The Structural Analysis and Redesign of Boyds Bear Country in Pigeon Forge, Tenneessee and Its Related Systems

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Structural Option
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Boyds Bear Country

Pigeon Forge, Tennessee

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http://www.arche.psu.edu/thesis/eportfolio/2007/portfolios/lew152/

Project Team:

Owner: Boyds Collections, Ltd.
Architecture: LSC Design
Structural: C.S. Davidson, Inc.
Construction Management: Kinsley Construction
Site Contractor: Blalock and Sons
General Construction: Rouse Construction
Structural Steel: Quality Machine and Welding
Mechanical: Engent Plumbing and Heating
Electrical: Advent Electrical, Inc.
Elevator: Otis Elevator Company **Sprinkler:** MASCO

Structural System:

Steel Structural System clad in Decorative Wood
Masonry Walls: both 1500psi CMUs and 2800psi Ivany
Composite Slab Floors: 3" x 20 gauge Type VL galvanized
Timber Truss Roof Framing: Pressure Treated Southern Pine
Lateral System: Concentric Braced Frames and Masonic Shear Walls
Wall Framing: Cold Formed Steel with Plywood Sheathing
Additional Design Loads considered for Large Scale Christmas Decorations

Building Envelope:

Front façade: 18" wide snap-on metal batten wall panels on CMUs
Accents: 6" think fieldstone or 6" colored CMUs on cold-formed steel
Windows: aluminum clad wooden frames, reaching ~30' in height.
Louvers: aluminum and wood ranging in height from 2' to nearly 30'
Roof finish: 18" wide structural vertical seam metal roof panels, galvalume finish
.

Architecture:

Large scale Pennsylvania Dutch barn.
Mural: ~40'x60' of the company's trademark bears constructing and decorating the building
Steel silo: Large Boyds logo, measuring 20' dia. and domed at 65' high
Cupolas: Two 25' high topped with flags and one 36' high with life sized metal bear

Mechanical System:

13 AHUs ranging from 3100 – 8400 cfm
17 VAV Terminal Reheat Boxes heating to 98º
2 Boilers at 1030 mbh output serving supplemental hot water heaters
Supplemental electric heaters supply baths and stairwells
.

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Boyds Bear Country
Pigeon Forge, TN

Executive Summary

Boyds Bear Country, located in Pigeon Forge, Tennessee, is designed as a multi-functional space and tourist attraction for Boyds Collections Ltd. The 112,620 square foot building houses three floors of retail space with multiple cashier and information desks. Warehouse storage, a loading dock, a full sized restaurant, food court, ice cream parlor, and special events areas are scattered through the building, and offices occupy the fourth and top floor. The building is massive in scale, with each floor measuring 17'-8" in height.

The structural framing as originally designed at Boyds Bear Country is primarily a composite steel grid with wooden roof trusses and masonry retaining / foundation walls. Standard steel shapes used as beams and girders support metal deck and 3 inches of cast-in-place concrete. The lateral system consists of concentric braced frames, some of which are encased in masonry at the lower level. Shallow foundations secure the building to the site.

In studying the existing structure of Boyds Bear Country, it became apparent that the building, as constructed, implemented a wide variety of materials and methods of construction. Not only does this create added difficulties in the design and analysis of the structure, but the coordination of trades and site work became more difficult than originally intended.

Two options are studied in this report: a pre-cast concrete structural system and an engineered wood structural system. These are studied and compared for their structural efficiency, cost, schedule, coordination impact, and architectural impact.

A pre-cast concrete system can be implemented to replace the current one, reducing the number of required trades on site. This design features a floor system of double-tees supported with pre-cast members. The lateral force resisting system of the structure is made of pre-cast concrete panels. All masonry in the building is replaced with concrete. The design includes fewer pieces, and larger bay sizes, opening the retail floors up for maximum utilization of space. It exhibits a decreased cost, more compact construction schedule, and a decrease in the required trades. However, the concrete does not fit the overall aesthetic design of the building and would have to be masked in a fashion similar to the existing structure.

An engineered wood system allows for the most seamless integration of a structural system into the desired aesthetic design. The gravity system is a combination of open-web wooden joists and parallam. The lateral force resisting system is made fo pre-cast concrete panels. All masonry in the building is replaced with concrete. The application of wooden columns and girders creates a look of nature and tradition applied in an updated, oversized fashion. The implementation of a wooden system would create a greater number of columns in the floor plan and retain area; however they could be incorporated into display functions. This system also exhibits a decreased cost, more compact construction schedule, and a decrease in the required trades.

It is recommended that a pre-cast concrete system be implemented in the design of Boyds Bear Country.

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Boyds Bear Country
Pigeon Forge, TN

Introduction

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Boyds Bear Country
Pigeon Forge, TN

Introduction:

Boyds Bear Country, located in Pigeon Forge, Tennessee, is designed as a multi-functional space and tourist attraction for Boyds Collections Ltd. The town of Pigeon Forge is said to be "Your All-American Getaway" with attractions such as Dollywood and Smokey Mountain WildWater Rafting. This setting creates an atmosphere where Boyds Bear Country is right at home, taking the place of an oversized barn, invoking ideas of traditional Americana while still holding its scale amongst other strong attractions.

The 112,620 square foot building houses three floors of retail space with multiple cashier and information desks. Warehouse storage, a loading dock, a full sized restaurant, food court, ice cream parlor, and special events areas are scattered through the building, and offices occupy the fourth and top floor.

In studying the existing structure of Boyds Bear Country, it became apparent that the building, as constructed, implemented a wide variety of materials and methods of construction. Not only does this create added difficulties in the design and analysis of the structure, but the coordination of trades and site work became more difficult than originally intended. In order to minimize the complexity involved in all areas of construction, this report analyzes two alternative structural systems and their impact on the cost, coordination of trades, scheduling, and architecture of the building.

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Background of Existing Systems

Background of the Existing Structural System:

Framing Layout

The structural framing as originally designed at Boyds Bear Country is primarily a composite steel grid with wooden roof trusses. The main structural grid is made of standard steel shapes, listed below. A typical floor plan of the original framing system can be seen as Figure 1. It should be noted that all typical floor plans included in this report are from the second floor, as each floor is slightly different. A full set of all structural plans may be found in the appendix.

Structural Steel Shapes	Type	[ksi]
Wide Flanges and WTs	ASTM A992	50
Pipe – Type S, Grade B	ASTM A53	35
Tube – Grade B	ASTM A500	46
Plates	ASTM A36	36
Other Shapes	ASTM A36	36
¾" Diameter High Strength Bolts	ASTM A325	n/a

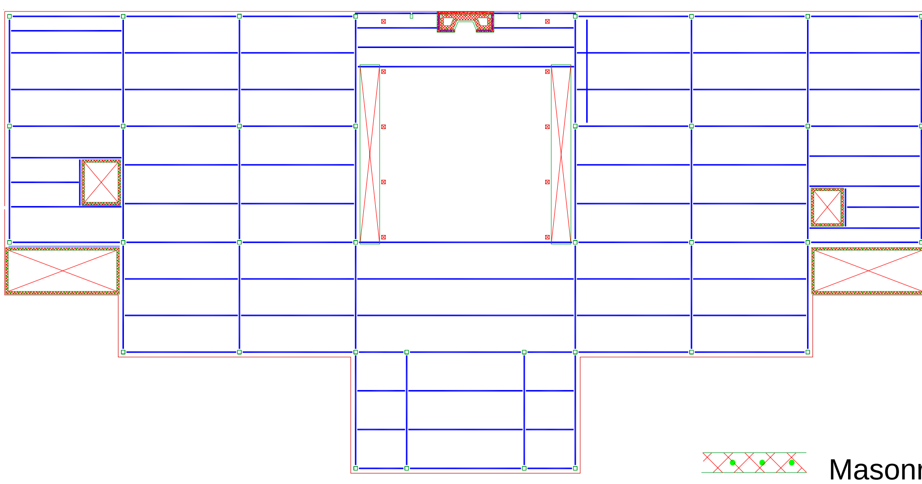

Figure 1: Original Structure Framing Plan

Typical bays measure ~30'x30' square with W16 beams, framing to W24 girders, which connect to steel tube columns. This framing grid varies around stairwells, elevators, and the front façade projection of the building.

Deeper members are located within the center bay, which features spans up to 60'. On the central floors, this center bay becomes and atrium flanked on either side by large escalators with decorative wooden timbers.

Structural wooden framing is located in other areas of the building, primarily in exterior seating areas. Structural joists, girders, and posts are typically specified as No. 2 Southern Pine. All roof framing consists of wooden trusses spaced 2' on center and were manufactured off site of primarily 2x4 No. 2 Southern Pine. These can be during construction in Figure 2.

Exterior walls on the ground floor are primarily concrete block, ranging from 8" to 16" thick; both common concrete blocks (1500 psi) and high strength Ivany blocks (2800 psi) are used. These blocks are also used in the construction of walls surrounding stairwells, mechanical rooms, and elevator shafts. It is important to note that a portion of these walls envelope the frames used for lateral resistance, and thus also contribute to the lateral stability of the structure. Interior walls throughout the building, and exterior walls on the upper floors, are constructed of cold-formed steel framing sheathed in plywood and gypsum board, as shown in Figure 3.

Figure 2: Roof trusses of 2x4 No.2 Southern Pine spaced at 2' OC.[1]

Figure 3: Light gauge steel framing with plywood sheathing[1]

Structural Slabs

Elevated slabs in the building are composite construction. All elevated slabs are supported on 3" x 20 gauge Type VL galvanized steel decking, and the slabs of the main structure are composed of 6½" thick, monofilament synthetic polypropylene fiber reinforced, 3,000 psi lightweight concrete. The slab of the Northeast pavilion / mechanical area is composed of 5½" of normal weight concrete. Secondary reinforcing consists of 6x6-W2.0xW2.0 welded wire mesh in both types of concrete. A cross-section of the typical interior slab can be seen in Figure 4 and a photo of the slab as placed in construction can be seen in Figure 5.

Interior floor slabs on grade are 4" thick, monofilament synthetic polypropylene fiber reinforced, 3,000 psi non-air-entrained concrete; with 6x6 W2.0x2.0 WWF on 4" of dense

gravel aggregate. Exterior slabs on grade are typically 5" thick, 4,000 psi air-entrained concrete; with 6x6 W2.0x2.0 WWF on 6" of dense graded aggregate.

