THE PENNSYLVANIA STATE UNIVERSITY
- ARCHITECTURAL ENGINEERING -
SENIOR THESIS WORKBOOK

BRIAN S. LOTT
STRUCTURAL OPTION

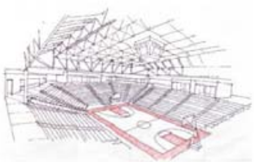
BUCKNELL ATHLETIC CENTER

Depth Study:
- Structural Design

Breadth Studies:
- Mechanical Systems
- Architecture

Professional Building Design Consultant:

Ewing Cole Cherry Brott



BUCKNELL ATHLETIC CENTER

BUCKNELL UNIVERSITY — **LEWISBURG, PA**

Location

The Bucknell University Recreation & Athletic Center will be fully completed by June 2003 in East Buffalo Township.
Ewing Cole Cherry Brott provided the AEI services, as R.S. Mowery & Sons handled the bulk of the Construction Management duties.

Project Higlights

A new 4,000 seat gymnasium/Sport Arena.

A 54-meter-by-25-yard Olympic pool.

5,000 sf student fitness center & instructional strength area.

Overview

Bucknell's Athletic Center is under construction and will connect to the existing facilities to create a campus union. The university has 3,200 students & 27 varsity programs.

Mechanical

· The air handling systems will consist of a combination of Constant Air Volume (CAV) and Variable Air Volume (VAV) systems.

Electrical

· A single three-phase padmount transformer will provide power for the new athletic facility. The basketball court will be illuminated with high bay metal halide sports luminaries, pendant mounted from the structural truss.

Plumbing

· Chilled water will be supplied from distribution mains - part of the campus's system upgrade. Varying pressure steam systems will serve hot water to the new and existing facilities.

Fire Protection

· Fire walls will be maintained at the entrance of the New Arena and the existing field house.

Structural

· Normal weight concrete will be used where vibration poses a problem.

· The balance of the roof construction will consist of galvanized metal roof deck supported on steel joists and wide flange beams & girders framing to wide flange steel columns.

· Many existing campus buildings have been supported by shallow foundation systems. Strip footings will be used to prevent uneven settlement under most New Arena, where potential sink holes are expected.

· Combinations of truss & frame lateral systems are used in gymnasium design.

THE PENNSYLVANIA STATE UNIVERSITY
BRIAN S LOTT
STRUCTURAL OPTION
DEPARTMENT OF ARCHITECTURAL ENG.

Table of Contents

Preface

Credits:

Building Owner –	Bucknell University Moore Avenue Lewisburg, PA 17837
A/E Design Firm –	Ewing Cole Cherry Brott Federal Reserve Bank Building 100 North 6th Street Philadelphia, PA 19106
Project Players –	Jared Loos, P.E. / Ewing Cole Cherry Brott Peter Welsh, P.E. / Ewing Cole Cherry Brott Bill McCullough, AIA / Ewing Cole Cherry Brott Angelo Vieceli / Bucknell Physical Plant Bill Mierzejewski / R.S. Mowery & Sons Inc.
AE Thesis Advisor –	Dr. Ali M. Memari, Ph.D., P.E. / Department of Architectural Engineering

Acknowledgements:

This years Senior Thesis process is devoted to all who have encouraged my efforts during my time at PSU.

Special thanks to all faculty members, professors, peers, family, and friends who have enhanced my AE experience.

Thank you for all your help, guidance, and advice over the years.

Executive Summary

The arena within Bucknell's New Recreational and Athletic Center has been analyzed and studied for roof framing, floor assembly, ventilation efficiency, and architecture redesign. The men's and women's basketball teams will enjoy an increase in attendance due to the transportation improvements throughout the facility. Spectators will enjoy a less obscured passageway in and around the event area. Dehumidification units have been recommended to not only alleviate high humidity levels, but to bring more fresh air into the building. Brick façades will counter any changes to interior columns that may affect the aesthetics of the arena. All other architectural requests and requirements were met.

Structurally, the existing roof system requires a truss and long span joists. In order to increase the amount of open space below, two trusses and a series of open web steel joist girders were implemented to lessen the amount of supporting columns. To match the roof framing, an open web steel joist (with concrete slab) was designed. There was minimal loss in ceiling height, although the mass was reduced creating some vibration issues. Electrical, mechanical, and plumbing configurations were not altered by these joists.

When visiting the arena, a relaxed sentiment will be gathered upon entering the building. In addition, the feel of a new arena will encourage players to put forth their best effort each time out. This in turn will push other athletic and educational programs to aim even higher than ever before.

Introduction

This project involves the design and construction of a new athletic center that is linked to neighboring recreational facilities. The new buildings include the Sports Hall of Fame, Student Fitness Center, Natatorium and a *new Arena* (gymnasium). Their arrangement attempts to maximize the green area in front of the athletic center for a recreational field and minimize site cost by careful considerations given to the placement to the buildings in the hillside at the back of the site adjacent to a cemetery. There are two phases to this project. Phase one will complete the new fitness center, natatorium, office and locker renovations. Phase two will complete the arena and the remaining office-locker renovations in the Davis Gym (existing).

Figure 1 : Site Plan depicting existing & additional facilities.

