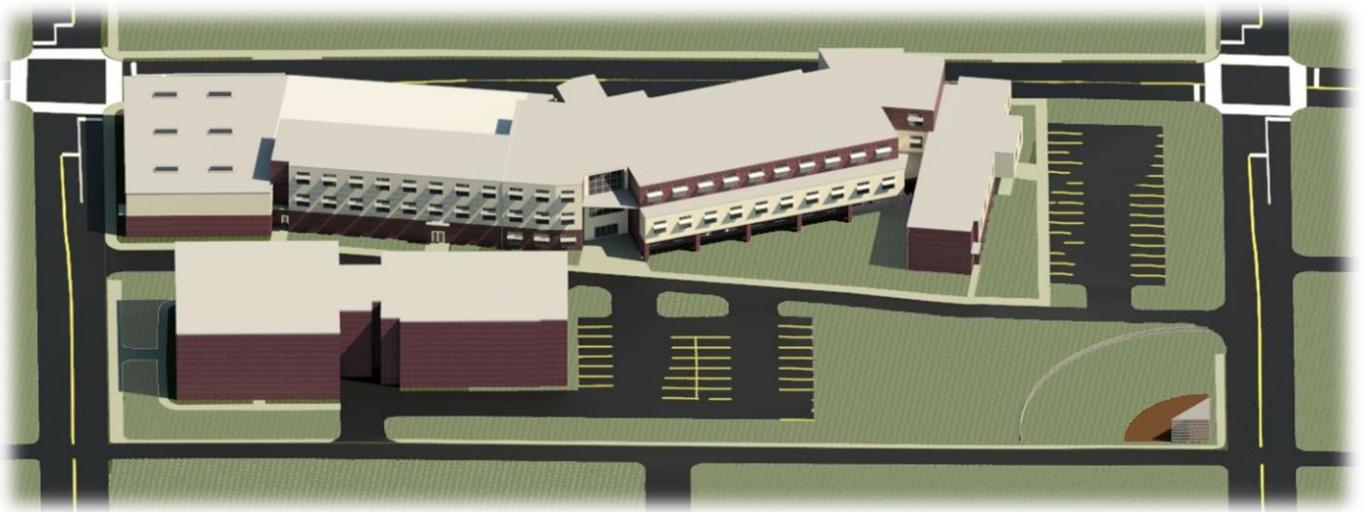


22 February 2013



STRUCTURAL SYSTEMS



Team Registration Number: 02-2013

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1. Introduction

1.1 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, the Reading area suffers from an above average crime rate, 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, several goals were developed 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 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 team members. The team utilized Building Information Modeling (BIM) software to achieve team goals and to ensure quality of the final product. In the end, the team feels the final building product is a unique solution that solves the specific challenges of the Reading Elementary School. Moreover, the structural team believes that the designed structural system provides a cost-efficient and owner-oriented solution that will satisfy the goals of both the design team and the Reading School District. By satisfying these goals, the end result is a high performance building not only structurally, but from all of the building systems complementing each other.

1.2 Owner Goals

To provide a building that best suits the needs of the Reading School District’s new Elementary School, the design team chose to develop goals that would satisfy the owner’s needs. The team 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, the report will use a system of icons to represent where certain goals were met. These icons are explained in Figures 1 and 2.

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. The team 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

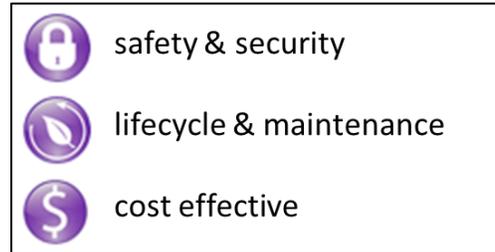


Figure 1: Owner Goal Icons

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 first costs 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, the team 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.

1.3 Nexus Team Goals

Achieving the listed owner goals is a vital part of delivering a quality project, but team objectives were also developed in order to help satisfy the owner requirements in an efficient manner. Three main focal points were developed for the project team to work toward while designing the building and its systems: integration, sustainability, and the provision of a learning environment.

