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Whiteland Village
Exton, PA
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AE 481W

Thesis Proposal
Structural Study of Alternate Lateral Systems

Executive Summary

This report is intended to be a detailed description and preliminary analysis of the structural design of Whiteland Village in Exton, PA. Whiteland Village is a 1,320,000 sq. ft. sprawling retirement community, which is slated for completion by November 2008. The physical components of the first phase of the complex include three 5 story residence buildings, a commons building, and a healthcare facility. The entire footprint has a basement level, which serves as covered parking and utility spaces. The phase one construction will be on the west side of the campus, including U-1 (renamed R-1), U-2 (renamed R-4), and the J building (renamed R-2). The other buildings will go into planning as soon as Whiteland Village becomes profitable, and will be connected with a pedestrian link.

The analysis for this proposal only examines the most current design of the three residence buildings, which were designed by Dever Architects. The current structural system consists of 8" hollow core precast plank, spanning approximately 30' between 10" CMU bearing walls. Lateral loads are resisted by a combination of concrete and masonry shear walls, steel moment frames, and steel braced frames.

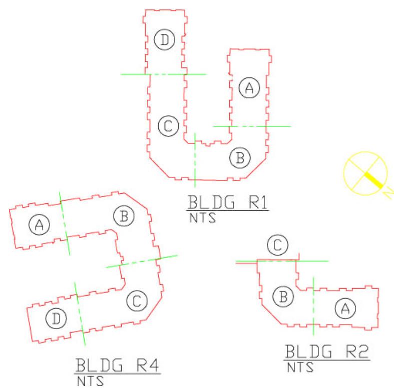
In order to reduce building weight and increase the potential for future renovation, the possibility of changing Whiteland Village to steel frame is being investigated. To determine the feasibility of this proposal, two different lateral systems will be investigated: staggered truss and partially restrained composite connections. A thorough study into the impact these systems would have on the construction management issues of the building is also outlined.

Additionally, the procedure for checking the current building envelopes for potential failures is also detailed. The proposed changes from this would result in a façade and roof that are more durable and economical.

Table of Contents

Building Overview

Whiteland Village is a 1,320,000 sq. ft. sprawling retirement community, which is slated for completion by November 2008. The site is located in Exton, PA, a few miles east of Philadelphia at the intersection of Route 30 and Business 30. The physical components of the first phase of the complex include three 5 story residence buildings, a commons building, and a healthcare facility. The entire footprint has a basement level, which serves as covered parking and utility spaces. The master plan for the site is included in the report as Appendix A. The phase one construction will be on the west side of the campus, including U-1 (renamed R-1), U-2 (renamed R-4), and the J building (renamed R-2). Floor plans for these buildings are included in Appendix B. The other buildings will go into planning as soon as Whiteland Village becomes profitable, and will be connected with a pedestrian link. A sketch of the shape and orientation of the three residences follows.



Due to the size and the location of Whiteland Village, it is being designed to be acceptable to both the West Whiteland Township Building Code, as well as the East Whiteland Township Building Code. Both codes are based on the 2000 International Building Code (IBC), which is published by the International Code Council and heavily reference ASCE 7. In addition, the municipalities have accepted the 1997 Fire Prevention Code, from the National Fire Protection Association (NFPA).

The residence buildings, designed by Dever Architects, were intended to resemble large typical suburban single family homes with the use of mansard roofs covered by fiberglass shingles and a central exhaust system to limit the amount of roof-mounted equipment and roof penetrations. Each condominium includes a balcony or patio.

HLM Design was hired to complete the design of the Commons. Since the design of the Commons building is not yet complete, the focus of this proposal will be on the three residence buildings. The following is a brief synopsis of each of the critical building systems.

Structure

Buildings in Whiteland Village are constructed using 8" hollow core precast plank, typically spanning 30'. The plank is supported by 10" CMU bearing walls and steel, typically W18x31 beams and (2) L6x4x3/4 angles. Lateral loads are resisted by a combination of concrete and masonry shear walls, steel moment frames, and steel braced frames. A more detailed description of the existing structural system is included later in this section.

HVAC

Air circulation occurs in the residences through a central exhaust system using an energy wheel. This allows for the use of recycled energy to condition air before it enters the building, significantly reducing overall heating and cooling costs. Chilled water cooling and gas hot water heating fulfill the complex's heating and cooling needs via a central distribution system.

Electric

Electrical service is 208Y/120V from a single 5kV transformer. Each floor of the residences is regulated by a 1000A distribution panel, which links to individual panels in each condominium. Power for the entire complex is created by an onsite co-generation plant, so Whiteland Village is only on the power grid during off-peak hours, as well as during emergencies requiring backup power.