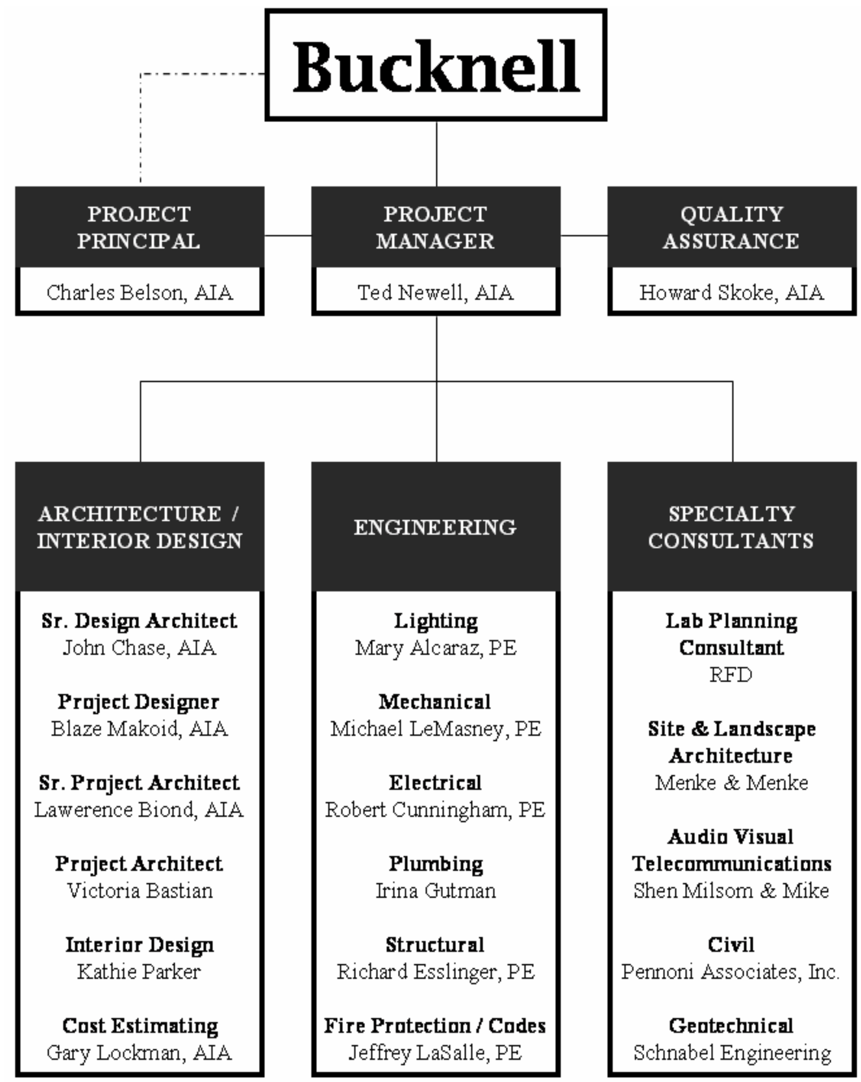
Light Yellow : Existing Recreational Buildings   Orange : New Additions (BAC)   Blue : New Arena

Project Players & Delivery

The main project players are employed by Ewing Cole Cherry Brott (ECCB), an AEI firm located in Center City, Philadelphia, PA. Specialists within Ewing Cole include Architectural, Structural, Mechanical, Electrical, Plumbing (MEP), and Fire Protection Engineers. Bucknell University is the owner/client, and their Project Manager is Angelo Vieceli of their Physical Plant. The Site Superintendent is Bill Mierzejewski of R. S. Mowery & Sons Inc. who handles the bulk of the construction management, along with the Project Executive - Bud Jones. The steel and concrete subcontractors are Stewart Amos, and Zartman Construction, respectively. There were a number of consulting firms including; Sports, Civil, Landscape, Acoustic/Rigging, Geotechnical, Food, and Pool services.

This project strays from the traditional Design-Bid-Build procedure. Ewing Cole acquired this job through a design competition. They head the Architectural, Structural, Fire Protection, & MEP engineering duties in conjunction with Rosser International. Different breakdowns of bid packages are submitted with respect to both discipline and facility space. Structurally for example, the Foundation Package is its own entity, while another bid package includes both floor system and lateral framing details. Throughout construction, the CM bids on each individual package for a guaranteed maximum price. The Value Engineering process occurred at the end of the Design Development phase.

Figure 2 : Flow Chart comprised of professions, project players & respective firms.



Project Background & Conditions

Bucknell University now has one of the finest sport-arenas in East Buffalo Township. It opened in late December, 2002. The seating configuration for the Bucknell Athletic Center 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, coach offices, locker rooms, plenty of all-purpose seating, and utilizes natural light.

Figure 3 : SE corner of Bucknell Natatorium (middle-ground) & **Arena** (background) under construction.

^ Photo Courtesy of Bucknell University Athletics, Oct. 2002 ^

Existing Structural Divisions

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 9'-9" at support to 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 over an insulated metal panel system with aluminum window framing. The depth of roof deck was lessened because of ample truss spacing, including bridging & bracing. The finish of exposed structural steel was compatible with the type of water treatment and it protected against corrosion. The exterior shell consists of Ethyleen Propyleen Dieen Monomeer (EPDM) layers over 2 inch rigid insulation.

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, a fully 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 seating bowl consists of precast concrete seating tiers supported on wide flange steel beams and girders framing to wide flange steel columns. It is designed to resist the superimposed live load from the concourse area, as well as an additional dead load. The precast concrete plank manufacturer coordinated the size and location of all openings and embeds with the mechanical, electrical, and plumbing contractors.

There are two main mezzanine levels at opposite corners of the building (northeast & southwest). These areas are used for additional electrical and mechanical spaces. Other partial mezzanine levels may be used as elevated coach offices and press boxes. These levels utilize a 7 foot high aluminum window system that provides an extra outdoor perspective.

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.

Design Criteria:

- BOCA BOCA National Building Code – 1999 Edition
- ASCE American Society of Civil Engineers,
  Minimum Design Loads for Building & Other structures – ASCE 7-95
- AISC American Institute of Steel Construction – Ninth Edition
- SJI Steel Joist Institute
- AWS American Welding Society
- ACI American Concrete Institute – ACI 318
- FM Factory Mutual Requirements

* This study references IBC 2000 & ASCE 7-98.

Floor & Roof Steel Systems:

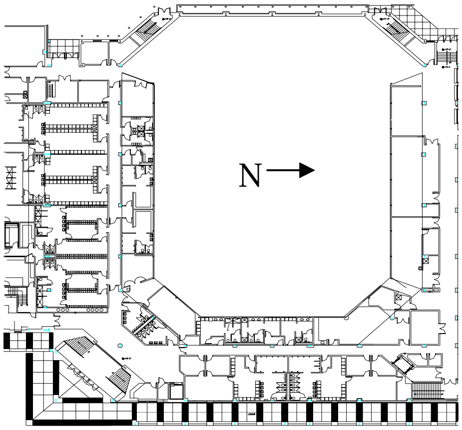


Figure 4 : Ground Floor Plan

The structure is supported by continuous strip footing foundations. This type of foundation system was used 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.