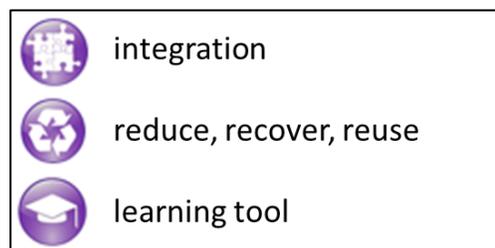


Figure 2: Nexus Overall Design Team Goal Icons

The most important goal for the design team is integration. Collaboration between the different disciplines is critical for the success of any project, and it was a main focus of the team 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 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. A major consideration involving this goal was LEED certification. According to LEED specifications (See page 32) [13], using recyclable building materials and

minimal use of materials are hugely important to the sustainability of a building. This goal 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, a focus was put on using the elementary school as a learning tool for elementary school children to better understand buildings and how they work. This goal helped 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 team goals made it easier for each discipline to make design decisions that would best serve the Reading Elementary School as an enhanced learning environment.

1.4 Structural Team Goals

In order to achieve team and owner objectives, each discipline focused on certain aspects of making design decisions. The formation of these goals is represented in Figure 3. The 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. These considerations directly affect LEED certification of the building which is an important concern for the entire design team. 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.

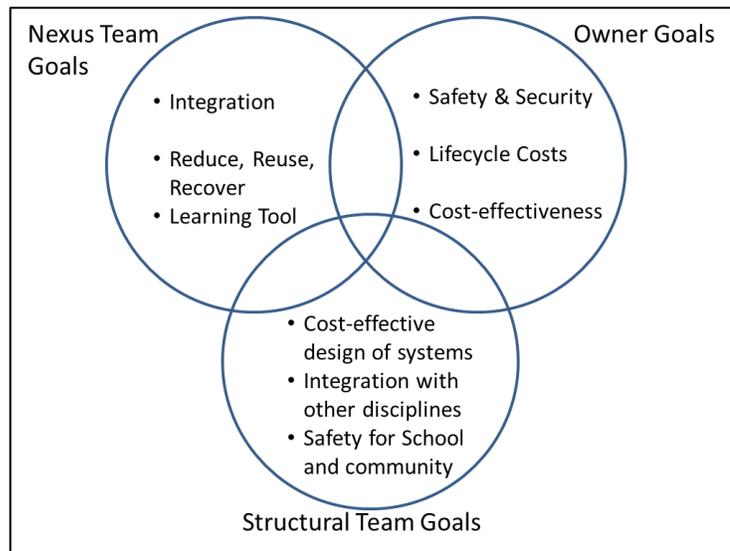


Figure 3: Project Goals and Focused Goals for the Structural Team

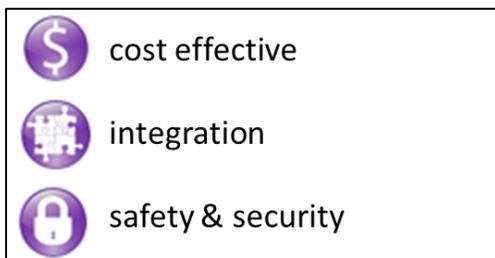


Figure 4: Structural Team Goal Icons

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, it is understood that teaching methods will evolve

over time and may necessitate changes to the building that should be easily accommodated by the structure. By achieving these goals, the structure will contribute to the goals of the design team and the

goals of the owner, and when combined with these goals, it will ultimately result in an efficient high-performance building.

2. Structural Systems

2.1 Foundation System



2.1.1 Description of System

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 provided for the site suggested three different solutions for the foundation: compaction grouting, site excavation and replacement, and driven piles. After evaluation of the three options and discussions with the construction team, it was determined that the best solution will be driven piles and pile caps. Using the 10-in. 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 lateral support for lateral loads, the ICF walls transfer forces directly to the rigid floor diaphragms at the floor levels and at the slab on grade where applicable.