Fire Protection

Throughout the community, fire protection is provided by a wet sprinkler system. In the residences, a 1000 GPM electric fire pump is used to pressurize the standpipes.

Envelopes

The exterior cladding of the residences consists of manufactured stone and traditional vinyl siding, with fishscale vinyl siding under the roof eaves. Building entrances are detailed using a manufactured store front system. Roofing is comprised of fiberglass shingles on 5/8" plywood supported by cold form steel over-framing. At the center of the building, sloped insulation is used to direct water into roof drains.

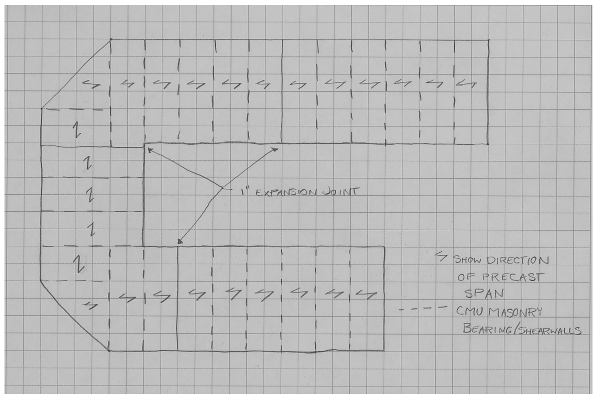
Description of Existing Structural System

All structural systems for Whiteland Village were designed using the Allowable Stress Design (ASD) Method. In the design of Whiteland Village, the American Institute of Steel Construction's (AISC) Manual of Steel Construction was utilized. This is the accepted industry standard for steel construction. The Building Code for Reinforced Concrete published by the American Concrete Institute (ACI), as well as the Precast/Prestressed Concrete Design Handbook (PCI), were referenced during design as industry standards.

Framing and Lateral Load Resistance

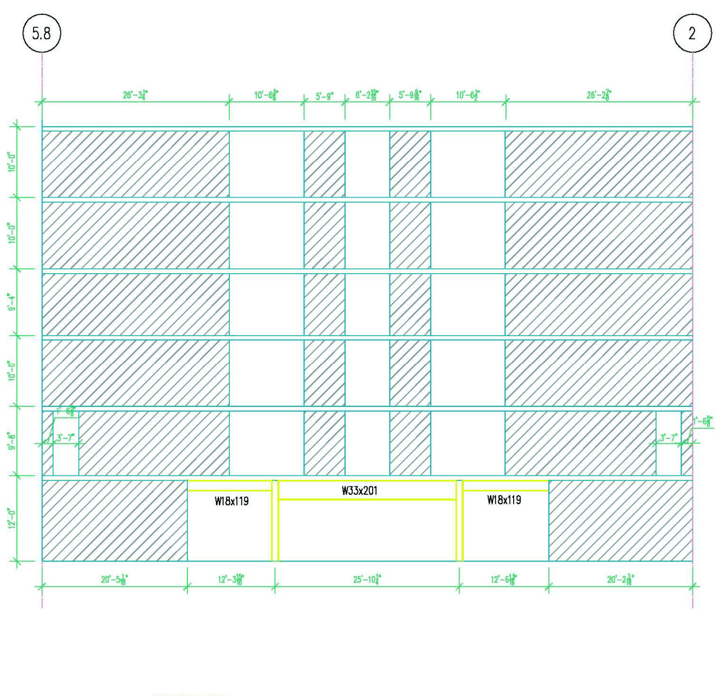
Gravity loads are taken into the overall building structural system by 8" hollow core precast plank spanning approximately 30' at each level. The planks will be designed by the precast contractor to have the required capacity. Both bearing plank ends frame into a 10" CMU wall that runs from the 5th floor ceiling to the 1st floor. These reinforced masonry walls also act as shearwalls for the system, transferring lateral loads from the higher floors to the first floor. PCI 3.6.2 allows for untopped precast plank to be considered as a rigid diaphragm if shear keys are grouted. On this project, all shear keys are grouted solid to ensure shear transfer between planks.

The following is a sketch of the masonry shear walls and plank spans for a typical intermediate floor.



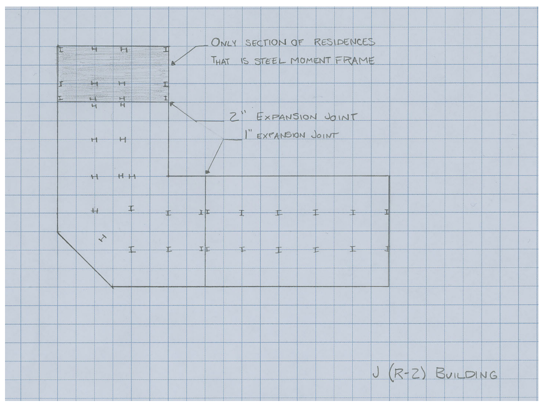
Grade A992 wide flange steel beams are positioned under the 5 story walls to pick up the loads, so the basement can have the open space necessary to allow vehicular traffic. These beams range from a W18x50 to a W36x359, with spans of 7'4" to 30'0".

