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- Structural
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- Bucknell Recreation & Athletic Facility
- Lewisburg, PA
- Wednesday, December 5, 2002
- BAC Thesis Proposal

Executive Summary

The proposed thesis will include an investigation of an open web steel joist and trussed roof system, four (corner) composite concrete and steel columns supporting a precast seating tier, open web steel joist floor framing system with concrete topping, and a masonry shear wall framing system.

Computer models in STAAD/Pro, RAM, and PCA Col for respective elements will be generated to provide gravity load, rigidity, moment and axial capacities, and sway information. Vibration characteristics will be examined separately due to a less stiff floor framing system. All design criteria has been brought up to standards stated in the IBC 2000. Formerly, the structure was designed by the regulations of BOCA 1999.

There were changes made to the mechanical systems and architectural layout. A different type of CAV unit is offered. Changes in HVAC equipment will affect the overall the arrangement of ductwork. Finally, some architectural modifications of the interior wall finishes, floor space, and attendee transportation will be studied. Each breadth, or non-structural, proposal will be relate to the overall change in cost.

Problem Background

Bucknell University possesses one of the finest sport-arenas in East Buffalo Township. It is scheduled to open in late December, 2002. The seating configuration for the Bucknell Recreation and Athletic Center *Arena* will attract large crowds and community participation for major basketball games, concerts, and convocations. It is equipped with two elevators, retractable floor area, multiple corridor egress & staircase exits, elevated coach boxes/offices, locker rooms, plenty of all-purpose seating, and utilizes natural light.

Figure 1: SE corner of Bucknell Natatorium (middle-ground) & **Arena** (background) under construction.

^ Photo Courtesy of Bucknell University Athletics; http://bucknellbison.ocsn.com, Oct. 2002 ^

The building envelope of the arena is composed of four steel braced frames, and one steel moment frame. At roof levels, certain joints in each frame, members possess connections that have both gravity and lateral resistance in order to transfer the loads from upper levels. Roof construction over the performance space and seating bowl consists of 3 inch galvanized metal roof deck supported on super long span steel joists spanning 160 feet. Each joist has an approximate tributary width of 11 feet. There is horizontal and diagonal bridging, and well as top and bottom chord bracing. On the west side of the basketball playing area, the roof framing is supported by a truss, also spanning 160 feet, varying in depth from 12' - 2" at the ridge of the center panel. The balance of the roof construction consists of 1 ½ inch galvanized metal roof deck supported on steel (open web) joists and wide flange steel beams and girders framing into wide flange steel columns. Loads are transferred to these components from a 3 inch exposed metal standing seam roof system. At the base of the exterior roof system, is a section of painted aluminum coping, then an insulated metal panel system with aluminum window framing.

The seating bowl consists of precast concrete seating tiers supported on sloping wide flange steel beams and girders framing to wide flange steel columns. A composite slab/deck on a composite beam system was designed for the majority of the floor framing. The system exists with shear studs welded to the wide flanged steel beam, an entirely composite floor system. Typical framing consists of a concrete slab, galvanized composite metal deck with welded wire fabric.

Exterior Walls, including the arcade on the East elevation, consist of Flemish bond brick masonry with 8 inch concrete block backup for the majority of the first story. In certain areas, ground face concrete masonry units (G.F. CMU) were used instead of brick to cut cost. For the upper levels, much of the exterior consists of metal panels and aluminum window framing. Minimum reinforcement is used for all masonry walls, including continuous bond beam sections.

The structure is supported by continuous strip footing foundations. The basic reasoning for using this type of foundation system was to span over potential sink holes. Footings were designed to span over an 8 foot loss of support at any given point, and have a minimum width of 36 inches regardless of the bearing pressure developed.

An expansion joint is located between the Arena and the adjacent Natatorium. The expansion joint maintains the structural independence of the two buildings at all supported levels. This was accomplished by a double line of steel wide flange columns on each side of the expansion joint.

*See Figure 2 (pg. 3) on the next page for the basic floor plan of the Arena, including locker room, lavatory, and outdoor walkway areas.