2.1.2 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

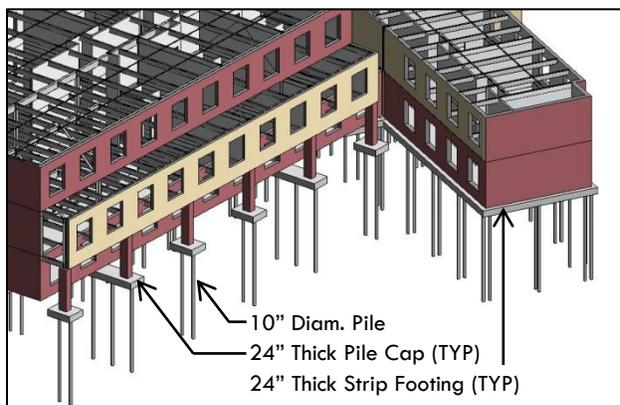


Figure 5: Driven Pile Foundation System

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 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 like those shown in Figure 5 were chosen as 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. By using the recommended size pile of a 10-in diameter and 0.2-in thickness, and filling the piles with 4000 psi concrete, it was found that more than enough support will be provided and will also be more economical than using three piles.

2.2 Column Grid



2.2.1 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 without putting a column in the middle of the room. 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 and six small columns on the south side of the building to support the overhanging south side classrooms.

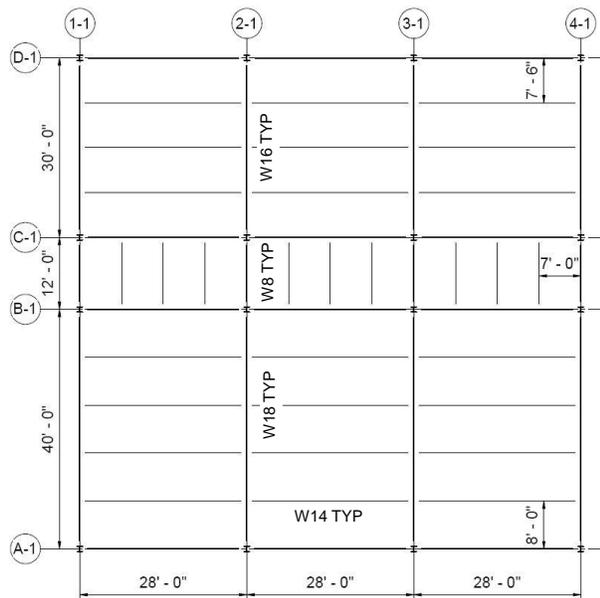


Figure 6: Original Structural Grid Layout

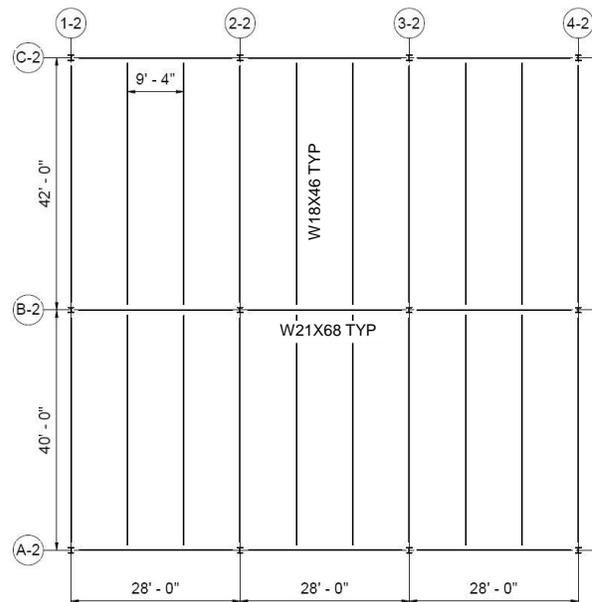


Figure 7: Modified Structural Grid Layout

2.2.2 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. To attain this goal, the team decided to use as few columns as possible in the building. 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. With the increased span, the total load on the interior columns was actually reduced by 13% when comparing the two interior columns in the original layout against the modified layout, which allows the columns to be supported by just two piles per pile cap instead of the recommended three piles. To use the central wing corridor as an example, the column size required is a W12x87 which carries the required load of 784 kips on each column at an unbraced length of 14 ft. 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.