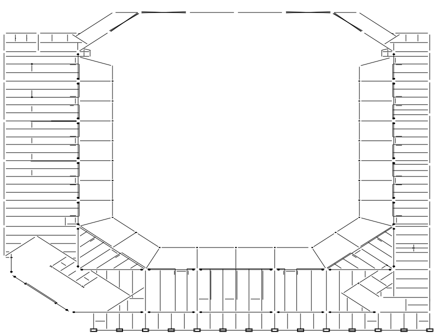


Figure 5 : Concourse Level Plan

A composite slab/deck system exists with shear studs welded to the wide flanged steel beam, a fully composite floor system. The typical framing panel consists of a 4 ½ inch concrete slab, galvanized *composite* metal deck with 6×6 - W2.9×W2.9 welded wire fabric.

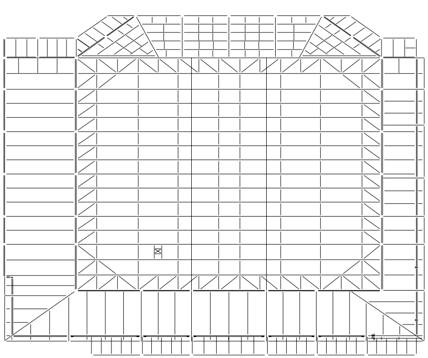


Figure 6 : Roof Level Plan

Long roof spans are on the order of 150 feet to 170 feet. These spans are accomplished with steel trusses supported by steel columns. The 3 inch depth of metal roof deck allows 10 to 15 foot spacing of structural members.

Lateral Resisting System:

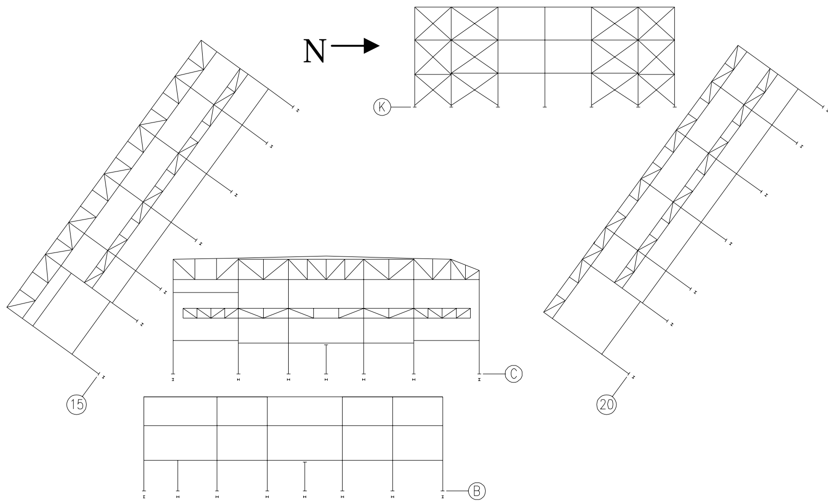


Figure 6 : Isometric Framing Representation

The building envelope is composed of four steel braced frames, and one steel moment frame (B). At roof levels, members possess connections that have both gravity and lateral resistance in order to transfer the loads from upper levels.
Note:
Frames 15 & 20 are graphically skewed to illustrate where they are located in the structure.

Depth Study

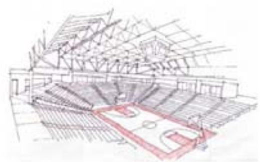
Problem Statement:

Floor loadings are 100 psf in most areas; public, moveable seating, concessions, and stairs. Office areas have a 70 psf loading applied. Fixed seating areas have a loading of 60 psf. Higher loads are used for storage and mechanical areas, 125 and 150 psf, respectively. Typical roof loading is 30 psf, with loads increased at areas of snow drifting and sliding. Lewisburg, Pennsylvania is categorized as wind exposure 'B'. A basic wind speed of 90 mph with 3 second gusts, were applied to create a lateral load resisting system to contradict these forces (lateral loads referenced ASCE 7-95). For each structural frame, wind loads vary from 17 to 21 psf at heights from 0 – 15 feet to 50 – 60 feet. Varied loadings were applied to architectural secondary components; walls, roof panels, the roof perimeter, corners, and overhangs. Seismic effects were countered with a dual system of ordinary moment frames of steel and concentrically braced frames.

The previously stated loadings have been compared to the values given in the IBC (2000). Changes in arena's design abide to the following list load 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



There are 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 were designed to resist wind, 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 were assumed to act vertically on the horizontal projection on a *face*.

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, span, and tributary width of the steel joist and/or truss used. The typical superimposed roof load is 5 psf.

This study investigates the roof and lateral framing systems. Naturally, these alterations affected the floors framing into the lateral system, so the typical floor system will undertake a change. As these proposed structural issues were resolved, a study of how these modifications impacted the architectural outlook and mechanical system took place.

Problem Solution:

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. The loads of this superstructure can be carried by fewer 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 need to be supported by larger interior columns, since three were eliminated.

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 have been explored. Due to the grand concourse and mezzanine floor-to-floor height, there was very little change in floor thickness. However, the advent of open web steel joists adjusted the ceiling heights.

Structural Redesign

Gravity load information was compiled through STAAD/Pro 2000 and indeterminate analysis checks. Minimum requirements for deflection, ponding instability, and general roof construction conform to the structural provisions in the IBC. Configuration, geometry, bracing, and designation conform to the NUCOR/Vulcraft-Group catalog, and are compared to the 1998 SJI manual (Steel Joists and Joist Girders)*. Steel is designed in accordance with the LRFD (Manual of Steel Construction). Concrete and overall floor assembly references ACI 318-02 (Building Requirements for Structural Concrete) and 1999 Steel Deck manual, respectively. Some vibration effects are considered due to floor vibration characteristics by AISC guidelines.

