Proposal

Rendering provided by DCS Design

Kingstowne Section 36A
5680 King Center Drive
Kingstowne, VA 22315

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Structural Option

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EXECUTIVE SUMMARY

Kingstowne Section 36A (KT36A) is a 200,000 SF mixed use building currently being constructed in Fairfax County Virginia. When completed, the lower half of the building will serve as a parking garage serving the office tenants of the upper half of the building. In its current and built design, the parking garage levels are built with flat slab concrete construction while the office levels are a composite steel construction. A more thorough description of the existing structure can be found in the first half of this report.

It was found in Technical Report 2 that the existing composite steel system at the office levels of KT36A is the most expensive structural system of the analyzed existing and alternative systems. The proposed thesis work for the spring semester of 2013 will replace the existing steel system with reinforced concrete to make the entire building reinforced concrete, flat slab construction. It is anticipated that this will lead to a reduced overall building cost. Gravity system and lateral system elements will be redesigned at the office levels while the existing columns at the parking levels and foundations will also be analyzed for adequacy to complete the redesign of the structure. If necessary, existing elements will be redesigned if they are deemed inadequate in the analysis. A structural model created in ETABS will be used to supplement the design of the gravity system and will be used heavily in the design of the lateral system.

The main goal of this thesis work is to learn more about advanced computer modeling of structures through designing the building against progressive collapse. Once the preliminary concrete redesign is complete, effects of progressive collapse inducing events will be analyzed using SAP2000 to aid in the design process, based on guidelines given by the United States General Services Administration (GSA) and the Unified Facilities Criteria (UFC).

Two breadth studies will also be conducted in areas that are not specifically structural engineering. The intent of the studies is to create a more complete overall design against a progressive collapse situation. A site layout redesign will be completed for the first breadth with the intention of reducing risks that have the potential of causing progressive collapse inducing damage to the building. The second breadth topic will study the existing façade to design a façade that thermally performs as well as or better than the existing system while being blast resistant to aid in the risk mitigation of the building.

BUILDING INTRODUCTION

Kingstowne Section 36A (KT36A) is a 200,000 ft^2, 8 story office building to be located in Fairfax County Virginia. It will contain 4 levels of concrete structure parking garage and 4 levels of composite steel construction office space. Floor space has also been allocated for about 5,000 square feet of retail area on the ground floor (Parking Level 1). KT36A will be 86'-11" in height when measured from the average grade. The reason the building height is measured from average grade is because there is a significant grade elevation change from the south side of the building to the north side, on the order of 26'-8" (See Figure 1). This poses unique challenges in the structural design of the building since the geotechnical report states the soil placing a load of 60psf/ft in depth below grade surface on the structure. This means that there is more than 1600 psf of soil load on the foundation walls at the lowest slab levels. This load alone had enough impact on the building that six 12" thick shear walls had to be constructed at parking level 1 to transfer the loads safely.

When completed, KT36A will be part of a master planned development for retail and office space owned by the Halle Companies. Being a part of a master planned development, the building was designed to match the appearance of the surrounding buildings. This appearance can be characterized by a rectilinear footprint, pink velour brick, aluminum storefront with glass of blue/black appearance, and precast concrete bands around the circumference of the building.

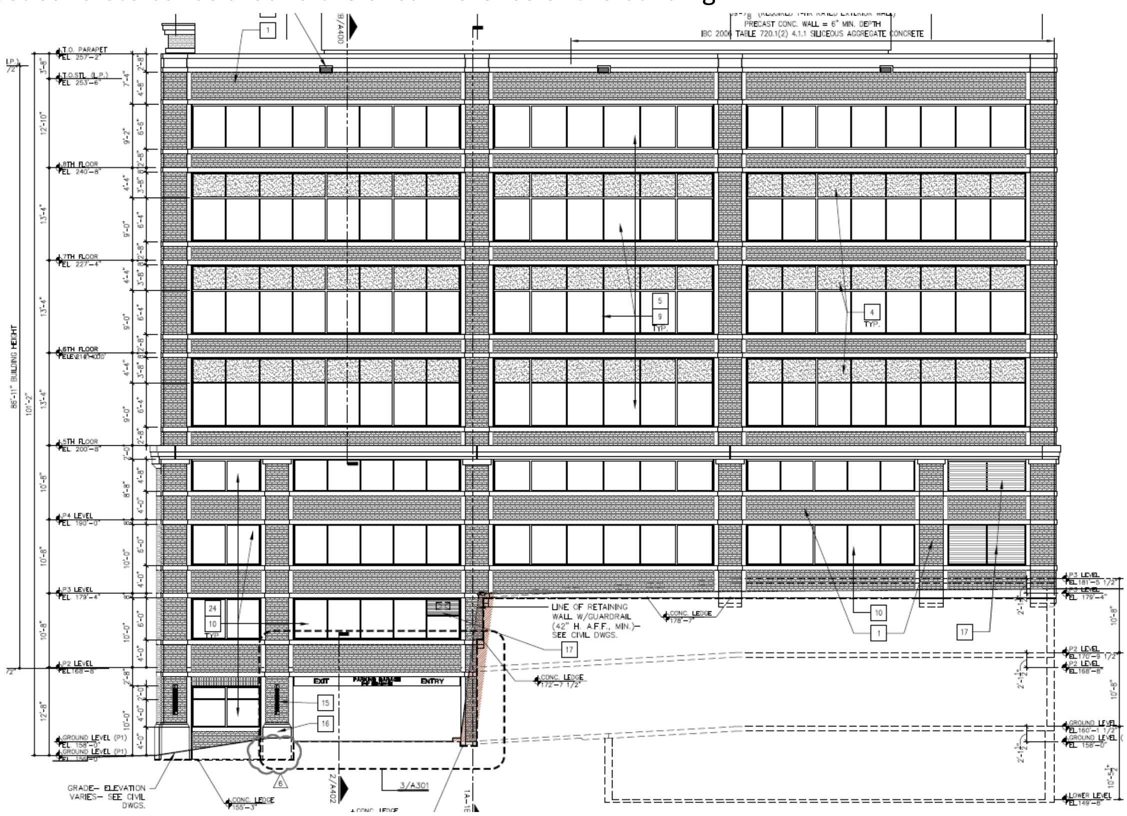


Figure 1: Elevation Looking East Showing Grade Differences (Source: DCS Design Drawing A-301)

