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PSU AE STRUCTURAL OPTION

FOREMAN FIELD GAME DAY BUILDING

NORFOLK, VA

THESIS PROPOSAL

12/12/2008

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Executive Summary

The Foreman Field Game Day Building is a new four story reinforced concrete stadium complex. It is located at the south end-zone of Old Dominion University's existing football field in Norfolk, VA. It houses primarily luxury boxes, training and support facilities, and some bleacher seats. The Game Day Building is approximately 55,000 square feet and 50 feet tall. The existing gravity system is 12" flat plate slabs supported on 18"x18" concrete columns. The lateral system is composed of seven cast-in-place concrete shear walls. The foundation is provided by nearly 200 precast concrete friction piles, driven to a depth of 100'.

This thesis study will focus on redesigns of the Game Day Building's existing, gravity and lateral systems, and the resulting impacts on the foundation system requirements. The floor system will be redesigned as a one way slab system supported on post tensioned beams. Analysis of a typical bay indicates that such as system will optimize the use of materials reducing the building's weight. The lateral system will be redesigned using concrete moment frame system. The existing shear walls will be eliminated if possible. The effects on the foundation of the change in dead load of the gravity system and forces distribution in the lateral system will be studied in detail.

A detailed study of the cost and schedule impacts of the redesigned systems will be performed as a breadth. Special attention will be paid to finishing by the current completion deadline. Current Industry information and RSMeans data will be used to complete this study.

A second breadth study will be done on the impact of a façade redesign. Schedule acceleration will be a key factor in selecting alternative cladding systems. The structural connection details and thermal resistance changes of the alternative systems will be determined and compared to the existing conditions.

Background

Introduction

The Foreman Field Game Day Building is Old Dominion University's new stadium facility in Norfolk Virginia. It is a four story 55,000 sq-ft reinforced concrete building with a curved plan and cantilevered seating. The Game Day Building is intended to be an iconic addition to the existing stands. Currently under construction the building is scheduled to be completed at the end of summer 2009 in time for ODU's first football season in nearly 70 years. It houses primarily luxury boxes, training and support facilities, and bleacher seats. The estimated cost of the project is approximately $11.9 million. The site is zoned as an Institutional Campus District which does not impose any notable occupancy or construction limits. The project is being built under a Design-Build contract between Old Dominion University and a collaboration of Ellerbe Becket Architects, Clark Nexsen Engineers, and S.B. Ballard Construction Company.

Building Envelope

The majority of the façade is clad in brick masonry with cast stone trim. Additionally, there are portions clad in cast stone masonry, storefront glazing systems with anodized aluminum framing, painted metal railings, and cast in place concrete with a rubbed finish. The south face of the building is accentuated by five one story and one three story entry archway clad in cast in stone masonry adorned with two aluminum flag polls. The north façade is distinguished by the cantilevered balconies with seating, large areas of glass curtain wall, and a scoreboard. The roofing system is provided by a 12" concrete slab topped with single-ply EPDM membrane over cover board and roof insulation.

Foundations

Forman Field Game Day Building rests primarily on square precast prestressed concrete (SPPC) piles. The subsurface soil conditions across the site are a combination of wet sands and clays down to a depth of 110 ft. The soil conditions necessitate a deep foundation of friction type piles to achieve required bearing capacities. A total of 199 (SPPC) piles, all 12" wide and 100' long from tip to cutoff, are located below columns and shear walls in groups of one to 18. Individual piles have capacities of 85 tons in axial compression, 40 tons in axial tension and 5 tons in lateral resistance. The piles are topped with 36" to 40" deep pile caps. A half wall on the east side of the ground floor is supported by spread footings, designed to bear on soil with an allowable bearing pressure of 1500 psf at least 18" below grade.