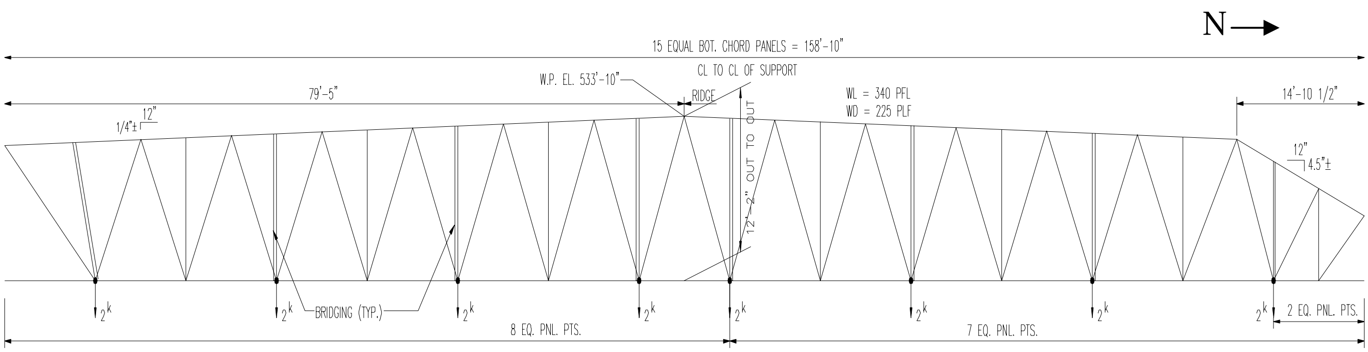
* Provided by The New Columbia Joist Company (NCJ).

Existing SLH Joist:

Super long span joists are not recognized as a SJI category. Vulcraft lists super long span joists (in their catalog), but these members are proprietary and not SJI standard. Also, the arena joists are deeper than those listed in the catalog. All structural members specify ASTM (American Society for Testing of Materials) A36 steel. The joist manufacturers designed the joists based upon the loading criteria provided by the structural designers at Ewing Cole.

There are two long span open web steel joists supporting the arena's roof ('A'&'B'). They span 158'-10" in the North-South direction. There only difference is in their loading. Due to rigging conditions, joist type 'B' is designed for additional 2000 lb. point loads applied at the bottom chord bridging locations. These point loads are spaced every two panel, approximately every 21'-2" (excluding ridge). Both joists sustain uniform live & superimposed dead loads. Each joist is located approximately 43 feet above the ground floor. The loading on joist type 'B' is considered for analysis.

Figure 7 : Long Span Open Web Steel Roof Joist (No Uniforms Loads *Shown*)



Geometry –

Span: 158'-10", CL to CL of support

Tributary Width: 11'-0" (Typ.)   Tributary Area: 1747 sf

Loads –

Dead: 10.5 psf (Decking, Insulation, EMPD) + Self Weight

Live: 30 psf (Roof)

STAAD Output ("SLH.std", Appendix A) –

Maximum Node displacement: 1.171 in. (down)

Deflection Limit*: ΔLL/240 = 7.944 in., therefore OK.

* IBC 2000, Section 1604.3

Ponding vs. Node Displacement –

Vertical Distance from Joist Ridge to End Support: 2.03 in.

1.17 < 2.03, therefore NO Ponding Instability*.

* IBC 2000, Section 1611.2

Joist-to-Truss Load Transfer –

Reactions (F_y): $^{+}$109.56 (Left End)* $^{+}$91.65(Right End)*

* Combined top and bottom chord reactions

Approx. Vertical Loads (onto Girder):

Distributed: (109.6 + 91.7)/2 = 100.7 kips

Point: 100.7/2 = 50.3 kips @ each end (support)

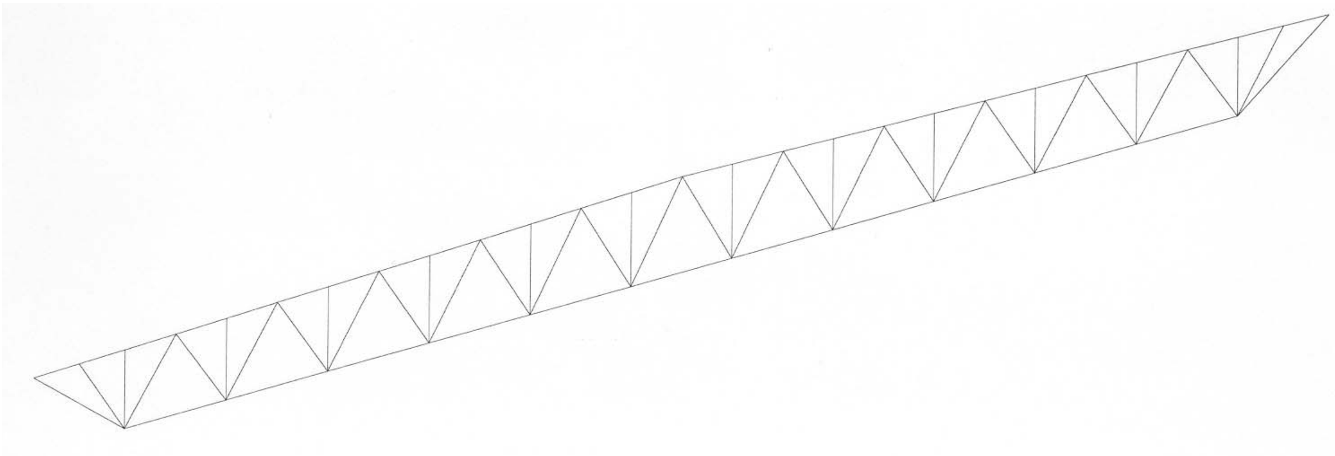
There are 14 total joists. Therefore, there would be 14 (50.3k) point loads along each new E-W Truss.

