

Executive Summary:

For this report alternate floor systems were analyzed for the 250 West Street building in Columbus, Ohio. These included the current composite system, a new composite system with the framing reversed, a non-composite system, steel joists and concrete pan joists. A preliminary design was completed for each floor system and then compared to the others and to the requirements of the building. The building requires that each system be economical, meet the required fire rating on its own, and have a reasonable depth. From the analysis, it was determined that the steel joist system be eliminated predominately because of its fire resistance requirements. The concrete system was also eliminated because of its higher cost even though it is 8 ½ inches more shallow than the current system. The new composite system with the framing reversed and the non-composite system need to be further analyzed as alternatives to the current floor system.

Introduction:

During the study of alternate floor systems for 250 West Street, the first thing determined was the floor systems most appropriate for the building. As a constraint for this investigation, the current column locations were maintained, due to the fact that the exterior columns’ location coincided with the location of the brick columns on the exterior. This helps maintain the integrity of the design that the architect intended. Using this column layout creates bays that are rectangular in shape, ruling out using a two-way system because of the dramatic unequal span distances in each direction. Wood was also ruled out because of the spans and fire protection requirements. This narrowed the floor systems down to one-way steel and concrete systems. As a result, the following floor systems were looked at: composite beams in the north-south direction, non-composite beams in the east-west direction, steel joists, concrete pan joists and the current floor system of composite beams in the east-west direction. To simplify this initial design study, all the floor openings in the central core of the building and the loads the exterior walls transfer onto the spandrel beams were neglected in the design. Each floor was designed
with an 80 psf live load, 20 psf partition load and 20 psf construction live load, 20 psf miscellaneous dead load and the dead load of the building materials with the exception of the original design which used a 50 psf live load. Also for the investigation, lateral loads were neglected even though they have a potential effect on the member sizes. In each case the current steel braced frame lateral system can be used with the exception of the concrete system. For this system, the floor beams would also have to be designed for lateral loads or some type of shear wall to replace the steel braced frames.

**Current Floor System:**

The current floor system uses composite beams and a composite deck frame each floor. Girders span from column to column in the north-south direction and have a size between W12x14 and W27x84 with 5 to 32 shear studs on each girder. The girders then support beams that span in the east-west direction. The beams have a typical size of W21x44 with 18 shear studs in the 40 foot span between lines A & C and D & F, while a W12x14 with 6 shear studs is used in the 18 foot span between lines C & D. The steel framing is then covered with a 3 inch composite deck and 3 ½ inches of lightweight concrete to complete the system. The total assembly brings the depth of the system to 33 ½ inches. Figure 1 on page 8 illustrates this system.

**New Composite Steel Floor System:**

In this system, composite steel beams and a composite deck are also utilized. The difference is the direction of the framing. Between lines A & C and D & C the girders span in the east-west direction with the beams running in the north-south direction. This is the exact opposite of the current framing system. The idea behind this was that even though the span and size of the girders will be increased, the length of the beams will be shortened up to 50% in some places and therefore reduce the size of the beams. The beams between lines C & D remained in
the east-west direction. As a result of this design, the girders are required to have a size between W16x26 with 35 shear studs and W27x84 with 103 shear studs. The beams are sized between a W10x12 with 8 shear studs as the smallest size and a W16x26 with 23 shear studs as the largest shape. Just like the original design, a 3 inch composite deck with 3 ½ inch lightweight concrete was used to meet the required fire separation. The total depth of the system is 33 ½ inches. Figure 2 on page 9 exhibits this system.

**Non-Composite Steel Floor System:**

The non-composite floor system uses girders that span between each column in the north-south direction. Each end of the members was assumed to be simply supported with the exception of the corners of each building. The spandrel beams in the north-south direction in these locations were cantilevered over the columns on lines 2 and 9. The girders range in size from W18x40 in the shortest span and W36x135 in the longest span. The beams then span in the east-west direction with approximately a 40 foot span between column lines A & C and D & F and an 18 foot span between lines C & D. The size of these members range in size from W12x19 to W14x22 in the short span and W21x50 to W24x68 in the long span. To create the floor of the system, the 3 inch composite deck with a 3 ½ inch lightweight concrete topping was used, as used in the original design, bringing the total depth of the system to 42 ½ inches. This system also meets a 2 hour fire resistance with fire proofing of the steel shapes. Figure 3 on page 10 displays this system.

**Steel Joist Floor System:**

The steel joists floor system utilizes steel wide flange members as supports for the steel joists. Wide flange girders span the columns on lines C & D and are also used as spandrel beams along the perimeter of the building. The joists then span in the east-west direction perpendicular to the girders and are spaced at 4 feet on center. An exception, however, is the bays that frame
the offset in the front of the building. Here wide flange girders span from the columns on lines 4, 5, 6 & 7 to the girders running down line D with the steel joists spanning in the north-south direction. This was the most logical solution since the beams in the offset do not have a column to directly frame into at lines 4 & 7. This also allowed for smaller joist sizes in this area. Overall, the wide flange members range in size from W10x12 to W33x118 and the joists from 18LH04 to 28LH09. To create the floor of the system, a 1 ½ inch composite deck with a 3 ½ inch lightweight concrete cover was designed, bringing the total depth of the system to 38 inches. This type of flooring system is very cheap if floor fire separation is not considered partly due to the fact that the materials are used very efficiently in the joist. However, in the case of this building the floor system needs to provide a fire separation rating of at least 2 hours. The floor system alone will not satisfy these requirements without some additional fireproofing. Fireproofing the joists is very difficult to accomplish; therefore, a fire-rated ceiling would have to be installed on each level. This creates a lot of extra costs that do not appear in the structural costs of the system. Fire dampers for the ceiling penetrations are just one example of the many additional costs. Another factor is that the building is designed to be finished once tenants are arranged for the spaces. A temporary ceiling would have to be installed until the tenants determined the final design of the space. One final issue with this type of floor system is that it may have some vibration issues that need to be examined if the system is used. Figure 4 on page 11 demonstrates this system.