The typical shear wall, including basement layout, is seen in the sketch below. It consists of two W12x96 columns with a W33x201 spanning between and a W18x119 spanning from the column and bearing on the masonry walls on each side.



At the first floor, lateral loads are redistributed at the first floor to the building perimeter. By doing so, the basement columns are only required to resist gravity loads and axial loads induced by the overturning of the lateral system above. In design, this means the basement columns can be smaller and be attached with simpler pin connections to the first floor framing.

There is one section of the residence buildings which differs from this basic plan. In the J Building (R-2), the first section between the commons (separated with a 2” expansion joint) and the 2” expansion joint within the building footprint is 8” hollow core precast plank, spanning 15’ and 30’. On the top 2 floors, the plank bears on a 12” CMU wall. At the third floor, the precast is supported by a wide flange A992 steel frame. Framing members range from a W30x90 to a W36x194 beam size. To resist lateral loading, the third floor framing is braced with W8x31 knee braces. The second floor has no framing because it is part of a 2 story atrium. At the first floor, the steel framing is connected with moment connections to resist lateral load, ranging in size from W24x49 to W24x131. The location of this section is indicated with shading on the following sketch of the J Building.

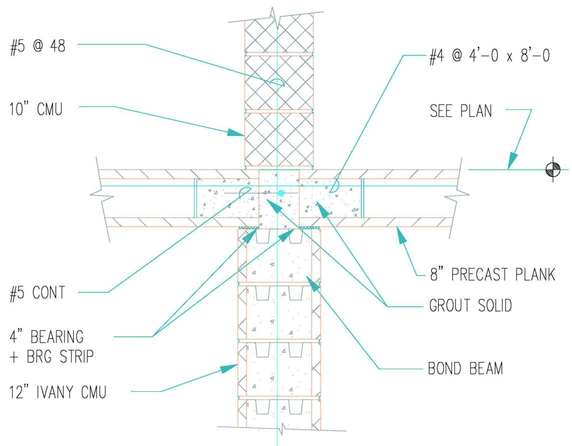


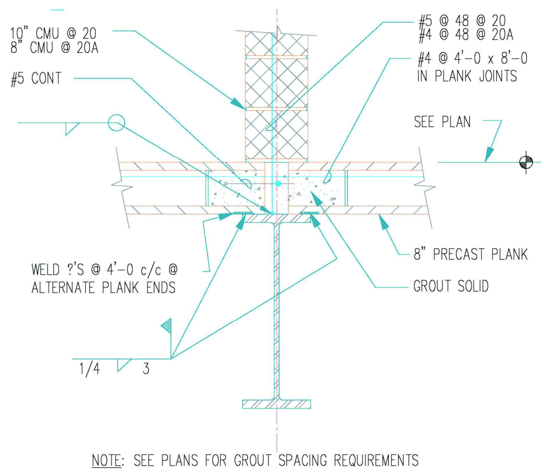
Floor System

The current floor system in Whiteland Village is untopped 8” hollow core precast plank, spanning approximately 30’ and bearing on 10” CMU shear walls. Since the buildings are condominiums, the floor system was designed primarily for the following live loads, as dictated by ASCE 7-02:

- 40 PSF in dwelling areas
- 100 PSF in corridors
- 100 PSF in stairs
- 125 PSF in storage areas

A sketch of the current framing plan and the typical sections detailing the connections used in the current system follow.





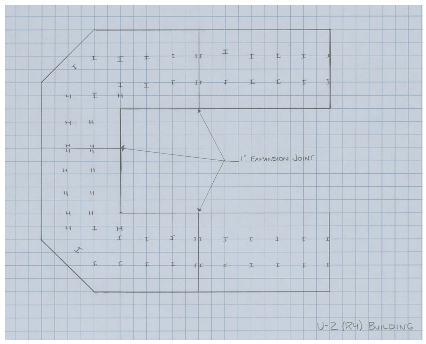
Precast plank has distinct benefits that are easily utilized in the Whiteland Village project. The floor systems are limited to a maximum depth of 1'-8" due to the zoning restriction on height, restricting mean roof height to 65'. In addition to allowing more plenum space for mechanical systems, a shallower floor system allows for higher ceilings in the condominiums. The following are other benefits of this shallow floor system:

- Ready to assemble
- Easily sequenced
- Not impacted by weather
- 1 or 2 hr assembly rating
- Excellent sound attenuation