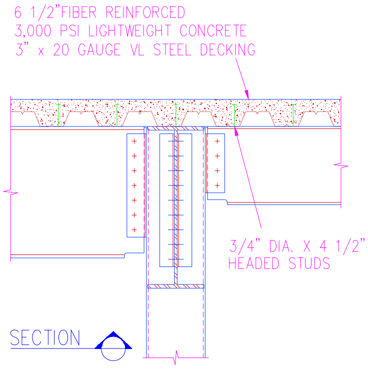

Figure 4:
Cross-section of typical slab

Figure 5: Composite slab as placed during construction[1]

Lateral Resisting System

Original drawings for Boyds Bear Country in Pigeon Forge, Tennessee call out two lateral systems, that of masonry shear walls and steel braced frames. In specific study of the design documents, it can be found that the primary lateral resistance system is concentric steel braced frames. A secondary masonry lateral resistance system can be found in 5 of the 8 braced frames in the building. These frames sit on either one or two masonry piers which are incorporated within reinforced block walls. In more detailed study of the building and its performance, it has been shown that lateral forces are collected and resisted by solely the braced frames; the masonry portions incorporated into the bases of the frames is merely a continuation of surrounding block walls. The two types of frames, chevron and crosses, can be seen in Figures 6 and 7. All eight of the concentric steel braced frames can be seen, highlighted in red, in Figures 8 and 9.

Figure 6: Frame with Double Angle Cross-Bracing[1]

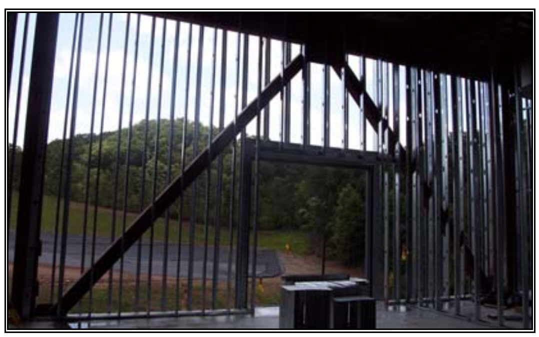

Figure 7: Frame with Tube Chevron Bracing[1]

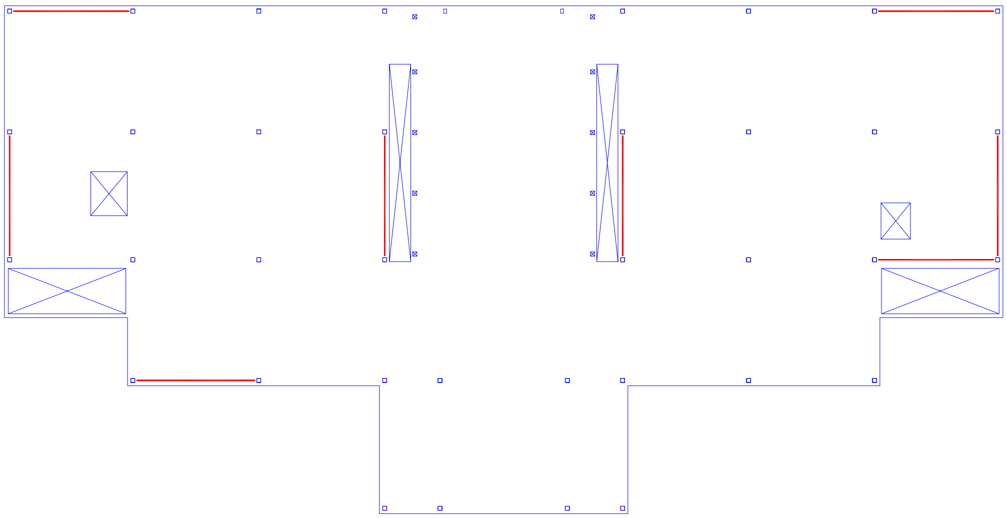

Figure 8: Original Lateral Resistance System Plan

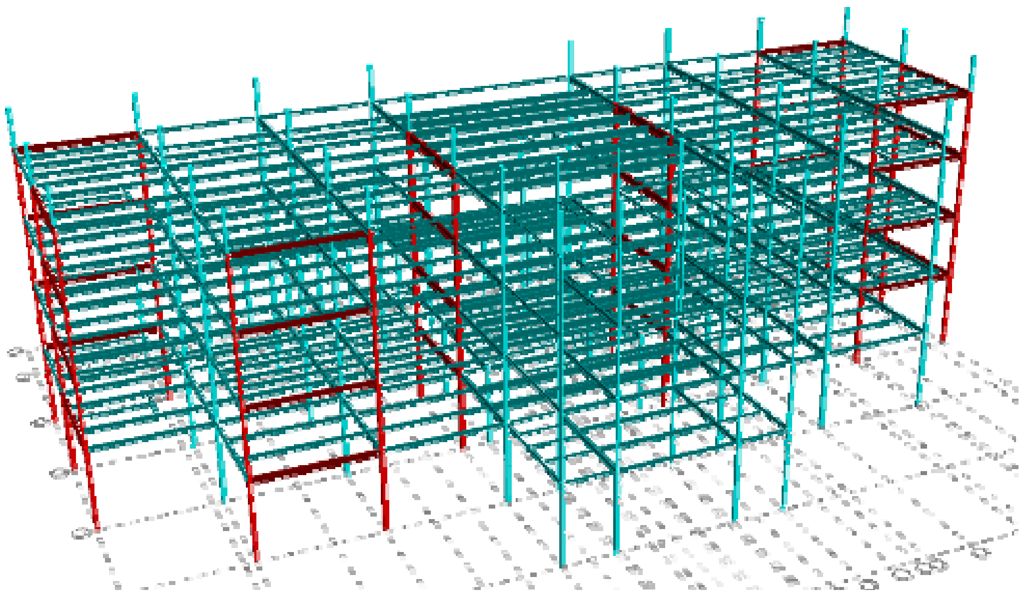

Figure 9: Original Lateral Resistance RAM Model

The floor system of composite steel beams, girders, and concrete deck acts as a diaphragm, transferring lateral forces to the frames at each of four elevated floor levels. Both wind and seismic forces are imparted as lateral loads on the structure, and through design calculations included in this report, it is found that seismic forces control the design of the structure.

Foundation System

Foundations of the building consist of shallow footings. All wall footings are simple thickened slabs measuring 2'-0" wide and 1'-0" thick. Column footings extend to a maximum of 3'-0" thick. Masonry piers are located scattered through the building, above grade. These tie the lateral force resisting braces to the foundation and are mainly located underneath columns adjacent to bathrooms and mechanical areas.

Foundations of the building are designed with a bearing pressure of 3,000 psf based on geotechnical investigations of the site. Typically, exterior footings extend to 3' below finished grade, to account for frost depths.

Footings consist of 3,000 psi cast in place concrete with reinforcing billet steel of ASTM A615, grade 60, with class B splices. Masonry piers in the building are constructed of Ivany block. Footings which have a pier surrounding a column are highlighted in Figure 10. The footings supporting typical columns measure 12.5 feet square and 30 inches deep. Figure 10 shows this typical footing circled.

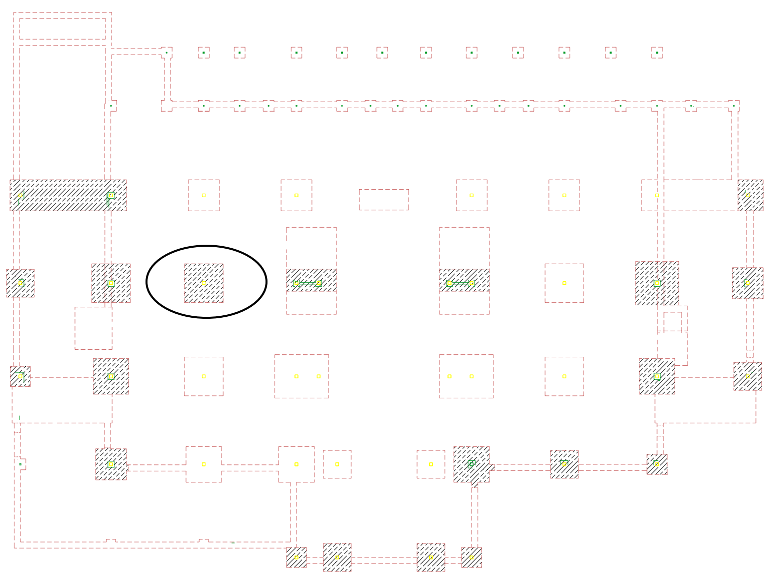

Figure 10: Original Foundation Plan

Expansion and Movement Joints

Vertical control joints are located at intersections of reinforced and un-reinforced CMU walls. Control joints in the floors slabs are required at 15'-0" OC in each direction. Control joints are not readily visible in the finished structure as they are covered with hardwood flooring and wooden column covers.

The main building itself, designed as a steel structure with a maximum length of 240', does not feature an expansion joint.

Proposal Problem
and
Potential Solutions

Proposal Problem and Potential Solutions:

Statement

Boyds Bear Country in Pigeon Forge, Tennessee was built as a combination of several materials, creating difficulties in both construction and design. The materials present in the building can be categorized as follows:

Steel
- Hot rolled structural members
- Metal decking
- Shear studs
- Bolted / welded connections
- Light gauge steel framing

Concrete
- Cast-in-place elevated slabs
- Lightweight cast-in-place elevated slabs
- Cast-in-place slab on grade
- Shallow foundations

Masonry
- Normal CMU block
- Ivany (high strength) CMU block
- Structural Piers

Wood
- Manufactured trusses
- Timbers

Variety of Finish Materials
- Gypsum board
- Plywood, etc.…

The design is complicated by the number of materials used in the building. These require additional analyses of material properties and interactions which can impact nearly all aspects of design. Structurally, one result of the use of numerous materials can be seen in the lateral resisting system. Here, the use of concentric steel braced frames is further complicated by the introduction of masonry piers and masonry walls, creating a large amount of additional considerations to successfully analyze system's behavior. Other services required, such as mechanical duct work, electrical wiring and lighting, all must be altered to adapt to these materials. Mechanical systems must account for variations in thermal properties, electrical systems must account for variations in conductivity, and lighting layouts must account for variations in the quality of finish materials. Overall, the inclusion of multiple materials in the building creates additional difficulties and considerations within the design process.

Completing the construction of a building also becomes more complicated with the use of numerous materials. This requires the attainment and coordination of many contractors. In the case of Boyds Bear Country, separate suppliers were used for each

trade including structural steel members, masonry block, cast-in-place concrete, wooden trusses, wooden timbers, mechanical equipment, electrical equipment, elevators, and sprinklers. A separate contractor was used for site work, general contracting (which included aspects such as roof trusses, exterior stone work, and light gauge steel), structural steel, mechanical systems, electrical systems, elevator systems, and sprinklers. With the addition of each contractor and each supplier, the required amount of coordination and the potential for error increases.