Gravity System

The Game Day Building's typical floor system is a 12" deep reinforced concrete flat plate slab. #5 reinforcing spaced between 3.5" to 12" on center both top and bottom is used to reinforce the flat plate slab. A typical bay size is 31'-6" by 17'-0". In plan, a majority of the building is a shallow curve with column lines being radial spokes in the short direction and curves at set radii in the long direction. This leads to many bays not being exactly rectangular. Embedded three foot long shear rails in both directions at every column corner, except along the slab edges, provide additional shear capacity to combat punching shear. The slabs are held up by the columns and load bearing walls. Columns are typically 16"x16", with eight #7 vertical bars and #3 ties at 12" on center. Most of the roof is also 12" concrete flat plate with typical reinforcement. The first floor is a slab on grade. Some atypical areas are the bleacher seating area and the kitchen roof. The stepped down seating area on the north side of the second floor is supported by 14"x19" to 36"x21"concrete beams and sloped girders. The kitchen roof is supported by cold formed steel framing.

Typical Floor Framing Plan

Figure 1

Columns and Load Bearing Walls are in Red

Lateral System

Seven building height reinforced concrete shear walls are designed to provide the building's lateral stiffness. They are reinforced with two curtains of #5 rebar at 12" on center for shear resistance. Flexural reinforcement is provided by two #6 to seven #9 vertical rebar varying between walls and decreasing with height within a wall. No boundary elements were used in the shear wall flexural design. Additional vertical, horizontal, and diagonal rebar is located around openings cut through the shear walls for M.E.P ducts and doorways. The Game Day Building is designed so that lateral loads flow from the façade into the 12" slabs on every floor, which act as rigid diaphragms, distributing the load amongst the seven shear walls based on relative stiffness. The shear walls all rest directly on pile caps or grade beams between pile caps. Several piles per shear wall are 'tension piles' with broom ends of prestressing strands extending into the pile caps, allowing them to take tension load and resist overturning moment. The lateral stiffness, inherently present in the frame formed by the columns and slabs, was neglected in the design of the building's lateral system.