Foundations

The foundation system of Whiteland Village consists of a 5" slab on grade, reinforced with 6x6 – W2.9xW2.9 welded wire fabric, on top of 4" of drainage fill, with a continuous spread footing around the entire perimeter and under all interior foundation level walls. This spread footing is typically 3' wide when supporting exterior walls, and 6' wide when supporting interior wall sections. Interior columns are supported by spread footings, which range in size from an 8' square to a 12'x19'. The footings are approximately spaced in a 30'x30' grid running through the center of the building. There are thickened slabs below all elevator shafts. The foundation system is very shallow, with the top of the deepest footing only 3'4" below the top of the slab. All reinforced concrete in the foundation is 3000 psi, and is reinforced with 60 ksi rebar. The reinforced CMU exterior foundation walls are designed to withstand 68 PCF of equivalent fluid pressure from the surrounding soil, as dictated by the geotechnical report.

The following is a rough sketch showing the column layout in the U2 building, which is typical for all the residences.



Statement of Problem

One of the major issues with the current structural system is the difficulty of future renovations. The use of shear walls would make changing door or opening locations very challenging, especially considering the numerous openings already detailed. Many condominium owners want to be able to customize their space to make it fit their individual lifestyles. This is nearly impossible with the current structural system. Changing from shear walls to a steel system would significantly increase the flexibility of renovating the condominiums.

The new steel-based lateral system would need to be relatively shallow, less than 1'-8", due to the 65' maximum building height zoning restriction described earlier. However, the new lateral system could potentially be floor to floor where shear walls are currently located. Utilizing a different lateral system could also result in using an alternate floor system. This would also have to meet the floor ceiling envelope requirements previously outlined. Additionally, the floor system would also need to be designed to resist all dead loads, equipment loads, and live loads as outlined in ASCE 7.

Another issue with the current structural system is the weight. Since so many of the walls are 10" CMU and are grouted at less than 48" intervals, the walls and columns in the basement level have to carry significant gravity loads. By switching to an alternative system, the reduced gravity loads would result in a smaller seismic load.

Other considerations relating to changing the nonbearing walls or using an alternate floor system include the following:

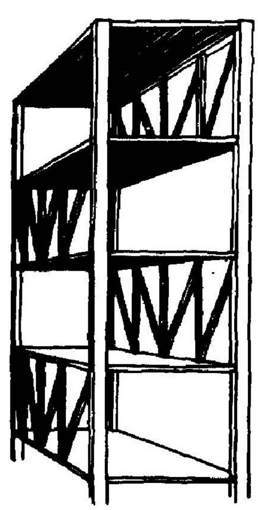
- Constructability
- Sound attenuation
- Vibration
- Fire protection
- Depth and size
- Cost
- Weight
- Impact on architecture

Proposed Alternate Lateral Systems

In order to solve some of the issues discussed above, changing the building to steel seems like a logical switch. Steel would provide more of an opportunity for open framing, making future renovations feasible. Changing to steel would allow alternate lateral resistance systems to be used. The two that will be investigated are staggered truss and partially restrained composite connections. In both cases, a maximum overall structure depth of 1'-8" will be used and columns will be limited to 10" flange widths so that room dimensions are not affected by the change in systems.

Staggered Truss

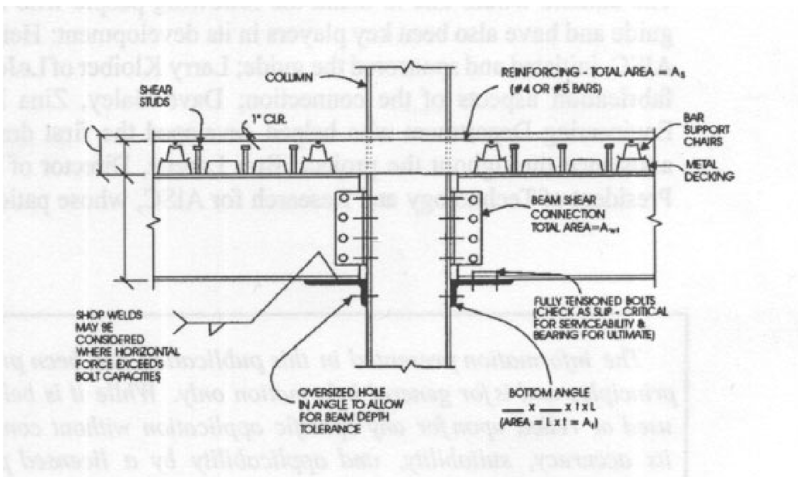
The staggered truss system was developed in the 1960s. The basic elements of the system are full story trusses that span the entire transverse width of the building at alternate floors at every column line. Gravity loads are transferred through the floor diaphragm to the top chord of a truss and the bottom chord of the adjacent truss. It is advantageous in buildings that are long and narrow, because typically the wind loads on the large face of the building are substantial and need to be resisted in the smaller dimension. The following is an example of the framing for a staggered truss system.



