Executive Summary

This report explores multiple structural design alternatives for the Residence Inn by Marriott. The existing system, precast concrete plank on steel, is the basis for comparison with the alternatives. Four alternative systems were explored:

1. Composite steel
2. Form deck on steel
3. Waffle slab concrete
4. Flat plate concrete

Resulting from research contained in this report, it is determined that the composite steel or form deck systems are not better alternatives to the existing system. The two steel alternatives are at best just as good as the existing system. While the composite system is not as deep as the existing system, it is more costly to construct due to increased connections and the addition of shear studs. The form deck system is very similar to the existing system due to similar member sizes and system depth but it requires more fireproofing and labor in connections than the existing system.

The two concrete systems explored, waffle slab and flat plate, both are viable design alternatives to the Residence Inn. Each system is more resistive to lateral loads than the steel systems explored and both are less costly for labor and fire-resistance than the steel options.

The flat plate system has the shallowest system depth of all systems explored, but it is also the heaviest. The waffle slab system is not as heavy has the flat plate system, but it is heavier than the steel systems. The increased weight of the concrete systems over the existing and other steel systems will have to be explored further to determine its affect on foundation design.

Concrete systems are more difficult to construct during inclement weather, especially the cold, which will be of importance to this project since the hotel is located in Connecticut. The effect of weather will have to be examined more to determine its exact effects.
Code Usage for Design and Loading

The design is governed by BOCA 1996 in conjunction with the 1999 Connecticut Supplement. The hotel is classified as a Type 1B structure, requiring a three hour fire rating for all columns, two hour rating for floors and ceiling assemblies and a one hour rating for corridors.

BOCA 1996 requires a superimposed live load of 40 pounds per square foot be applied in hotel guest room areas. Dead loads are approximated based on the material weight of each individual system and a superimposed dead load of 30 pounds per square foot is applied to account for partition, ceiling and MEP applied loads.

Steel systems are designed following LRFD specifications set forth by the Third Edition of the AISC LRFD steel manual and concrete systems follow the ACI 318-02 Code.

All steel members are A992, Fy=50 ksi, and Fy =60 ksi for all reinforcing steel.

Existing System Design and Assumptions

The existing structural floor system design for the Residence Inn is steel framed with an eight inch precast concrete plank slab. Hollow core planks are used in most areas with a ¾ inch gypcrete topping. In the mechanical rooms, solid core planks are used with a two inch concrete topping. Typical beam to column connections are shear connections; moment connections are only used at the cantilevered beams located in the balcony areas.

Assuming a concrete plank similar to SpanDeck made by Nitterhouse Concrete is used, the two hour floor rating for the slab will be met without additional fire proofing. However, beams and columns do require fire proofing to be added, this is achieved by sprayed fibrous fireproofing.

An analysis of a typical bay of this system was performed using RAM Steel for Technical Assignment #1. To obtain a column size for a column subjected to loading from multiple floors, point loads were added to the columns as if the typical bay were on the ninth floor. These loads were found by a column load takedown including appropriate live load reduction governed by BOCA 1996. Superimposed dead load of 30 psf, not including structural system material weight, is applied to account for MEP and partition wall loading. A superimposed live load of 40 psf is applied as per BOCA 1996 specifications.

See Figure 1 below for typical bay design.
Figure 1 – Existing System Typical Bay

**Advantages**
- Quick erection time
- Lighter than concrete systems
- No shoring required
- Less steel to steel connections than alternate steel systems
- Erection in cold weather less problematic than systems with site cast concrete
- Overall system depth fits within allowable range

**Disadvantages**
- Concrete plank and steel lead time could be an issue, requires additional coordination
- Vibration and deflections need further analysis
- High cost for precast concrete planks
- Fireproofing required on beams and columns
Design Alternative #1 – Steel Composite Construction

The first design alternative explores the use of a composite steel framed system. Design was performed using RAM Steel for the same bay on the ninth floor of the hotel. Composite steel systems are typically not as deep as other steel framed systems and are lighter than concrete. Composite systems generally are also lighter than other steel systems.

For the design, the girder and column locations are unchanged. The deck span direction is rotated to the N-S direction from the E-W direction of the existing system.

See Figure 2 below for typical bay design.

Design Assumptions
- 2” USD Lok-floor deck
- 3” light-weight concrete above deck flutes
- $f'_{c} = 3$ ksi
- $\frac{3}{4}''$ $\Phi$ studs, 4 1/2” total length

![Figure 2 – Composite Steel Framed Typical Bay](image-url)
Advantages

- Lighter than concrete and other steel systems
- Shallow steel system
- Less inclement weather sensitive than concrete systems

Disadvantages

- High labor cost in connections and erection
- Vibration effects of lighter system
- Fireproofing required for entire system, sprayed or otherwise
- Shoring required

Design Alternative #2 – Form Deck Steel System

Alternative #2 is designed as a steel framed system with a form deck slab. As with other steel systems analyzed, RAM Steel was used for design. Form deck is similar to the precast concrete plank in that similar beam depths are obtained. However, form deck takes longer to construct than precast plank due to the site cast slab.