Shear Wall Location Plan

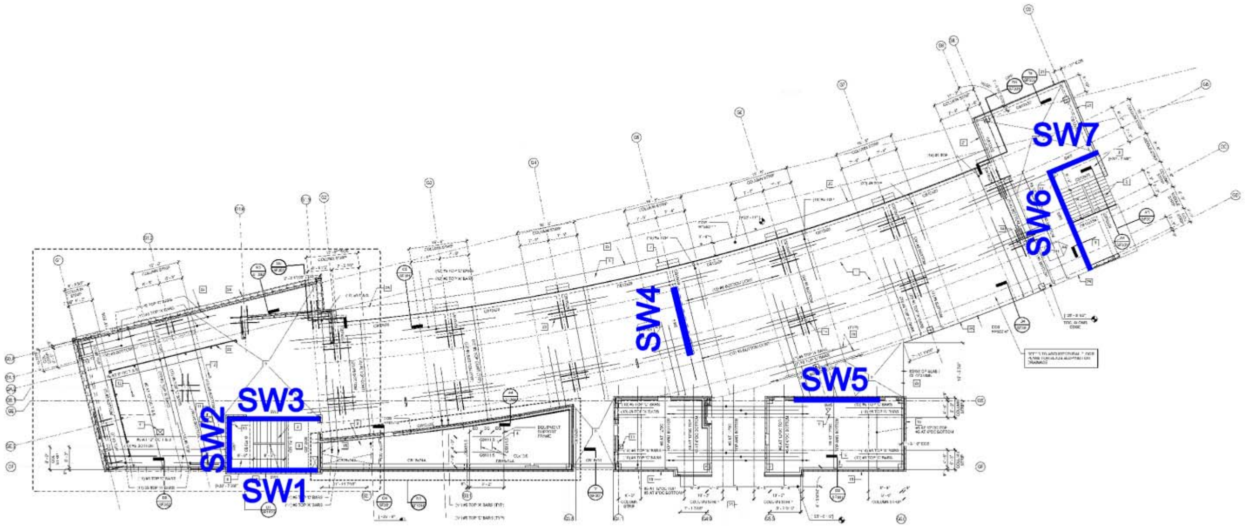

Figure 2

Shear Walls are in Blue

Problem Statement

The current design of the Game Day Building utilizes 12" deep flat plate reinforced concrete floor slabs on all elevated floors, including the roof. When considered in combination with the high live load of 100psf required by the building's function, the 150psf dead loads of the 12" flat plates result in high gravity loading. These high gravity loads are very likely partially to blame for the massive amount of 100' deep friction piles required for the foundation. Analysis performed during the course of Tech Report 2 determined that because the aspect ratio of most bays approach or exceed 2:1, a two way flat plate is inherently not the most structurally efficient system.

Seven shear walls compose the Game Day Building's lateral system currently. Analysis preformed in Technical Report 3 found that the shear walls had significant excess capacity in resisting shear, flexure and deflection. The stiffness of the equivalent moment frames created by the concrete columns and flat plate slabs was neglected in the design of the shear walls. They were neglected because they are relatively flexible compared to the shear walls and therefore take very little load. The shear wall system's excess capacities indicate that decreasing the building stiffness is permissible. This indicates that the lateral system should be optimized.

Proposed Solution

Tech Report 2 indicated that a one way slab in the short direction supported by beams in the long direction could reduce the average slab depth and thus dead load significantly. In typical bays, the use of one way slabs can reduce the slab depth to 8". In order to further minimize the dead load, the supporting beams and possibly atypical bay slabs will be post tensioned when possible.

With the increase in moment frames' stiffness due to the addition of beams along column lines to support the one way slabs, neglecting their stiffness in the lateral design would be a waste. Therefore, the building lateral system will be re-designed utilizing moment frames only and eliminating the excessively stiff shear walls. The moment frame will be compared in structural performance and efficiency to the existing shear walls.

A breadth study on the cost and schedule ramifications of these redesigns will be performed. A second breadth investigation will be performed on the building façade. It will focuses specifically on the interactions with the structural system and effects on project cost and schedule. A more in depth discussion of the breadth topics can be found in the Breadth Options section.

Solution Methods

The gravity and lateral systems will be designed in accordance with the requirements of the 2003 International Building Code and ASCE 7-05. The design of the new floor system will begin by laying out beam locations and span directions. Then, the one way slabs will be initially designed with PCA slab and checked with hand calculation methods. The superimposed gravity loadings will be determined by hand based on tributary area, in accordance with the design values used in the initial design and ASCE 7-05 requirements. The self weight will be iteratively calculated assuming normal weight concrete. The post tensioned beams will be designed by a combination of hand calculations and RAM Concept analysis in accordance with ACI 318, the PTI handbook and technical design notes. A RAM Concept finite element model will be used to determine initial beam sizes and tendon layout requirements. The design outputs will be checked and refined by hand calculations.

The lateral system redesign will be done with a 3D Etabs model verified by hand calculations and PCA column analysis. Wind loadings will be determined in accordance with ASCE 7-05 section 6.5, the analytic procedure. Seismic loadings will be determined in accordance with ASCE 7 -05 section 12.8, the equivalent lateral force procedure. A static linear elastic and a dynamic analysis of the structure including $P\Delta$ effects will be performed with Etabs to determine member loadings. The lateral loading member forces will be applied in conjunction with gravity loading forces to design the lateral system elements. The columns will be designed by a combination of hand calculations and PCA column analysis. The beams will be designed by hand calculations. This process will be repeated until a system with satisfactory lateral performance is designed.

Once the gravity and lateral systems have been redesigned, their foundation demands will be compared to those of the existing systems. Where significant differences are found, the foundation system will be redesigned in accordance with ACI 318 using the soil conditions stated in the geotechnical report.