Specific difficulties in the construction of this building occurred with the coordination of masonry walls and structural steel. Masonry portions of the structure are designed as both non-retaining and retaining walls, and surround structural steel framing. During construction steel was erected and block placed around the basement level areas during the process of installing the first floor steel. After the masonry had set, the basement and first floor steel was plumbed, ripping apart the completed masonry walls. Difficulties such as this are less likely to occur as more construction is completed off-site and few trades are required.

Proposed Solutions

In order to lessen the downfalls created by the application of multiple structural materials, involving a number of different trades, two options are further considered in this report to transform the building into primarily a single material. Both of these materials lessen the amount of construction completed on site to be decreased. In doing so, the complications of contractor and site coordination can be further minimized.

Pre-Cast Concrete Alternative

The first option to be studied in depth is be the application of structural pre-cast concrete system. This pre-cast system focuses on double-tees supported by pre-cast beams, girders, and columns. The application of double-tees adapts well to the grid system currently developed for the building, and utilizes columns spaced at 30' and 60' on center. The individual member strength of this system adapts well to areas of varied loading, found supporting storage areas of the building. Stability and lateral force resistance is provided by pre-cast shear walls located near areas of vertical transportation. Specialized attention is required for the connections associated with the shear walls in order to ensure proper stability. Additional changes are made to the structural system in changing the retaining and foundation walls to cast-in-place concrete from the original masonry block. This eliminates a highly labor intensive material from the construction site, while utilizing a material already present in other phases of construction. Wooden trusses frame the roof, as currently applied in the structure. This allows for the completion of a roof with several complicated gables, as originally designed. Foundations will be concrete poured on site.

The breakdown of included materials can be listed as follows:

Steel
- Welded member connections
- Light gauge steel framing

Concrete
- Pre-cast concrete members
- Member toppings
- Cast-in-place retaining / foundation walls
- Cast-in-place slab on grade
- Shallow foundations

Wood
- Manufactured trusses
- Timbers

Variety of Finish Materials
- Gypsum board
- Plywood, etc….

Engineered Wood Products Alternative

The second option to simplify the use of materials in the structure comes in the use of wooden framing. Primary members of the structure are engineered wood products as opposed to large scale timbers; ensuring members free of large defects, with known properties, with higher strengths, and supporting sustainable design. Typical bays measure 22.5' by 30' and vary in size as required in lobby areas. Pre-cast concrete shear walls are utilized as the lateral force resisting system. Additional changes are made to the structural system in changing the retaining and foundation walls to cast-in-place concrete from the original masonry block. This eliminates a highly labor intensive material from the construction site, while utilizing a material already present in other phases of construction. Wooden trusses frame the roof, as currently applied in the structure. This allows for the completion of a roof with several complicated gables, as originally designed. Foundations will be concrete poured on site.

The breakdown of included materials can be listed as follows:

Steel
- Member connections

Concrete
- Pre-cast concrete shear walls
- Cast-in-place retaining / foundation walls
- Cast-in-place slab on grade
- Shallow foundations

Wood
- Manufactured floor trusses
- Laminated structural members
- Floor planks
- Manufactured roof trusses
- Stud wall framing

Variety of Finish Materials
- Gypsum board
- Plywood, etc….

Solution Methods

A combination of manufacturer supplied load tables, hand calculations, and computer programs are used to determine the proper structural members implemented in the structure. These are often material specific, and are detailed below.

Pre-Cast Concrete Solution Methods

The pre-cast concrete redesign option is completed using 15' wide double-tees, selected using load tables provided by the supplier, in this instance, by High Concrete Structures in Denver, Pennsylvania. Supporting members are designed to meet PCI and ACI 318-05 standards with finite element analysis using RISA-3D, PCA-Column, and PCI load tables. Shear walls are designed using RISA-3D, allowing for an accurate calculation of member drift. Additional considerations such as floor diaphragms are designed in MathCAD. The retaining and foundation walls are designed using hand calculations in MathCAD.

As a more massive system, the application of pre-cast concrete results in changes to the lateral force resisting and foundation systems. Lateral loads increase under seismic conditions, thus requiring a stronger system than currently applied to the building. This is accounted for in the design of pre-cast concrete shear walls, replacing the existing steel braced frames. The foundation system is required to carry larger loads than the existing system. Shallow foundations satisfy the loading created by this new system and are designed using MathCAD.

Engineered Wood Products Solution Methods

The wooden redesign option is completed using engineered wood products and thus designed using supplier load tables and backed by hand calculations, MathCAD calculations, and WoodWorks designs. All members are designed to meet NDS requirements. Additional requirements in the areas of vibration, deflection, fireproofing and other member protection issues, are completed by matching IBC and NDS requirements with available materials and suppliers.

Pre-cast concrete shear walls are designed to meet ACI 318-05 requirements with finite element analysis, using RISA-3D, MathCAD and hand calculations. The retaining and foundation walls are designed using hand calculations in MathCAD.

As a lighter system, the application of a wooden structure results in changes to the lateral force resisting and foundation systems. Lateral loads are decreased under seismic conditions, thus causing wind loading to control the design of the structure. Calculations are included determining the controlling lateral forces on the structure, and thus determine proper members to resist the selected forces. The foundation system also is required to carry lighter loads than in the existing system. Shallow foundations are adjusted to satisfy the loading created, including a design with special attention paid to areas supporting the masonry shear wall and its connections.

Structural System Analysis and Redesign

Structural Requirements

Pre-Cast Concrete Design

Engineered Wood Design

Structural System Analysis and Redesign:

Structural Requirements
Gravity System Requirements

As Boyds Bear Country is home to multiple use spaces, it is subject to multiple loading conditions. In the application of the alternate framing systems, the only gravity loading condition to vary is that of floor dead loads. Gravity loading requirements can be seen below.

Original Design Floor Dead Loads:	**[psf]**
Composite Floor Slab 5½" with 3" Deck	50
Beams / Columns	8
Flooring Finish	1
Ceiling Finish	1
Mechanical / Electrical	5
Total	**65**

Pre-Cast Concrete Design Floor Dead Loads:	**[psf]**
Double-Tee	82
Girders / Columns	25
Flooring Finish	1
Ceiling Finish	1
Mechanical / Electrical	5
Total	**114**
Compared to Original Steel System	**175%**

Wooden Design Floor Dead Loads:	**[psf]**
Joists / Sheathing	15
Girders / Columns	3
Flooring Finish	1
Ceiling Finish	1
Mechanical / Electrical	5
Total	**25**
Compared to Original Steel System	**38%**

Design Floor Live Loads:	[psf]
Retail Areas	100
Office Areas	100
Stairs, including landings, platforms, and exits	100
Light Storage Area	125

Design Roof Dead Loads:	[psf]
Wooden trusses	15
Sheathing and finish	5
Total	**20**

Design Roof Live Loads:		[psf]
Minimum Roof Live Load		20
Ground Snow Load	Pg	15
Flat Roof Snow Load	Pf	15.0
Snow Exposure Factor	Ce	1.0
Snow Load Importance Factor	I	1.0
Thermal Factor	Ct	1.0

Additional Design Dead Loads:		Unit
Escalators (each)	30	kips
Stairs	100	psf
Elevator	100	psf
Decorative Timbers (each)	10	kips
Fireplace (ground to 2nd floor) (3rd and 4th floors)	150 75	pcf pcf
Exterior Light Gauge Walls	10	psf

Special considerations are made for additional systems in the original structural design, and are likewise applied to each redesign. Additional loads are supplied by decorative wooden timbers, at 10 kips each, the masonry fireplace, which is considered to carry its own weight, and two large escalators, weighing approximately 30 kips each. Stairwells and elevators are designed as would be in any typical building at 100 psf.

Lateral System Requirements

The original lateral design of Boyds Bear Country references both ASCE 7-95 and ASCE 7-98 within its calculations in addition to the requirements of the Standard Building Code. All of these calculations were completed using Allowable Stress Design methods, and steel members were originally chosen using AISC Manual of Steel Construction, 9th Edition (1989).

For the purposes of this redesign, current codes are applied, including the 2003 International Building Code and ASCE 7-05. New members are selected using Load Factor and Resistance Design. Load combinations applied to the design are as follows:

1.4 Dead
1.2 Dead + 1.6 Live + 0.5 Roof Live
1.2 Dead + 1.6 Roof Live + (0.5 Live or 0.8 Wind)
1.2 Dead + 1.6 Wind + 0.5 Live + 0.5 Roof Live
1.2 Dead + 1.0 Earthquake + 0.5 Live + 0.2 Roof Live
0.9 Dead + (1.0 Earthquake or 1.6 Wind)

The controlling load combination for the lateral system of both the original structural system and the pre-cast concrete system is 1.2 Dead + 1.0 Earthquake + 0.5 Live + 0.2 Roof Live. The controlling load combination for the lateral design of the wooden structure is 1.2 Dead + 1.6 Wind + 0.5 Live + 0.5 Roof Live. Derivations of these loads may be found in the appendix, while the resulting lateral load values of each can be seen below.

Original System Vertical Seismic Distribution:	**$w_x h_x$**	**C_{vx}**	**V [kips]**	**V / Wall**
1st floor	51541	0.113	101	25
2nd floor	89984	0.197	176	44
3rd floor	126276	0.277	246	62
4th floor	187889	0.412	366	92
Total (Base)	**455691**	**1.000**	**889**	**222**

Pre-Cast Concrete System Vertical Seismic Distribution:	**$w_x h_x$**	**C_{vx}**	**V [kips]**	**V / Wall**
1st floor	69642	0.108	105	26
2nd floor	121499	0.188	183	46
3rd floor	173549	0.269	261	65
4th floor	279921	0.434	421	105
Total (Base)	**644611**	**1.000**	**968**	**242**

Wooden System Vertical Seismic Distribution:	$w_x h_x$	C_{vx}	V [kips]	V / Wall
1st floor	37061	0.109	56	14
2nd floor	64772	0.191	97	24
3rd floor	87352	0.258	131	33
4th floor	149618	0.442	225	56
Total (Base)	**338803**	**1.000**	**510**	**127**

Wooden System Vertical Wind Distribution:	Wall A [sf]	Roof A [sf]	V [kips]	V / Wall
Wind Loading E-W				
Grade	2088	0	41.8	10.4
1st floor	4152	0	85.4	21.4
2nd floor	4152	0	92.3	23.1
3rd floor	4152	0	96.6	24.2
4th floor	2064	7368	288.4	72.1
Total (Base Shear)	**16608**	**7368**	**604.5**	**151.1**
Wind Loading N-S				
Grade	1044	0	16.8	4.2
1st floor	2076	0	34.6	8.6
2nd floor	2076	0	38.0	9.5
3rd floor	2076	0	40.2	10.0
4th floor	3795	921	97.2	24.3
Total (Base Shear)	**11067**	**921**	**226.7**	**56.7**

Foundation System Requirements

Existing foundations of Boyds Bear Country consist of shallow footings. All wall footings are simple thickened slabs measuring 2'-0" wide and 1'-0" thick. Column footings extend to a maximum of 3'-0" thick.