STRUCTURAL OVERVIEW

Kingstowne Section 36A consists of two different primary structural systems; cast-in-place concrete for the lowest four floors of the building and a composite steel system for the remaining four floors. The concrete floors are used for the parking garage and retail space while the steel system is used at the office occupancy levels. Lateral forces in the concrete levels are resisted with 12" thick concrete shear walls of varying height. When the building transitions to steel construction, lateral forces are transferred to the concrete columns and shear walls through concentrically braced frames, eccentrically braced frames, and rigid moment frames. Per sheet S-001, components such as steel stairs and curtain wall/window systems were not included in the scope for the structural design of this building.

FOUNDATIONS

In their report submitted August of 2009, Burgess & Niple, Inc. (B&N) advised that shallow foundations not be used on this project due to settlement concerns based on subsurface conditions. They performed five new soil test borings, ranging from 45 to 100 feet in depth below the grade surface. In addition, they reviewed 14 borings from previous investigations, ranging in depth from 10 to 55 feet below grade surface.

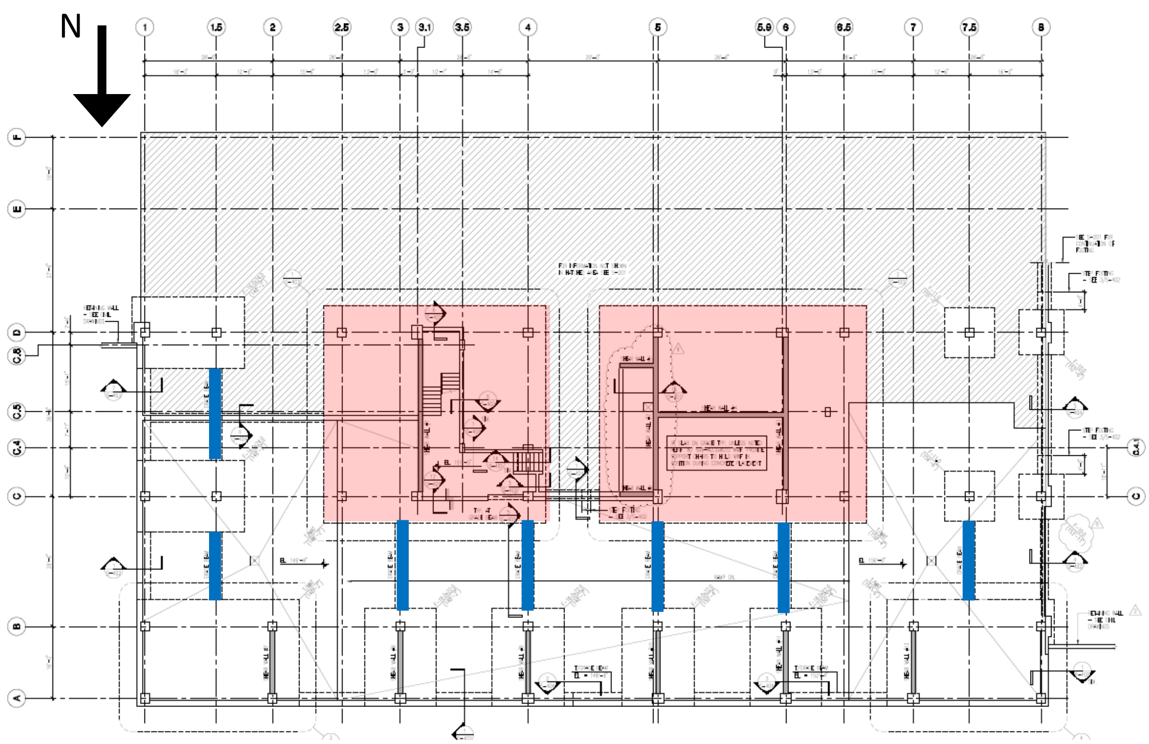


Figure 2: Foundation Plan (Level P0) Showing 48" Thick Mat Foundations Shaded in Red (Source: Cagley & Assoc. Drawing S-200)

Each of the borings found lean clay and fat clay fills with varying amounts of sand, residual soils consisting of lean to fat clay, and clayey to silty sands. Based on the fill materials being encountered between 4 and 48 feet below grade, B&N offered two foundation options. An intermediate foundation system consisting of spread and strip footings bearing on rammed aggregate piers (Geopiers) was chosen for KT36A over the alternate option of a deep system consisting of spread and strip footings bearing on caissons. Geopier diameters typically range from 24 to 36 inches and are compacted using a special high-energy impact hammer with a 45-degree beveled tamper. Per B&N report, footings supported by Geopier elements can be designed using a maximum bearing pressure of 7,000 psf.

Using the information provided by B&N, Cagley & Associates designed spread footings ranging from 27" to 44" in depth to support the columns of KT36A. 48" thick mat foundations bearing on Geopiers are located at the central core of the building to transfer forces in the main shear walls to the soil (See Figure 2). Grade beams (Blue lines in Figure 2) of 30" depth are used throughout level P0 to also transfer forces from the shear walls to the column footings. Foundation walls are supported by continuous wall footings designed for an allowable bearing pressure of 2,500 psf. All foundations are to bear a minimum of 30" below grade unless stated otherwise.