Breadth Options

As a breadth, a detailed study of the cost and schedule impacts of the system redesigns will be performed. This study will include assemblies cost estimates and unit cost estimates of the original and redesigned structural systems. The costs will be based on actual supplier and vendor price quotes when available. RSMeans Assemblies and Building cost guides will be used when actual quotes are unavailable. The effects on the schedule of the redesigned systems will be determined with special attention being paid to the completion deadline. Input from contractors and comparative case studies dealing with post tensioned concrete floor systems and concrete moment frames will be used to help determine the cost and schedule implications.

The choice to use a somewhat structurally inefficient concrete flat plate by the original designers was driven by constructability issues. Specifically, the contractors desired a flat slab to economize the forming of the slab system. The proposed one way slab system will require additional formwork and shoring and introduce post tensioning. This will clearly increase the construction cost and schedule requirements of the floor slabs by some extent.

A second breadth study will be done on the impact of a façade redesign. Considering the new gravity system may take longer to complete and a firm completion deadline is in place, a key goal of the façade redesign will be schedule acceleration. A detailed survey of the existing façade will be carried out. Alternative wall types, that can maintain the current architectural aesthetics, will be compared to the original in both cost and on site erection time. One such system that shows promise is the SlenderWall architectural precast panels. The SlenderWall panels are shallow precast concrete panels backed by metal studs with architectural finishes, including brick and stone, similar to the existing masonry veneer of a large portion of the Game Day Building.

The structural connections of the alternate façades selected will be analyzed and designed. The connection failure analysis will rely heavily on the concepts taught in the master’s level steel connection class offered by Penn State’s Architectural Engineering department. Concrete connection failures will be researched and designed as necessary. The relative thermal properties of new systems selected will be compared to those of the existing systems. Approximate heating and cooling demand changes will be determined.

Tasks and Tools

I. Gravity System Redesign

1. Establish Trial Member Sizes
    a. Layout beams and determine slab directions
    b. Determine slab depth based on deflection span to depth ratios
    c. Determine beam sizes based on typical PT beam span to depth ratios
2. Determine Floor Loads
    a. Find self weight based on trial member sizes
    b. Apply superimposed live and dead loads in accordance with existing design
    c. Calculate uplift wind loads in accordance with ASCE 7-05
3. One Way Slab Design
    a. Design the one way slabs with PCA slab
    b. Check PCA slab, slab designs compliance with PT beam interaction requirements by hand calculations and with RAM Concept analysis as necessary.
4. Gravity Beam Design
    a. Create a RAM Concept finite element model of the floor system using the trial beam sizes and the designed one way slabs.
    b. Analyze and refine the trial beam sizes in RAM Concept until a viable design is determined
    c. Analyze and refine the beam designs found in RAM Concept by hand considering PTI recommended design criteria.

II. Lateral System Redesign

1. Establish Trial Member Sizes
    a. Select beam and column combinations to be used as lateral moment frames.
    b. Set column and beam sizes to maximum required for gravity loading cases
2. Determine Lateral Loads
    a. Determine wind loading in accordance with ASCE 7-05 section 6.5
    b. Determine seismic loading in accordance with ASCE 7-05 section 12.8
3. Model and Analyze the System
    a. Create a model of the lateral system in Etabs using the trial member sizes
    b. Apply the wind loadings at the center of pressure at each floor
    c. Apply the seismic loadings at the center of mass at each floor
    d. Analyze the lateral system in Etabs assuming rigid diaphragms
    e. Assess the performance of the trial system and resize members as required
    f. Determine critical lateral loading per member with Etabs model

4. Integrate Lateral and Gravity Loading
    a. Determine critical combinations of lateral and gravity loadings on lateral system members
    b. Design columns with a combination of hand calculations and PCA column.
    c. Design the beams with a combination of hand calculations and RAM concept.