Foundations of the building are designed with a bearing pressure of 3,000 psf based on geotechnical investigations of the site. Typically, exterior footings extend to 3' below finished grade, to account for frost depths.

Footings consist of 3,000 psi cast-in-place concrete with reinforcing billet steel of ASTM A615, grade 60, with class B splices.

Portions of the Structure Unchanged in Redesign Options

Several portions of the existing building are designed in a manner which clearly is the best option available. As such, these portions of the structure will remain consistent in all variations of structural designs considered.

The roof framing is accomplished through the use of wooden trusses, manufactured to specifically meet the requirements of the building. The trusses used in the original structure were designed and manufactured by Witt Building Materials of Knoxville, Tennessee. Trusses are spaced at 2 feet on center across the roof of the building. Variations in this layout are introduced to incorporate gables and copulas incorporated into the roof structure. These roof trusses are the most efficient and effective means of roof support, and thus will remain generally unchanged in all three structural designs.

All forms of vertical transportation are to remain generally the same as well. The two large escalators flanking the interior atrium of the building are specially designed for the space. Two elevators service the building. In the structural redesigns, one of these elevators is relocated to mirror the location of the other; however the elevator itself is left unchanged. This relocation allows for a symmetrical placement of shear walls and a continuous diaphragm. The walls surrounding the elevators are changed from masonry to pre-cast concrete panels to allow for a decreased requirement of field labor and to match the shear walls. Two stairwells are located in the building as well. These remain in the same location in all designs, and similarly to the elevators, the walls of the stairwells are changed from masonry to pre-cast concrete panels.

The existing wall framing system is composed of cold-rolled steel studs. This system remains in place as is in the pre-cast concrete redesign. Wall framing in the wooden redesign is adjusted to traditional wood stud framing. Standard dimension studs may be used in all cases.

In addition to the main structure, Boyds Bear Country also features several small buildings on the property, a silo, and pavilion or porch spaces. These areas are not part of the main structure and not included in either of the structural redesigns.

Pre-cast Concrete System Design

Floor System Design

The conversion from structural steel to pre-cast concrete allows for larger spans and thus larger bays within the building as determined by specific member designs. Bay size in this application is increased from 30'x30' to 30'x45', allowing for a decrease number of columns, connections, and individual members. The typical framing layout may be seen in Figure 11.

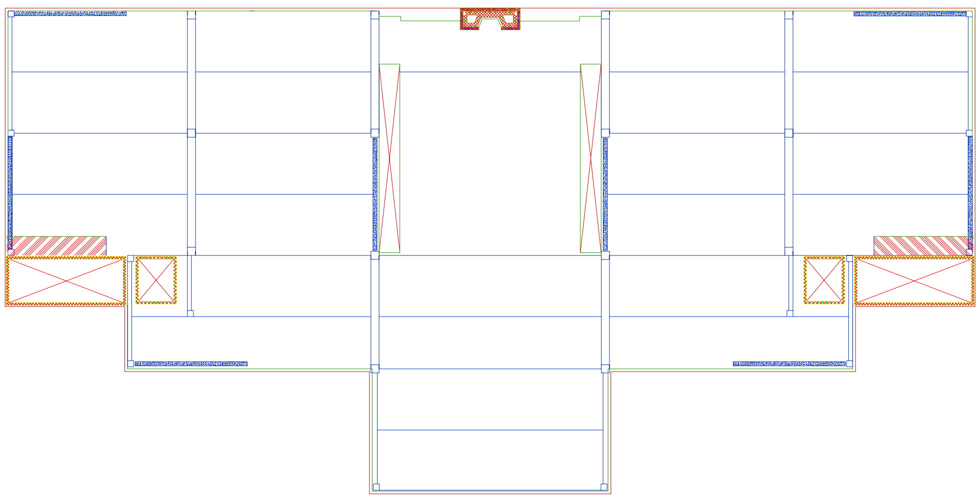

Figure 11: Pre-Cast Concrete Floor Plan

The major framing component of the pre-cast concrete gravity system is the standard 15' wide double-tee. These members were designed by determining live load requirements and desired spans. Manufacturer supplied load tables were then used which conform to standard PCI section design, and are included in the appendix. Double-tees located in the majority of the building, subject to retail and office loading, are designed to withstand 100 psf of live load. Double-tees located below mechanical areas, along the Eastern and Western faces of the structure, are designed to withstand 125 psf of live load. Members subject to the typical 100 psf live load are selected as 15DT34 128-S members, a 34" deep section with 12 half-inch pre-stressing strands in each stem. Members subjected to 125 psf live load are selected as 15DT34 168-S members, a 34" deep section with 16 half-inch pre-stressing strands in each stem.

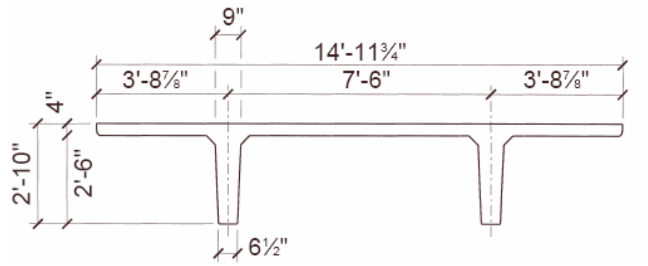

Figure 12: 15DT34 Cross-Section

The double-tees are supported with pre-cast L and inverted T girders, which are designed using similar load tables. The L girders are used where the structure frames into only one side of the beam, while the inverted T girders are implemented where the structure will be framing into both sides of the beam. Loading is determined by the live load applied to the supported double tees, and the girders span the width of two double-tees. All L girders in the structure are 12LB36 118-S sections, being a 36" deep section with 11 half-inch pre-stressing strands. Inverted T beams are designed as 24IT36 228-S and 24IT36 268-S sections, being 36" deep with 22 or 26 half-inch strands respectively.

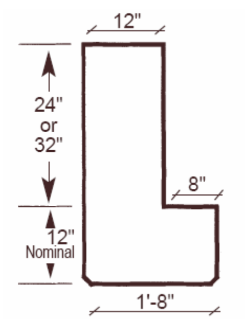

Figure 13: 12LB36 Cross-Section

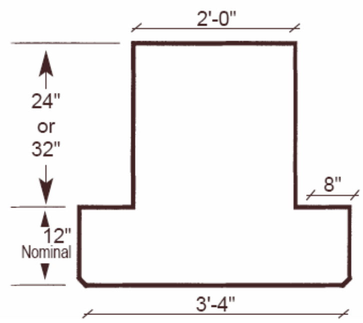

Figure14: 24IT36 Cross-Section

The pre-cast double-tees which act as the bulk of the floor system allow for larger spans then the original steel framing. As a result, bay sizes may be increased and the amount of columns required in the structure may be reduced. As applied in Boyds Bear Country, bay sizes increase from 30'x30' to 30'x45' and 30'x60'. Typical bay sizing can be seen in floor plans included in the appendix. The implementation of larger bay sizes allows for a reduced number of columns. Within a typical floor, the number of columns decreases from 36 to 28.

The columns used in this system are pre-cast concrete as well. All columns are considered to support only gravity loads, the loading of which was determined of both dead and live loads; internal loading was determined from these values using RISA-3D. These internal loading results were then applied to PCAColumn, which determined required sizes for both concrete and steel. Interior columns measure 24"x24" and all exterior columns measure 18"x18". Concrete strengths range from 6,000 psi to 8,000 psi as required by loading conditions. All specific calculations and final designs of pre-cast columns may be found in the appendix.

Lateral System Design

In the implementation of a fully pre-cast floor system, pre-cast concrete panels may be used as shear walls to resist lateral loads in the structure. These panels can be manufactured at, and shipped from, the same plant as all pre-cast floor members previously selected. The panels and the fully connected unit of the shear walls were designed using finite element analysis in RISA-3D. Specific information from these models can be found within this section, in the appendix, and remaining information is available upon request.

In the pre-cast concrete structural system seismic loads control the design. Lateral forces are applied at each floor level as were determined previously, and gravity loads are applied at each floor on the East-West force resisting walls.

All shear walls in the building are sized equally, each measuring 26.5 feet wide, 14 inches thick, and composed of 7,000 psi concrete. With all panels and the shear walls being the same size and composition, their relative stiffnesses are all equal, thus simplifying the analysis of the structure and minimizing influences such as building torsion.

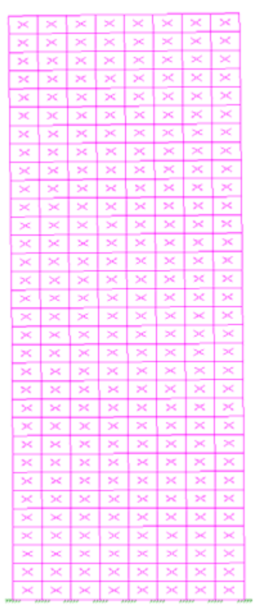

Figure 15: Deflected Shape of
East-West Force Resisting Wall
Magnified 40 Times in Pre-Cast System

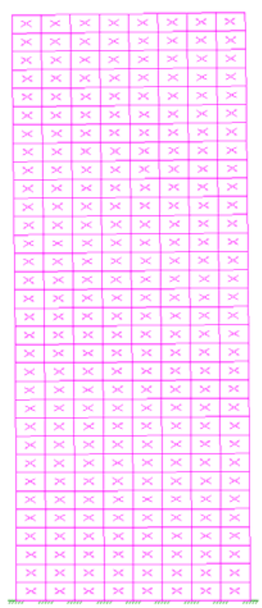

Figure16: Deflected Shape of
North-South Force Resisting Wall
Magnified 40 Times in Pre-Cast System

Total seismic base shear for the concrete redesign is 1237 kips. As all the shear walls in the structure possess the same rigidity, the building base shear may be evenly distributed amongst the walls, resulting in the loading conditions which may be found in

previous sections and the appendix. The controlling applied loads at the base of the member are as follows:

Shear walls resisting East-West forces: 91.3 kips/ linear foot
Shear walls resisting North-South forces: 111.8 kips/ linear foot

Both of these values fall below the required stress limit for pre-cast concrete members of $\frac{5\sqrt{f'c}\cdot b\cdot d}{12\cdot 1000}$ = 155.2 kips / linear foot.

Deflection at the top of the shear wall is minimal, calculated at a maximum of 0.17". This value is below the suggested live load deflection maximum of L/360 which results as 2.3".

