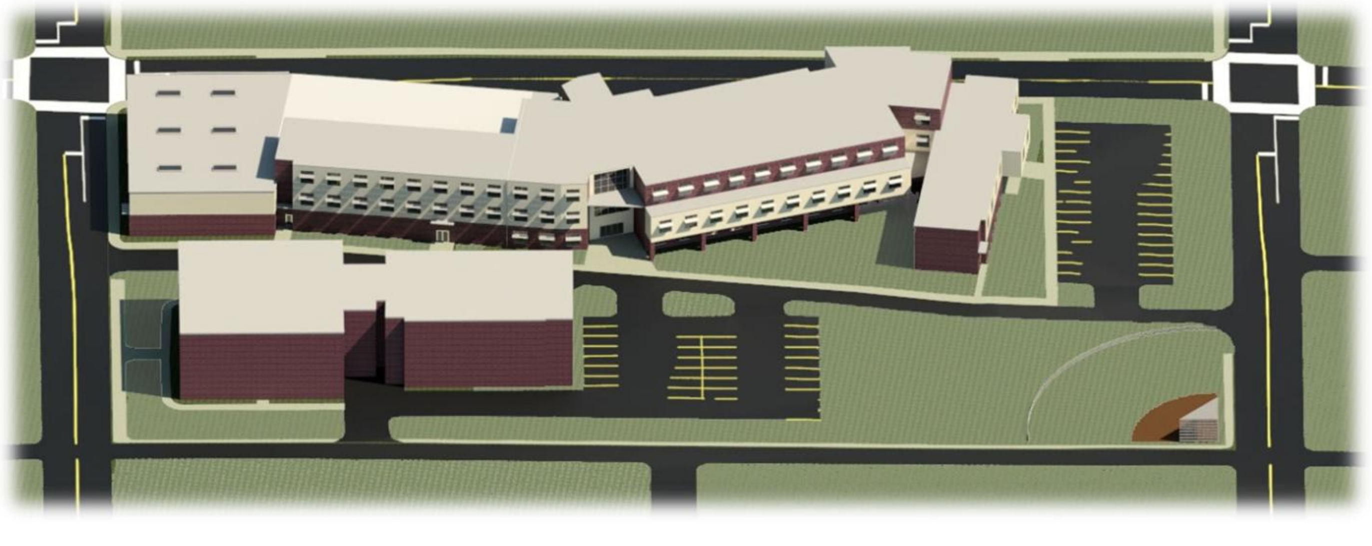
22 February 2013

nexus

Structural Systems



Team Registration Number: 02-2013

Table of Contents

Summary Narrative

The proposed Elementary School and swimming pool project for the Reading School District is a project that poses several unique challenges. The Reading School District, located in southeastern Pennsylvania, is among the poorest school districts in the nation. Additionally, crime is a problem in the Reading area, and security in the school is a concern for the School District. The project site is located in a downtown region of Reading at the (fictional) intersection of Thirteenth Street and Park Street. Currently, there are several existing structures on the site that will be demolished to make way for the new school building. An existing elementary school building also exists on the site, and may be kept as part of the project if the School District chooses to do so. Finally, an important provision for the school is the use of the gymnasium as an emergency shelter for the community.

To provide the Reading School District with an elementary school that satisfies their requirements and creates a successful learning environment, Nexus developed several goals that drove the decisions for the project. The project team's goals included low life-cycle cost, a versatile building layout, and an integrated design approach. These goals were created in an effort to solve the environmental challenges facing this project while also considering the unique economic conditions of the area.

The Nexus structural team worked with the other disciplines and team members to provide a building that is innovative but efficient. Some of these design decisions included the use of Insulated Concrete Form exterior walls, a reduction in the number of columns used in the building, and the use of concentric steel braces and shear walls for the lateral system. Each of these design decisions posed additional challenges that needed to be addressed by the structural team as well as other team members. These challenges will be discussed throughout this document.

Another important aspect of the project is the interdisciplinary collaboration amongst the Nexus team members. Nexus utilized Building Information Modeling (BIM) software to achieve team goals and to ensure quality of the final product. In the end, Nexus feels the team was able to come up with a unique solution that solves the unique challenges of the Reading Elementary School. Moreover, the Nexus structural team believes that the designed structural system provides a cost-efficient and owner-oriented solution that will satisfy the goals of both Nexus and the Reading School District.

Introduction

<u>Owner Goals</u>

In order to provide a building that best suits the needs of the Reading School District's new Elementary School, Nexus chose to develop goals that would satisfy the owner's needs. Nexus evaluated the specific challenges of this project to develop these goals. For example, the economic conditions of the Reading Area were a focal point for determining owner goals related to short-term and long-term costs. To illustrate how goals are achieved in the project, Nexus developed a system using icons to represent where goals were met. These icons are explained in Figures 1 and 2.

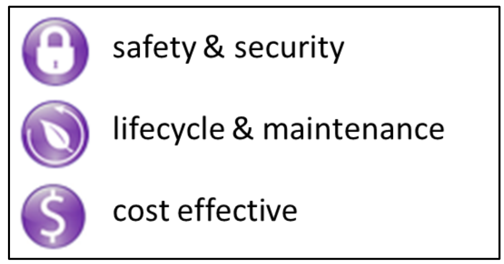


Figure 1: Owner Goal Icons

The first goal established for the building is safety and security. Because of the high crime rate of the Reading area and the poor economic conditions, safety is paramount in an urban elementary school. Nexus sought to design the building in a manner that satisfied the requirements for safety of the young children coming to school each day. Many of the decisions related to safety and security are reflected in the adjustments made to the building's floor plan, which will be discussed later. Additionally, the use of the building as an emergency shelter was an important reason for safety and security to be considered. Another goal designed to help the building owner is lifecycle and maintenance costs. Again, since the Reading School District faces financial challenges, the up-front cost of the building will be a very important consideration for the owner. However, since the building is an elementary school that could potentially be used for up to a century or more, the lifecycle and maintenance costs of the building will be just as important for the owner and the local taxpayers. Finally, Nexus aimed for the building to be as cost-effective as possible. The up-front cost of the building needs to be balanced with long-term lifecycle costs to best serve the needs of the School District.

<u>Nexus Team Goals</u>

Achieving the listed owner goals is a vital part of delivering a quality project, but Nexus also developed team objectives in order to help satisfy the owner requirements in an efficient manner. Nexus determined there are three main focal points for the project team to work toward while designing the building and its systems.

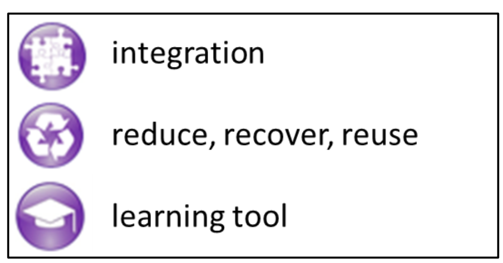


Figure 2: Nexus Overall Design Team Goal Icons

The most important goal for Nexus as a team is integration. Collaboration between the different disciplines is critical for the success of any project, and Nexus wanted to be sure that the team realized this throughout the course of the design process. Many, if not all, of the decisions made by the Nexus structural team were part of a collaborative process that determined how structural design decisions would affect the other disciplines. Another objective set by the team is the philosophy of "Reduce, Recover, Reuse." This mindset helped the team to be cost-effective and satisfy the owner goals relating to up-front cost and lifecycle costs. It also helped to establish more communication between the disciplines by ensuring that "Reduce, Recover, Reuse" was feasible for all of the systems in certain situations. This idea was also particularly important when considering that the school will likely be used for a long time. Lastly, Nexus wanted to focus on using the elementary school as a learning tool for elementary school children to better understand buildings and how they work. This goal helped Nexus to create a more involved learning environment, but it also allowed for different cost-saving techniques such as exposed ceilings that showed mechanical systems, structural beams, piping, and other components. The Nexus goals made it easier for each discipline to make design decisions that would best serve the Reading Elementary School as an enhanced learning environment.

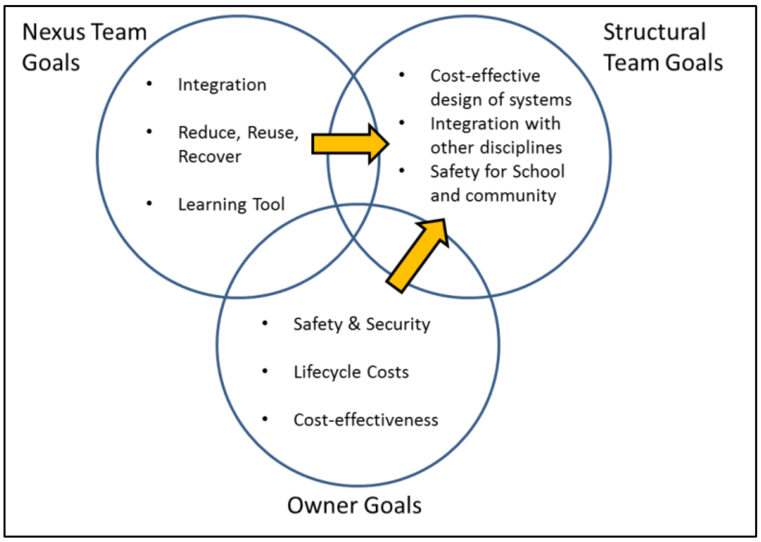


Figure 3: Project Goals and Focused Goals for the Structural Team

Structural Team Goals

In order to achieve team and owner objectives, each discipline focused on certain aspects of making design decisions. The Nexus structural team is predominantly focused on providing a cost-efficient solution that minimizes the number of structural members and also limits the structural floor framing system to a reasonable depth. The team also wanted to positively impact the lifecycle cost of the structure by working with the other disciplines. Finally, the team wanted to ensure safety for the occupants, whether part of the school or the community. These goals will be evident in the systems design decisions explained later and will be signaled by the corresponding icons shown in Figure 4. When an icon is displayed in a section of the report, it indicates that goal is a priority for that section and is met by the proposed design.