GARAGE LEVELS

FLOOR SYSTEM

As previously mentioned, KT36A utilizes cast-in-place concrete for the support structure in the garage. With the exception of the 5" thick slab on grade, this system consists of 8" thick two-way, flat slab construction with drop panels that project 8" below the bottom of structural slab. The drop panels are continuous between grid lines C and D to help the slab span the increased distance of 36'-6" in this bay, otherwise, they are typically 10'-0" x 10'-0" in size. Due to the need for vehicles to circulate vertically throughout the parking garage levels, the floor is sloped on 3 sides of the central core to achieve this.

Since a two-way, flat plate concrete floor system is subjected to both positive and negative moments, reinforcing steel is required in the top and bottom of the slab. The typical bottom mat of reinforcement in KT36A consists of #4 bars spaced at 12" on center in each direction of the slab. Additional bottom reinforcement in certain middle strips and continuous drop panels is also noted on the drawings. Top reinforcement is comprised of both #5 and #6 bars, both oriented in the same fashion as the bottom mat, with the #6 bars typically being used in the column strips to resist the larger negative moments present there (see Figure 3 for a typical bay layout). A typical bay size for the concrete levels is 28'-6" x 29'-0".

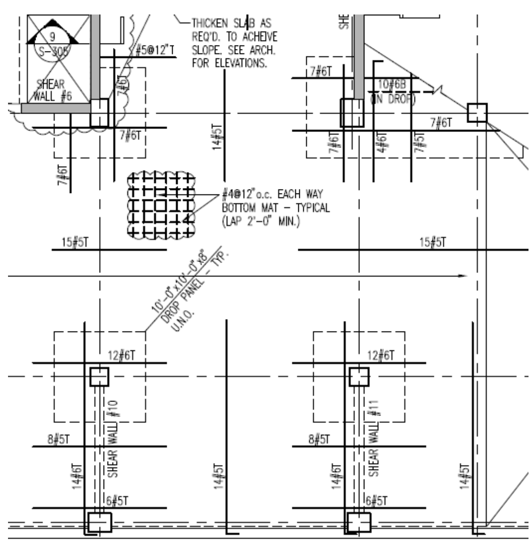


Figure 3: Partial Plan Level P1 (Source: Cagley & Assoc. Drawing S-201)

FRAMING SYSTEM

Supporting the floor slabs are cast-in-place concrete columns constructed of 5000 psi concrete. The most common column size is 24" x 24" reinforced with a varying number of #8 bars and either #3 or #4 ties. Columns of this size primarily account for the gravity resisting system of KT36A. The largest columns used are 36" x 30" reinforced with a varying number of #11 bars and #4 stirrups. The larger columns are located at the ends of the large shear walls in the central core of the building. A small number of concrete beams are also present in the project, typically at areas of the perimeter where additional façade support was needed and at large protrusions in the floor slab.

LATERAL SYSTEM

Cast-in-place concrete shear walls resist the lateral forces present in the parking garage levels of KT36A. All of the twelve walls present in the building are 12" thick and cast using 5000 psi concrete. Six of the shear walls (#1 - #6, see Red lines in Figure 4) extend 4-5 stories from the 48" thick mat foundations to office level 1 which is also the 5th elevated floor of the building. Three of the six walls are oriented to resist lateral forces in the N-S direction while the other three walls are oriented in the E-W direction. The remaining six walls (#7 - #12, Green lines in Figure 4) are only one story tall and are oriented to best resist the lateral soil load at the lowest level of the below grade parking.

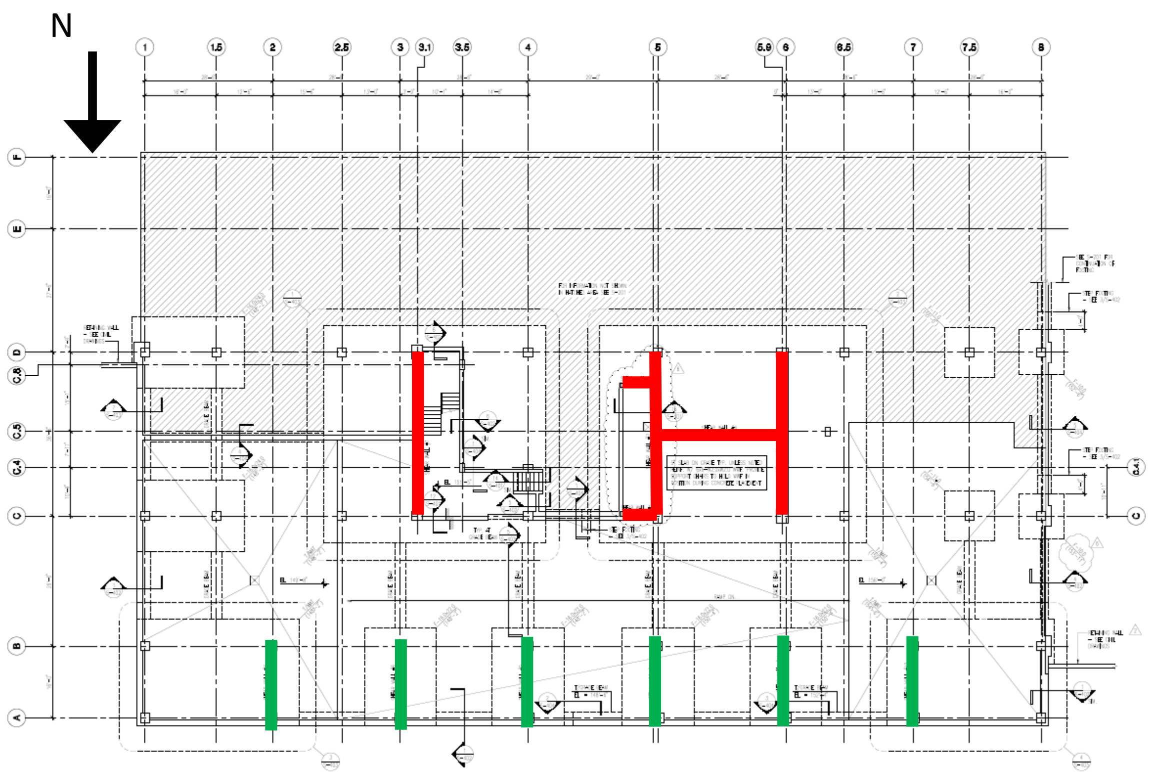


Figure 4: Foundation Plan (Level P0) Showing Shear Walls (Source: Cagley & Assoc. Drawing S-200)