2.3 Exterior Bearing Wall



2.3.1 Description of System

One of the most unique features of the structural system is the exterior bearing wall system. The system uses 6-in. thick reinforced concrete bearing walls and Insulated Concrete Forms (ICF). 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 provides a virtually airtight building envelope.

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. The walls were designed to maximize the efficiency of the steel reinforcement. The design uses #8 vertical bars spaced 12-in. on-center and #4 horizontal bars spaced 15-in. on-center. Refer to page II-8 of the supporting documentation for a more detailed description of the design considerations for the reinforcement.

2.3.2 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.

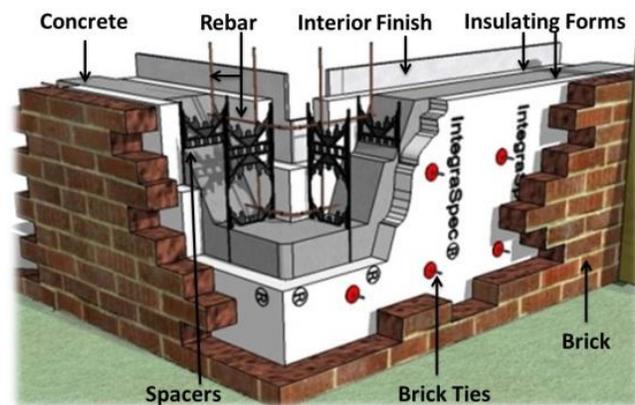


Figure 8: Insulated Concrete Form Wall Cutaway
(adapted from ConstructionPi.com)

In addition to providing benefits to the mechanical systems, the 6-in. 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 318 Section 14.8 [2] 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 in the section dealing with the design of the emergency shelter, the walls also provide adequate protection against airborne projectiles. Moreover, the strong exterior wall system can protect against gunfire, a ballistics calculation (see page 31) was done to check this [12]. This is a critically important characteristic of the wall for added safety, especially in light of recent security failures and tragic shootings in schools.

2.4 Floor System



2.4.1 Description of System

The floor system consists of composite steel beams and girders along with a 3-in. thick slab on a 3-in. 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-in. slab on 3-in. deck helps to avoid deflection issues over the long span and also limits the effects of vibrations on the floor system. The composite beams will have a 1-in. camber to offset deflections caused by the wet concrete and they will also have 28 shear studs per beam. The composite girders will have a 1.25-in. camber to offset wet concrete deflections, and will have 24 shear studs per girder.