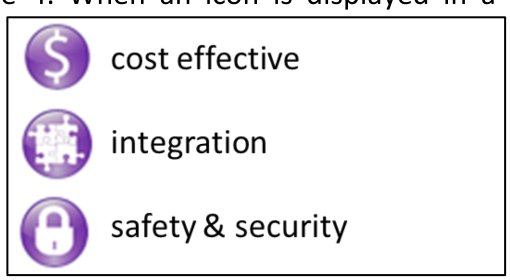


Figure 4: Structural Team Goal Icons

The project provided several requirements for the structural team that needed to be addressed. One obvious challenge is the use of the gymnasium as an emergency shelter. In order to design the gymnasium for this condition, a number of factors were considered for other portions of the building as well. Another important requirement of the project is versatility of the floor plan. Since the building is an elementary school that will be used over a number of decades, Nexus understands that teaching methods will evolve over time and may necessitate changes to the building that should be easily accommodated by the structure. One of the most important project requirements for the structural team is a result of the site conditions. According to the geotechnical report, the site is located on fill that has little soil bearing capacity and is extremely prone to sinkholes. The geotechnical report listed three different options for the foundation system that were each considered and evaluated by the structural team.

Structural Systems

Foundation System

Description of System

As mentioned previously, the soil conditions on the site are not favorable. The geotechnical report provided for the site suggested three different systems for the foundation: compaction grouting, site excavation and replacement, and driven piles. After evaluation of the three options and conversations with the construction team, it was determined that the best solution would be driven piles and pile caps. Using the 10” diameter steel piles suggested by the report, the structural team determined that for many of the isolated columns, two piles will be sufficient instead of the three recommended by the report. The piles are driven through the soil until they bear on bedrock approximately 30 feet below the surface. In order to assure adequate lateral support of the foundation system, the ICF walls transfer forces directly to the rigid floor diaphragms at the floor levels and at the slab on grade where applicable.

Rationale for System Selection

The poor soil conditions were the driving force in choosing the foundation system. As previously mentioned, the geotechnical report suggests three options: compaction grouting, excavation and compaction, and driven piles with pile caps. The option to excavate and compact was discussed with the construction team early during the design process. It quickly became clear that this option would be very expensive and time-consuming. Although it would likely give the structural team the opportunity to use a simple shallow foundation system, it was determined to be a poor choice because of cost concerns. The second option, compaction grouting, was also looked at carefully. A major concern with using compaction grouting was the unknown subsurface soil

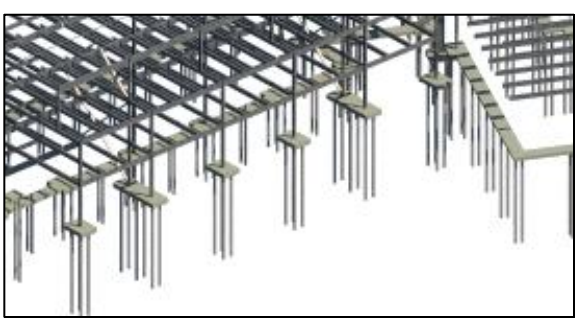


Figure 5: Driven Pile Foundation System

conditions and uncertainty about the exact depth of the bedrock. Since the amount of compaction grouting required to successfully reinforce the soil is a large unknown, the cost of the project was again a major concern for the design team.

As a result, driven piles and pile caps seem to be the best option for the building due the unknown costs stemming from the uncertainty of the subsurface soil conditions. Although the installation of the piles can be an expensive process, the structural team believed that they could limit the number of required piles to a minimum by making changes to the structural bay sizes in the building. Also, the team investigated the piles recommended by the geotechnical report and determined that for many of the isolated columns in the building, only two piles will be needed as opposed to the recommendation for three piles in the report.

<u>Column Grid</u>

Description of System

After reviewing the provided floor plans, the structural team noticed that there were three transverse structural bays in the central and west wings of the building as shown in Figure 6. The bays were sized at 30 ft, 12 ft, and 40 ft. As a cost-saving move, the structural team combined the 30 ft and 12 ft bays into a single 42 ft bay since a 40 ft bay was already needed to accommodate the overhanging portion of the second floor. Figure 7 shows the new bay configuration. This move eliminates a column line from the building and saves a considerable number of columns and foundations for the project. Aside from the interior column line, the building requires only four additional isolated columns which are used to create the braces for the lateral system.

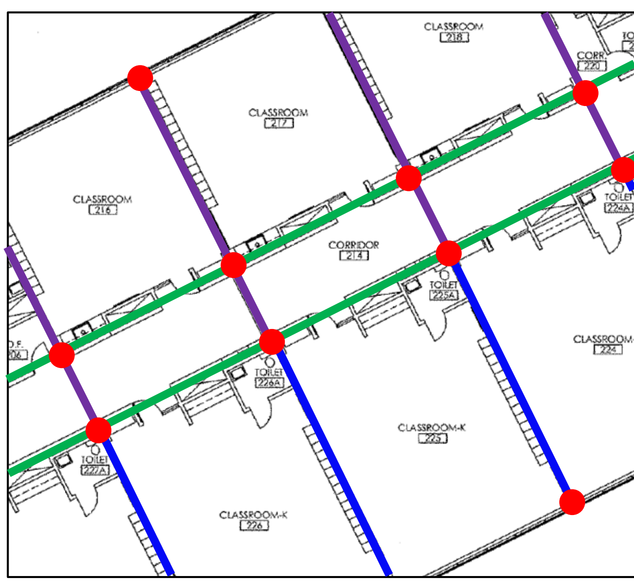


Figure 6: Original Structural Grid Layout

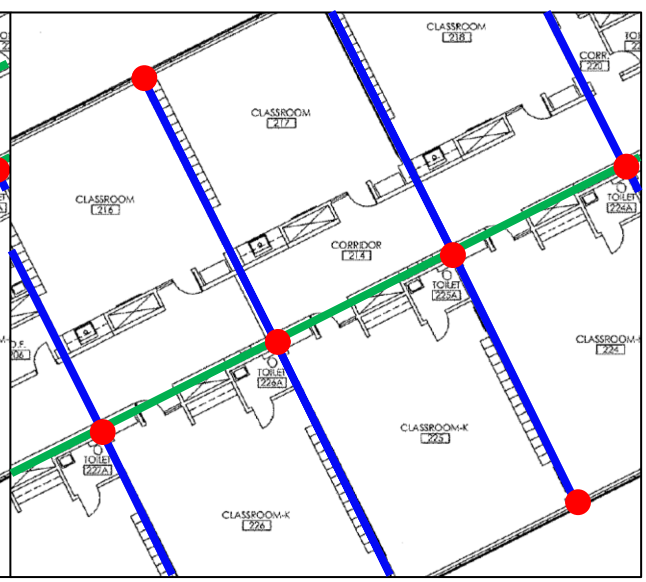


Figure 7: Modified Structural Grid Layout

Rationale for System Selection

One of the important goals for the structural team to save money was to minimize the cost of the foundation system by limiting the number of driven piles and pile caps required for the project. In order to do this, the team wanted to use as few columns as possible in the building. The team noticed that in the three-bay configuration proposed by the original building floor plans, the bay sizes were 30 ft, 12 ft, and 40 ft. Since a 40 ft span was already part of the structural layout, the team decided that combining the 30 ft and 12 ft spans into a single 42 ft span would be an economical decision. This way, the building only has a single line of isolated columns in most portions of the structure, reducing the number of required pile caps and piles for isolated columns. Even with the increased span, the loads on the interior columns were not increased significantly enough to require more than the recommended three piles per pile cap.
To use the central wing corridor as an example, the column size required is a W12x87 which carries the required load of 889 kips on each column at an un-braced length of fourteen feet. In conclusion, the decision to eliminate a column line from the structure seemed like a logical one based on the dimensions of the floor plan, and it is also a great way to improve the cost-efficiency of the structure.

<u>Exterior Bearing Wall</u>

Description of System

One of the most unique features of the structural system is the exterior bearing wall system. The system uses 6" thick reinforced concrete bearing walls and Insulated Concrete Forms (ICFs). ICFs are stay-in-place forms built with two pieces of foam insulation held together by plastic bridging. ICFs have a number of advantages including ease of construction due to their modular nature. The ICF system provides a structural purpose for the building, but it also has several thermal advantages and is virtually airtight. The ICF manufacturer also provides forms for beam seats that make it easy to transfer loads from the floor systems. Finally, the ICF walls are also able to be utilized as shear walls for the building's lateral force-resisting system.

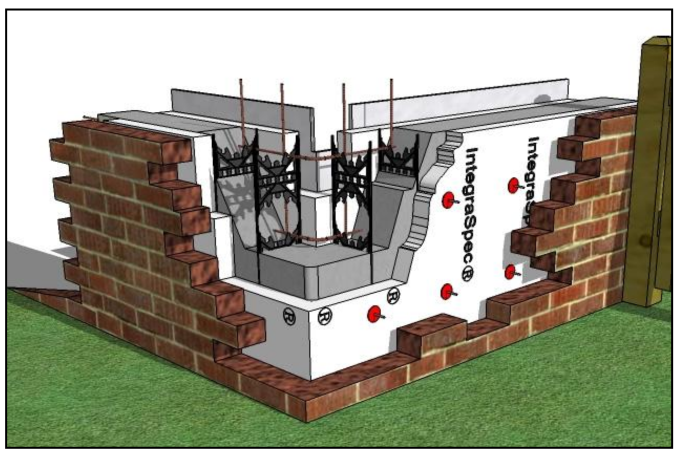


Figure 8: Insulated Concrete Form Wall Cutaway

Rationale for System Selection

The exterior bearing wall system for the building serves a number of purposes. The walls are used as part of both the gravity system and lateral system of the structure. However, another important reason the design team opted to use Insulating Concrete Form (ICF) walls is to provide thermal insulation. The ICF wall solution is one that was reached through discussion and research among both the structural and mechanical designers. The ICF walls help to provide significant savings in lifecycle costs of the building by reducing the loads on the mechanical system. The construction team also saw many advantages in using the ICF wall system. Not only are the ICF blocks easy to install due to their modular nature, but the system greatly reduces the cost of formwork and the labor that is involved in building and removing formwork.

In addition to providing benefits to the mechanical systems, the 6” thick ICF walls designed for the building proved to be a great choice for the structural system. The walls are useful for both the gravity and lateral systems, which will be discussed next in this document. There was some initial concern with the stability of the bearing walls, especially in the pool and gym areas. The walls were checked for incidental out of plane eccentric loads according to ACI Section 14.8 and the wall was found to be stable. Additionally, the ICF walls help contribute to the safety and security of the building. As will be explained with the emergency shelter, the walls also provide adequate protection against projectiles. Moreover, the strong exterior wall system can provide against gunfire. This is a critically important characteristic of the wall for added safety, especially in light of recent security failures and tragic shootings in schools.