OFFICE LEVELS

FLOOR SYSTEM

Office level 1 is constructed of the same cast-in-place style of construction as the garage floors below it with the exception of the top of slab elevation being uniform throughout the floor. The remaining floors are constructed using a composite steel system. This system is comprised of 3 ¼" thick lightweight concrete on 2" x 18 gage galvanized composite steel decking. The 3000 psi lightweight concrete (115 pcf) coupled with the decking yields a total slab thickness of 5 ¼". Reinforcement for the slab is provided by 6x6-W2.1xW2.1 welded wire fabric.

According to sheet S-001, all decking should meet the three span continuous condition. The decking typically spans 9'-6" perpendicular to cambered beams of varying size. Shear studs of ¾" diameter placed along the length of the beams make this a composite system capable of more efficiently carrying the loads when compared to a non-composite system. The studs must be minimum length of 3 ½" but no longer than 4 ½" to meet designer and code requirements.

FRAMING SYSTEM

The composite floor system mentioned above is supported by structural steel framing comprised of primarily wide flange shapes. W21's and W18's account for most of the beams while the columns range in size from W12x40 to W14x109. A majority of the beams in KT36A are cambered between ¾" and 1 ¼", a function of the span and load demand on the beams. With the exception of four W30x99 sections cambered 1", most of the girders fall within the same size range as the beams. The four W30x99 girders each span 44'-0" which warrants the use of the camber to satisfy the total deflection criteria. The columns are all spliced just above the 7th floor (office level 3) where they are reduced in size to more economically carry the lighter axial loads. See Figure 5 below for a typical office floor level layout.

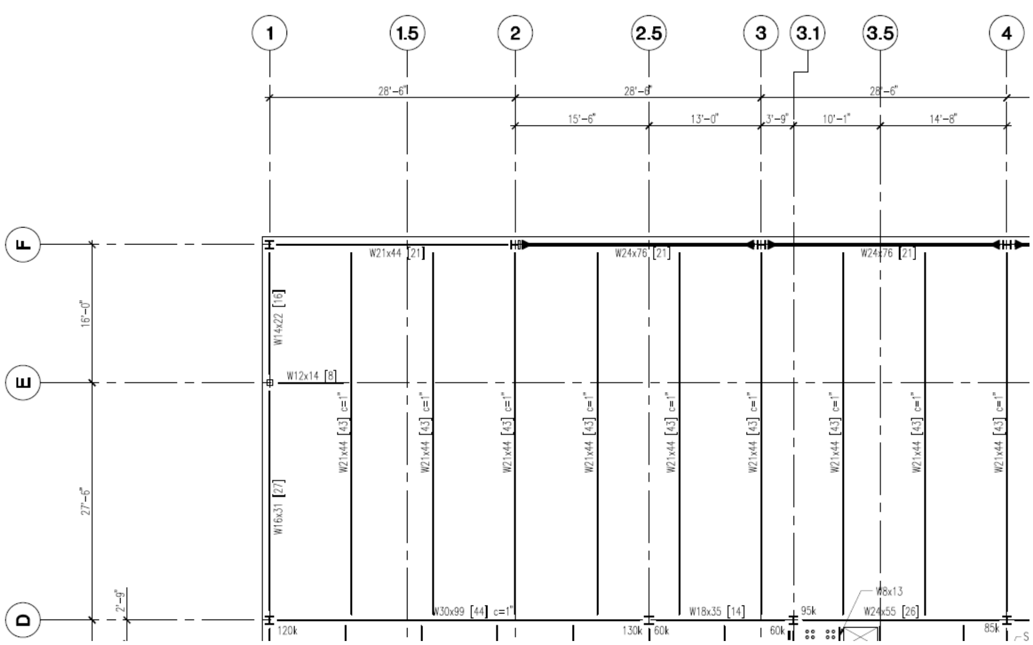


Figure 5: Typical Composite Slab Partial Plan (Level OL3) (Source: Cagley & Assoc. Drawing S-207)

LATERAL SYSTEM

Lateral forces at the office levels are transferred to the concrete shear walls through three different frame systems. Concentrically braced (Green Line) and eccentrically braced frames (Purple Lines) work in the north – south direction while ordinary steel moment frames (Orange Lines) resist the loads in the east – west direction. See Figure 6 for their location and orientation within the building. The eccentrically braced frames were necessary to maintain enough clearance for a corridor in that area of the building. Diagonal bracing for the frames consists of either HSS10x10 or HSS9x9 of varying thickness. Moment frames were most likely chosen for the east – west direction so as not to obstruct the occupants view to the exterior and lower lateral loads acting on the building in this direction.