Truss Design:

Versions of open web steel trusses, used as primary framing members, may be considered as joist girders. Joist girders are typically designed as a simply supported truss. Ideally, the concentrated loads are at panel points, eliminating bending in the chord angles. Off panel loads can be accommodated, but they can increase chord size requirements. They are designed as simple spans supporting equally spaced concentrated loads are considered to act as the panel points of the joist girders. Depth is defined at the centerline of the joist. All joists are fabricated with camber unless otherwise specified.

As mentioned in the problem statement, instead of having two trusses spanning in the same direction as the roof joists (N-S) and frame into girders and columns, trusses were designed spanning the East-West direction. The open web steel roof joists will directly frame into the trusses. The vertical point loads produce are concentric, introducing no moment into the truss. The design has been regulated by Vulcraft & SJI for the configuration chosen.

Figure 8 : Truss Isometric Representation



* SEE "EWTruss.std" in Appendix B for STAAD input & output relating to the following material.

Geometry –

Span: 171'-5 1/2", CL to CL of support

Panel Length: 13'-4 13/16" (Typ.)

Depth @ Support: 10'-0"

Depth @ Ridge (Centerline): 12'-8 1/8"

Tributary Width: 97'-0" (Typ.) Tributary Area: 16,631 sf

Interior Supports (2) –

Node # 5: 65'-7 7/16" from left end (105.84' from right end)

Node #13: 119'-2 7/8" from left end (52.22' from right end)

Loads –

Dead*: Self Weight

Live: 30 psf; 30 psf X 97' = 2.91 klf (distributed)

* Supermposed Dead Load was considered in joist design, i.e. transferred here by the point loads (STAAD).

Long Span Configuration –

Top Chord Pitch: 3/8"/1' (No Bottom Chord Pitch)

of *Interior* Panels: 11 (reduced from 13)

Vulcraft & SJI Comparison by Configuration –

SJI BG Series; Load Spacing / Girder Depth = 13.4/11.632 = 1.152, therefore load both diagonals and verticals.

Vulcraft SLH; Minimum Pitch (Double Pitched Top Chord): 1/4"/1' (camber)

Member Sizes –

Top Chord:	W30X108	A36
Web Members:	W18X35	A36
Bottom Chord:	W12X16	A36

Average Weight –

Typical Panel Length: 13'-4 13/16", Between Beams 46 & 49

3rd from the left (excluding tapered end into support).

Approx. Panel Member Weights: W30X108 = 1450 lb. (Top Chord)

W18X35 = 469 lb. (Bottom Chord)

W12X16 (2) = 424 lb. (Diagonal Web Members)

W12X16 (2) = 372 lb. (Horizontal Web Members)

Approx. Truss Weight (Wt.): 11 Panels + Tapered End Weight (2) = 2.72k(11) + 1.73k(2) = 33.4k

33.4k / 171.46ft. = 0.1947 klf

Web Members Requirements –

Tension Members; Design Tensile Strength - LRFD manual, 6-44

Tributary Area: Panel Length X Tributary Width = 1301 sf

Total Panel Load: 201(SW) + 30(LL) = 231 psf

A36 Properties: $F_y = 36$ ksi $F_u = 58$ ksi

Yielding	Fracture
$\Phi_t = 0.90$	$\Phi_t = 0.75$
$Pn = F_y Ag$	$Pn = F_u Ae$
$Ag = Pn/\Phi F_y$	$Ae = Pn/\Phi F_u$

Pn, Tension in Web = Trib. Area [sf] X Load [psf]

Pn = 1301(231) = 300.5k

$Ag_{(REQ'D)} = 300.5k/(.9(36))$ [k/ksi]
$= 9.27\ in^2$ *

$Ae_{(REQ'D)} = 300.5k/(.75(58))$ [k/ksi]
$= 6.90\ in^2$

Other Possible Web Shapes –

W12X50: 14.7 in^2

W12X45: 13.2 in^2

W12X40: 11.8 in^2

W10X45: 13.3 in^2

W10X39: 11.5 in^2

Design Compressive Strength (Top Chord) - LRFD of Steel Structures, 6.4

W30X108 Properties: $A = 31.7\ in^2$ $Ix = 4470\ in^4$ $Iy = 146\ in^4$

Euler Buckling Load: $P_{cr} = (\pi^2 EIy)/L^2 = (3.14^2(29_E^{3})146) / 2057.5^2$

$P_{cr} = 9.86k$

$P_{ACTUAL} = 1.38k$

A new SLH joist will be designated upon the loading information provided in the previous two sections (Existing SLH Joist & Truss Design). Joist geometry changes include; spacing, depth, and pitch. The span and loads will remain the same. Corresponding horizontal & diagonal bridging for will also be acknowledged. The following details were taken from the Vulcraft SLH Series catalog.

New SLH Joist:

The existing open web steel joists may be reduced in depth and quantity while providing adequate roof support. This alteration may allow some supporting members to be removed. Although the distributed load over the roof will remain the same, the rearrangement of point loads may allow certain framing members to be decreased. Hence, the tributary width of each joist has been altered.

* SEE "SLH.std" in Appendix A for STAAD input & output relating to the following material.

Geometry –

Span: 158'-10", CL to CL of support (N-S)

Tributary Width: 14'- 3 7/16" (Typ.)

Loads –

Dead: Self Weight (included in SLH designation)

Live: 30 psf X 14.29 ft. = 429 plf

Designation; 112SLH21 –

Depth: 112"

Approx. Wt.: 91 plf

Total (Safe) Capacity: 770 plf

LL / ft: 516 plf

Therefore, this joist has minimum capacity requirements & meets general geometrical needs.

112SLH21 Bridging Spacing –

Min. Bolt Diameter: 5/8" A325

Min. Spacing of Bridge Lines: 30'-0"

112SLH21 Horizontal & Diagonal Bridging –

Spacing: .66 X Depth = 6'-1"

Horizontal & Diagonal Angle Size: 2 ½"x2 ½"x3/16"

New Open Web Steel Joist (with Concrete Slab) Floor System:

* For Existing Floor Framing See Figure 5, pg. 7.

* For New Floor Framing See Figure 9, pg. 16.