2.4.2 Rationale for System Selection

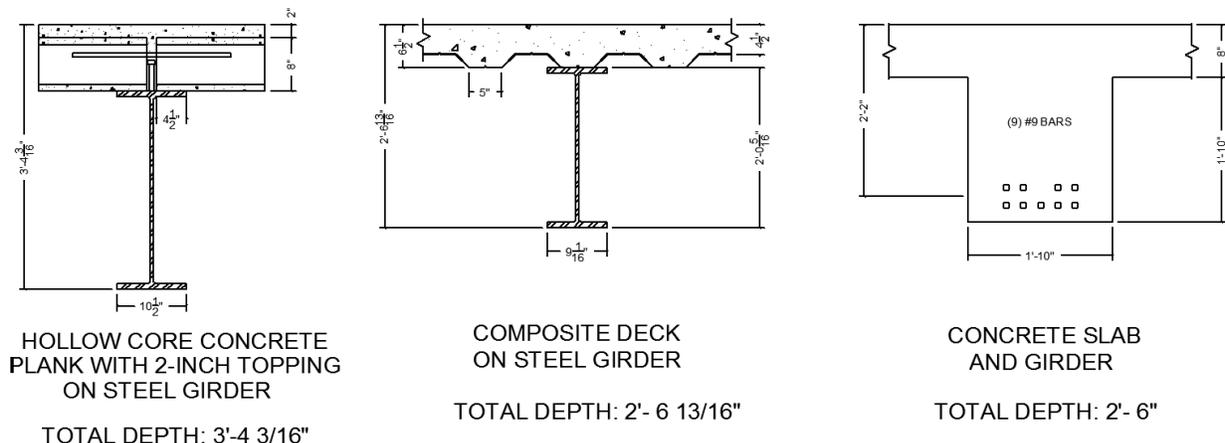


Figure 9: Comparison of Depth for Investigated Floor System Options

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.

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 floor framing is more common in Reading than concrete. An all-concrete solution would also be heavier and potentially require more foundation piles. Subcontractors in the area are likely to have more experience with steel frame buildings, so using steel for this project is 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 figure 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 have the lowest base shear. This is due to the significant reduction in weight from the absence of ICF walls. Admittedly, the base shear from the proposed design is nearly the same as the base shear for a lighter, concentrically braced steel frame system without ICF walls, so the structural team is satisfied with this decision.

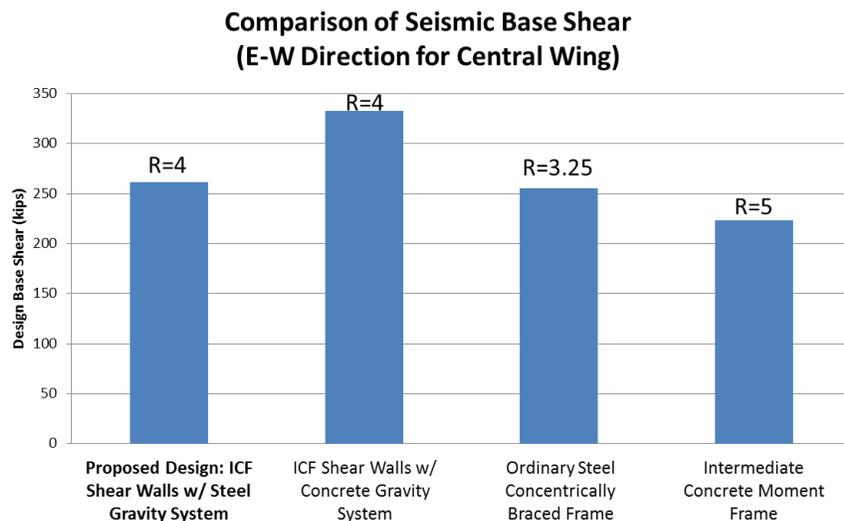


Figure 10: Comparison of Design Seismic Base Shear for Different Combinations of Gravity and Lateral Systems

Originally, the team designed the floor system with a 4.5-in. slab on 3-in. 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-in. slab on 3-in. 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) [6]. After reviewing this document, it was determined that the designed floor system configuration should 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 do not present a problem and long spans do not always present a problem, it is rather the intermediate spans (25 ft.-35 ft.) that can cause problems. The floor vibrations were also checked using the equations in AISC Design Guide II [3], and the resulting calculations also confirmed that floor vibrations would not be a concern. Because of this, it was determined that the floor system will not have any vibration issues.

2.5 Roof System



2.5.1 Description of System

The roof system over the pool consists of long-span steel joists, type 60DLH18 (taken from Vulcraft Joist Catalog [10]), with non-composite metal roof deck, type 3N (taken from Vulcraft Deck Catalog [11]). The roof system over the gymnasium also uses long-span steel joists, but with a 3-in. non-composite deck and 3-in. 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 93 psf at the worst-case location of the building (see page 16 of supporting documentation).