<u>Floor System</u>

Description of System

The floor system consists of composite steel beams and girders along with a 3” thick slab on a 3” composite metal deck that typically spans 8’-4” between beams. The floor system was chosen largely on the desire to use as few columns as possible. Composite deck and W18x46 beams were able to provide the long spans that were required to achieve this, while still providing a manageable structural depth. The 3” slab on 3” deck helps to avoid deflection issues over the long span and also limits the effects of vibrations on the floor system.

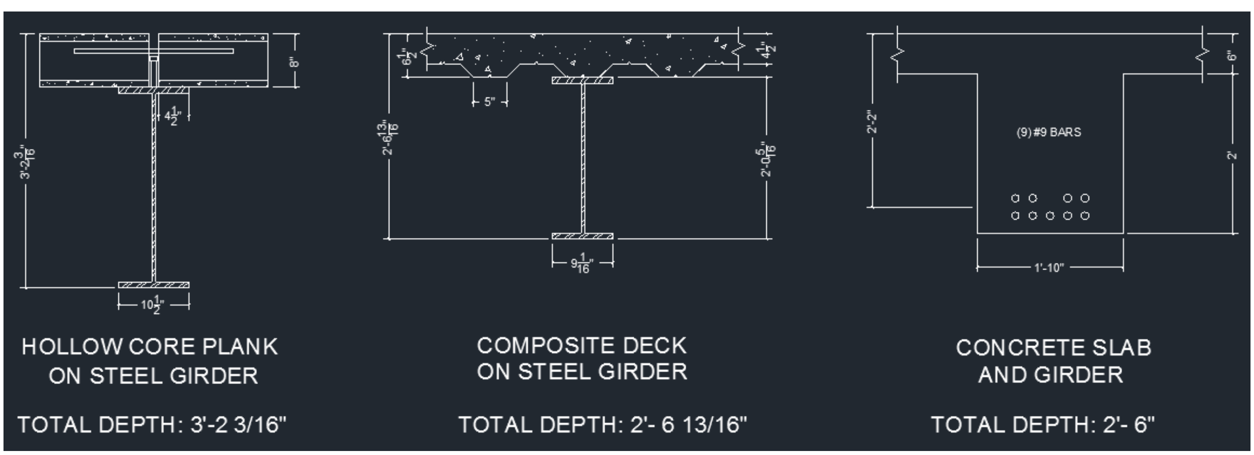


Figure 9: Comparison of Depth for Investigated Floor System Options

Rationale for System Selection

One of the challenges resulting from the increased structural bay sizes is the long spans that must be supported by the floor beams. The team determined that it was best to span the beams in the long direction of the bay and the girders in the short direction. Even though this configuration requires slightly deeper beams, it greatly reduces the required girder depth. Based on the direction in which the mechanical duct runs through the building, it was necessary to limit the depth of the structural system running across the hallway. This was an important factor in choosing a structural floor system.

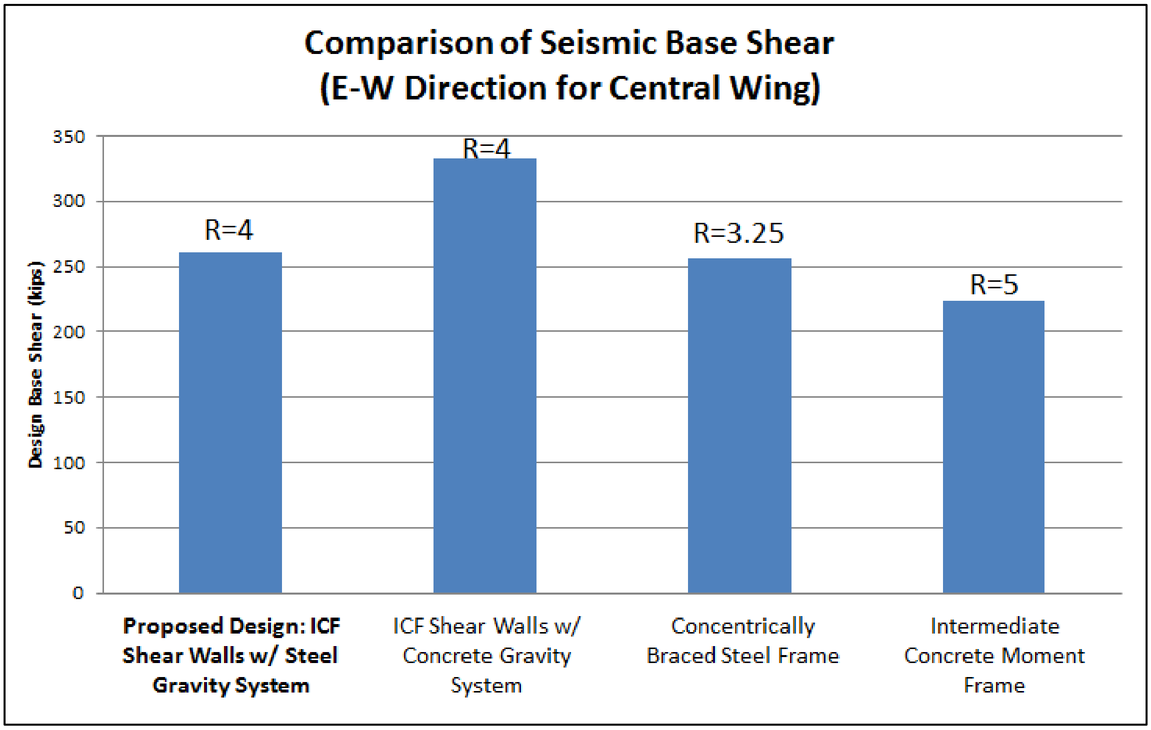


Figure 10: Comparison of Design Seismic Base Shear for Different Combinations of Gravity and Lateral Systems

The structural team came to the conclusion that a steel frame with composite floor deck is the most appropriate choice for the building. The team primarily investigated three options for the floor systems: steel framing with hollow-core concrete planks, concrete one-way slab on concrete beams, and steel framing with a concrete slab on composite metal deck. A comparison of the required depths for each system described in Figure 9 shows that the steel frame with composite deck provides an acceptable structural depth. In a typical 40 ft by 28 ft bay in the central wing of the building, the structure uses W18x46 floor beams spaced at 9'-4". The girders along the 28 ft span are W24x68 section beams. The use of a steel structural system was also a preferred choice of the construction team since steel is more common in Reading than concrete. An all concrete solution would also be heavier and require more piles. Subcontractors in the area are likely to have more experience with steel frame buildings, so using steel for this project seemed like a logical decision.

Another driving factor for the selection of the structural floor system was the resulting lateral loads that act on the building. Figure 10 shows a comparison of the design base shear for typical structural systems used with or without exterior ICF walls. As the diagram shows, the proposed design has a significantly lower base shear than the option to use exterior ICF shear walls with a concrete gravity load system. This occurs since the concrete system is much heavier, but value of R for the shear walls remains the same and is taken as 4. This is not true for the case of an intermediate concrete moment frame without shear walls. In this case, R can be taken as 5, and the result is a building with the lowest seismic base shear of the options investigated. One drawback to the ICF walls is the significant amount of weight that is added to the building, but without the benefit of a high R. However, since it was a team decision to use the exterior ICF walls to improve thermal efficiency and reduce energy costs, the steel concentrically braced frame system proved to be the best choice. Admittedly, the base shear from the proposed design is nearly the same as the base shear for a concentrically braced steel frame system, so the structural team is satisfied with this decision.

Originally, the team designed the floor system with a 4-1/2” slab on 3” deck in order to achieve a two-hour fire rating. After investigating the International Building Code more thoroughly, it was determined that the structural system does not need to be fire-rated so long as the entire building has a sprinkler system. The team opted to include a sprinkler system in the building, and as a result, the slab thickness was reduced to a 3” slab on 3” metal deck. This size slab was chosen in order to prevent deflection and to help prevent floor vibration issues. Vibration in the floor system due to the long span of the beams was a concern that the structural team wanted to investigate more thoroughly. To do this, the team reviewed a document on office floor vibrations (*Preliminary Assessment for Walking-Induced Vibrations in Office Environments,* Hanagan and Kim) [4]. After reviewing this document, it was determined that the designed floor system configuration will not be sensitive to vibration issues. According to the research presented in this document, there is a “soft spot” in beam spans where vibrations become a problem. In other words, short spans usually to not present a problem and long spans do not present a problem, it is rather the intermediate spans (25 ft.-35 ft.) that can cause problems. Because of this, it was determined that our floor system will not have any vibration problems.

<u>Roof System</u>

Description of System

The roof system over the pool consists of long-span steel joists with non-composite metal roof deck. The roof system over the gymnasium also uses long-span steel joists, but with a 3” non-composite deck and 3” concrete slab over the gym to help satisfy FEMA shelter requirements, and is explained in the following section. The roof system over the classrooms consists of non-composite beams with non-composite metal roof deck. The biggest concerns for the roof were snow drift loads, which were calculated to be a maximum of 49 psf for a school in Reading.

Rationale for System Selection

Long span steel joists like those shown in Figure 11 were chosen to be used in the pool and gym areas not only because of the long spans, but also since the exterior concrete bearing walls are available to support the roof system. Since there is no need for interior columns in these spaces, the depth of the joists was controlled by optimizing the joist spacing in both rooms.

Figure 11: Pool Roof System

The roof over the classrooms is supported by steel beams and roof deck. This was preferred over using roof joists in order to keep a reasonable structural depth. Due to the long spans that would be required by the joists, deep joist sections would be required to control deflections. The biggest concerns pertaining to roof loads throughout the building were the snow loads and snow drift loads. A local provision of 35 pounds per square foot of ground snow load was used in calculating the snow loads. Because of the different roof levels, snow drift is a concern, and it was found that the average snow drift load is 49 pounds per square foot. This was used when designing the roof system for all of the two story-height roofs.