Each joist span should not exceed 24 times the depth of the joist. Depending on the orientation, horizontal or diagonal bridging may be required. The spacing of the joist is related to the floor load magnitude, span capacity of decking, load carrying capacity, and desired floor depth. Existing smaller W-Shapes may still be needed for lateral resistance.

Geometry –

Long Direction: 39'-0" (N-S)

Short Direction: 33'-6" (E-W)

Slab Depth: 2 ½"

Deck Depth: 9/16" Form Deck, USD-99 pg. 52.

Floor Thickness: 3'-1/16"

Joist Span: 33'-6" (E-W)

Joist Tributary Width: 6'-6"

Joist Tributary Area: 217'-9"

Designation; 18K5 –

Depth: 18"

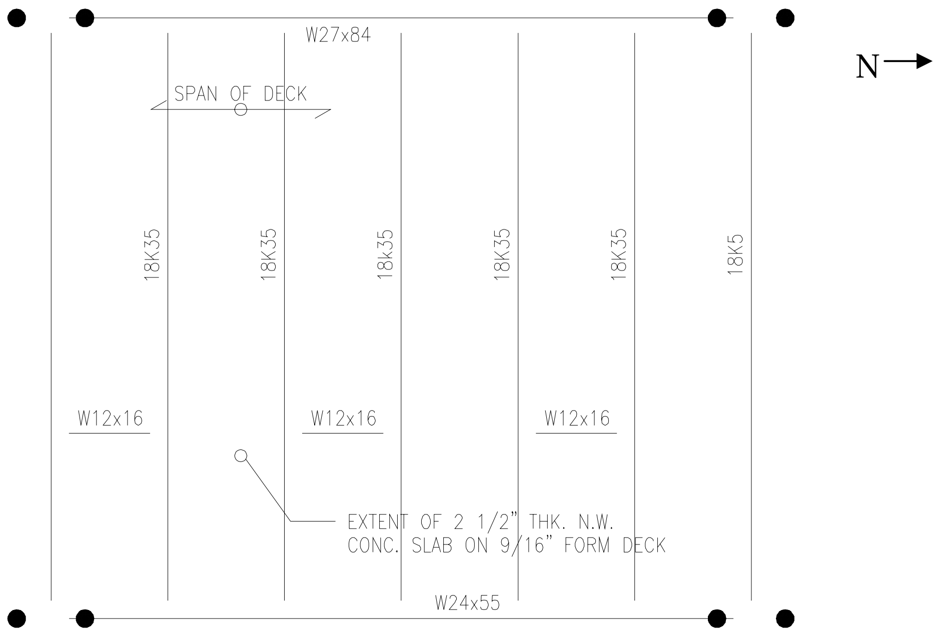
Approx. Wt.: 34 plf

Total (Safe) Capacity: 214 plf

LL / ft: 110 plf

} Load values wrt 18K5 joist designation for a 34ft. span.

Figure 9 : Open Web Steel Joist Floor Framing (Typ.)



^ Solid Dots Indicate Moment Connections at Beam/Column Joints ^

Floor Vibration:

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. So, the required ceiling heights can remain relatively unchanged.

An open web joist is typically supported at the ends by a seat on the girder flange. The bottom chord is not connected to the girder. The seats are designed by NCJ to resist bearing forces, however, the connections to the supporting structure must be designed by the specifying professional. This support (detail) provides much less flexural continuity than shear connected beams, reducing both the lateral stiffness of the girder panel and the participation of the mass of adjacent bays in resisting walker-induced vibration.

Breadth Study

Mechanical:

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. 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 a space. Examples of these are unit heaters, cabinet unit heaters, and fan coil units.

The air handling systems will consist of a combination of Constant Air Volume (CAV) and Variable Air Volume (VAV) systems. There are 13 new air handling units (AHU) serving the new and renovated spaces. CAV 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 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.

Central exhaust systems will serve toilet rooms, showers, locker rooms, janitor closets, electrical closets, and support spaces throughout the facility. Exhaust ductwork will be combined and run to inline centrifugal fans located in the new mechanical room. Exhaust fans will discharge though louvers to the outside.

Mechanical Redesign:

Structural changes have not affected the mechanical system much at all. The duct work running between filler beams and within roof framing does not have to be adjusted. The largest ductwork lies within the roof framing over the outskirts on the event area. These 42 inch ducts can be constructed and serviced through the roof joists, even with a 4 inch outer layer of insulation.

A different type of unit is a CAV unit was used in the adjoining natatorium, but it varies slightly from the CAV system above. They are direct expansion units that have air-cooled condensing units mounted on grade. This system could be applied to the arena, but more attention was directed to the utilization of neighboring spaces (natatorium) and the dehumidification process.

Pushing cool, *dry* air indoors and exhausting the warm, dry air (humidity) outdoors is the dehumidification concept. Naturally, this is not only important in swimming pool areas, but all athletic event areas. Temperatures on the event floor are unable to be regulated due to player activity. This process is intended to increase the comfort of spectators and other occupants.

One air handler, in the adjacent natatorium, is oversized to condition the air for the audience. The manufacturer chosen did not make a 100% outdoor air unit. When serving a high occupancy space, the number of people drives up the outdoor air requirement (ASHRAE Std. 62). The designers and the client wanted a pool unit. Pool units have better insulation and better coils to resist the corrosive pool environment. A normal AHU with a coated coil would save money and space. The unit only needs to be 8,000 CFM.

Mechanical Recommendations:

Des Champs, A Unit of Entrodyne Corporation –

Des Champs is a leader in developing innovative solutions for energy recovery, outside air conditioning, improved indoor air quality, and air-to-air heat exchangers. The company was founded in 1973 with the invention of the Z-Duct® air-to-air heat exchanger. Since then, Des Champs has obtained 15 patents and introduced a host of new products recognized for their engineering innovation. Des Champs has developed and patented products that solve indoor air quality (IAQ) problems. The Wringer®, introduced in 1990, has become the standard outside air dehumidifier and the preferred solution for efficient code-required ventilation.