**Concrete Pan Joist Floor System:**

The concrete floor system uses pan joists equally spaced in the east-west direction and are supported by girders running between each column in the north-south direction. This system relies on the joists and girders to be equal depths in order to cut down on the formwork costs and make the system more economical. The required slab thickness was first determined to meet the
required fire rating, which turned out to be 5 inches thick for the 2 hour rating. To determine the depth of the rest of the system, the critical joist was looked at. After a few calculations, it was determined a reasonable size and spacing of the joists to be 48 inches on center and an 18 inch projection below the slab. The critical joists are then reinforced with 3 #8 bars in the top and 2 #7’s in the bottom. As a result of this, the critical girders in the center of the building are 48 inches wide with the same 18 inch projection below the slab. They are reinforced with 12 #10’s in the top and 11 #9’s in the bottom. A big reason the girder is so wide is because of the strain requirements the code places on the steel reinforcing. If the girder was narrower, the equivalent stress block in the concrete would be deeper and as a result reduce the strain in the steel below the .005 required by the code. However, if more detailed calculations were performed, the addition of compression steel could possibly reduce the width of the girder. These members are the critical sections and thus have the most reinforcing. Overall, the system has a depth of 25 inches and the appropriate fire rating without the need for additional fire proofing. Figure 5 on page 12 illustrates this system.

**System Comparison:**

Each system has both its positives and negatives. To better understand them, it is important to know the requirements of the floor system. First of all, the system must be economical. The floor system also needs to meet the fire rating that the code specifies on its own. The interior finishes of the building are not currently designed and will not be until tenants are found to occupy the space. If a fire rated floor/ceiling assembly was installed it would have to be modified or replaced once the tenants decide how they want the space finished, thus increasing costs. The assembly itself is also labor intensive since all the penetrations in the ceiling would need to be protected for each light, diffuser, sprinkler head and so on. The depth of the floor system is not really a major issue for this project; therefore the cost of the system is
more important than making it thin. A final requirement is that the system not be susceptible to major vibration issues.

The current system meets all these requirements and is the reason it was used in the building. The new composite system also meets all the requirements and is the same depth as the current system. The non-composite system is deeper than the current system but still meets all the requirements. The steel joist system does not meet the fire rating on its own and would require a fire rated ceiling adding to the costs. It is also possible that it could have some vibration issues. The concrete system also meets all the requirements of the building but is 8 ½ inches shallower than the current system. This, however, comes at an increased cost over the current system. The increase in cost is approximately $314,000 according to the 2002 R.S. Means square foot cost data. Table 1 summarizes each floor system and the requirements of the floor system.

Table 1 - Floor System Comparison

<table>
<thead>
<tr>
<th>Floor System</th>
<th>Depth</th>
<th>Meets Fire Rating (Floor System Only)</th>
<th>Current Lateral System</th>
<th>Structural Only Cost</th>
<th>Significant Addition Non-Structural Cost</th>
<th>Vibration Problems</th>
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</thead>
<tbody>
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<td>Current</td>
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<td>✓</td>
<td>✓</td>
<td>⇑</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Non-Composite</td>
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<td>✓</td>
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<tr>
<td>Steel Joists</td>
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<td>✓</td>
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<td>¶</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Concrete</td>
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<td></td>
<td></td>
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</tbody>
</table>

Conclusion:

After comparing each floor system, some systems may be eliminated from consideration for 250 West Street while others still need some further investigation and are summarized in Table 2. The steel joist system can be eliminated because of its increased depth, fire protection
issues and possible vibration problems. The concrete system can also be eliminated because of its increased costs. The additional costs associated with reducing the floor system depth are not justified for this project even though it is 8 ½ inches shallower than the current system. The rest of the systems need to be further investigated. The new composite floor system needs to be analyzed in order to determine the validity of saved material over the current system and how its costs and schedule compares. The non-composite system is also a viable floor system to the building. The cost and schedule of this system also need to be analyzed, as well as, the impact of using a deeper system on the other building systems.

Table 2 - System Status

<table>
<thead>
<tr>
<th>Floor System</th>
<th>Eliminated</th>
<th>Needs Further Analysis</th>
</tr>
</thead>
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<tr>
<td>Current</td>
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</tr>
<tr>
<td>New Composite</td>
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<tr>
<td>Non-Composite</td>
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</tr>
<tr>
<td>Steel Joists</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>✓</td>
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</tr>
</tbody>
</table>
Floor Type: New Composite

Figure 2 - New Composite Floor System
Floor Map

Floor Type: Non-Composite

Figure 3 - Non-Composite Floor System
Figure 4 - Steel Joist Floor System
Figure 5 - Concrete Floor System