Multipurpose Room and Shelter

Description of System

Because the community determined there may be a need for an emergency shelter, the feasibility of allowing the gymnasium to also function as a shelter was investigated, and it was determined that it could be accomplished with little added cost to the project. The gym structure was designed according to the FEMA document P-361 [3], Design and Construction Guidance for Community Safe Rooms. Since the exterior walls are 6”-thick concrete bearing walls, they

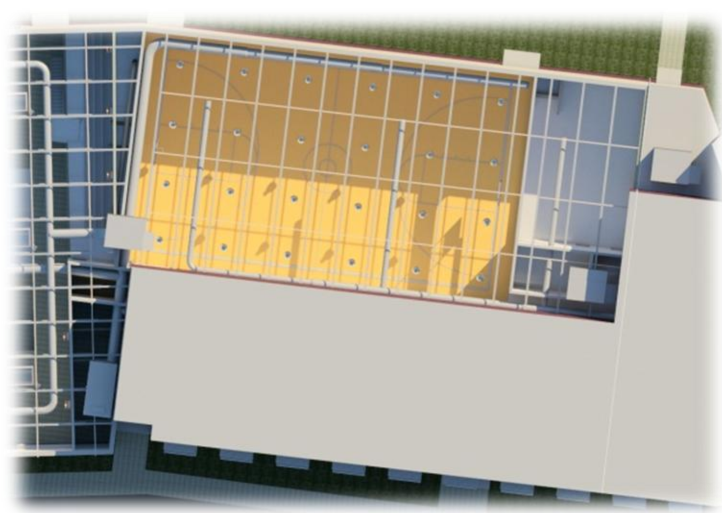


Figure 12: Overhead view of the Gym/Shelter area

meet the FEMA projectile requirements. The interior walls were able to be designed as concrete shear walls to resist wind forces of a major hurricane. In order to meet FEMA requirements of wind uplift resistance and vertical projectiles, the structural team decided to use a 3" concrete slab on a 3" non-composite steel deck. The roof joists were then upsized accordingly in order to support the added weight. The major additions to the structural system in order to qualify the gym as a shelter included adding the slab to the roof and increasing the size of the roof joists.

Rationale for System Selection

FEMA Document P-361: Design and Construction Guidance for Community Safe Rooms [3], was used in order to design the gym as a community shelter. The need for a community shelter was determined by the school board along with the community. The project documentation suggested the need for a "community shelter in the event of a power outage or emergency." As discussed earlier, it was determined that the gym could be designed as a FEMA certified community hurricane shelter without much added cost. The roof material was changed from metal roof deck to a non-composite 3" slab on 3" deck in order to add weight to the system and reduce uplift effects. A composite slab-deck configuration is unnecessary because the weight of the assembly controls the design over the flexural strength and depth of the roof system. The steel long-span joists were slightly enlarged from an initial design of 36" to 40" in size in order to support the increased weight of the roof. No windows or skylights were put into the gymnasium. While this isn't ideal for a normal gymnasium, it is ideal for a hurricane shelter and to prevent projectile penetration through windows. This eliminated the need for expensive impact-resistant glass. It was determined by the project team that it made more sense to not have to use projectile resistant windows and to not have significant day lighting in the gym, which is typically artificially lit anyways. The resilient concrete exterior walls are helpful for creating a shelter as well due to their ability to resist projectiles.

<u>Lateral Force-Resisting System</u>

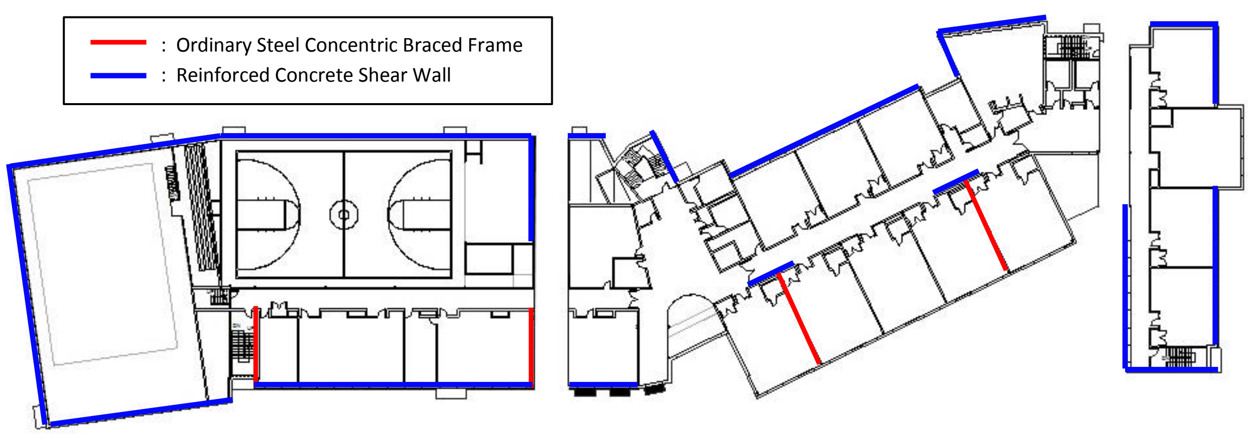


Figure 13: Plan View Illustrating the Three Structure Segments and the Lines of Lateral Resistance Used Throughout the Building

Description of System

Using the guidelines of ASCE 7-05 [2] (a requirement of the Pennsylvania UCC [6]), it was determined that seismic forces are the controlling factor for the design of the building's lateral force resisting system. As previously discussed with the selection of the floor systems, the large amount of weight added to the structure by the exterior concrete bearing walls was a significant reason causing the seismic forces to dominate wind forces. However, the exterior bearing walls provide an advantage since they are also utilized as lateral force-resisting shear walls for the building. Since the building is broken into three independent structures, each section is designed slightly different from the others.

The west wing of the building, which features the pool and gymnasium/emergency shelter, is designed with an importance factor of 1.5 since this portion of the structure is considered essential during an emergency situation. Lateral forces in the east-west direction are resisted by the 6"-thick exterior shear walls of the building. Shear walls also provide lateral resistance in the north-south direction of the building, but ordinary concentrically braced steel frames are also included to provide lateral resistance for the three-story portion of the structure that includes the library and several third-floor classrooms. The concentric braces are comprised of HSS 6"x6"x1/4" steel members that fit within the thickness of the walls between rooms.

The central wing of the building, which features most of the classrooms and learning spaces, is designed with an importance factor of 1.25 since its structure is independent from the shelter structure. Like the west wing, the central wing uses exterior shear walls to provide lateral resistance in the east-west direction. Since the south façade of the building features an extended second floor, a continuous bearing wall was not a viable option. Instead, the south façade is built as a curtain wall hung from a steel frame. This necessitated additional lateral force resistance in the east-west direction, so two 8"-thick shear walls were added along the hallway to provide the required resistance. In the north-south direction, the same concentric bracing scheme used for the west wing is used again.

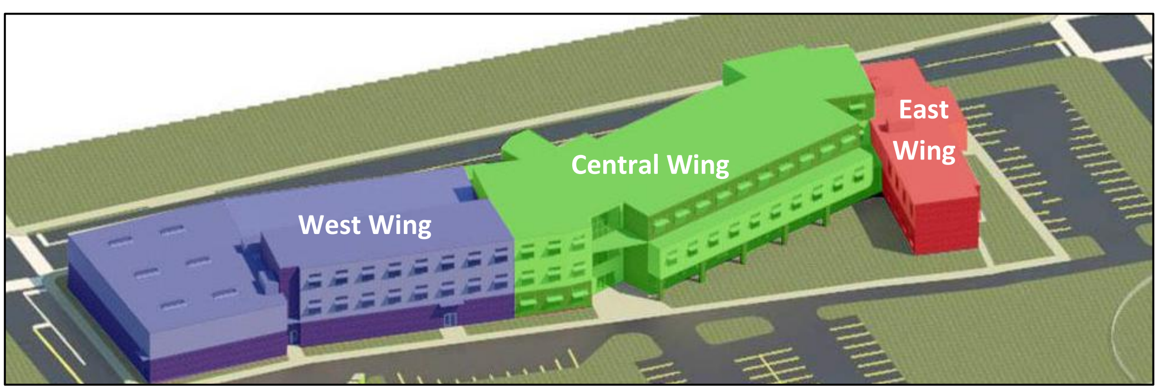


Figure 14: Illustration Showing the Three Separate Structures

Rationale for System Selection

During the design process, it was discovered that an important consequence of using the exterior concrete bearing walls in the building is the large increase in weight of the structure. Due to the high weight of the building because of the bearing walls, it was discovered that the seismic loads on the building control the lateral design over the wind loads. Another challenge that arose from this situation was the effect of torsion created by the unique geometry of the building floor plan. Especially where the central wing and east wing of the building form sharp corner, torsional effects became a concern for the structural team. An investigation of some earthquake design techniques suggested that an attractive option for reducing the torsional forces was to isolate separate wings of the structure by adding an expansion joint. This became another major decision made by the structural team for the design. Although several columns were added to the structure at the expansion joints, adjacent columns are still able to share a pile cap. This was especially important to the team since minimizing the number of piles and pile caps was a driving factor for many of the other decisions made for the structural system.

In addition to separating the structure between the central and east wings, the structural team also saw advantages to separating the structure between the central and west wings as well. Since the west wing includes the emergency shelter, the building requires an importance factor of 1.5 for seismic loads according to ASCE 7-05 [2]. However, isolating the west wing of the building from the rest of the structure would require that only the west wing has an importance factor of 1.5. The rest of the building can be considered as just an elementary school, and therefore use an importance factor of 1.25. This change was useful in helping to reduce the impact of adding an emergency shelter on the loads for the rest of the building.

In each of the three wings of the building, the east-west direction lateral system utilizes the exterior bearing walls as shear walls. For simplification, since the walls are interrupted by classroom windows, the shear walls in those areas are assumed to be 7 ft long segments. The west wing of the building uses shear walls in the north-south direction as well. However, in order to provide lateral support for the third floor of the west wing in the north-south direction, two lines of concentric braces were added. The same type of braces are used to provide lateral resistance in the north-south direction for the central wing since this wing is unable to rely on shear walls in the north-south direction. The designed braces include HSS 6x6x1/4 tubes that fit into the walls between classrooms. Like the west wing, the central wing uses two lines of bracing to provide the required resistance. Because the south side of the central wing uses a curtain wall system instead of a bearing wall, two 8” thick shear walls were added along the hallway to meet the demand of the lateral forces. The east wing of the building is able to rely on the exterior bearing walls in both directions to provide adequate resistance.