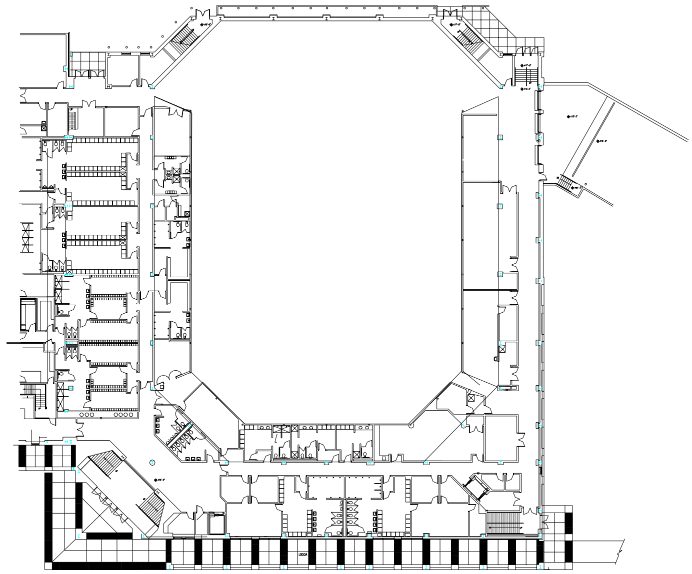

Figure 2: ^ Typical Ground Floor Plan ^

Problem Statement

The new arena was designed to resist live loads per BOCA 1999* and ASCE 7-95*. Floor loadings will be 100 pounds per square foot (psf) in most areas; public, moveable seating, concessions, and stairs. Office areas have a 70 psf loading applied. Fixed seating areas will have a loading of 60 psf. Higher loads were taken in storage and mechanical areas, 125 psf and 150 psf, respectively. Typical roof loading considered is 30 psf, with loads increased at areas of snow drifting and sliding, with a maximum drift/sliding load of 170 psf. Lewisburg, Pennsylvania is categorized as wind exposure ‘B’. A basic wind speed of 90 miles per hour (mph) with 3 second gusts, were applied to create a lateral load resisting system to contradict these forces. Wind loads vary from 17 psf to 21 psf at heights from 0 – 15 feet to 50 – 60 feet (ft.), for each structural frame. Varied loadings are applied to architectural secondary components; walls, roof panels, the roof perimeter, and roof corner(s) & overhang(s). Seismic effects were countered with a dual system of ordinary moment frames of steel and concentrically braced frames.

* BOCA 1999 : Building Officials Code Administrators, 1999 Edition.
* ASCE 7-95 : American Society of Civil Engineers, Volume 7, 1995 Edition.

The previously stated live loads will now be compared to the values given in the IBC 2000*. Any change in arena’s design will have to abide to the following design criteria.

Minimum uniformly distributed live loads –

- Gymnasium, Main Floors & Balconies: 100 psf
- Moveable Seating, Concessions, & Stairs: 100 psf
- Coaches Offices: 50 psf
- Fixed Seating: 60 psf
- Storage: 125 psf
- First Floor Corridors: 100 psf
- Corridors above First Floor: 80 psf

Consequently, there will be exceptions and live load reductions depending on the application and use at special areas. Mechanical room/area loadings vary, but average 150 psf. The structural supports of roofs and marquees shall be designed to resist wind and, where applicable, snow and earthquake loads, in addition to the dead load of construction and the appropriate live loads in multiple sections of the IBC. The live loads acting on a sloping surface shall be assumed to act vertically on the horizontal projection on a *face*. These particular segments pertaining to wind, snow, and seismic will be addressed as the redesign unfolds.

* IBC 2000 : International Building Code, 2000 Edition.

Representative dead loads for the typical composition of the existing structure have been compiled. Each floor load will vary highly on the size of the wide flange steel member used. The typical load created by the topping slab, metal decking, and finishes is approximately 45 psf. The roof load will vary highly on the type of the steel joist and/or truss used. The typical roof load superimposed is approximately 5 psf. Also, each precast seating tier has an additional load of 25 psf applied.
The live load criteria addressed previously will now be compared to the values of IBC 2000.