Uplift forces are created within the base of the shear walls as the result of an overturning moment generated through the height of the wall about its base. In walls resisting East-West lateral forces, an uplift force of 313 kips is created; in walls resisting North-South lateral forces, an uplift of 277 kips is created. Both forces are counteracted with the placement of 4 number 11 bars in each corner. The summations of all forces on both walls results in a positive reaction value, causing no overturning in the wall as a whole.

The lateral forces of the structure are transferred to the shear walls through the diaphragm. This is accomplished with additional reinforcement placed in the pour strips on the surface of the double-tees. The full calculation of the required amount of reinforcement can be found in the appendix. In the North-South Direction, 2 #6 bars should be run continuously along the edges of all 8 bays, and in the East-West direction 4 #6 bars should be run continuously along the edges of all 4 bays.

The layout of shear walls within the building was determined so that building torsion is kept to a minimum and lateral forces are evenly distributed throughout the building. The placement of these walls may be seen in Figure 17, and a floor plan of the original steel design may be seen in Figure 18. In order to successfully connect the diaphragm to the shear walls, it was necessary to relocate the Southern mechanical chase. More information regarding this adjustment may be found in the architectural floor plan analysis.

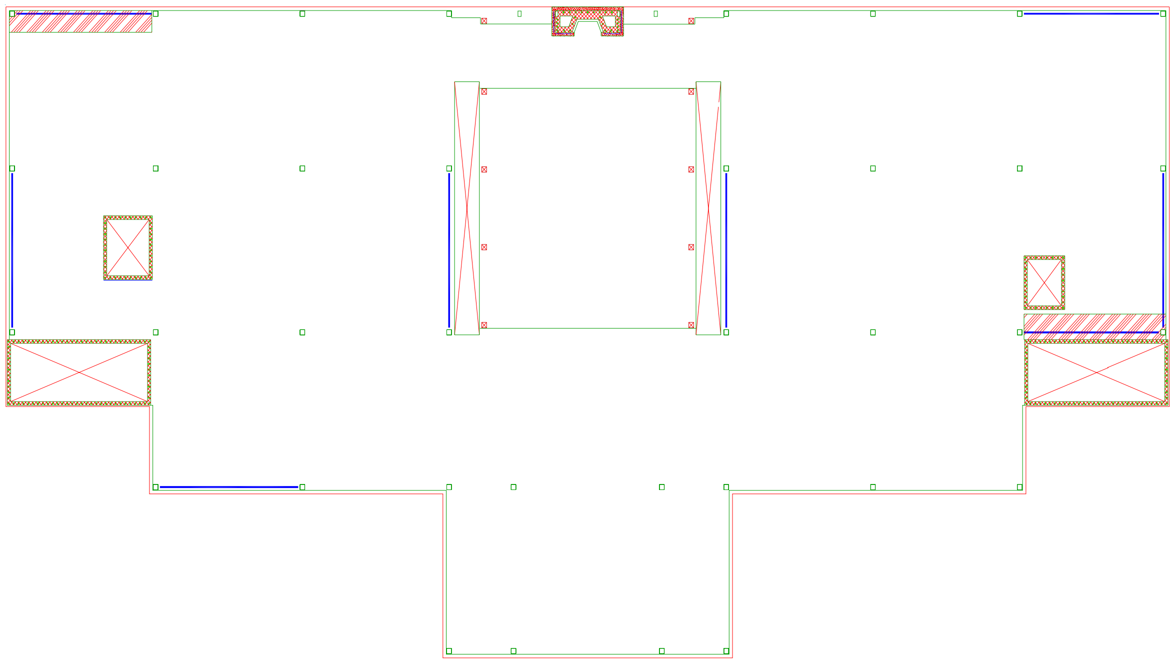

Figure 17: Original Steel Lateral System Plan

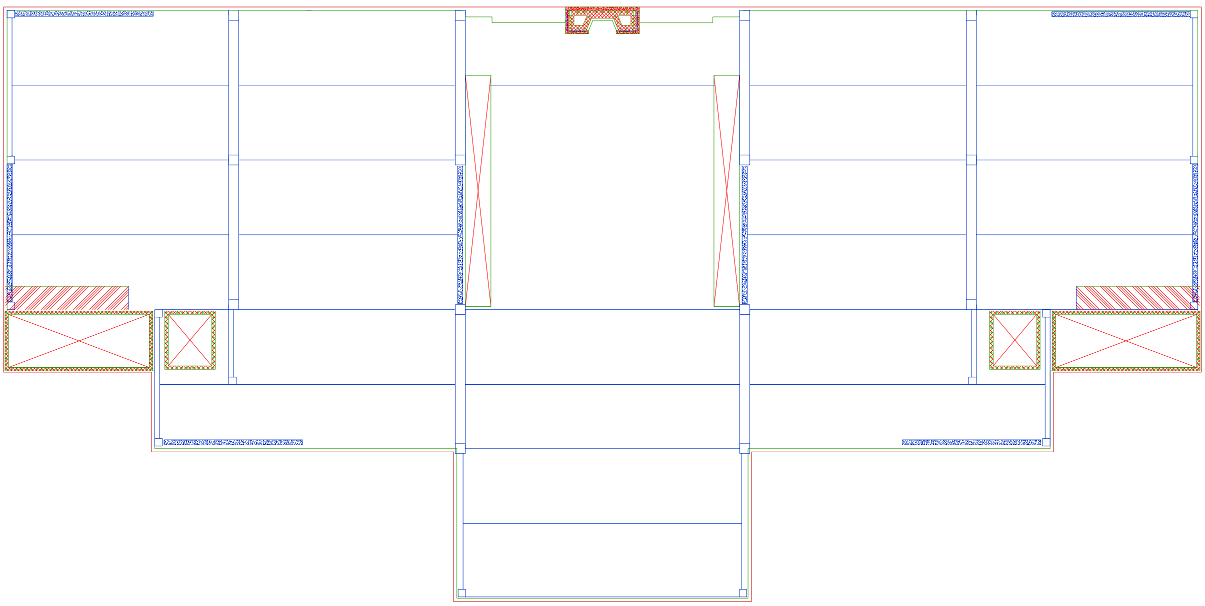

Figure 18: Pre-Cast Concrete Lateral System Plan

Effects on Foundation Design

Foundations supporting the structure have altered requirements under the loading conditions created by the change from a steel structure to a pre-cast concrete structure. The column footings decrease in number and increase in size under the adjusted loading conditions.

The specific design of the footings is completed using hand calculations in MathCAD. In the case of typical column footings, no lateral load is to be carried, and thus overturning and uplift are not considered on the foundation itself. The typical column footings are designed to satisfy ACI requirements of punching shear and one-way shear. Specific calculations may be seen in the appendix.

In the design of the footing supporting typical interior column, the width of the footing remains the same at 12.5 feet, however the depth of the footing is increased from 30 inches to 36 inches. This represents a 20% increase in individual volumetric footing size. When the adjusted number of footings throughout the building is considered, there is approximately a 15% increase in total footing volume.

Wooden System Design

Floor System Design

The conversion from structural steel to engineered wood products creates the need for smaller spans and thus smaller bays within the building, controlled by specific member design. Bay size in this application is decreased from 30'x30' to 22.5'x30'; this causes an increase in the number of columns, connections, and individual members, however more traditional installation methods may be used in construction. The typical framing layout may be seen in Figure 19.

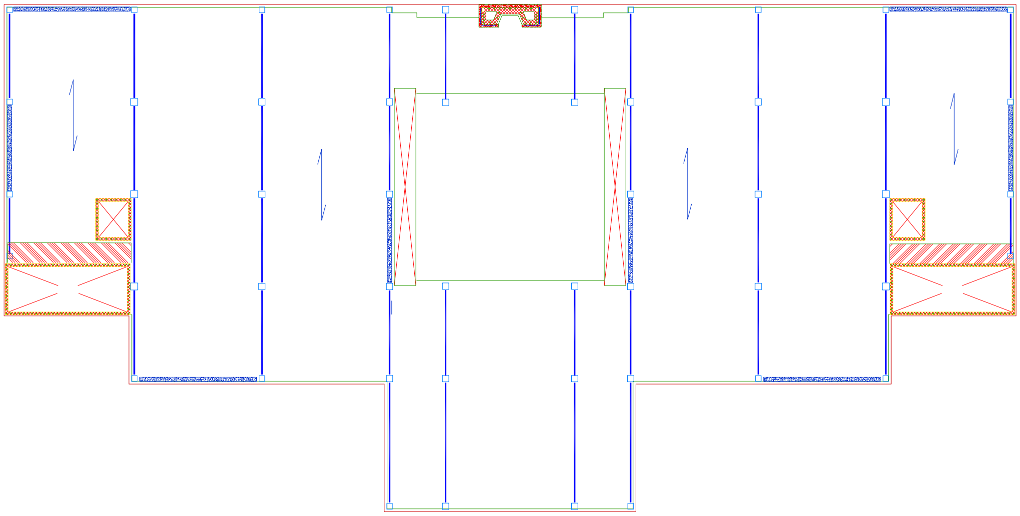

Figure 19: Engineered Wood Floor Plan

The main floor structure is composed of open web floor trusses, as specified by iLevel and Trus Joist commercial. These members were designed by determining the supported live loads and total loads of trusses spaced at varying distances. In order to balance strength and service requirements without exceeding a reasonable member depth, all trusses are designed at 30 inches deep, spanning 30 feet, and spaced at 2 feet on center. The selection of these members also allows for the use of standard pieces, minimizing additional design and manufacturing casts.

TJM trusses with parallel chords are selected to support typical areas subject to 100 psf live load. TJH trusses with parallel chords are selected to support areas subject to mechanical loads of 125 psf. Specific information regarding the sizing and construction of TJM and TJH trusses may be found in the appendix.

Supporting the trusses are Parallam PSL girders, also specified by iLevel and TrusJoist. These members were designed using hand calculations in MathCAD, and follow all NDS requirements. These calculations are included in the appendix. Most adjustment factors

apply as a factor of 1.0 in the design of the girders as the members are used in a climate controlled building and not subject to unusual loading conditions. Standard adjustments are made to account for member size and volume as required. Supported loads applied to the girders are idealized as a uniform load.

Girders span approximately 22 ½ feet each and all selected members are of standard dimensions to minimize required lead time and construction costs. Typical girders measure 10 ½ inches thick and 28 inches deep. Girders supporting higher loads extend to 34 inches deep.

Columns are selected in a similar manner to that of the girders, and are made of SP 50 N1D14 Glu-lam, following requirements of NDS, and available from any engineered wood manufacturer. Columns are designed to reach the full height of each floor; however a bracing point is included on each column at the lower surface of the plenum. This is accomplished by including additional girder style members within the exiting ceiling system along all column lines. The existing structure has non-structural wooden members in similar application, as can be seen in Figure 20. In the central atrium where a ceiling plenum does not exist, diagonal bracing is applied, as in the original structure. The effect of this bracing creates an effective column length of 10 feet and can be seen in Figure 21.