The current system shear walls provide an excellent layout for trusses. The floor-to-floor height restrictions will not affect the depth of the beams within the truss; however, allowances for future renovations may dictate revisions to the layout. Additionally, either the existing floor system could be used or the system could change to an alternate, such as composite.

Partially Restrained Composite Connections

Another alternate lateral system is to use a steel frame with a composite slab using Type 3, or partially restrained connections. Partially restrained composite connections (PR-CCs) are flexible moment connections in which the reinforcing in the slab is used to create the top portion of the moment resistant mechanism. In traditional moment connections, this top portion would be an angle or plate on top of the slab. Shear resistance is provided at the bottom of the connection by a steel seat angle. A section of a typical PR-CC is seen below.



Advantages to PR-CCs include:

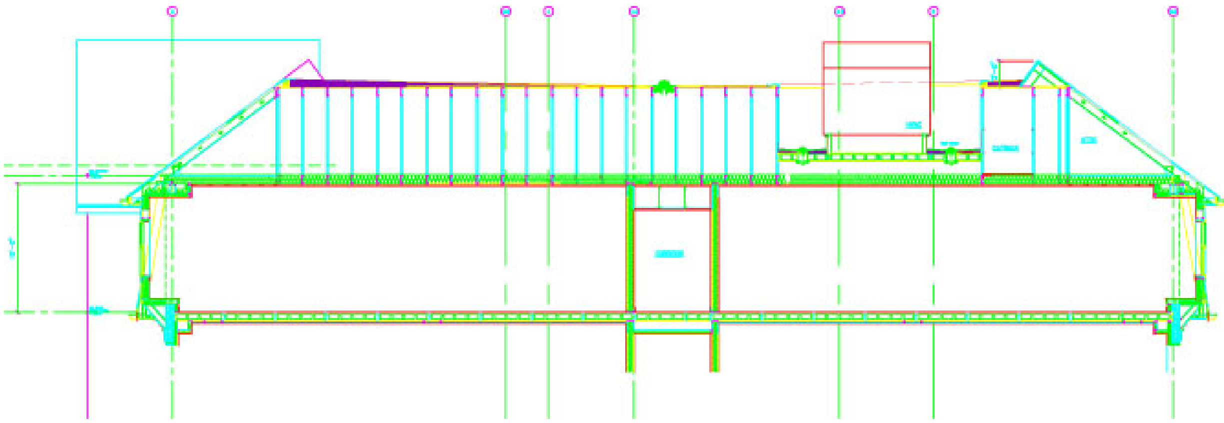
- Eliminate top angle or top plate
- Capacity controlled by amount of steel
- Composite action reduces beam size, deflection, and vibration
- Eliminate need to cut and shore decking around supports

This connection type suits the building well since it is most applicable to buildings less than 10 stories and in an area with low to moderate seismic risk.

Breadth Topics

Such sweeping changes in the structural system will result in significant changes in the constructability of Whiteland Village. In order to gain a better understanding of the impact of the proposed changes, an in-depth study into construction management issues will be conducted. The study will include research in site planning, staging, schedule, and cost analysis.

In addition, an analysis of the current building envelopes in terms of bulk water, moisture and thermal performance will be completed. Both facades and roofing will be investigated, and changes will be proposed based on the findings. This is especially critical at the roof sections where mechanical units are mounted on the roof. To allow for these units, the over-framing is cut into, creating a well in the roof as seen in the section below. There is huge potential for water and moisture failure at the mechanical units with the current drainage and flashing details.



Additionally, it does not appear that the thermal performance of this section has been carefully considered. Although cool roofs are desirable to prevent ice dams, it may not be the most advantageous choice to not insulate the wells, where snow is bound to accumulate.

Solution Method

In order to make the proposed changes, a column layout must first be created. After that is finalized, a preliminary design for the steel will be completed using the ASD method outlined in the AISC Steel Manual. Analysis for gravity loads will be completed using RAM Structural System, a computer program, and verified with hand calculations. Analysis will be done for full live and dead loads.

To design the staggered truss system, the method outlined in AISC Design Guide 14 *Staggered Truss Framing Systems* will be followed. The design will be added to the RAM model and verified for the required lateral loads, as determined by using ASCE 7.

The PR-CCs will be designed using AISC Design Guide 8 *Partially Restrained Composite Connections*. The design loads for each connection will be determined using output from the RAM Structural model.

A cost estimate for each alternate will be produced by using MC^2 ICE 2000 software. That data along with information from RS Means will be used to create a detailed erection sequence and schedule on Primavera software. A construction site plan will also be included for each system.