As with the composite system, the deck span direction is also rotated to the N-S direction from E-W direction of the existing design. Column and girder locations are also unchanged.

See Figure 3 below for the typical bay design.

Design Assumptions

- 2” form deck, USD UF2X, 2 psf material weight
- 3” NW concrete above deck flutes, $f'_c = 3$ ksi
Figure 3 – Form Deck on Steel Typical Bay

Advantages
- Lighter than concrete systems
- Quicker erection than concrete systems and composite steel (less connection labor)
- No shoring required
- Less inclement weather sensitive than concrete systems
- Meets depth requirement

Disadvantages
- Fireproofing required for all system component
- Deeper than other systems
- More connections and members than the similar precast plank system, may offset cost savings gained by not using precast plank.

Design Alternative #3 – Waffle Slab

Waffle slab concrete construction is a two-way concrete system with joists spanning in both directions creating a ‘waffle’ pattern. The system is built using resuable pan forms with typical sizes being 30”x30” or 19”x19”. The 19”x19” dome size is typical for spans less than 25 feet and it is used here.
To obtain a preliminary design, the 2002 CRSI Design Handbook was used. According to Appendix C of the handbook, even though the design tables are based on ACI 318-99, the 2002 CRSI Handbook does follow ACI 318-02. See Figure 4 below for typical bay design.

See Appendix A for reinforcement design summary.

**Design Assumptions**
- 10” rib, 4 ½” slab, total depth = 14 ½”
- Ribs 24” o.c.
- $f'_c = 4$ ksi
- 19”x19” dome size
- Total factored load rounded from calculated 110 psf to 150 psf to be conservative and use table
- 14’-8” and 21’-9” spans rounded up to 15’ and 22’ respectively for simplicity in CRSI Handbook

![Figure 4- Waffle Slab System](image-url)
Advantages

- Reusable formwork
- Cheap to install, less skilled labor required than steel
- Meets depth requirement
- Vibration not critical
- More laterally resistive than steel systems explored
- Less concrete than other concrete systems
- No fireproofing required

Disadvantages

- Heavier than steel systems
- Shoring required
- Concrete construction heavily effected by weather

Design Alternative #4 – Flat Plate Concrete Without Drop Panels

Flat plate concrete construction is also a two-way system and its defining characteristic is the uniform depth achieved across the entire floor area. Flat plate construction can be done in two ways, with or without drop panels at columns. Drop panels are usually required for spans over 25 feet and/or in heavily loaded conditions; the hotel does not require the inclusion of drop panels.

As with the waffle slab design, the 2002 CRSI Design Handbook was used for preliminary design. According to Appendix C of the handbook, even though the design tables are based on ACI 318-99, the 2002 CRSI Hanbook does follow ACI 318-02. See Figure 5 below for design typical bay design.

See Appendix A for reinforcement design summary.

Design Assumptions

- $f'_c = 3$ ksi
- 8” slab
- 14’-8” and 21’-9” spans rounded up to 15’ and 22’ respectively for simplicity in CRSI Handbook
Figure 5- Flat Plate Concrete

Advantages
- Simple, reusable formwork
- Simple reinforcement layout
- Only 8 inches total depth
- Vibration not critical
- No fireproofing required
- More laterally resistive than steel systems explored

Disadvantages
- Possibly heaviest system analyzed
- Shoring required
- Concrete construction heavily effected by weather
## System Comparison Chart

<table>
<thead>
<tr>
<th>System</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Potential</th>
</tr>
</thead>
</table>
| **Steel with concrete plank** | Quicker than concrete systems  
Lighter than concrete systems  
Meets depth requirement  
Less labor than other steel sys.  
No shoring  
Weather effects erection less | Vibration and deflection  
High cost of plank  
Fireproofing required  
Ineffective resisting lateral loads | Existing |
| **Composite Steel**     | Possibly lightest system  
Shallowest steel system                                                                 | Higher cost than other steel sys.  
More connections than existing  
Fireproofing required  
Shoring required  
Vibration and deflection  
Ineffective resisting lateral loads | No        |
| **Form deck steel**     | Quicker than concrete systems  
Lighter than concrete systems  
Meets depth requirement  
No shoring  
Weather effects erection less | Deeper than concrete systems  
Fireproofing required  
More connections than existing  
Vibration and deflection  
Ineffective resisting lateral loads | No        |
| **Waffle slab**         | Simple formwork, cheap labor  
Meets depth requirement  
Vibration not critical  
No fireproofing required  
More laterally resistive | Heavier than steel systems  
Shoring required  
Difficult to erect in bad weather | Yes        |
| **Flat plate**          | Simple formwork, cheap labor  
Shallowest system analyzed  
No fireproofing required  
More laterally resistive  
Simple reinforcement layout | Possibly heaviest system  
Shoring required  
Difficult to erect in bad weather | Yes        |
Systems Summary

By analyzing several structural systems as design options using the same loading and dimensional characteristics, several conclusions can be made as to which system or systems are best suited as the design solution for the Residence Inn located in Stamford Connecticut.