III. Foundation Analysis and Design

1. Compare redesigned and original buildings foundation requirements
2. Perform analysis and design as necessary to change foundation from original design

IV. Façade Redesign

1. Survey existing façade and research alternative cladding options
2. Analyze and design connections of new cladding systems
3. Study the impacts of difference in thermal properties of the alternative cladding systems

V. Cost and Schedule Analysis

1. Research cost and schedule Information
2. Perform cost take offs of existing and redesigned structural and cladding systems using actual quotes and RSMeans cost guide data
3. Perform Schedule Impact analysis of the redesigned systems using Microsoft Project or Primavera scheduling software

VI. Research summarization

1. Write Thesis Final Report summarizing findings and drawing conclusions of the redesigns' feasibility.
2. Prepare Thesis Power Point presentation

Time Table

Proposed Work Schedule

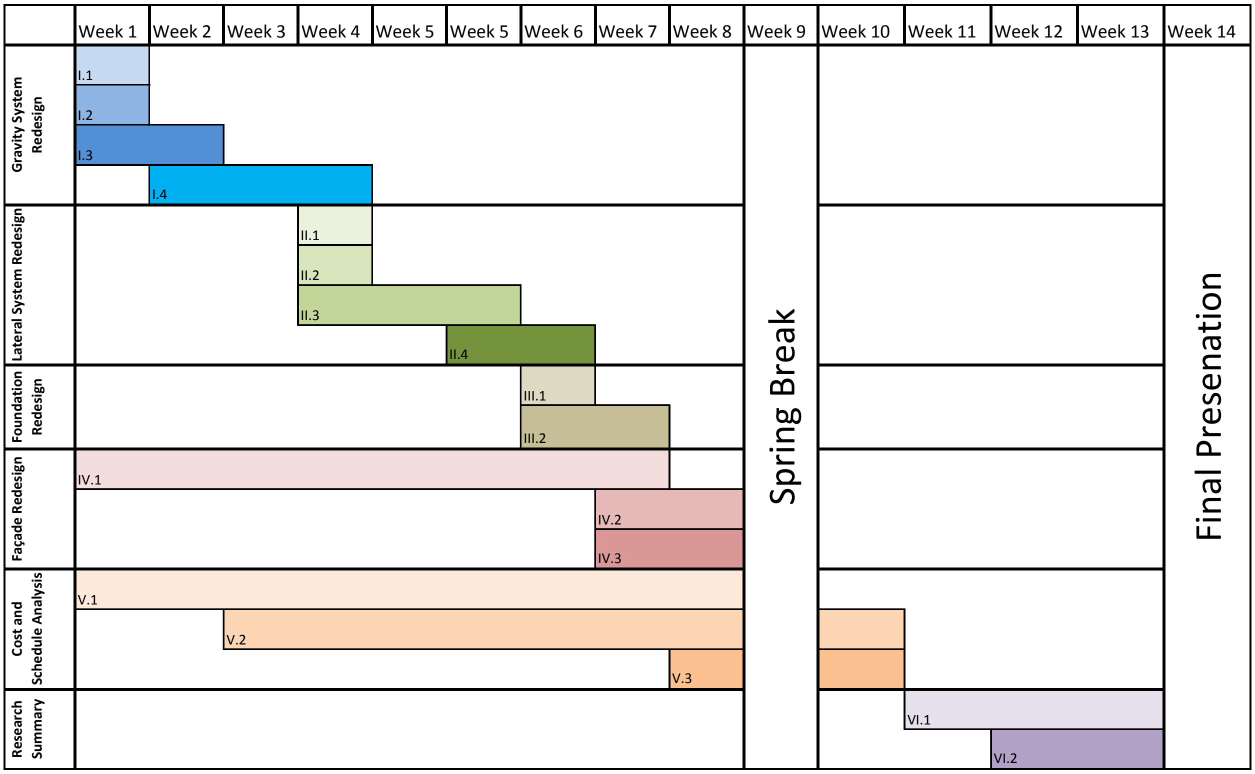

Figure 3