Wringer® 2000 –

^ Indoor Pool Dehumification Product ^

www.deschamps.com

The Wringer 2000 is a 100% outside air all-season pool dehumidification unit. It uses energy recycling to heat pool water and air efficiently and cost effectively. Operating costs are lower since only outdoor air is used, without compressor operation, to dehumidify for most of the year. It automatically changes its operating mode to match seasonal climatic changes. It selects the most economical operating mode for the conditions, and recovers energy in the dehumidification process.
Units are available from 1,000 CFM through 24,000 CFM.
Optional space sensible cooling and domestic water heating are available.

Architecture:

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. The hilltop campus slopes into Victorian Lewisburg, a town in which historic preservationists have much influence throughout the community.

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

Architectural Redesign:

The transportation problem has two aspects to explore; interior column placement, and corridor size. The arrangement of the columns and adjoining walls is crucial in providing efficient space for occupants to travel throughout the concourse. However, the erection of some interior steel columns can be avoided due to the implementation of a new primary roof truss. In the recent years, there has been a tendency for university projects, event halls, and stadiums to devise relatively narrow corridors. In the arena, the largest corridor width is 12 feet, located on the ground floor. This same area has a width averaging 5 feet on the concourse and mezzanine levels. Also, there is a larger variance in corridor size when occupants pass through the arena into the natatorium at any level.

The elimination of three columns along the East and West seating sections increase the flow people throughout the event area. If more columns were removed, even more space would be generated. However, the immensity of the remaining columns would be an eyesore due to a drastic increase in volume. If corner columns were to be designed, the side walls would be changed from Ground Face CMU to smaller masonry units. Also, a slightly higher hue than the existing exterior brick is recommended, so that the lighting accents the wall and not the columns.

Original Interior Columns –

Length of Seating Access, E-W (Corridor-to-Seating): 135'-6"

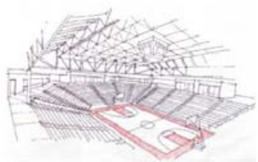
Average Uninterrupted Access, E-W (Corridor-to-Seating): 29'-3"

New Interior Columns –

Length of Seating Access, E-W (Corridor-to-Seating): 135'-6"

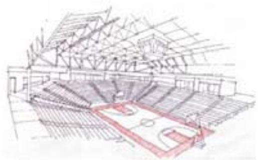
Average Uninterrupted Access, E-W (Corridor-to-Seating): 52'-10" *

* SEE "EWTruss - SproEdit" in Appendix A for column/support placement (STAAD Input).



Conclusion

The blueprint of this facility was minimally impacted by the new design elements. All architectural criteria were met and adequately satisfied. Structural analysis of the gravity system, lateral braces, and roofing concept revealed favorable results. The massive roof trusses and joist girders do not constrain the HVAC systems. Rigging and acoustical equipment arrangement will be altered, but the existing sections are movable. Different light positioning, along the corridors, will augment a material change along interior walls. If these improvements invoke a more pleasurable experience in attendees, a higher crowd turnout can be expected.



APPENDIX A

The STAAD (Reported) Output Could *Not* Be Included (in this PDF).
The Following Data *Is* Included - SproEdit (text editor).

SLH - SproEdit

```
STAAD PLANE SLH
START JOB INFORMATION
JOB NAME Gravity Load Analysis - SLH
JOB CLIENT amm - Dr. Ali Memari
JOB NO 1
JOB PART B
JOB REF S2.4F
ENGINEER NAME B.Lott
ENGINEER DATE 16-Mar-03
END JOB INFORMATION
INPUT WIDTH 79
UNIT FEET KIP
JOINT COORDINATES
1 0 0 0; 2 10.59 0 0; 3 21.18 0 0; 4 31.77 0 0; 5 42.35 0 0; 6 52.94 0 0;
7 63.53 0 0; 8 74.12 0 0; 9 84.71 0 0; 10 95.3 0 0; 11 105.89 0 0;
12 116.48 0 0; 13 127.07 0 0; 14 137.66 0 0; 15 148.24 0 0; 16 153.54 0 0;
17 158.83 0 0; 18 0 10 0; 19 7.93 10.22 0; 20 15.89 10.44 0; 21 21.19 10.58 0;
22 26.47 10.72 0; 23 31.77 10.87 0; 24 37.06 11.01 0; 25 42.35 11.16 0;
26 47.65 11.3 0; 27 52.94 11.44 0; 28 58.24 11.59 0; 29 63.53 11.73 0;
30 68.78 11.88 0; 31 74.12 12.02 0; 32 79.42 12.12 0; 33 84.71 12.03 0;
34 90.01 11.89 0; 35 95.3 11.76 0; 36 100.59 11.61 0; 37 105.89 11.48 0;
38 111.18 11.34 0; 39 116.48 11.07 0; 40 121.77 11.07 0; 41 127.07 10.93 0;
42 132.36 10.79 0; 43 137.66 10.65 0; 44 143.96 10.49 0; 45 148.24 8.85 0;
46 153.54 6.79 0; 47 158.83 4.79 0;
MEMBER INCIDENCES
1 18 19; 2 19 20; 3 20 21; 4 21 22; 5 22 23; 6 23 24; 7 24 25; 8 25 26;
9 26 27; 10 27 28; 11 28 29; 12 29 30; 13 30 31; 14 31 32; 15 32 33; 16 33 34;
17 34 35; 18 35 36; 19 36 37; 20 37 38; 21 38 39; 22 39 40; 23 40 41; 24 41 42;
25 42 43; 26 43 44; 27 44 45; 28 45 46; 29 46 47; 30 18 2; 31 19 2; 32 2 20;
33 20 3; 34 3 21; 35 3 22; 36 22 4; 37 23 4; 38 24 4; 39 24 5; 40 25 5;
41 26 5; 42 26 6; 43 27 6; 44 28 6; 45 28 7; 46 29 7; 47 30 7; 48 30 8;
49 31 8; 50 32 8; 51 32 9; 52 33 9; 53 34 9; 54 34 10; 55 35 10; 56 36 10;
57 36 11; 58 37 11; 59 38 11; 60 38 12; 61 39 12; 62 40 12; 63 40 13; 64 41 13;
65 42 13; 66 42 14; 67 43 14; 68 44 14; 69 44 15; 70 15 46; 71 45 15; 72 46 16;
73 16 47; 74 1 2; 75 2 3; 76 3 4; 77 4 5; 78 5 6; 79 6 7; 80 7 8; 81 8 9;
82 9 10; 83 10 11; 84 11 12; 85 12 13; 86 13 14; 87 14 15; 88 15 16; 89 16 17;
MEMBER PROPERTY AMERICAN
1 TO 29 TABLE ST W24X104
74 TO 89 PRIS YD 1.275 ZD 0.875 YB 1.123 ZB 0.0542
30 TO 73 TABLE LD L60608
UNIT INCHES KIP
CONSTANTS
E 29000 MEMB 1 TO 89
POISSON 0.3 MEMB 1 TO 89
DENSITY 0.000283 MEMB 1 TO 89
ALPHA 6e-006 MEMB 1 TO 89
UNIT FEET KIP
SUPPORTS
1 17 18 47 PINNED
MEMBER TRUSS
30 TO 73
LOAD 1 UNIFORM LIVE LOAD
MEMBER LOAD
1 TO 29 UNI GY -0.34
LOAD 2 RIGGING ADD'NL LOAD
JOINT LOAD
4 6 8 9 11 13 FY -2
LOAD 3 SUPERIMPOSED DEAD LOAD
MEMBER LOAD
1 TO 29 UNI GY -0.225
LOAD 4 SELF WEIGHT
SELFWEIGHT Y -1
LOAD COMB 5 D+L
3 1.2 4 1.0 1 1.6
LOAD COMB 6 D+L W/ RIGGING
3 1.2 4 1.0 1 1.6 2 1.6
PERFORM ANALYSIS
FINISH
```