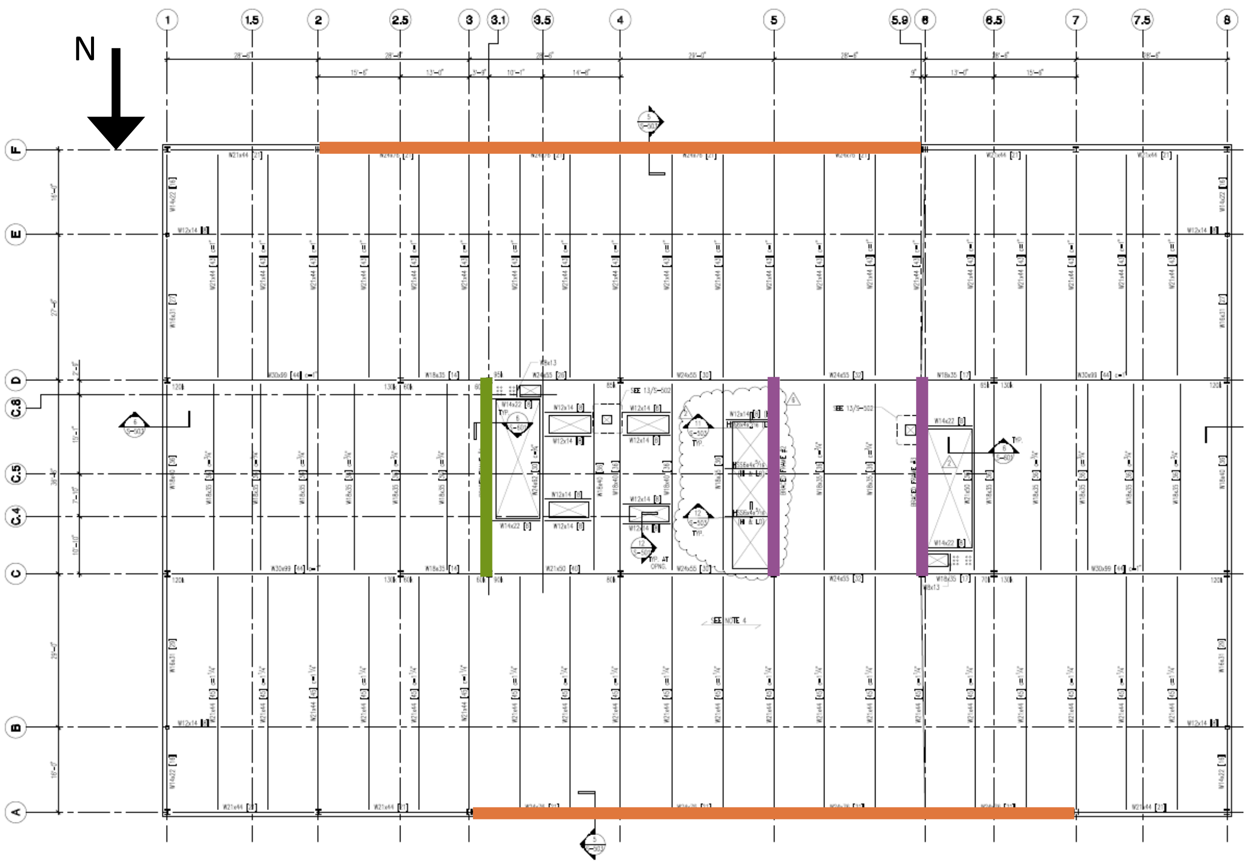
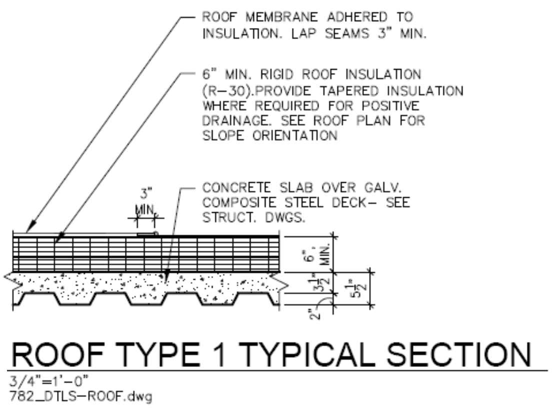
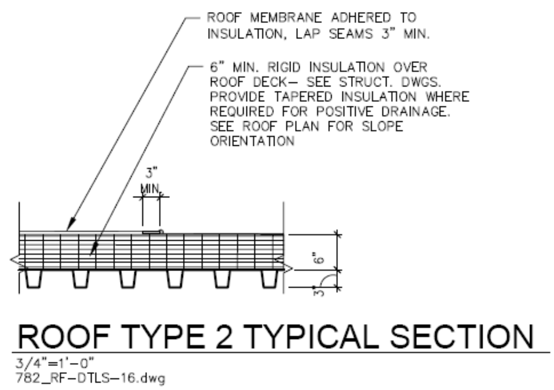


Figure 6: Typical Composite Slab Plan (Level OL3) (Source: Cagley & Assoc. Drawing S-207)

Roof System

The roofing system consists of a white EPDM membrane fully adhered over 6" minimum of R-30 continuous rigid roof insulation. The seams of the membrane must be lapped a minimum of 3" to ensure a watertight seal. Where mechanical equipment is located (see Figure 9), the roofing materials are supported by 2"x 18GA galvanized composite steel deck with a 3.25" thick light-weight concrete topping. The load carrying capacity that this type offers is required to support the four 17,000lb roof top mechanical units needed to condition the air for the building occupants. In all other areas of the roof, the system is supported by 3"x 20GA type N roof deck. Each of the roof types are supported by steel W-shapes that are sloped to achieve proper drainage.