Computer Modeling

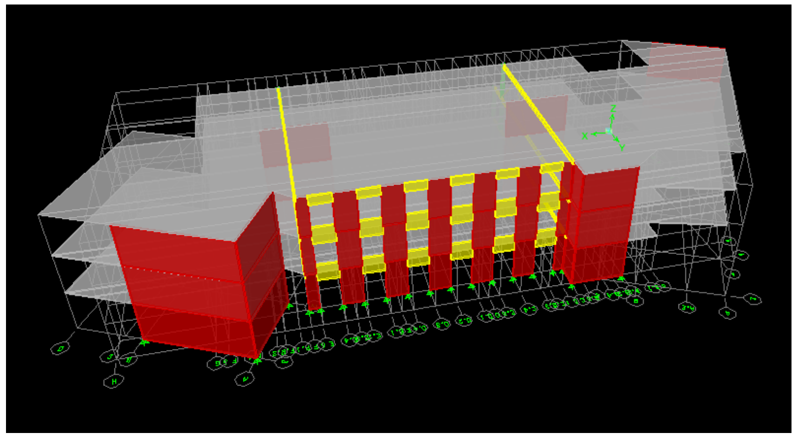


Figure 15: Sample ETABS Model Showing Walls and Coupling Beams

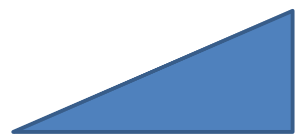
In order to more accurately evaluate the structure's lateral systems, the team created an ETABS computer model of each of the three wings of the building to analyze forces and check displacements. The ETABS model was important in determining the size of the expansion joints between the separate building wings. The models showed that the maximum displacement for a structure at any of the expansion joint locations was never greater than 1". Therefore, it was determined that a 2" expansion joint will be satisfactory. In order to more accurately simulate the behavior of the exterior bearing walls, the model walls are meshed into 12" squares, and the wall material properties are defined to have half of the actual modulus of elasticity in order to simulate a cracked wall section. Additionally, 6 ft deep coupling beams are modeled between walls to simulate those walls which include classroom windows. The modal response time periods from these models are used to help determine the C_s coefficients and the seismic forces on the building. Corresponding seismic and wind forces for these analyses are shown in the document appendix spreadsheets.

ROOF/SNOW LOAD CALCULATION SPREADSHEET

According to Provisions of ASCE 7-05

Snow Load

p_g=	35 psf	p_f=	27 psf
C_e=	1	p_s=	54 psf
C_t=	1	p_d=	49
I=	1.1	w=	10.5
h_d=	2.625		
ɣ=	18.55		



Roof Live Load

LL=	20 psf	A_t=	200
R_1=	1		
R_2=	1		
LL Reduced=	20		

Superimposed DL

10 psf

Total Load

55 psf

15.4336
38.584

Roof Deck

		Capacity	3-Span-Max Span
1.5B	1.7 psf	87 psf	6'11"

Joist

TL=	0.34 klf	24K6	10.1 plf

Joist-Girder

TL= 4.9

60' span	G10N60	41 plf

6.5

Pool

65'

0.2756

WIND LOAD CALCULATION SPREADSHEET

According to Provisions of ASCE 7-05

Building Classification	Basic Wind Speed	Exposure	Building Hieght	Gust Factor
III	90 mph	B (urban)	42'	0.85

Velocity Pressure
qz=0.00256KzKztKdV^2I

Kz=	0.81
Kzt=	1
Kd=	0.85
V=	90
I=	1.15

	Kz			qh (psf)	
	Case 1 (C&C)	Case 2 (MLFRS)		Case 1 (C&C)	Case 2 (MLFRS)
0-15	0.7	0.57	0-15	14.188608	11.5535808
20	0.7	0.62	20	14.188608	12.5670528
25	0.7	0.66	25	14.188608	13.3778304
30	0.7	0.7	30	14.188608	14.188608
40	0.76	0.76	40	15.4047744	15.4047744
50	0.81	0.81	50	16.4182464	16.4182464

Internal Coefficient	
Probably +/-	0.55
Maybe +/-	0.18

External Pressure Coeff. Part. Enc.	Open
Lee	-0.5
Windward	0.8
Side	-0.7

Roof Ex. Press. Coeff.	
0-h	-0.9
h-2h	-0.5
>2h	-0.3

MWLRS p=qh [(GCpf)-(Gcpi)] Positive Internal
Case 2 (MLFRS)

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
8.2091232	-9.933039072	-12.72414096	-15.51524285	-9.93303907	-7.141937184

MWLRS p=qh [(GCpf)-(Gcpi)] Negative Internal
Case 2 (MLFRS)

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
14.1196919	-4.022470368	-6.813572256	-9.604674144	-4.02247037	-1.23136848

C&C p=qh [(GCpf)-(Gcpi)] Positive Internal
Case 2 (MLFRS)

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
8.2091232	8.2091232	8.2091232	8.2091232	8.2091232	8.2091232

C&C p=qh [(GCpf)-(Gcpi)] Negative Internal
Case 2 (MLFRS)

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
-8.2091232	-8.2091232	-8.2091232	-8.2091232	-8.2091232	-8.2091232

Wind Load Study: Safe Room

Building Classification	Basic Wind Speed	Exposure	Building Hieght	Gust Factor
III	160 mph	B (urban)	42'	0.85

Velocity Pressure
qz=0.00256KzKztKdV^2I

Kz=	0.81
Kzt=	1
Kd=	0.85
V=	160
I=	1.15

	Kz			qh (psf)	
	Case 1 (C&C)	Case 2 (MLFRS)		Case 1 (C&C)	Case 2 (MLFRS)
0-15	0.7	0.57	0-15	44.8	36.5
20	0.7	0.62	20	44.8	39.7
25	0.7	0.66	25	44.8	42.3
30	0.7	0.7	30	44.8	44.8
40	0.76	0.76	40	48.7	48.7
50	0.81	0.81	50	51.9	51.9

Internal Pressure Coefficient	
+/-	0.55

External Pressure Coeff. Part. Enc.	Open
Lee	-0.5
Windward	0.8
Side	-0.7

Roof Ex. Press. Coeff.	
0-h	-0.9
h-2h	-0.5
>2h	-0.3

MWLRS p=qh [(GCpf)-(Gcpi)] Positive Internal
Case 2 (MLFRS)

Windward	Lee	Side
6.7	-50.6	-59.4

MWLRS p=qh [(GCpf)-(Gcpi)] Negative Internal
Case 2 (MLFRS)

Windward	Lee	Side
63.8	6.5	-2.3

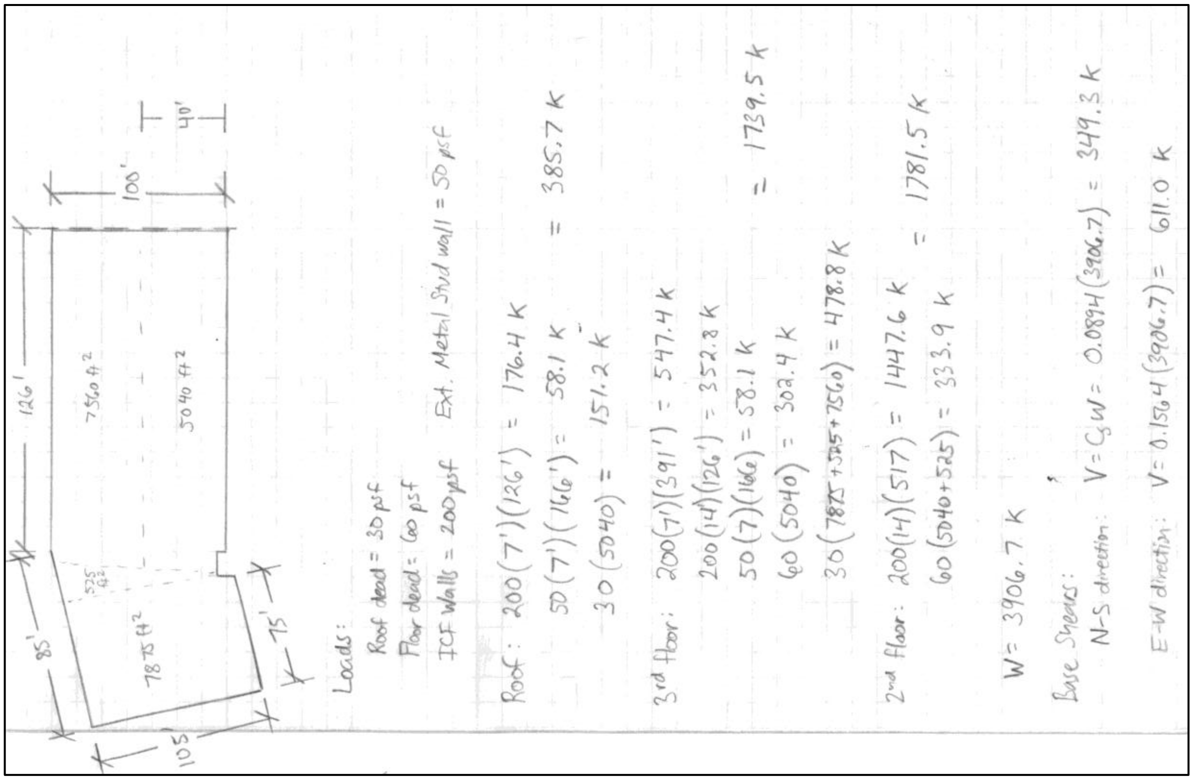
C&C p=qh [(GCpf)-(Gcpi)] Positive Internal
Case 2 (MLFRS)

Roof (0-h)	Roof (h-2h)	Roof (>2h)
-59.0	-43.7	-36.1

C&C p=qh [(GCpf)-(Gcpi)] Negative Internal
Case 2 (MLFRS)

Roof (0-h)	Roof (h-2h)	Roof (>2h)
-9.6	5.6	13.2

ROOF, WALL, AND FLOOR AREA CALCULATIONS



Loads:

Roof dead = 30 psf
Floor dead = 60 psf
ICF Walls = 200 psf   Ext. Metal Stud wall = 50 psf