Figure 20: Existing Faux Girders[2]

Figure 21: Existing Diagonal Column Bracing[2]

Wooden column sizes vary by floor due to the effects of supported cumulative loads, and only support gravity loads. Specific calculations may be found in the appendix, and a summary of typical sizes may be seen in the table below.

Typical Column Sizes			**[in]**
	Typical Loading	Central Span	Mech. Loading
Supporting Roof	7 x 7	7 x 7	7 x 7
4th Floor	12 x 12	14 x 14	12 x 12
3rd Floor	15 x 15	18 x 18	16 x 16
2nd Floor	18 x 18	20 x 20	20 x 20
1st Floor	20 x 20	22 x 22	22 x 22

In order to create the actual floor of the wooden floor system, standard wooden plank is used. These members were designed using hand calculations in MathCAD, and NDS requirements. Select Structural grade Southern Pine plank of nominal measurements of 2 inches by 6 inches span the joists spaced at 2 feet on center. The use of Southern Pine allows for the application of an economical product, as compared to engineered wood, and exhibits more highly researched strength and performance conditions, as compared to other species of woods.

Lateral System Design

In the preliminary design of the engineered wood system, masonry shear walls were to be applied as the lateral fore resistance system; through further investigation, pre-cast panels were selected to replace the initial masonry walls. This alteration in design adds an additional material to the structural system of the building, as masonry is used in the foundation and retaining walls. However, pre-cast panels prove to be more efficient and effective in this application and in this structure. Concrete panels are more highly suited to reach the heights required in the structure, reaching to 70 feet tall. The amount of site construction required for installation is greatly decreased, as the construction of the walls will only require the grouting of pre-installed connections. With the application of pre-cast concrete in the shear walls of the structure, pre-cast may also be used to surround the stairwells and elevators, thus lowing construction time and costs in additional areas of the building.

The individual panels and the fully connected unit of the shear walls were designed using finite element analysis in RISA-3D. Lateral loads are applied at each floor level as transferred from the wooden diaphragm. Gravity loads are applied to the North-South resisting walls at each floor level as well. Diagrams of the walls may be seen below.

Shear walls in the same direction are sized equally, with East-West load resisting walls measuring 26.5 feet wide and North-South resisting walls measuring 20 feet wide. All shear walls in this system are 12 inches thick, and composed of 7,000 psi concrete. With panels and the shear walls in the same direction being the same size and composition, their relative stiffnesses are equal, thus simplifying the analysis of the structure and minimizing influences such as building torsion.

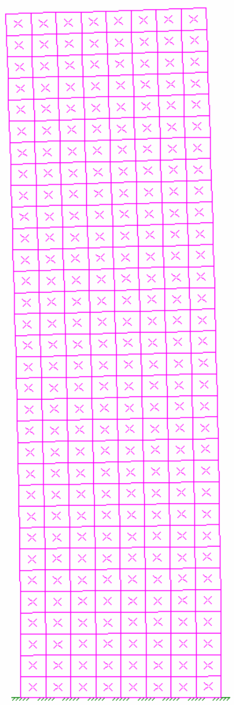

Figure 22: Deflected Shape of East-West Force Resisting Wall Magnified 40 Times in Wooden System

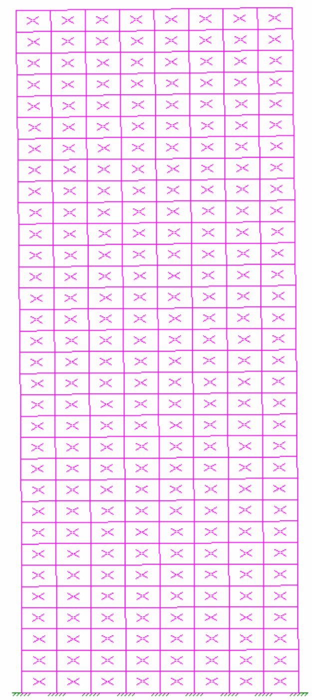

Figure 23: Deflected Shape of North-South Force Resisting Wall Magnified 40 Times in Wooden System

Total un-factored wind induced base shear for the wooden redesign is 605 kips. As all the shear walls in a direction possess the same rigidity, the building base shear may be evenly distributed amongst the walls, resulting in the loading conditions which may be found in the appendix. The controlling applied loads at the base of the member are as follows:

Shear walls resisting East-West forces: 102.8 kips/ linear foot
Shear walls resisting North-South forces: 53.3 kips/ linear foot

Both of these values fall below the required stress limit for pre-cast concrete members of $\frac{5\sqrt{f'c}\cdot b\cdot d}{12\cdot 1000}$ = 100.4 kips / linear foot and 133.0 kips / linear foot, respectively.

Deflection at the top of the shear wall is minimal, calculated at a maximum of 0.461" in the East-West force resisting walls and 0.193" in the North-South force resisting walls. Both of these values are below the suggested live load deflection maximum of L/360 which results as 2.3".

Uplift forces are created within the base of the shear walls as the result of an overturning moment generated through the height of the wall about its base. In walls resisting East-West lateral forces, an uplift force of 309 kips is created; in walls resisting North-South

lateral forces, an uplift of 230 kips is created. Both forces are counteracted with the placement of 4 number 11 bars in each corner. The summations of all forces on both walls results in a positive reaction value, causing no overturning in the wall as a whole.

The layout of shear walls within the building was determined so that building torsion is kept to a minimum and lateral forces are evenly distributed throughout the building. The placement of these walls may be seen in Figure 24, and a floor plan of the original steel design may be seen in Figure 25. In order to successfully connect the diaphragm to the shear walls, it was necessary to relocate the Southern mechanical chase. More information regarding this adjustment may be found in the architectural floor plan analysis.

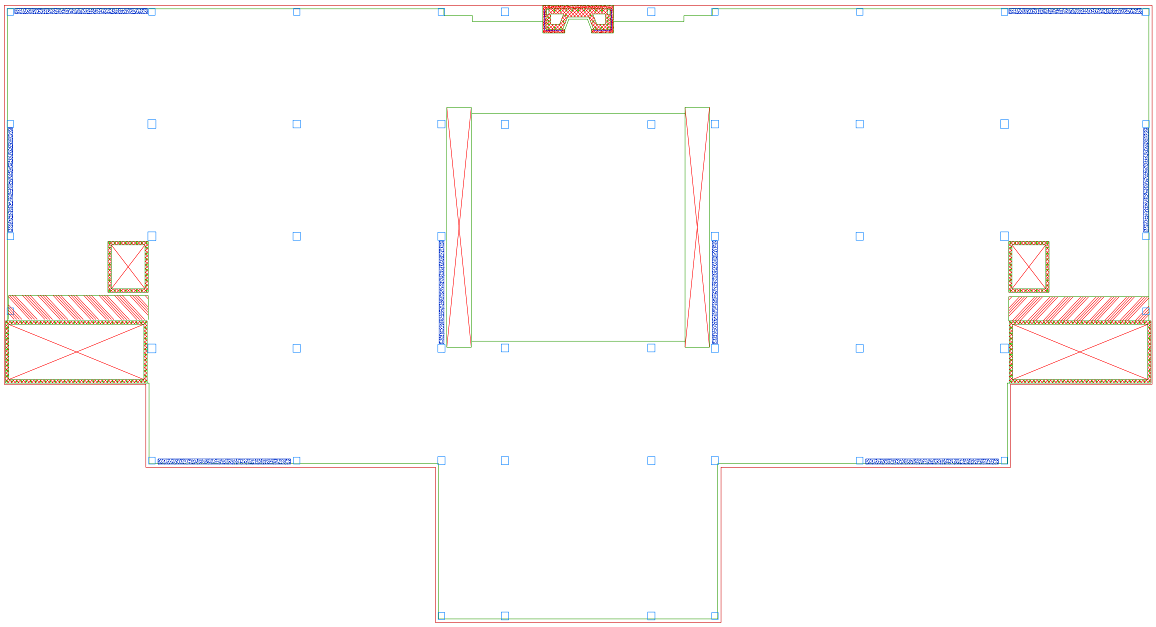

Figure 24: Engineered Wood Lateral System Plan

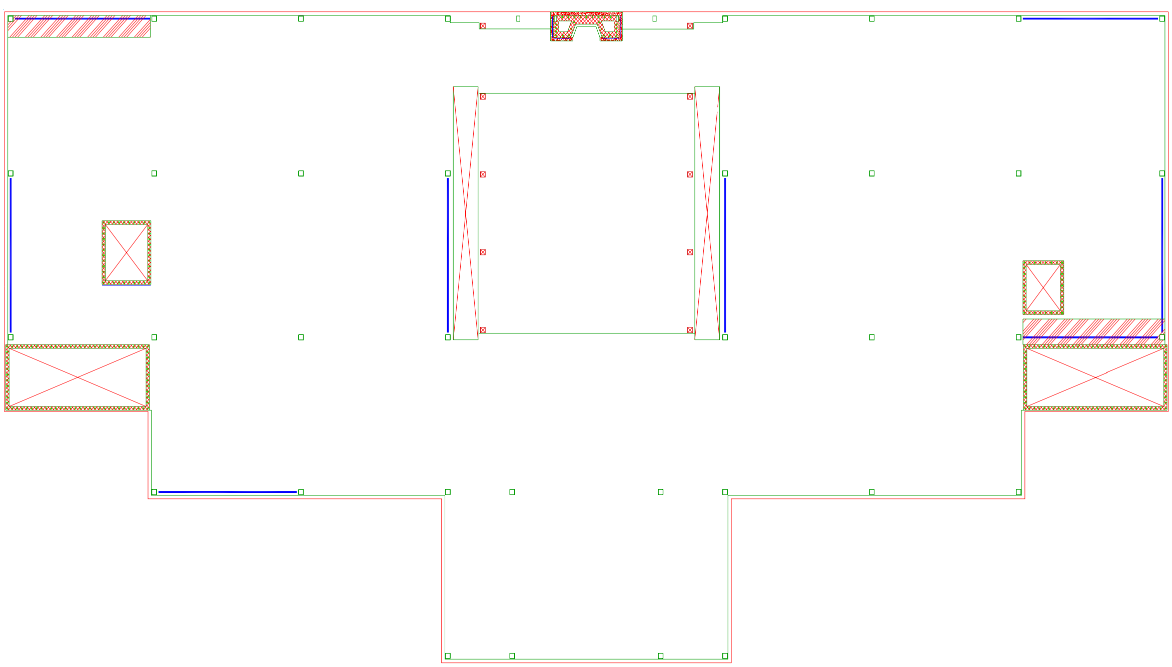

Figure 25: Original Steel Lateral System Plan

Effects on Foundation

Foundations supporting the structure have altered requirements under the loading conditions created by the change from a steel structure to an engineered wood structure. The column footings increase in number and decrease in size under the adjusted loading conditions.