2.5.2 Rationale for System Selection

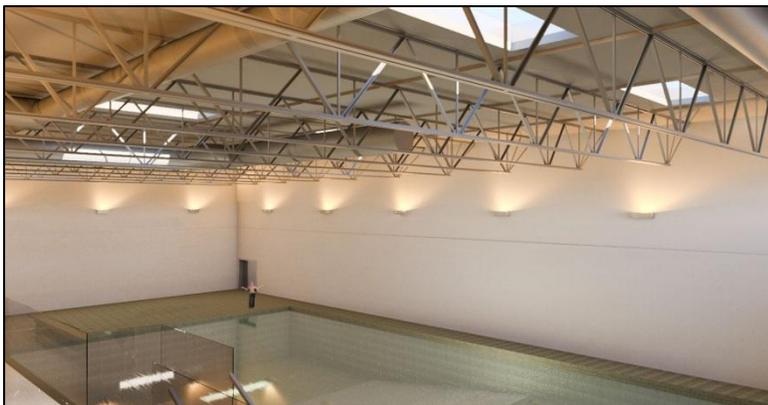


Figure 11: Pool Roof System

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.

The roof over the classrooms is supported by roof deck on steel beams. 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 maximum snow drift load is 49 pounds per square foot over the gymnasium. This was used when designing the roof system for all of the two story-height roofs.

2.6 Multipurpose Room and Shelter



2.6.1 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 [5], Design and Construction Guidance for Community Safe Rooms. Since the exterior walls are 6-in. thick concrete bearing walls, with the same reinforcing as the rest of the bearing walls in the building, they meet the FEMA projectile requirements. The



Figure 12: Overhead view of the Gym/Shelter area

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-in. concrete slab on a 3-in. steel deck. The roof joists were then increased in size accordingly to support the added weight, and 40LH15 joists were used in this area (taken from Vulcraft Joist Catalog [10]). The major additions to the structural system for the multipurpose room to suffice as a shelter included adding the slab to the roof and increasing the size of the roof joists, though only by 14 pounds per linear foot of joist. The joist selected from the Vulcraft joist catalog increased from a 40LH11 to a 40LH15.

2.6.2 Rationale for System Selection

FEMA Document P-361 [5] 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-in. slab on 3-in. 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, in other words, a composite joist would have to be upsized anyways in order to hold the dead load of the wet concrete. The steel

long-span joists were slightly enlarged from an initial design of 36 in. to a 40 in. size to support the increased weight of the roof. Although the pool space contains skylights, no windows or skylights were put into the gymnasium. While this is not 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 also helpful in creating a shelter due to their ability to resist projectiles.

2.7 Lateral Force-Resisting System



2.7.1 Description of System

Using the guidelines of ASCE 7-05 [4] (as required by the Pennsylvania UCC [8]), it was determined that seismic forces are the controlling load case 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 is a significant reason the seismic forces dominate over the 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 and analyzed slightly different from the others. The overall building lateral systems are illustrated below in Figure 13.

The west wing of the building, which features the pool and gymnasium/emergency shelter, is designed with an importance factor of 1.5 for all loads. This portion of the structure is considered essential during an emergency situation and is therefore in Occupancy Category IV. Lateral forces in the east-west direction are resisted by the exterior shear walls of the building. Shear walls also provide lateral resistance in the north-south direction of the building, but ordinary steel concentrically braced 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 HSS 6"x6"x1/4" steel members that fit within the thickness of the partitions between rooms.