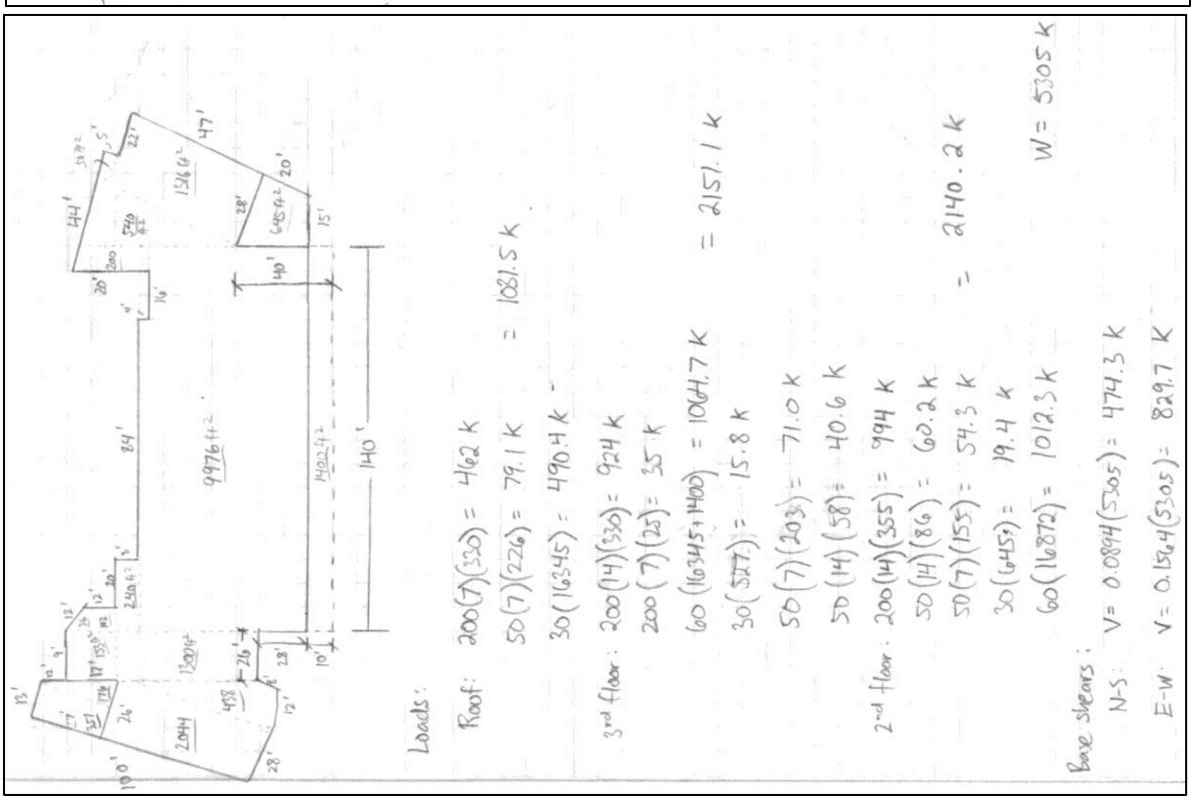
Roof: 200(7')(126') = 176.4 k
50(7')(166') = 58.1 k   = 385.7 k
30(5040) = 151.2 k

3rd floor: 200(7')(391') = 547.4 k
200(14)(126') = 352.8 k
50(7)(166) = 58.1 k   = 1739.5 k
60(5040) = 302.4 k
30(7875+525+7560) = 478.8 k

2nd floor: 200(14)(517) = 1447.6 k   = 1781.5 k
60(5040+525) = 333.9 k

W = 3906.7 k

Base Shears:
N-S direction: $V = C_s W = 0.0894(3906.7) = 349.3$ k
E-W direction: $V = 0.1564(3906.7) = 611.0$ k



Loads:

Roof: 200(7)(330) = 462 k
50(7)(226) = 79.1 k   = 1081.5 k
30(16345) = 490.4 k

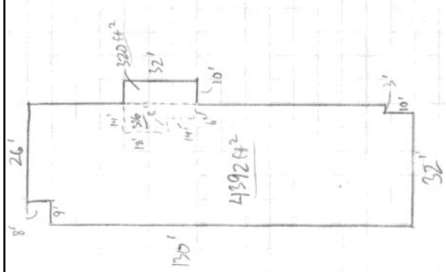
3rd floor: 200(14)(330) = 924 k
200(7)(25) = 35 k
60(16345+1400) = 1064.7 k   = 2151.1 k
30(527) = 15.8 k
50(7)(203) = 71.0 k
50(14)(58) = 40.6 k

2nd floor: 200(14)(355) = 994 k
50(14)(86) = 60.2 k
50(7)(155) = 54.3 k   = 2140.2 k
30(645) = 19.4 k
60(16872) = 1012.3 k

W = 5305 k

Base shears:
N-S: $V = 0.0894(5305) = 474.3$ k
E-W: $V = 0.1564(5305) = 829.7$ k

ROOF, WALL, AND FLOOR AREA CALCULATIONS (CONT.)



Loads:

Roof: $200(7)(250) = 350\ k$
$50(7)(52) = 18.2\ k$ $= 520\ K$
$30(5048) = 151.4\ k$

2nd floor: $200(14)(250) = 700\ k$
$50(7)(52) = 18.2\ k$
$60(5048) = 302.8\ k$ $= 1042\ K$
$50(7)(60) = 21\ k$

$W = 1562\ K$

Base Shears:

E-W: $V = 0.0894(1562) = 139.6\ k$

N-S: $V' = 0.1564(1562) = 244.3\ k$

Force Dist.:

Roof $W = 520$ $h = 28'$ $C_{vr} = \frac{520(28)}{29148} = 0.500$ E-W: $0.5(139.6) = 69.8\ k$ N-S: $0.5(244.3) = 122.2\ k$

2nd floor $W = 1042$ $h = 14'$ $C_{v2} = \frac{1042(14)}{29148} = 0.500$ E-W: $0.5(139.6) = 69.8\ k$ N-S: $0.5(244.3) = 122.2\ k$

C_S Coefficient Calculation

Spectral Response Acc. (from ASCE 7-05)		Building Data			Story Heights		
S_s=	0.25	Total Height:	28	ft	Roof	0	ft
S_1=	0.06	Ct value:	0.02		3rd Floor	28	ft
F_a=	2.5	x:	0.75		2nd Floor	14	ft
F_v=	3.5	Imp. Factor:	1.25				
T_L=	6	R (N-S)=	4		**Time Period (from ETABS)**		
		R (E-W)=	4		=	0.289	s

S_{DS}=	0.417
S_{D1}=	0.140
T_0=	0.067
T_L=	6
T_S=	0.336
T_a=	0.289
S_a=	0.417

N-S:		E-W:	
R=	4	R=	4
C_s=	0.1302	C_s=	0.1302
C_s=	0.1514	C_s=	0.1514
C_s=	**0.1302**	**C_s=**	**0.1302**

Loads:		
Roof dead=	30	psf
Floor dead=	60	psf
ICF Walls=	125	lbs/per sf wall area
Curtain Walls=	50	lbs/per sf wall area

Trib Areas:			
Roof Level	Roof=	0	ft^2
	Floor=	0	ft^2
	ICF Wall=	0	ft^2
	Curtain Wall=	0	ft^2
3rd Floor Level	Roof=	5048	ft^2
	Floor=	0	ft^2
	ICF Wall=	1750	ft^2
	Curtain Wall=	364	ft^2
2nd Floor Level	Roof	0	ft^2
	Floor	5048	ft^2
	ICF Wall	3500	ft^2
	Curtain Wall	784	ft^2

EARTHQUAKE LOAD CALCULATION SPREADSHEET (CONT.)

Roof Level Load
W= 0.0 kips

3rd Floor Load
W= 388.4 kips

2nd Floor Load
W= 779.6 kips **Total W= 1167.97 kips**

Load Distributions:

N-S:		E-W:	
Base Shear=	152.1 kips	Base Shear=	152.1 kips

k= 1

C_{VR}= 0.0000

C_{V3}= 0.4991

C_{V2}= 0.5009

N-S:		E-W:	
Roof	**0.0** kips	Roof	**0.0** kips
3rd Floor	**75.9** kips	3rd Floor	**75.9** kips
2nd Floor	**76.2** kips	2nd Floor	**76.2** kips

EXTERIOR BEARING WALL DESIGN SPREADSHEET

	Pu
1st Floor	47.2
2nd Floor	41.2
3rd Floor	41.2
Roof	17.6
Total	147.2
x2	294.4

$\phi P_n = 0.55\phi f_c' A_g[1-(kl_c/32h)^2]$

Empirical Design Method

Wall Dimensions

0.50	x	7	504
			(A_g)

$\rho_{min\ vert}$	$\rho_{min\ horiz}$	s	k
0.0015	0.0025	12	1

10.08

h	l_c	f_c'
12	504	4

1.8

106.7797

$\phi P_{n,max} = 0.80\phi[0.85 f_c'(A_g - A_{st}) + f_y A_{st}]$

Compression Members

A_{st}	A_g	f_y	f_c'
6.16	504	60	4

ϕ	$\phi P_{n,Max}$
0.85	1402.334

6.16

0.54

$V_c = 2\lambda f_c'^{\wedge 1/2} hd$

Shear in Walls

$V_s = A_v f_y d/s$

λ	f_c'	h	d	ϕ
1	4000	6.00	67.2	0.75

V_c	V_s	s	A_v	bar#
51.00121	49.28	18	0.22	3

ϕV_n
75.21091

1.833333 22 0.634371 0.539216

3.745 194.3333

0.01471

174.9

Composite Beam Design Spreadsheet

LL	Reduced LL	K_{LL}	
27 psf	22 psf	2	

Superimposed DL	Deck depth	Slab depth	Total depth
15 psf	3 in.	3 in.	6 in.

Span	Spacing	Deck and Slab DL	Beam Self Weight Assumption
40 ft	9.33 ft	56 psf	5.2 psf

W_{DL}	W_{LL}	W_{UL}	Concrete strength
0.71 klf	0.3 klf	1.35 klf	4 ksi

V_U	M_U
27.0 kips	269.7 kip-ft

b'	b_{Eff}		Q_n	$\Delta_{LL\ Allowable}$
56 in	112 in.	interior	17.2 kips	1.33 in.
	56 in.	exterior		

I_{min} (From $\Delta_{LL\ Allowable}$)	a (assumed)	y_2
375.39 in^4	2 in.	5 in.