I have decided to investigate much of the design for the roof and lateral framing systems. Naturally, these alterations will have an effect on the floors and seating framing into the lateral system, so the typical floor system will undertake a change. After all these proposed structural issues are resolved, an analysis of how these modifications impact the architectural outlook, mechanical system, occupant transportation (throughout the facility), and cost.

Proposed Structural Solutions of the Problem

A series of wide flange steel columns support one truss and the super long span joists (SLH), spanning in the North-South direction along the roof. I propose that the loads of this superstructure can be carried by less open web steel joist members. The ends of each joist will rest on panels of two trusses that span 170 feet in the East-West direction. These main trusses will be supported at each of the four corners of the seating bowl by 5 foot diameter composite concrete and steel columns. Thus, eliminating many interior structural columns and bearing walls in the East-West direction.

To match the appeal of the roof system, an open web steel joist with concrete slab floor framing system can replace the existing composite slab/deck system. The open-web system lessens the necessary thickness of concrete topping, and the mass of the overall floor system. Since this floor system will be less stiff than the existing, vibration considerations will have to be explored. Due to the floor to floor height of the concourse and mezzanine levels, there will be very little change in floor thickness, with the advent of open web steel joists, regarding necessary ceiling heights.

The crossed-braced steel frames resisting the lateral forces on the facility may be replaced by reinforced masonry shear walls. Also, these load-bearing masonry walls will support floor frames of the concourse level at those areas. This will be accomplished by pilaster design at sections of the wall comparable to the positioning of the existing wide flange steel members. Fully grouted CMU pilasters will suffice in these areas. A brick exterior veneer will still be implemented (as in the existing design) with interior walls having Flemish bond pattern as well.

Method to be used for each Solutions

The sizing of the steel joists that frame the roof will conform to the standard specifications for Open Web, LongSpan, and Deep Longspan Steel Joists, and Joist Girders provided by NCJ* of the SJI*. Steel structural members, specifications, and codes will be based on the LRFD* Manual of Steel Construction. Supporting the steel joists, the composite concrete and steel columns will be designed by Chapter 17 of ACI* 318-02 *Building Code Requirements for Reinforced Concrete*. The concrete of the new floor framing system will coincide with service loads by strength design of Chapter 8 – General Requirements with emphasis on 8.3.3 and 8.7. Where the dimension of a bay exceeds the requirements for one-way design, or assumptions for slabs and supporting members provided, section 13.7, the Equivalent Frame Method, of ACI 318-02 will be utilized. The design approach for reinforced masonry walls will be ASD (or Limit States).

Analysis of gravity loads will be completed by the 2000 release of the computer program STAAD/Pro, produced by Research Engineers, Inc. RAM Structural System (copyright RAM International 2000, version 7.0) will provide the computer output for lateral design. Along with the design of the floor system, preliminary check will be made with the computer program ADOSS, an implementation of the

Equivalent Frame Method. Composite steel and concrete column design will be aided by PCA* *Column* (version 2.30). PCA Col concentrates on the design and investigation of concrete column sections.

* NCJ : The New Columbia Joist Company
* SJI : Steel Joist Institute
* LRFD : Load & Resistance Factor Design
* ACI : American Concrete Institute
* ASD : Allowable Stress Design
* PCA : Portland Cement Association

Design Procedures

This section consists of a brief understanding on how some problems will be conquered, but does not include the processes involved with computer program models.