APPENDIX B

The STAAD (Reported) Output Could *Not* Be Included (in this PDF).
The Following Data *Is* Included - SproEdit (text editor).

EWTRUSS - SproEdit

```
STAAD PLANE EW TRUSS
START JOB INFORMATION
JOB NAME Joist Transfer Analysis
JOB CLIENT amm - Dr. Ali Memari
JOB NO 2
JOB PART i
JOB REF 24f.dwg
ENGINEER NAME B.Lott
ENGINEER DATE 06-Apr-03
END JOB INFORMATION
INPUT WIDTH 79
UNIT INCHES KIP
JOINT COORDINATES
1 144 0 0; 2 304.864 0 0; 3 465.728 0 0; 4 626.592 0 0; 5 787.452 0 0;
6 948.32 0 0; 7 1109.18 0 0; 8 1270.06 0 0; 9 1430.91 0 0; 10 1591.77 0 0;
11 1752.64 0 0; 12 1913.5 0 0; 13 0 120 0; 14 72 122.25 0; 15 144 124.5 0;
16 224.432 127.013 0; 17 304.864 129.527 0; 18 385.296 132.04 0;
19 465.728 134.554 0; 20 546.16 137.068 0; 21 626.592 139.581 0;
22 707.024 142.095 0; 23 787.456 144.608 0; 24 867.888 147.122 0;
25 948.32 149.635 0; 26 1028.75 152.15 0; 27 1109.18 149.635 0;
28 1189.61 147.122 0; 29 1270.05 144.608 0; 30 1350.48 142.095 0;
31 1430.91 139.581 0; 32 1511.34 137.068 0; 33 1591.77 134.554 0;
34 1672.21 132.04 0; 35 1752.64 129.527 0; 36 1833.07 127.013 0;
37 1913.5 124.5 0; 38 1985.5 122.25 0; 39 2057.5 120 0;
MEMBER INCIDENCES
1 13 14; 2 14 15; 3 15 16; 4 16 17; 5 17 18; 6 18 19; 7 19 20; 8 20 21;
9 21 22; 10 22 23; 11 23 24; 12 24 25; 13 25 26; 14 26 27; 15 27 28; 16 28 29;
17 29 30; 18 30 31; 19 31 32; 20 32 33; 21 33 34; 22 34 35; 23 35 36; 24 36 37;
25 37 38; 26 38 39; 27 1 2; 28 2 3; 29 3 4; 30 4 5; 31 5 6; 32 6 7; 33 7 8;
34 8 9; 35 9 10; 36 10 11; 37 11 12; 38 13 1; 39 14 1; 40 15 1; 41 16 1;
42 16 2; 43 17 2; 44 18 2; 45 18 3; 46 19 3; 47 20 3; 48 20 4; 49 21 4;
50 22 4; 51 22 5; 52 23 5; 53 24 5; 54 24 6; 55 25 6; 56 26 6; 57 26 7;
58 27 7; 59 28 7; 60 28 8; 61 29 8; 62 30 8; 63 30 9; 64 31 9; 65 32 9;
66 32 10; 67 33 10; 68 34 10; 69 34 11; 70 35 11; 71 36 11; 72 36 12; 73 37 12;
74 38 12; 75 39 12;
MEMBER PROPERTY AMERICAN
1 TO 26 TABLE ST W30X108
27 TO 37 TABLE ST W18X35
38 TO 75 TABLE ST W12X16
SUPPORTS
5 8 13 39 PINNED
CONSTANTS
E 29000 MEMB 1 TO 75
POISSON 0.3 MEMB 1 TO 75
DENSITY 0.000283 MEMB 1 TO 75
ALPHA 6e-006 MEMB 1 TO 75
UNIT FEET KIP
MEMBER TRUSS
38 TO 75
LOAD 1 SELF WEIGHT
SELFWEIGHT Y -1
LOAD 2 SLH POINT LOADS
JOINT LOAD
1 TO 12 FY -50.3
LOAD 3 UNIFORM LIVE LOAD
MEMBER LOAD
1 TO 26 UNI GY -2.91
LOAD COMB 4 D+L  W/ SW
2 1.2 3 1.6 1 1.0
LOAD COMB 5 D+L  W/O SW
2 1.2 3 1.6
PERFORM ANALYSIS
FINISH
```