Figures 7 and 8: Typical Roofing Details (Source: DCS Design Drawing A-410)

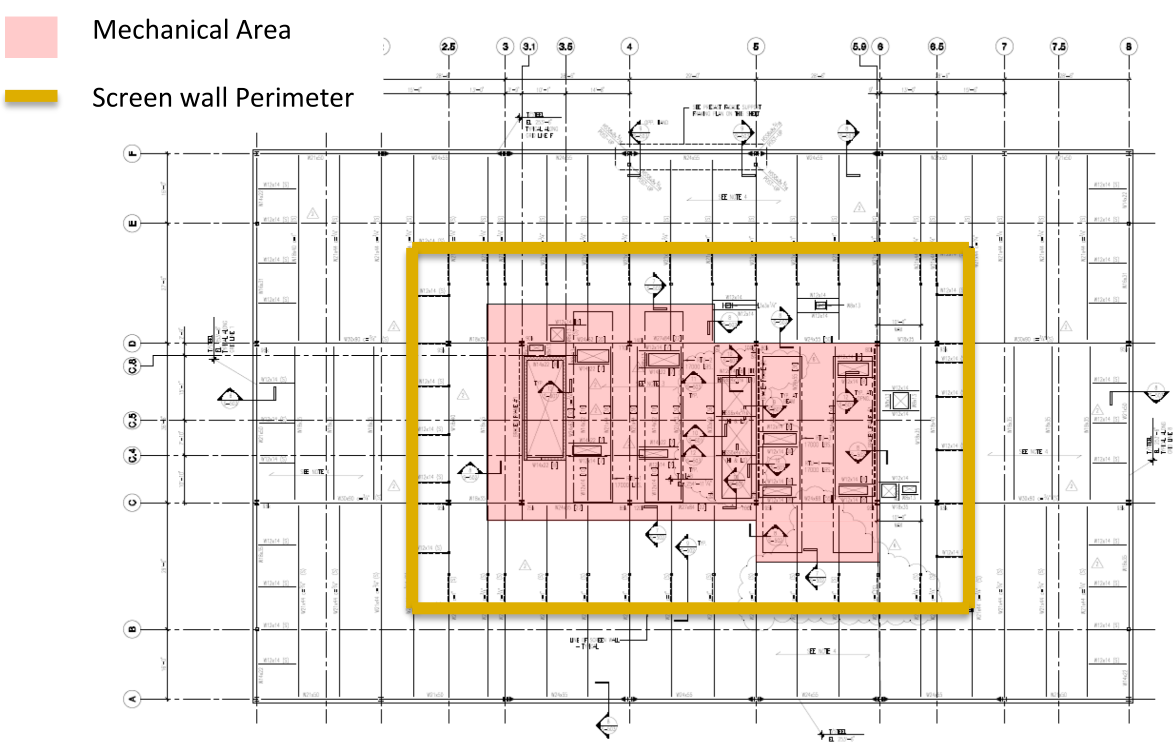


Figure 9: Structural Roof Plan (Source: Cagley & Assoc. Drawing S-209)

DESIGN CODES

Per sheet S-001, Kingstowne Section 36A was designed in accordance with the following codes:

- 2006 International Building Code
- 2006 Virginia Uniform Statewide Building Code (Supplement to 2006 IBC)
- Minimum Design Loads for Buildings and Other Structures (ASCE 7-05)
- Building Code Requirements for Structural Concrete (ACI 318-08)
- ACI Manual of Concrete Practice, Parts 1 through 5
- Manual of Standard Practice (Concrete Reinforcing Steel Institute)
- Building Code Requirements for Masonry Structures (ACI 530, ASCE 5, TMS 402)
- Specifications for Masonry Structures (ACI 530.1, ASCE 6, TMS 602)
- AISC Manual of Steel Construction, 13th Edition
- Detailing for Steel Construction (AISC)
- Structural Welding Code ANSI/AWS D1.1 (American Welding Society)
- Design Manual for Floor Decks and Roof Decks (Steel Deck Institute)

Codes / Manuals referenced for the purposes of this report:

- 2009 International Building Code
- ASCE 7-10
- ACI 318-11
- AISC Manual of Steel Construction, 14th Edition
- 2008 Vulcraft Decking Manual

MATERIAL PROPERTIES

Minimum Concrete Compressive Strength	
Location	**28 Day f'c (psi)**
Footings	3000
Grade Beams	3000
Foundation Walls	5000
Shear Walls	5000
Columns	5000
Slabs-on-Grade	3500
Reinforced Slabs	5000
Reinforced Beams	5000
Elevated Parking Floors	5000
Light Weight on Steel Deck	3000

Max. Concrete W/C Ratios	
f'c @ 28 Days (psi)	**W/C (Max)**
$f'c \leq 3500$	0.55
$3500 < f'c < 5000$	0.50
$5000 \leq f'c$	0.45
Elevated Parking	0.40

Reinforcement:

- Deformed Reinforcing Bars — ASTM A615, Grade 60
- Welded Wire Reinforcement — ASTM A185
- Slab Shear Reinforcement — Decon Studrails or Equal

Masonry:

- Concrete Masonry Units — Light weight, Hollow ASTM C90, Min. f'c = 1900 psi
- Mortar — ASTM C270 – Type M (Below Grade)
Type S (Above Grade)
- Grout — ASTM C476 – Min. f'c @ 28 days = 2000 psi
- Horizontal Joint Reinforcement — ASTM A951 – 9 Gage Truss-type Galvanized

Structural Steel:

- Wide Flange Shapes and Tees — ASTM A992, Grade 50
- Square/ Rectangular HSS — ASTM A500, Grade B, F_y = 46 ksi
- Base Plates and Rigid Frame Continuity Plates — ASTM A572, Grade 50
- All Other Structural Plates and Shapes — ASTM A36, F_y = 36 ksi
- Grout — ASTM C1107, Non-shrink, Non-metallic
f'c = 5000 psi

Gravity Loads

Dead Loads

Superimposed Dead Loads	
Plan Area	**Load (psf)**
Office Floors	15
Roof	30
Parking Garage Floors	5

Dead loads resulting from system self-weights were calculated and estimated based on the drawings provided.

Live Loads

Live Loads			
Plan Area	**Design Load (psf)**	**IBC Load (psf)**	**Notes**
Lobbies	100	100	
Mechanical	150	N/A	Non-reducible
Offices	80	80	Corridors used, otherwise 50 psf
Office Partitions	20	15	Minimum per section 1607.5
Parking Garage	50	40	
Retail	100	100	Located on first floor
Stairs and Exitways	100	100	Non-reducible
Storage (Light)	125	125	Non-reducible
Roof Load	30	20	

PROBLEM STATEMENT

As previously stated in the structure overview, Kingstowne 36A is constructed of two completely different structural systems. Since the construction practices for the two systems are also different, separate trades are required to complete the work. This leads to increased costs since separate labor forces need to be mobilized and more complex construction sequencing.