In order to verify façade and roof conditions, the program WUFI 4 will be utilized. This program charts moisture and temperature gradient through envelopes based on climate data. Additionally, architectural sections will be studied for bulk water issues, such as poor flashing details.

Tasks and Tools

Verify Column Layout

Staggered Truss Design

1. Establish trial member sizes using RAM Structural Steel
    a. Use ASCE 7 for determining gravity and live loads
    b. Restrict overall depth to 1’8”
2. Determine lateral load using methods in ASCE 7
3. Design truss using AISC Design Guide 14
    a. Verify design using RAM Structural Steel
4. Create design documents
    a. Plans, sections, and elevations
    b. Detail connections with floor system

Partially Restrained Composite Design

1. Establish trial member sizes using RAM Structural Steel
    a. Use ASCE 7 for determining gravity and live loads
    b. Restrict overall depth to 1’8”
2. Determine lateral load using methods in ASCE 7
3. Use RAM Structural to determine the moment in each connection
4. Design connections using AISC Design Guide 8
5. Create design documents
    a. Plans, sections, and elevations
    b. Detail connections with floor system

Construction Management Breadth

1. Site layout
    a. Required equipment
    b. Staging and storage requirements
2. Create detailed estimates for systems using MC^2 software
    a. Reference RS Means
    b. Verify with local construction managers
3. Create a schedule using Primavera
    a. Use estimate as a basis for time
    b. Discuss general conditions costs with local construction managers

Envelopes Breadth

1. Determine façade and roof failures using WUFI 4
    a. Input sections
    b. Input climate data, using National Weather Service database
2. Determine bulk water problems with flashing details
    a. Utilize *Whole Building Design Guide*
    b. Reference SGH presentations
3. Propose alternatives
    a. Consult with envelopes experts
    b. Consult *Whole Building Design Guide*

Timetable

	Week 1	**Week 2**	**Week 3**	**Week 4**
Staggered Truss	Establish Trial Member Sizes in RAM Structural, Determine Lateral Loads	Design Truss		Verify Design
Partially Restrained Composite Connections	Establish Trial Member Sizes in RAM Structural, Determine Lateral Loads		Design PR-CCs	Verify Design
Construction Management				
Envelopes			Complete WUFI Analysis	Complete Bulk Water Analysis
General				

	Week 5	**Week 6**	**Week 7**	**Week 8**	**Week 9**
Staggered Truss	Begin Design Documents	Design Documents	Design Documents	Design Documents	Verify Design Docs with Engineers
Partially Restrained Composite Connections	Begin Design Documents	Design Documents	Design Documents	Design Documents	Verify Design Docs with Engineers
Construction Management		Begin Estimate of Systems	End Estimates; Begin Schedules	Complete Schedules	Verify Estimates and Schedules with CMs
Envelopes	Propose Changes				
General					Spring Break