Pick Section From Steel Manual	W	18	x	46	I (Non-Composite)	ϕM_P
					712 in^4	340 kip-ft

I	$\sum Q_n$
1220 in^4	239 kips

# of studs	Economy
28	2120

Δ

$\Delta_{TL\ Allowable}$	I_{min} (From $\Delta_{TL\ Allowable}$)	$LL_{Construction}$
2 in.	957	20 psf

$w_{Unshored}$	$M_{unshored}$
0.82 klf	165 kip-ft

$\Delta_{wet\ concrete}$	$w_{wet\ concrete}$
0.92581	0.6 klf

Check Self-Weight	a
4.9 psf	0.63 in.

Camber
1 in

COMPOSITE GIRDER DESIGN SPREADSHEET

P_D	P_L	P_U	Concrete strength	Deck and Slab DL
28.448	10.08	51.266	4 ksi	56 psf

Span	Spacing	b'
28 ft	40.00 ft	42 in

b_{Eff}		V_U	M_U
84 in.	interior	51.3 kips	478.5 kip-ft
42 in.	exterior		

I_{min} (From $\Delta_{LL\ Allowable}$)	$\Delta_{LL\ Allowable}$
504.53 in^4	0.93 in.

Q_n	a (assumed)	y_2
21 kips	2 in.	5 in.

Pick Section From Steel Manual

W	24	x	68

I (Non-Composite)	ϕM_P
1830 in^4	664 kip-ft

I	$\sum Q_n$	ϕM_n
2970 in^4	251 kips	916 kip-ft

# of studs	Economy
24	2144

Δ Checks

$\Delta_{TL\ Allowable}$	I_{min} (From $\Delta_{TL\ Allowable}$)	$LL_{Construction}$
1.4 in.	1286	20 psf

$P_{Unshored}$	$M_{unshored}$
43.53 kips	406 kip-ft

$\Delta_{wet\ concrete}$	I_{minWC} (From $\Delta_{TL\ Allowable}$)
1.295107	1693

Check Self-Weight	a
OK	0.88 in.

Camber
1.25 in

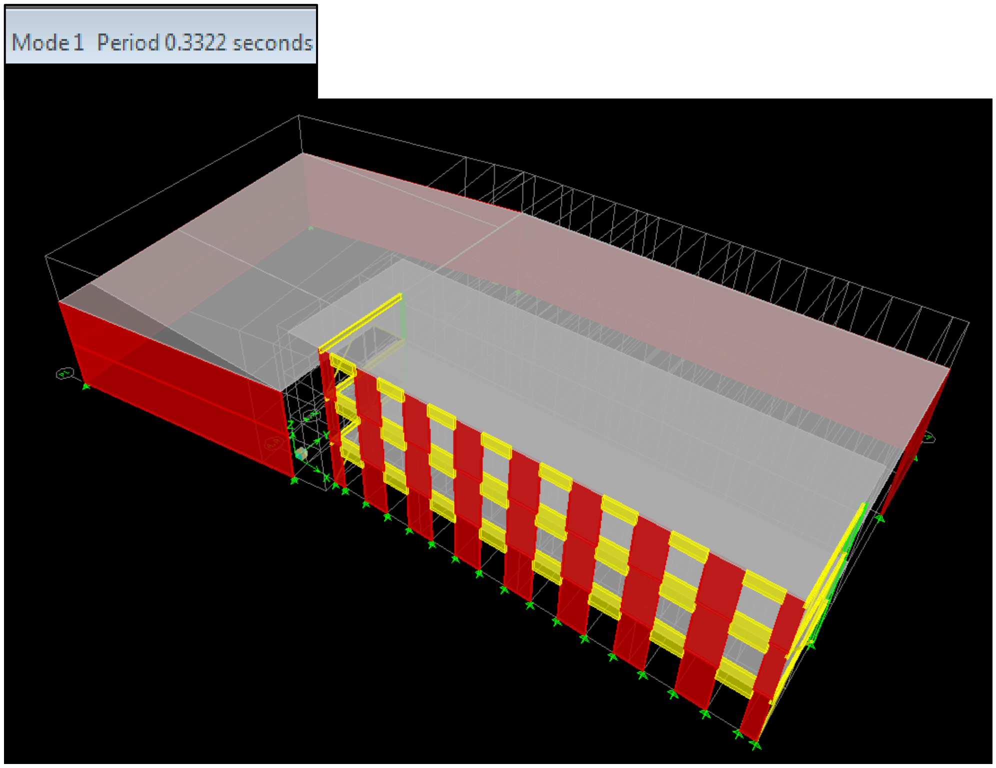


Figure A: West Wing ETABS Model and Modal Response Period

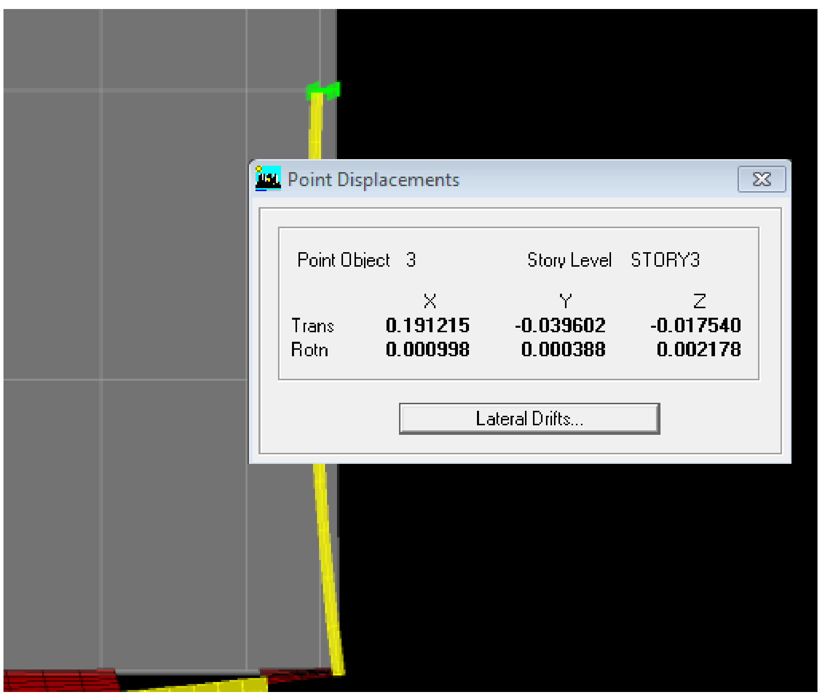


Figure B: West Wing Maximum Displacement at Expansion Joint

ETABS Modeling Summary (Cont.)

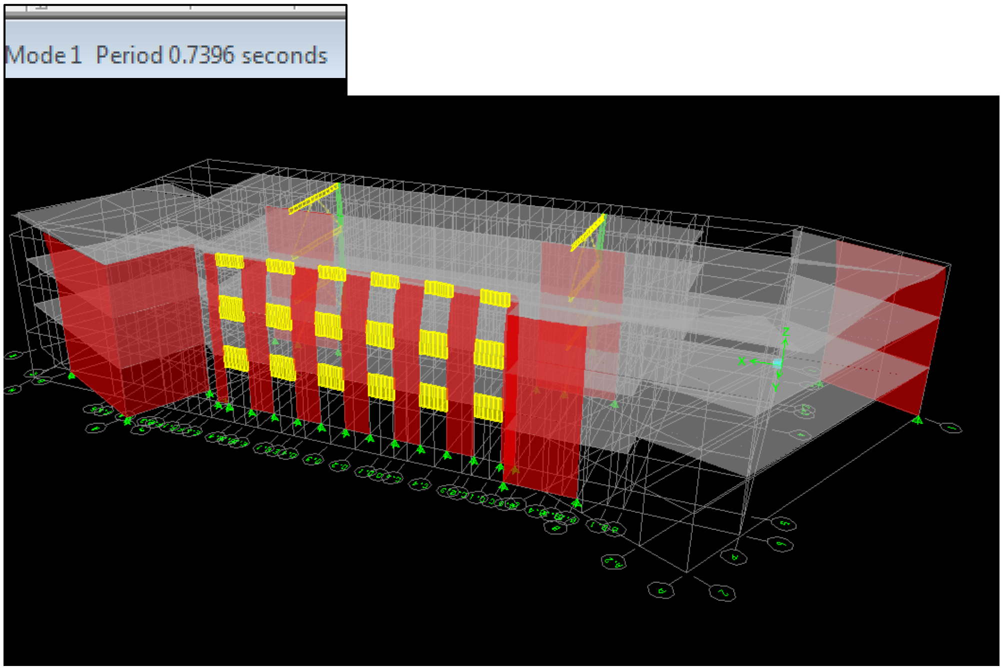


Figure C: Central Wing ETABS Model and Modal Response Period

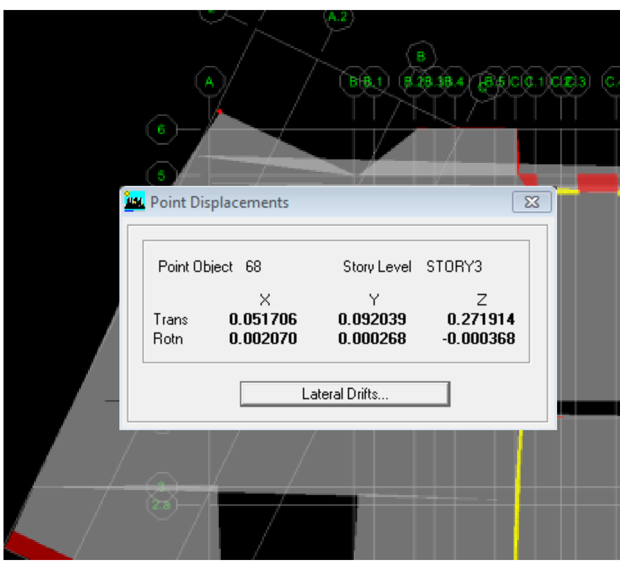


Figure D: Central Wing Maximum Displacement at West Expansion Joint

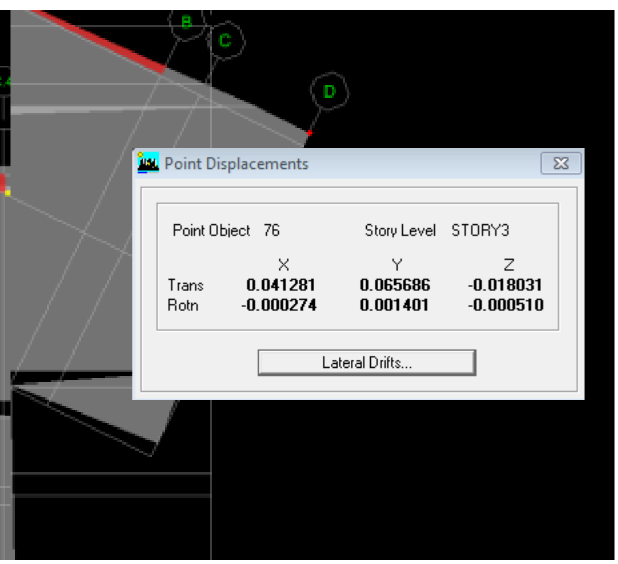


Figure E: Central Wing Maximum Displacement at East Expansion Joint

ETABS Modeling Summary (Cont.)