In addition of the increased costs of bringing different trades to the site, Technical Report 2 revealed that the existing composite steel system at the office levels is the most expensive of the considered floor systems. After comparing the existing and alternate floor systems, the cast-in-place concrete flat slab already being used in the garage levels was found to be one of the least expensive options. Considering this cost reduction and the previously mentioned factors, changing the structural system of the office levels to cast-in-place concrete flat slab could lead to a lower building cost and faster completion time.

PROPOSED SOLUTION

Cast-in-place concrete creating a flat slab structural system will be used to redesign the existing composite steel structure at the office levels of Kingstowne 36A. In their current configuration, the office levels have fewer column lines than the parking garage levels below. This is due to the steel system being able to efficiently span farther distances than the concrete system. Having greater span lengths and less columns in the office space allows a more flexible layout for the tenant which is likely the reasoning for switching to the steel construction at the office levels. This impact on the architecture and function of the interior layout will be considered acceptable for the purposes of the proposed analysis. A design for the first office floor level is contained in the provided structural drawings. Considering the remaining three office floors are identical to the first one, the concrete redesign will focus on the roof level where large mechanical equipment loads are located.

Upon being informed that the building would be entirely constructed of concrete now, a governmental agency has accepted tenancy in the building. Adhering to the guidelines of the United States General Services Administration, the building must now be designed to resist progressive collapse. Edge beams will be added to the perimeter of the building at the office floor levels to help transfer the loads in the event of removal of a critical structural component. In order to analyze the effects of a progressive collapse scenario, SAP2000 will be utilized to implement the alternate load path method for analysis in accordance with UFC-4-023-03 (Design of Buildings to Resist Progressive Collapse). Depending on the results of the analysis, a perimeter transfer girder system may be added at the roof level to aid in transferring the load to adjacent supporting elements.

Considering the fact that the concrete system will weigh significantly more than the existing steel system, increased dead load will be placed on the existing concrete columns and foundation systems. The current designs will be evaluated and adjusted based on the new loading conditions.

Breadth Topics

Site Layout Redesign

One of the best ways to protect against a progressive collapse situation is to reduce the risk of it happening in the first place. This is accomplished through site layouts that minimize potential risks such as explosions and vehicular impacts through strategic site logistics and landscape architecture. Modifications will be made to the existing site plan for Kingstowne 36A to minimize the potential risks. The modifications can include, but are not limited to; increasing stand-off distance, installing barriers, and employing energy deflection shields. The modified site plan will be presented showing the measures taken to create a safer building perimeter.

Building Envelope and Façade Study

Kingstowne 36A is currently clad in a precast-concrete panel, combined with thermal glass and plain glass, façade. This system, however, is most likely not resistant to blast loading. Cladding the building in a blast resistant façade will help to further mitigate the risks that can potentially cause a progressive collapse scenario. The current system will be evaluated with a heat transfer and performance analysis to determine the effectiveness of the façade. This analysis will then be used as the basis to design an alternative façade system that is blast resistant. An additional goal to obtain with the new façade system is to, at a minimum, match the performance of the existing façade.

MAE Requirements

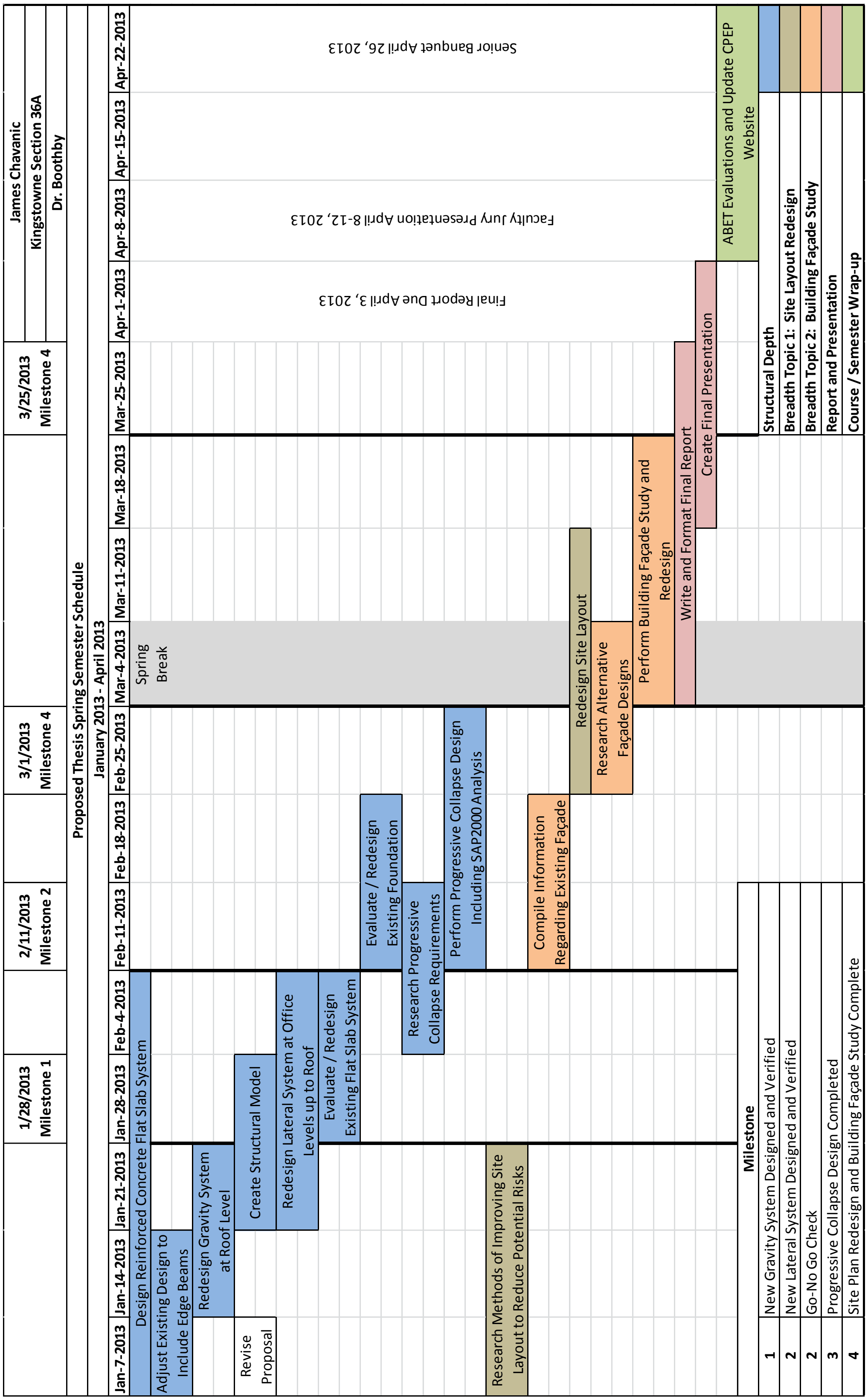
To meet the MAE curriculum requirements for the proposed senior thesis, knowledge and skills acquired from AE 530, Computer Modeling of Building Structures; AE 538, Earthquake Engineering; and AE 542, Building Enclosure Science and Design will be applied. Redesign of the existing structure to entirely cast-in-place concrete construction will be modeled in ETABS to aid in the analysis and design of the structure. Design methods presented in AE 538 will be used to design the new shear walls that will be added and determine if the existing shear walls have enough capacity to resist the seismic loads, considering seismic loads are expected to control the lateral design due to the increased weight of the structure. Material covered in AE 542 will be used to evaluate the existing façade system and design a replacement that is blast resistant.