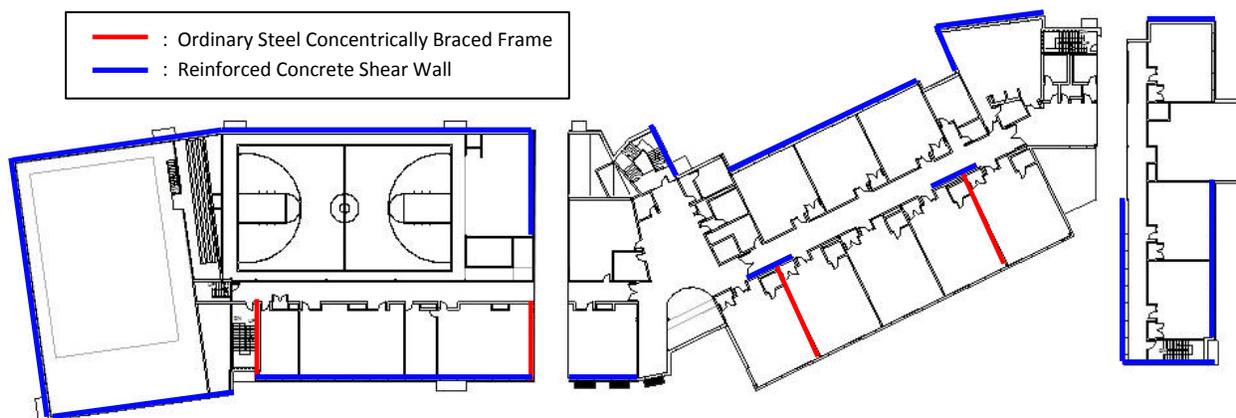


Figure 13: Plan View Illustrating the Three Structure Segments and Lines of Lateral Resistance that Exist Throughout the Building

The central wing of the building, which features most of the classrooms and learning spaces, is designed with an importance factor of 1.25 for all loads. Since this structure is independent from the shelter structure, it is in Occupancy Category III. 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 overhanging second floor, a continuous bearing wall was not a viable option. Instead, the south façade is built as a curtain wall hung from the steel frame. This necessitated additional lateral force resistance in the east-west direction, so two 8"-thick shear walls are included along the hallway to provide the required resistance. The shear walls are built with 4000 psi concrete and are reinforced vertically by #6 bars at 12 in. spacing and horizontally by #3 bars at 18 in. spacing. In the north-south direction, a similar concentric bracing scheme to the type used for the west wing is adopted for the central wing.

2.7.2 Rationale for System Selection

During the design process, the structural team also saw advantages to separating the structure between the central and west wings of the building. 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 [4]. 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.

It was also discovered during the design 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 determined 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.



Figure 14: Illustration Showing the Three Independent Structure Wings

In each of the three wings of the building, which are illustrated in Figure 14, 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 coupled 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 partitions 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, the 8-in. 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 solely on the exterior bearing walls in both directions to provide adequate resistance.

3. Computer Modeling

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 structural team followed the guidelines of Section 12.7 of ASCE 7-05 [4] to construct a code-approved computer model like the one shown in Figure 15. 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

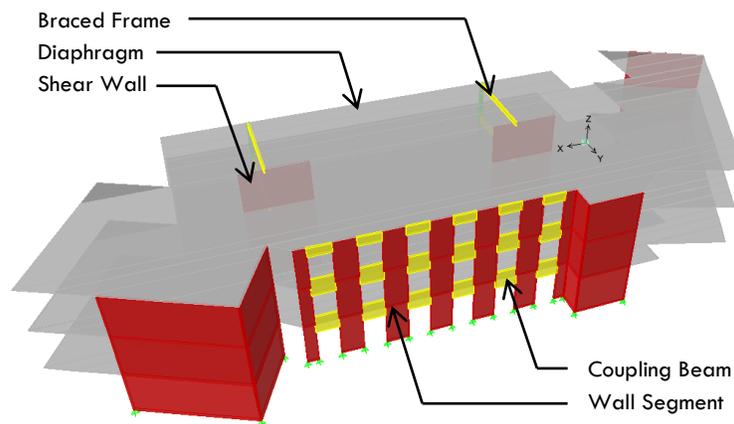


Figure 15: Sample ETABS Model of the Central Wing Showing Walls and Coupling Beams

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 area elements to model the shear 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 in accordance with Section 12.7.3 of ASCE 7-05 [4]. Additionally, 6-ft deep coupling beams spanning 7-ft window openings 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.