The specific design of the footings is completed using hand calculations in MathCAD. In the case of typical column footings, no lateral load is to be carried, and thus overturning and uplift are not considered on the foundation itself. The typical column footings are designed to satisfy ACI requirements of punching shear and one-way shear. Specific calculations may be seen in the appendix.

In the design of the footing supporting typical interior column, the size of the footing is decreased from 12.5 feet square by 30 inches deep to 10 feet square and 28 inches deep. This represents a 40% decrease in individual footing size. When the adjusted number of footings throughout the building is considered, there is approximately a 25% decrease in total footing volume.

Special Considerations – Deflection, Vibration, and Fireproofing

Vertical deflection is controlled as a summation of all individual member deflections. Wooden plank deflections are calculated to be minimal, as unsupported spans are limited to 2 feet. Floor truss deflections are controlled by manufacturer specifications and range from 0.446” to 0.47”. Girder deflections measure 0.45” under live loads and 0.577” under total loads. As a result, total floor deflections measure approximately 1” or a deflection of L/360 under full loading. Commercial building deflection limits of L/600 consider only the first 50 psf of live load, thus permitting the deflections of the system as designed.

Vibrations in this type of engineered wood system have been studied in depth, however no specific design process or criteria is currently in place. The TJH and TJM joists used in the new design can reach spans up to 70 feet, and by limiting member size to 30 feet, less than half of this maximum value, the occurrence of vibrations is less likely. Girders in the system are limited to a span of 22.5 feet, also decreasing the potential for vibration issues as compared to the 30 foot span of the original steel system. In the case of vibrations greater than desired present in the structure, bracing may be added to the joists. This bracing is available from the same provider as the trusses and is shown below in Figure 26 as designed by Trus Joist and iLevel.

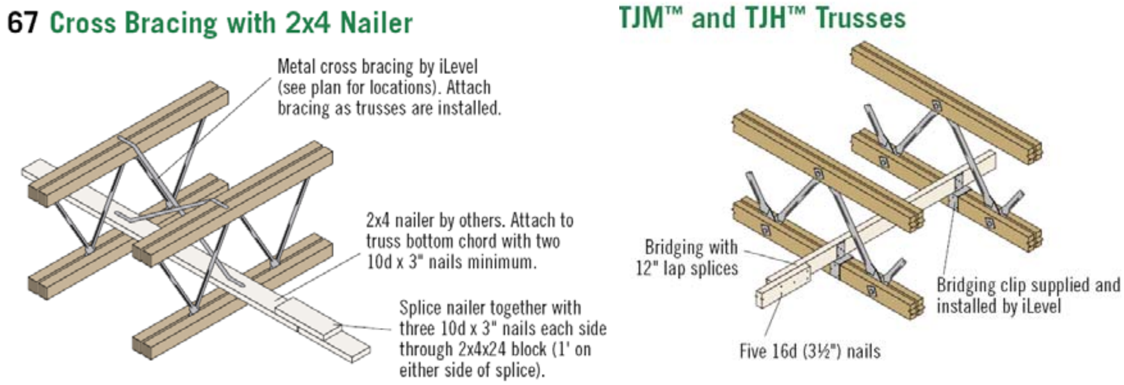

Figure 26: Examples of Approved Bracing for TJM and TJH Trusses

The requirements of the building range from one to two hour fire ratings. The original structure includes a complete sprinkler system on each floor. This is also applied to the redesigned wooden structure, giving the structure a higher hour fire rating. The engineered wood products alone have a fire rating satisfying 1 hour, but is raised to the minimum of 2 hours with the added sprinklers. APA, the Engineered Wood Association reports satisfactory wood dimensions for one hour fire ratings as shown in Figure 27.

TABLE 4

DIMENSIONS OF COMPONENTS FOR HEAVY TIMBER CONSTRUCTION (TYPICAL CODE PROVISIONS)

Heavy timber construction is generally defined in building codes and standards by the following minimum sizes for the various members or portions of a building:

	Inches, nominal
Columns	
Supporting floor loads	8x8
Supporting roof and ceiling loads only	6x8
Floor framing	
Beams and girders	6 wide x 10 deep
Arches and trusses	8 in any dimension
Roof framing – not supporting floor loads	
Arches springing from grade	6x8 lower half; 6x6 upper half
Arches, trusses, other framing springing from top of walls, etc.	4x6
Floor covered with 1-inch nominal flooring, 15/32 or 1/2-inch plywood, or other approved surfacing	
Splined or tongue-and-groove plank	2
Planks set on edge	4
Roof decks	
Splined or tongue-and-groove plank	2
Plank set on edge	3
Tongue-and-groove plywood	1-1/8

Figure 27: Minimum Dimensions of Wooden Members for Fire Requirements

Cost, Schedule and Coordination Analysis

Cost, Schedule and Coordination Analysis:

Cost Assumptions

The pricing of the structure was completed using several methods in order to best apply available information to each system. Only the structural systems of each option were considered in the cost estimate and included several assumptions. Materials included in the estimate include all gravity framing members, (beams, girders, columns, deck, double-tees, etc.) all lateral members, (frames or shear walls) foundation retaining walls, footings, and roof framing. Pricing for non-structural items are not included, as well as for many items which are left unchanged. Specific connection prices are not included; these would increase the cost of the structure, but do not exhibit an extreme difference in price between the systems.

Comparison of Costs

The original steel system cost was estimated using ICE 2000. All included materials are entered as drawn in provided structural design documents in the unit of measure required. The values of this system may be seen below:

Original Steel Structure Pricing	
note: Member prices include installation costs	
Values as reported from ICE, available in Appendix	
Material	**Total Price**
Masonry	
Mortar	$45,217.29
Block / Reinforcement	$235,343.74
Waterproofing	$11,843.88
Metals	
Structural Steel	$442,378.16
Metal Deck	$115,291.44
Fireproofing	$1,828,686.62
Concrete	
Slab on Deck	$157,673.32
Foundations	
Concrete	$31,491.99
Formwork	$22,406.77
Slab On Grade	
Concrete / Installation	$55,733.42
Roof	
Wood Trusses	$55,050.88
Wood Sheathing	$25,303.73
Accessories	$7,262.45
Total:	**$3,033,683.69**

The pre-cast concrete redesign was priced using specific piece costs for all pre-cast as provided by a sample supplier, High Concrete Structures. These costs are specified per member and additional costs are included for installation. This installation value is reduced for rural conditions as the site for Boyds Bear Country is expansive and allows for a great deal of on site storage. It is also estimated that each piece will be picked twice as they may all be stored on site for ease of shipping. Foundation costs are scaled by volume as previously determined, in this case approximately a 15% increase. No changes are made to the original roof framing system. The values of the system may be seen below.

Pre-Cast Concrete Structure Pricing					
note: Member prices do not include crane installation costs					
Member	**Measurement**		**Quantity**	**Unit Price**	**Total Price**
Double Tees					
15DT34-128S	45	ft	35	$5,457.00	$190,995.00
15DT34-168S	45	ft	33	$5,500.00	$181,500.00
15DT34-208S	60	ft	22	$6,931.82	$152,500.04
15DT34-248S	60	ft	16	$7,000.00	$112,000.00
Girders					
12LB36-118S	30	ft	32	$5,881.00	$188,192.00
24IT36-228S	30	ft	30	$5,250.00	$157,500.00
Columns					
18"x18" CHE	36	ft	32	$7,560.00	$241,920.00
24"x24" CHI	72	ft	14	$15,120.00	$211,680.00
Installation Costs					
Rural Location	Picks/Pc		Quantity		
Open Storage	2		214	$1,200.00	$513,600.00
Shearwalls					
30'x14" Panels	18.75	cwt	32	$59.69	$35,814.00
Foundation Walls					
Concrete	27.16	cuyd	16	$79.59	$34,586.63
Steel	352	cwt	1	$59.71	$21,017.92
Formwork	17360	sf	1	$11.73	$203,632.80
Foundations					
Concrete					$36,215.79
Formwork					$22,406.77
Slab On Grade					
Concrete / Installation					$55,733.42
Roof					
Wood Trusses					$55,050.88
Wood Sheathing					$25,303.73
Accessories					$7,262.45
Total:					**$2,244,938.39**

The engineered wood redesign was priced using a combination of RS Means 2002, ICE 2000, and manufacturer supplied cost information. These costs are specified in various units of measure, and input values of each member or material type is adjusted accordingly. All prices include the expenses of installation. Foundation costs are scaled by volume as previously determined, in this case approximately a 25% decrease. No changes are made to the original roof framing system. The values of the system may be seen below.

Wooden Structure Pricing				
note: Member prices include installation costs				
Member	**Measurement**	**Quantity**	**Unit Price**	**Total Price**
Floor Plank				
2"x6" T and G	160.1 MBF	1	$2,450.00	$392,245.00
Tubular Steel Trusses				
30" TJM	66000 sf	1	$4.10	$270,600.00
30" TJH	21600 sf	1	$4.32	$93,312.00
Girders				
10.5"x22" PSL	22.5 ft	24	$41.25	$22,275.00
10.5"x28" PSL	22.5 ft	103	$56.88	$131,819.40
Columns				
7" x 7"	8 ft	53	$14.20	$6,020.80
12" x 12"	17.7 ft	53	$38.32	$35,947.99
14" x 14"	17.7 ft	34	$55.00	$33,099.00
16" x 16"	17.7 ft	36	$71.84	$45,776.45
18" x 18"	17.7 ft	28	$90.92	$45,059.95
20" x 20"	17.7 ft	30	$112.25	$59,604.75
Shearwalls				
30'x12" Panels	16.07 cwt	16	$59.69	$15,347.49
20'x12" Panels	13.45 cwt	16	$59.69	$12,845.29
Foundation Walls				
Concrete	27.16 cuyd	16	$79.59	$34,586.63
Steel	352 cwt	1	$59.71	$21,017.92
Formwork	17360 sf	1	$11.73	$203,632.80
Foundations				
Concrete				$23,618.99
Formwork				$22,406.77
Slab On Grade				
Concrete / Installation				$55,733.42
Roof				
Wood Trusses				$55,050.88
Wood Sheathing				$25,303.73
Accessories				$7,262.45
Total:				**$1,612,566.71**

In comparing the three system prices, a great deal of savings can be seen in the two new systems. The pre-cast concrete system shows a savings of over $78,800, while the engineered wood system shows a savings of over $1,420,000. The substitution of concrete for masonry block in the retaining / foundation walls of the structure exhibits a savings of more than $33,000, included in the price difference above.