Tasks and Tools

1. Design Reinforced Concrete Flat Slab System
    a. Adjust existing design for Office Level 1 to include edge beams
        i. Investigate a reasonable beam size that will aid in load redistribution
    b. Redesign gravity system at roof level
        i. Design overall gravity load resisting system (slab, drop panels, reinforcement)
        ii. Design additional beams to transfer mechanical equipment load to columns
        iii. Design columns
    c. Redesign lateral system at office levels up to roof level
        i. Adjust seismic loads for new building weight
        ii. Design shear walls using existing shear walls at parking levels as a start point
        iii. Determine if any of the shear walls continued from below can be removed from the building or reduced in size
        iv. Check building torsion and drift
    d. Analyze existing flat slab system at parking levels
        i. Determine if existing columns have enough capacity
        ii. Redesign as necessary
    e. Check adequacy of redesign using ETABS structural modeling software
    f. Analyze Foundation
        i. Determine if existing foundation system will support increased loads
        ii. Redesign as necessary
2. Progressive Collapse Design
    a. Research requirements for progressive collapse design
        i. Unified Facilities Criteria (UFC)
        ii. United States General Services Administration (GSA)
    b. Select critical members and locations for design
    c. Utilize SAP2000 to run analysis on building
    d. Redesign members according to UFC and GSA guidelines
    e. Verify adequacy of design
3. Perform Site Layout Redesign
    a. Analyze existing site plan and identify areas for improvement
    b. Research methods of improving site layout to reduce potential threats
        i. GSA Guidelines
        ii. NISTIR 7396
    c. Devise ways to implement the researched methods to the site layout
        i. Barriers
        ii. Stand-off Distance
        iii. Energy deflectors
    d. Create and draft new site plan showing changes made to original layout

4. Perform Building Façade Study and Redesign
    a. Compile information regarding existing façade system
    b. Research alternative solutions considering
        i. Cost
        ii. Resistance to blast loading
    c. Redesign façade
    d. Compare original and new façade design
5. Final Report and Presentation
    a. Write and format final report
    b. Finalize report
    c. Outline presentation
    d. Create presentation slide show
    e. Practice presentation

SPRING SEMESTER TIMELINE



Conclusion

Proposed work for the spring semester will focus on designing Kingstowne 36A as an entirely reinforced concrete structure in place of the existing combined system of reinforced concrete and composite steel construction. The existing reinforced concrete gravity system lays a foundation for the design of the remaining office levels with slight modifications such as implementing an edge beam around the perimeter of the structure. Redesign of the structure at the roof will be the main focus of the gravity system redesign. Currently, the lateral system at the parking levels consists of 12 inch thick reinforced concrete shear walls. This system will be checked for adequacy in the redesign and will be continued to the roof of the building as the basis for the design of the lateral system at the office levels. Since the building will have a significant self-weight increase, the existing columns at the parking levels and the foundations will also need analyzed to determine if they are adequate for the new design. Upon completion of the preliminary reinforced concrete design, the building will also be designed to comply with progressive collapse requirements set forth by the Unified Facilities Criteria (UFC), and the General Services Administration (GSA).

Designing the building structure to resist progressive collapse is only one approach towards preventing such an event. Reducing the possibility of the collapse from happening in the first place is a much more effective way of preventing a progressive collapse situation. This can be done through properly designing the site layout around the building with the goal of mitigating potential events that can cause damage to the building resulting in progressive collapse. Thus, one of the breadth topics for the proposed thesis work will be modifying the site layout around Kingstowne 36A to minimize the risk of potentially damaging events. The remaining breadth study will look into cladding the building in a different façade that will thermally perform as well or better than the existing façade while being both cost efficient and resistant to blast loading to aid in reducing potential damage to the building structure.