Specific characteristic areas of focus for each system include: overall cost, system weight, time of construction, constructability issues, total floor system depth and system performance. By determining these characteristics for each system it is possible to see which system or systems are better design solutions for the hotel.

The existing system, steel framed with precast concrete plank, does not appear to be more advantageous than any of the other systems as it is difficult to determine if the shorter time it takes to erect and overall lighter system weight is offset by the negative effects of its lack of resistance to lateral loads and need for fireproofing. However, in comparison to the concrete systems, the existing system has fewer advantages.

The composite steel system is not cost effective for this project due to the high amount of connections and skilled labor required for erection. Composite steel requires more fireproofing than the existing system does because the composite deck would need to be fireproofed while precast concrete plank does not. Despite being the lightest system analyzed, composite steel does not have enough advantages to be considered further.

The steel framed form deck system is very similar to the existing system but has no advantages over the existing system or any of the concrete systems except that its system weight is lower than concrete systems’. Form deck requires less labor to install than composite steel and concrete. Erection is also less affected by weather than it is for concrete systems. However, this system will not be further analyzed since it is very similar to the existing system and in fact less advantageous than the existing system.

The two concrete systems analyzed are very similar to each other. Waffle slab and flat plate are both two way systems, each system is more resistive to lateral loads than the steel systems analyzed, no fireproofing is required to meet fire resistance codes and both systems require less skilled labor than steel systems to construct. The biggest disadvantage of the two concrete systems to the steel alternatives is that they are both considerably heavier. Increased dead load weight could adversely affect the design of the foundation system; it will have to be determined later if the site’s allowable soil pressure is high enough to use spread footings with either of these systems. Regardless, both concrete systems are candidates to be studied further.
Appendix A- CRSI Design of Waffle Slab and Flat Plate Systems
WAFFLE SLAB

- LESS DEAD LOAD THAN STANDARD FLAT PLATE.

- DESIGN - CRC HANDBOOK, 2002 chap 11
  - follows ACI 318-99
  - according to Appendix C. The design tables conform with the 2002 code.

Rib + slab depth = \( 10' + 4\frac{1}{2}' = 14\frac{1}{2}' \)

W 14" x 14" domes

Rib @ 24'

\( f_c = 4'000 \) ksi

\( f_y = 60'000 \) ksi

\( L_u = \frac{1.4(30) + 1.7(40)}{110} = \)

INTERIOR PANEL

- 22' x 22' panel 0.734 CF/15' = conc.

- Round 110 psf to 150 psf
  \( - d = 8.4'' \)

- 12" x 12" column, no stirrups, 2.25 m² = A
  Reinforcement (f.a. way)
  - Column strip
    - 5 ribs
    - 2 #4 bottom / rib
    - 16 #5 - top interior

  - Middle strip
    - 6 ribs
    - Bottom - long #4
    - Short #4
    - Top interior - 7 #5
**EDGE PANEL**

- 22' x 14' (USE 20' x 10') - CONSERVATIVE
  \[ d = 8.417'' \]
- 12'' x 12'' COLUMN, NO STIRUPS, 2.25'' x 2.25''

**REINFORCEMENT (EACH WAY)**

- COLUMN STRIP
  - TOP EDGE: 15 #8
  - BOTTOM: 5 RIBS, 2.14 #4, TOP INTERIOR: 15 #8
- MIDDLE STRIP
  - BOTTOM: 5 RIBS, LONG BARS: #4, SHORT BARS: #4
  - TOP INTERIOR: 6 #8

**Moments**

- \( M_{\text{EDGE}} = 72'' \cdot k \)
- \( M_{\text{BOT}} = 161'' \cdot k \)
- \( M_{\text{INT}} = 145'' \cdot k \)
SOLID FLAT PLATE - NO DROP PANELS
- SINGLE FORMWORK REINFORCING LAYOUT
- CHEAP - LABOR

Wt = 110 psf - FROM WAFFLE DESIGN
- DESIGN CONFORMS TO ACI 318-02 PER APPENDIX C
  - DESIGN CONFORMS TO ACI 318-02 PER APPENDIX C
  - INTR. EDGE
  - ROUND 110 psf TO 150 psf
  - 5" SLAB
  - 0.667 CF/15# CONC.
  - STEEL ~2.74 psf

REINFORCEMENT
- COLUMN STRIP
  - TOP 11 #7
  - BOTTOM 12 #4

- MIDDLE STRIP
  - TOP 11 #4
  - BOTTOM 10 #4

EXTERIOR (E - EXTERIOR)
18' x 22' (USE 20' x 20') - CONSERVATIVE
- 20' x 20' COLUMN
  - 0.667 CF/15# CONC.
  - STEEL ~2.42 psf

REINFORCEMENT
- COLUMN STRIP
  - TOP EXTERIOR = 11 #4
  - BOTTOM = 9 #5
  - TOP INTERIOR = 11 #6
- MIDDLE STRIP
  - TOP 13 #4
  - BOTTOM 9 #4