Schedule Assumptions

Making any comparison of schedules between a new method of construction and the original is difficult due to extraneous site conditions. The original construction schedule of the building was set to run from November 2004 to April 2005, a 6 month time period. In reality the construction process lasted into July 2005, adding an extra 3 months, or 50% to the planned schedule.

In reviewing conference notes from the duration of the construction, only 8 days are noted to be lost due to weather conditions. A large portion of time was included in the coordination of trades, during which one set of contractors were delayed by the work of another, or in the worst case scenario, the work of some contractors was inadvertently destroyed by others. Because of these issues, among others, it becomes difficult to create an accurate set of schedules for the project.

Comparisons of Schedules

Several general comparisons may be made amongst the systems. In general the pre-cast concrete members themselves will be able to be more quickly installed. The number of pieces which must be placed and connected is decreased dramatically. Every piece of pre-cast concrete installed replaces approximately two pieces of steel. This simple piece count difference creates a savings in both crane use and connection time. The connections of members in the re-cast system are generally completed with simple welds or grouting; the concrete used to cover these connections is already used on site in foundation work. These connection differences are likely to also reduce construction time, eliminating the need for bolting and shear stud installation.

The engineered wood members are more numerous than the concrete members used in the original structure; however the installation techniques are simpler. Instead of requiring an experienced crew to relocate to the site to complete steel construction, local contractors may be used to complete construction. These local contractors are more likely to be able to adapt to the requirements of local weather and site conditions, thus reducing the potential for lost time.

On of the largest time saving factors in both redesign options is in the replacement of all masonry work with either cast-in-place or pre-cast concrete. The installation and construction of these can be completed much more quickly, especially once including the considerations of the height of these items. The labor required to install a short concrete wall and an high concrete wall are fairly similar, where in the case of installing masonry, a 17 foot high wall requires a great deal of labor.

Overall, both systems show a general decrease in construction time; however specific site and contractor conditions have a great impact on the actual construction of the building. A schedule representing the time actually spent on the construction of the structure of Boyds Bear Country is located in the appendix.

Analysis of Coordination Issues

In the original construction is complicated by the number of materials used in the building. Completing the construction of a building becomes more complicated with the use of numerous materials. This requires the attainment and coordination of many contractors. With the addition of each contractor and each supplier, the required amount of coordination and the potential for error increases.

The breakdown of included materials in the original steel building is large and can be listed as follows:

Steel
- Hot rolled structural members
- Metal decking
- Shear studs
- Bolted / welded connections
- Light gauge steel framing

Concrete
- Cast-in-place elevated slabs
- Lightweight cast-in-place elevated slabs
- Cast-in-place slab on grade
- Shallow foundations

Masonry
- Normal CMU block
- Ivany (high strength) CMU block
- Structural Piers

Wood
- Manufactured trusses
- Timbers

Variety of Finish Materials
- Gypsum board
- Plywood, etc….

The breakdown of included materials in the pre-cast building can be listed as follows:

Steel
- Welded member connections
- Light gauge steel framing

Concrete
- Pre-cast concrete members
- Member toppings
- Cast-in-place retaining / foundation walls
- Cast-in-place slab on grade
- Shallow foundations

Wood
- Manufactured trusses
- Timbers

Variety of Finish Materials
- Gypsum board
- Plywood, etc….

The breakdown of included materials in the wooden structure can be listed as follows:

Steel
- Member connections

Concrete
- Pre-cast concrete shear walls
- Cast-in-place retaining / foundation walls
- Cast-in-place slab on grade
- Shallow foundations

Wood
- Manufactured floor trusses
- Laminated structural members
- Floor planks
- Manufactured roof trusses
- Stud wall framing

Variety of Finish Materials
- Gypsum board
- Plywood, etc….

By switching the structural system to either of these options, the amount of materials and contractors can be decreased. In accomplishing this goal, the likelihood of problems during construction decreases. A schedule may be clearer with fewer subcontractors required to be on site at varying times. If fewer materials are involved, there is a decreased opportunity for a clash between material interface and contractors. Overall, both of these systems decrease the required amount of work to be completed on site, and the number of subcontractors required in coordination.

Architectural Analysis

Architectural Analysis:

Background and Requirements

The building is designed as a large scale barn, in Pennsylvania Dutch style and tradition. It features a large mural on the East side of the building, approximately 40' high and 60' wide, showing the company's trademark bears working on the construction and decoration of the building. The front of the lot features a steel silo bearing the Boyds logo measuring 20' in diameter and capped by a dome at 65' of full height. The top of the structure is finished with 3 cupolas reaching 36' in height and featuring a human sized cut metal bear.

The interior of the building features a decorative wooden "structure" along with wooden column covers to disguise the load-bearing steel members. The floor-to-floor height of the retail spaces is 17’-8” with a drop ceiling at approximately 10 feet from the finished floor height, allowing 7 feet of depth available for the floor system. The plenum is composed of a drop ceiling grid, in most cases without ceiling panels installed. This construction allows for the feeling of openness without the overwhelming scale of the full structure. The central bay of the building features a two-story atrium with large wooden timbers, picture windows, and a stone fireplace. Decorative timber trusses are located at the top of the atrium, and are not structural.

It is most important that the retail and support areas of the building be as functional as possible while still balancing the country barn aesthetic.

Figure 28: Central Atrium [5]

Figure 29:Exterior Mural [1]

Floor Plan Comparison

The largest differences in plan between the three structural systems are the alteration of bay sizes and thus the number of columns present in each floor. The original composite steel structure has 30’x30’ bays and 36 steel tube columns per floor. The pre-cast concrete redesign has 45’x30’ bays and 27 square concrete columns. The engineered wood redesign has 30’x22.5’ bays and 50 wooden columns. The removal of columns in the pre-cast concrete system is desirable as to increase useable floor area and traffic flow.

As discussed previously, the Southern mechanical chase was moved from the rear face of the building to the front face in order to ensure diaphragm continuity in both redesigns. The movement of this mechanical chase will require a few changes in the basement design including minor alterations to the kitchen storage and preparation area. Mechanical rooms are located on the North and South end of the building, and the relocation of the Southern chase does not require a severe change in the ducts between the two.

The mechanical chase relocation also allows for the relocation of the Southern elevator in both redesigns. The placement of the elevators is now symmetrical about the center of the building and located adjacent to the stairwells. The adjustment of the elevator location creates a larger open area within the Northern-most and Southern-most bays of the building; it also creates a small nook just to the East of the elevators which can easily be created into niche displays within the expansive retail area.

Interior Appearance Comparison

In existing application of steel columns, those columns which are exposed to retail and public areas are disguised with wooden coverings, illustrations of which may be seen in Figure 30. The interior pre-cast concrete columns measure 24 inches square, a significant increase from the original steel tubes. It is expected that in order to mimic the appearance of timbers, a similar covering would be applied to the concrete columns, further increasing their size. The engineered wood columns range is size from 7 inches square to 22 inches square, being comparable in size on retail floors to the original system, an example of which may be seen in Figure 31. The wood columns could be exposed as is, exhibiting the finish of the wood itself. In individual member appearance, the engineered wood columns are most desirable to fit the architectural needs of the barn.

Figure 30: Examples of Steel Tube Columns Disguised as Wood in Situ [2]

Figure 31: Pre-Cast Column Sample [3]

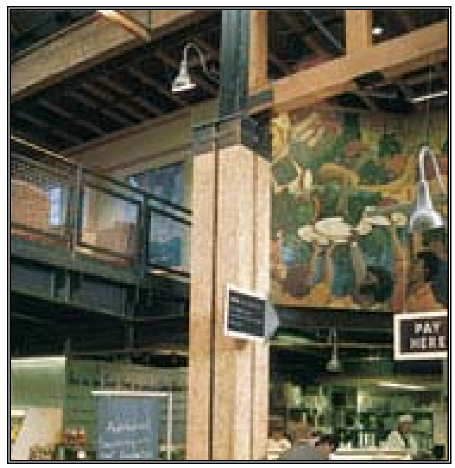

Figure 32: Engineered Wood Column Sample [4]

The appearance of the floor system from below is also an influence on the interior architecture of the space. The use of pre-cast concrete members would create a lighter ceiling color and thus would make the plenum and faux ceiling more noticeable. In order to keep the desired interior scale the concrete would most likely be required to be painted black. The wooden framing option would not require any additional finishing.

Conclusions

Conclusions:

Summary

The original structural design of Boyds Bear Country was accomplished with a composite steel system. This basic system is supplemented with wooden roof trusses, masonry walls, and concrete slabs. The inclusion of all of these systems creates difficulty in design and construction.

A pre-cast concrete system can be implemented to replace the current one, reducing the number of required trades on site. This design includes fewer pieces, and larger bay sizes, opening the retail floors up for maximum utilization of space. However, the concrete does not fit the overall aesthetic design of the building and would have to be masked in a fashion similar to the existing structure.

An engineered wood system allows for the most seamless integration of a structural system into the desired aesthetic design. The application of wooden columns and girders creates a look of nature and tradition applied in an updated, oversized fashion. The implementation of a wooden system would create a greater number of columns in the floor plan and retain area; however they could be incorporated into display functions.

Both replacement systems show a decrease in cost and construction time.

Comparison of 3 Systems

Area of Concern:	Original Composite Steel System	Pre-Cast Concrete System	Engineered Wood System
Gravity System	30' x 30' Bays	30' x 45' Bays	22.5' x 30' Bays
	3 Beams per Bay	2 Double-Tees per Bay	Joists at 2' OC
Lateral System	Combination of Steel Frames and Masonry	Decreased Number of Columns	Increased Number of Columns
		Pre-Cast Panels	Pre-Cast Panels
		Decreased Number of Members	Decreased Number or Members
	Seismic Controlled	Seismic Controlled	Wind Controlled
	2.08" Deflection	0.174" Deflection	0.461" Deflection
Foundations		~15% Larger by Volume	~25% Smaller by Volume
		Less Formwork required	More Formwork Required
Cost / Schedule / Coordination		$78,800 Savings	$1,420,00 Savings
		Decreased Construction Time	Decreased Construction Time
		Less Site Construction Required	Less Site Construction Required
		Fewer Contractors Required	Fewer Contractors Required
Architecture		Reduced Number of Columns	Higher Number of Columns
		Finish Work Required	Less Finish Work Required

Recommendation

It is recommended that the pre-cast structural system be utilized in the design of Boyds Bear Country in Pigeon Forge, Tennessee. This option creates a streamlined structural system with larger bays, fewer columns, and decreased number of required materials, a decreased amount of site work, and an overall savings of more than $78,800.

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Photo Credits

1: Photos courtesy of Kinsley Construction.
2. Photos by Lauren Wilke.
3. Photos courtesy of High Concrete Structures.
4. Photos courtesy of iLevel.
5. Photos courtesy of Boyds Bear Country.

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