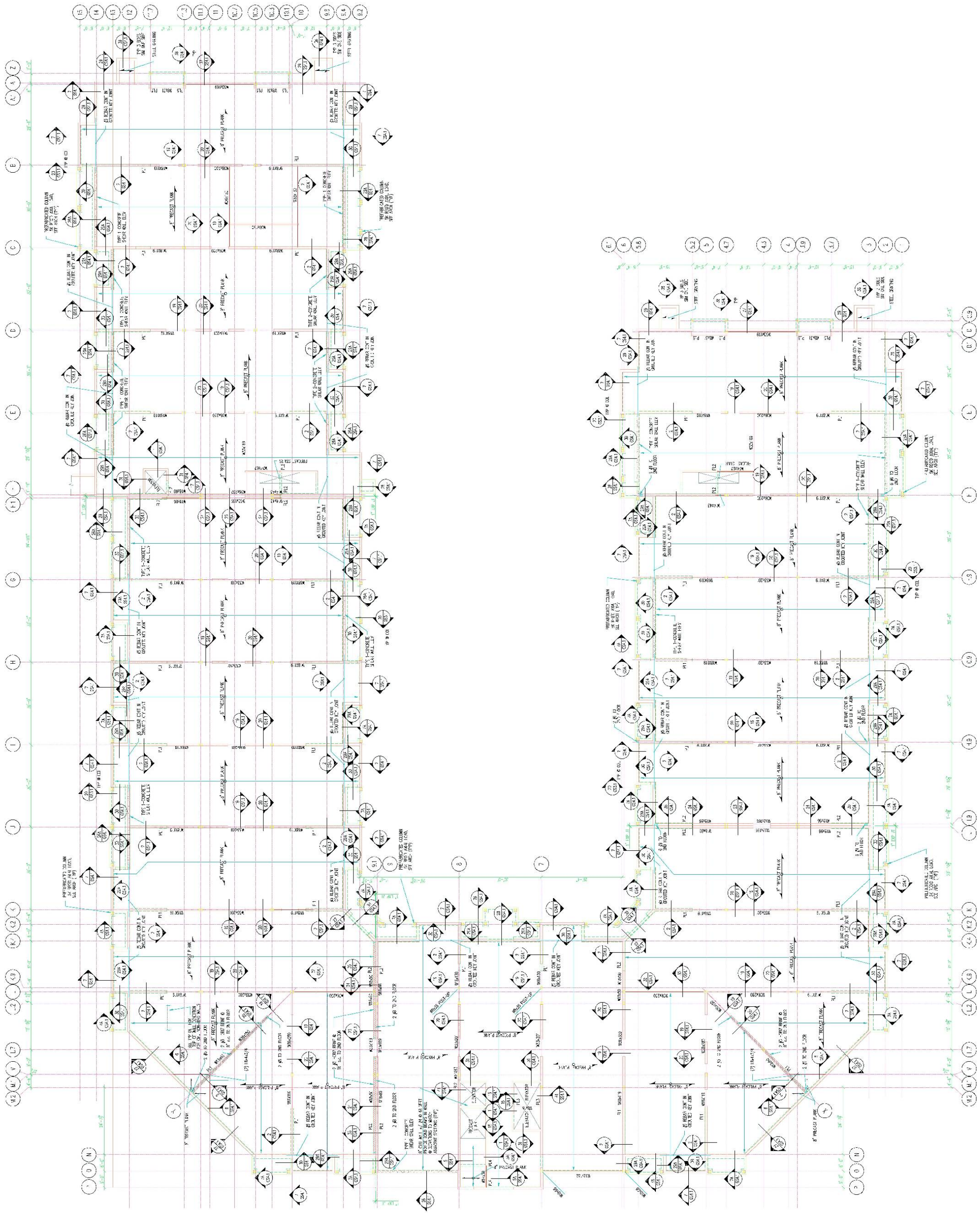
	Week 10	Week 11	Week 12	Week 13
Staggered Truss	Complete Any Remaining Tasks			
Partially Restrained Composite Connections	Complete Any Remaining Tasks			
Construction Management	Complete Any Remaining Tasks			
Envelopes	Complete Any Remaining Tasks			
General		Begin Presentation; Finalize Thesis	Presentation; Review Thesis	Turn in Thesis; Finalize Presentation

Conclusion

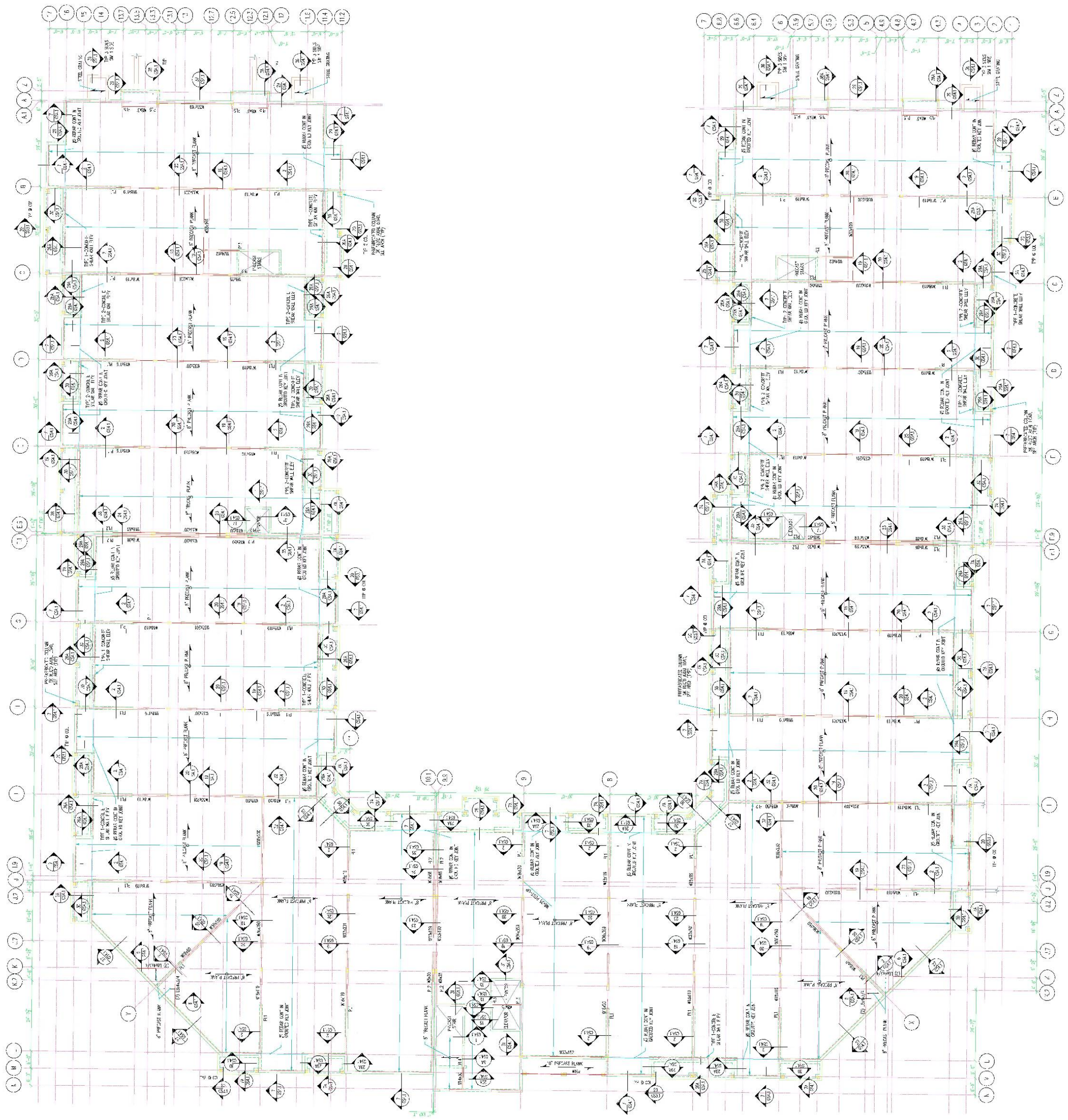
In order to increase the potential for future renovations at Whiteland Village, as well as reduce building weight, investigation into steel construction seems appropriate. Since this will require the use of an alternate lateral system, staggered truss and partially restrained composite connections will be considered. A complete site layout, estimate, and schedule will be completed for each system for comparison. In addition, the current design will be studied for possible envelope failures in terms of bulk water, moisture, and thermal performance.