I. Open Web Steel Roof Joists

1. Determine Loading
    a. Comprise a list of all loads transferred to the member.
    b. Determine typical chord forces and end moments.
    c. Calculate the Effective Moment of Inertia to compensate for shear deflections.
    d. Evaluate whether member camber is necessary, how vibration of elevated floors will contribute to its *action*, and other effects that may apply or exist (ponding, sloping joists, etc.)
2. Check geometry for minimum requirements and specifications (K-Series)
    a. Refer to pg. VI of the NCJ
3. Pick appropriate member
    a. Refer to the Standard Load Table for Open Web Steel Joists to choose a size.
    b. Deduct weight of Dead Loads, including the joists.
        1. Joist designation according to:
            i. Depth (with respect to Live Load capacities)
            ii. Span (with respect to Live Load capacities)

II. Open Web Steel Joist Floor Framing with Concrete Slab

* Refer to section I, above, for open web joist sizing (pg. 7).

1. Determine gravity loads from IBC 2000 and ASCE 7-98 including live load reductions.
2. Calculate trail sizes (hand-checks of ADOSS output).
3. Compare sizes from analysis of the existing structure – Composite Deck.
4. Check Deflection
5. Check Vibration
6. Determine new Load to Shear Stud ratio per LRFD, I5.5, pg. 6-68, required number of Shear Connectors.

III. Load Bearing Masonry Shear Walls (ASD)

1. Choose trial member size, reinforcement, bonding, grouting, & material.
2. Find loads on member (wall section)
3. Pilaster Design *Basis*
    a. Allowable Axial Force P_a calculated on the basis of h/r (cross section properties).
    b. Allowable Bending Moments in both directions
        1. Pressure
        2. Tension on Web
        3. Suction
        4. Tension on Flange
4. Shear Wall Design
    a. Find distribution of Lateral Forces by Rigidity.
    b. Calculate Flexural & Shear Displacements.
        1. Calculate Lateral Element Stiffnesses.
    c. Calculate Centroid and Center of Rigidity (C.O.R.).
    d. Determine Lateral Force Elements.
        1. Direct Effects
        2. Torsional Effects
    e. Determine Moment of Wall due to its Loading & Eccentricity.
    f. Check Deflection

IV. Composite Columns (Steel & Concrete at Corners of Seating Bowl)

1. Choose trial size
    a. Outer dimension and size of interior steel member.
2. Determine Loads & Load Combinations by ACI 318-02
    a. Design to resist forces; section 8.8.
    b. Transfer loads from all floors or roof, and find maximum moment & axial loads onto column; section 8.8.1.
    c. Consider how the column is arranged in the entire structure; section 8.8.2 - 8.8.4.
        1. Determine degree of curvature (single or double)
    d. Design under the provision of flexural and axial loading; section 10.3.
3. Check Basic Limitations
    a. Shear & Torsion; ACI 318-02, chapter 11.
    b. Eccentricity & Ultimate Buckling Load / Deflection, Column Strength Interaction Diagrams per ACI tables – Design of Concrete Structures by Nilson.
    c. Bearing Capacity; ACI 318-02, section 10.17.

Timetable & Schedule

January

Week # 1, Jan. 13th – Jan. 17th
- Review Thesis Proposal feedback

Week # 2, Jan. 20th – Jan. 24th
- **Begin Structural Redesign Of Roof System**
- Model (roof framing) structure in STAAD/Pro

Week # 3, Jan. 27th – Jan. 30th
- Finish Schematic Design of Roof System
- Tabulate loads from STAAD output
- **Finish Roof System Redesign & Computer Model**

February

Week # 4, Feb. 3rd – Feb. 7th
- **Begin Structural Redesign Of Lateral Resisting System**
- Enter later framing system into RAM

Week # 5, Feb. 10th – Feb. 14th
- **Finish ASD Design Approach For Shear Wall (Lateral) System**
- **Begin Alternate Floor System Design**
- Compare RAM results to STAAD results from Tech. Assign. # 3 (Rigidities)
- **Create A Schematic Design Combining The Roof & Lateral Systems Onto STAAD**

Week # 6, Feb. 17th – Feb. 21st
- **Begin PCA Col Analysis Of Composite Concrete & Steel Columns**
- Size & detail columns based on the trial size provided by PCA output
- **Finish Alternate Floor Framing System**