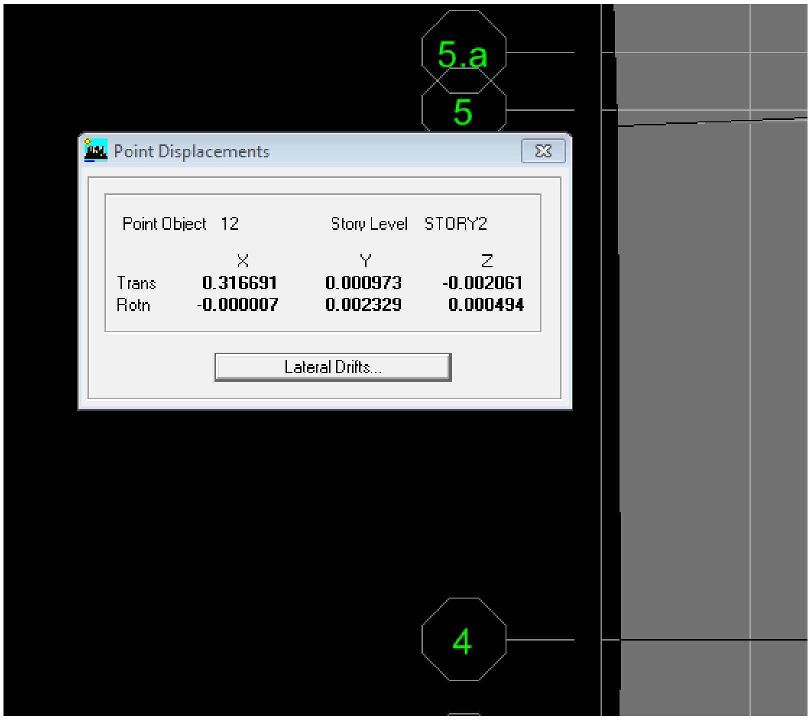


Figure G: East Wing Maximum Displacement at Expansion Joint

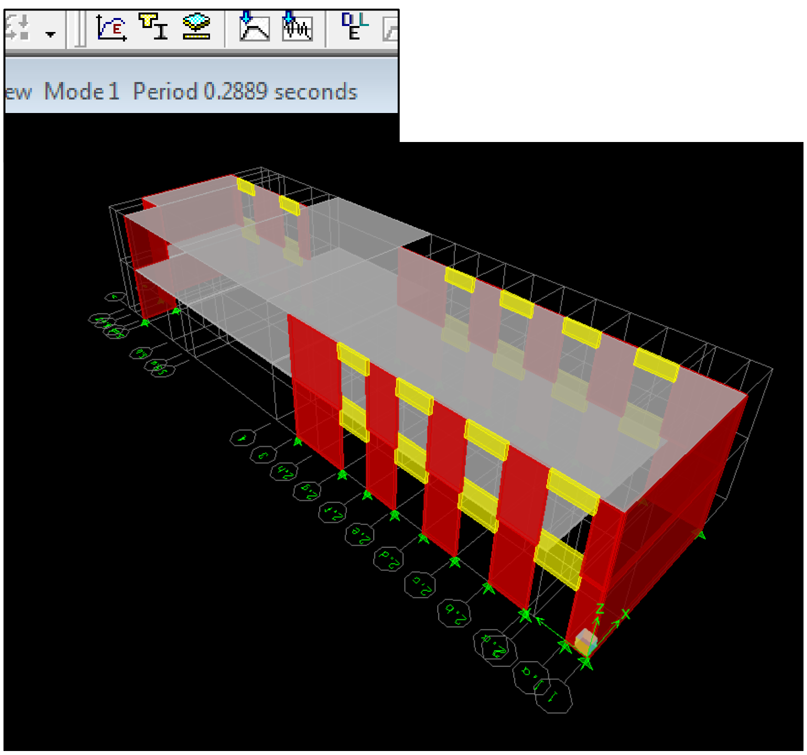


Figure F: East Wing ETABS Model and Modal Response Period

Since the elementary school is being designed with exposed ceilings, structural members, and mechanical components throughout the building, one of our important considerations was whether or not fireproofing would be required for the structure. Knowing that fireproofing would be an aesthetic issue, we evaluated the use of an approved sprinkler system in the building to determine if it would be possible to avoid fireproofing.

As outlined in Figure G, we looked at the options for an "E" classified building (education), and sought to satisfy the requirements for a Type II B construction, which does not require any structural fireproofing. According to the code table, the school would have to be limited to a height of two stories and 14,500 square feet of area per floor. However, the code allows for height and area modifications if an approved sprinkler system is added to the building. The addition of the sprinkler system allows for one additional story to be added to the building, meaning that our three-story design is allowed. Also, the automatic sprinkler increase outlined in Figure H allows for an additional 200% increase in the allowed square footage per floor. This increase results in a new allowable area of 43,500 square feet per floor. Our school's first floor, which has the largest area of any floor, is just under 40,000 square feet. Therefore, the addition of an approved sprinkler system means that we will be allowed to use Type II B construction for the building.

According to the code table outlined in Figure I, the use of Type II B construction requires no fireproofing for any structural members of the building. In conclusion, this makes the addition of an approved sprinkler system a logical choice for our design. The sprinkler system provides added fire safety to the building, but it also allows us to achieve our design goals for the classroom spaces.

		TYPE OF CONSTRUCTION						
		TYPE I		TYPE II		TYPE III		TYPE IV
		A	B	A	B	A	B	HT
	HEIGHT (feet)	UL	160	65	55	65	55	65
GROUP		STORIES (S) AREA (A)						
A-1	S A	UL UL	5 UL	3 15,500	2 8,500	3 14,000	2 8,500	3 15,000
A-2	S A	UL UL	11 UL	3 15,500	2 9,500	3 14,000	2 9,500	3 15,000
A-3	S A	UL UL	11 UL	3 15,500	2 9,500	3 14,000	2 9,500	3 15,000
A-4	S A	UL UL	11 UL	3 15,500	2 9,500	3 14,000	2 9,500	3 15,000
A-5	S A	UL UL	UL UL	UL UL	UL UL	UL UL	UL UL	UL UL
B	S A	UL UL	11 UL	5 37,500	3 23,000	5 28,500	3 19,000	5 36,000
E	S A	UL UL	5 UL	3 26,500	2 14,500	3 23,500	2 14,500	3 25,500

Figure G

SECTION 506
BUILDING AREA MODIFICATIONS

506.1 General. The *building areas* limited by Table 503 shall be permitted to be increased due to frontage (I_f) and *automatic sprinkler system* protection (I_s) in accordance with the following:

$$A_a = \{A_t + [A_t \times I_f] + [A_t \times I_s]\} \quad \textbf{(Equation 5-1)}$$

where:

A_a = Allowable *building area* per *story* (square feet).

A_t = Tabular *building area* per *story* in accordance with Table 503 (square feet).

I_f = Area increase factor due to frontage as calculated in accordance with Section 506.2.

I_s = Area increase factor due to sprinkler protection as calculated in accordance with Section 506.3.

506.2 Frontage increase. Every building shall adjoin or have access to a *public way* to receive a *building area* increase for frontage. Where a building has more than 25 percent of its perimeter on a *public way* or open space having a minimum width

506.3 Automatic sprinkler system increase. Where a building is equipped throughout with an *approved automatic sprinkler system* in accordance with Section 903.3.1.1, the *building area* limitation in Table 503 is permitted to be increased by an additional 200 percent ($I_s = 2$) for buildings with more than one *story above grade plane* and an additional 300 percent ($I_s = 3$) for buildings with no more than one *story above grade plane*. These increases are permitted in addition to the height and *story* increases in accordance with Section 504.2.

Exception: The *building area* limitation increases shall not be permitted for the following conditions:

1. The *automatic sprinkler system* increase shall not apply to *buildings* with an occupancy in Group H-1.
2. The *automatic sprinkler system* increase shall not apply to the *building area* of an occupancy in Group H-2 or H-3. For *buildings* containing such occupancies, the allowable *building area* shall be determined in accordance with Section 508.4.2, with the sprinkler system increase applicable only to the portions of the building not classified as Group H-2 or H-3.
3. *Fire-resistance rating* substitution in accordance with Table 601, Note d.

Figure H

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f, g] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	$1^1/_2$[b]	1[b, c]	1[b, c]	0[c]	1[b, c]	0	HT	1[b, c]	0

Figure I

List of References

[1] *2009 International Building Code.* Washington, DC: International Code Council, 2009. Print.

[2] *ASCE 7-05: Minimum Design Loads for Buildings and Other Structures*. Reston, VA: American Society of Civil Engineers, 2006. Electronic.

[3] Design and Construction Guidance for Community Safe Rooms, P-361 (FEMA 2008). Electronic.

[4] Hanagan, Linda, and Taehoo Kim. "Preliminary Assessment for Walking-Induced Vibrations in Office Environments." *Engineering Journal* (First Quarter 2005): 15-30. Electronic.

[5] "Nudura Insulated Concrete Forms." Nudura Integrated Building Technology. Web. Fall 2012.

[6] "Pennsylvania Uniform Construction Code." *Pennsylvania Uniform Construction Code*. Web. Fall 2012.

[7] *Steel Construction Manual.* Chicago, IL: American Institute of Steel Construction, 2011. Print.