Appendix A: Master Plan of Whiteland Village

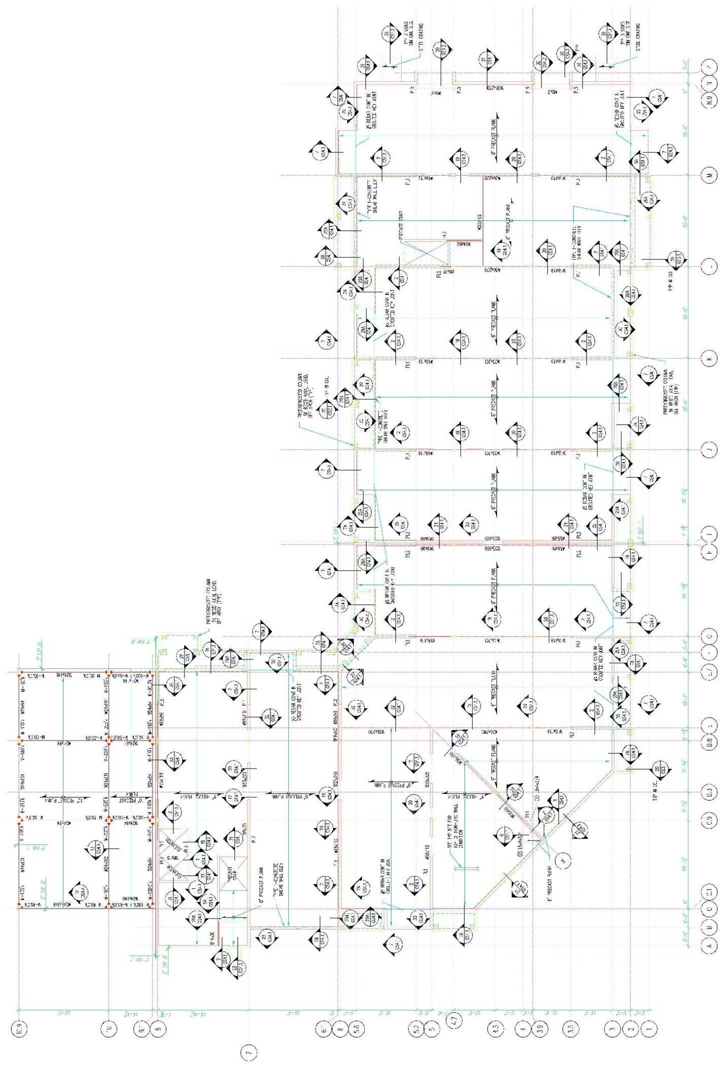
Appendix B: First Floor Plans of Residence Buildings



U-1 (R-1) Building



U-2 (R-4) Building



J (R-2) Building