Week # 7, Feb. 24th – Feb. 28th
- **Address Breadth (Non-Structural) Proposals**

March

Week # 8, Mar. 3rd – Mar. 7th

** Spring Break **

Week #9, Mar. 17th – Mar. 21st
- Address any faculty or consultant remarks
- **Begin PowerPoint Slide Presentation**

Week # 10, Mar. 24th – Mar. 28th
- Continue gathering information for PowerPoint slide show & oral presentation
- Convert all files into an usable format
- **Finish CPEP (Capstone Project e-Portfolios) Updates**

Week # 11, Mar. 31st – Apr. 4th
- Start preparing oral presentation (speech)
- Continue creating slides & PowerPoint format
- **Submit Entire Thesis Report (bound)**

<u>April</u>
Week # 14, Apr. 7th – Apr. 11th

- **Finalize PowerPoint Presentation**
- **Complete Speech Outline And Make Final Preparations**

Week # 15, Apr. 14th – Apr. 18th

** Thesis Presentations MTW **

Week # 16, Apr. 21st – Apr. 25th

** Corrections & Touch-Ups **

Week # 17, Apr. 28th – May 2nd

- Respond to any faculty responses to submission &/or presentation
- Meet with thesis administrators to ensure full completion of AE 482 duties.

Proposed Breadth Topics

- Mechanical

Existing Heating Ventilating and Air Conditioning (HVAC) System:

The athletic center is provided with chilled water and low-pressure steam from the campus's central utility network. Both services enter the new facility via underground piping. On the air side of the building's HVAC, there are 13 new air-handling units (AHU) serving the new and renovated spaces. The units used in the building can be broken down into two distinguishable types.

CAV, or constant air volume systems, supply a steady flow of air to the spaces they serve. This air is supplied at approximately 58°F and reheated to anywhere from 75 to 100 to maintain space comfort. Typically large assembly spaces and some office spaces are being served by CAV units.

VAV, or variable air volume systems, supply a changing air flow rate to the spaces they serve. This air is supplied at approximately 58°F. Then, the volume is reduced and the air reheated to anywhere from 75 to 100°F to maintain space comfort.

There are also numerous terminal units throughout the facility. These units are supplied with either chilled or hot water (or both) and are designed to handle the conditioning of on space. Examples of these are unit heaters, cabinet unit heaters, and fan coil units.

Mechanical Alteration:

A third type of unit is a CAV unit was used in the adjacent Natatorium, but it varies slightly from the CAV system above. It is *not* supplied with chilled water. They are direct expansion units that have condensing units mounted on grade. The application of this system could be used in the Arena also. Structural changes will affect the mechanical system as well. The duct work runs between filler beams and within roof framing. If duct resizing is necessary, the same cross sectional area will be used, but with different rectangular dimensions. When considering the size of the joists for analysis, the impact on the arrangement of the mechanical system has to be addressed.

- Architecture

Existing Architectural Scheme & Challenges:

The architecture is designed to form an edge to the main campus on axis with the main academic quad. Designed to be compatible with the surrounding Georgian architecture style, the new facility expands the recreational opportunities for students while accommodating many gender equality requirements.

Bucknell's Athletic Center is a transportation nightmare. There are three planned elevators. All three are being constructed, although one will possibly be used as a freight elevator. Also, there is one lift to an annex. The proposed use of the annex will be for elevated coaching offices. All main spectator entrance/egress areas are handicapped accessible. Three ramps have been implemented.

Architectural Alteration:

There will be a fire protection issue that will have to be resolved with the advent of brick faced interior walls. Also, the aesthetics of Flemish bond brick masonry versus running bond CMU walls will be addressed. The transportation problem has two aspects to explore.

The immense composite columns at the corners of the seating bowl will present a change in floor area around the member, concessions, and exits. Arrangement of the columns and adjoining walls is crucial to provide efficient space for occupants to travel throughout the concourse. However, the erection of many interior steel columns can be avoided, and openings in the proposed masonry shear walls may be formed in order to create more floor space.