4. Conclusion

As discussed in the report introduction, the structural design team approached the project with three specific goals in mind: a cost-effective solution, integration with the other building disciplines, and safety and security for students and community members. The design team believes these goals have been met. Through the use of innovative technologies such as insulated concrete form walls, cost and time of construction is reduced. The gravity load-bearing walls can also be utilized for the lateral force resisting systems and reduce the number of additional structural elements required for lateral support. A structural grid which is modified from the original proposal creates a more uniform and efficient structural layout and reduces the number of steel columns and foundation elements required for the building. The structural team also made sure to evaluate serviceability aspects of the building, including an investigation of the effects of walking-induced vibration in the classrooms.

To save costs, it is still necessary to take an integrated approach to design the building to avoid clashes and conflicts before they occur in the field. The structural team worked with the other design disciplines to ensure the building systems work well with each other. As the systems descriptions and rationales explain, many of the decisions made by the structural team are directly influenced by the requirements of the other disciplines. Some of these solutions include selecting a floor system with an acceptable depth, lateral bracing that provides adequate space for mechanical duct and electrical conduit, and an ICF building envelope that provides structural support as well as thermal efficiency.

Finally, safety is a particularly important issue in this building, and one that is societally relevant today. The structural team designed the building with this concern in mind. Using the ICF walls provide a strong barrier that will withstand gunfire from outside. The walls also provide protection against projectiles during storms and help to form a safe community shelter. The building is designed to withstand the required wind and earthquake forces that it may face over its lifetime. Fireproofing requirements were analyzed to ensure that the building will be sufficiently protected during a fire with an approved sprinkler system. In conclusion, the Nexus team has developed a building that satisfies all of the team's goals and tries to improve and optimize the original design presented in the competition guidelines. The end product is one that best serves the owner, the community, and the young occupants that use the building every day.

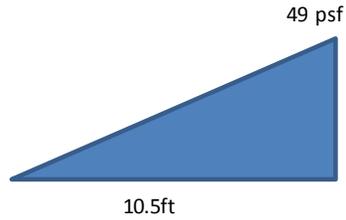


ROOF/SNOW LOAD CALCULATION SPREADSHEET

According to Provisions of ASCE 7-05

Snow Load On Gym Roof

$p_g =$	35 psf	$p_r =$	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		27psf
$\gamma =$	18.55		10.5ft



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

Roof Deck

1.5B 1.7 psf

Capacity
87 psf

3-Span-Max Span
6'11"

Joist

TL= 0.34 klf

24K6 10.1 plf

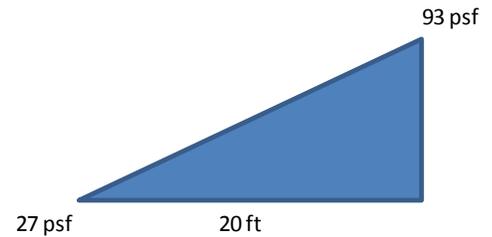
Joist-Girder

TL= 4.9

60' span G10N60 41 plf

Worst Case Snow Load

$p_g =$	35 psf	$p_r =$	27 psf
$C_e =$	1	$p_s =$	54 psf
$C_t =$	1	$p_d =$	93
$I =$	1.1	$w =$	20
$h_d =$	5		
$\gamma =$	18.55		



WIND LOAD CALCULATION SPREADSHEET

According to Provisions of ASCE 7-05

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

Velocity Pressure
 $qz = 0.00256KzKztKdV^2$

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

Kz	Case 1 (C&C) Case 2 (MLFRS)		qh (psf)		
	Case 1 (C&C)	Case 2 (MLFRS)	Case 1 (C&C)	Case 2 (MLFRS)	
0-15	0.7	0.57	0-15	14.2	11.6
20	0.7	0.62	20	14.2	12.6
25	0.7	0.66	25	14.2	13.4
30	0.7	0.7	30	14.2	14.2
40	0.76	0.76	40	15.4	15.4
50	0.81	0.81	50	16.4	16.4

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)	
	8.21	-9.93	-12.72	-15.52	-9.93	-7.14

MWLRs	$p=qh [(GCpf)-(Gcpi)]$	Negative Internal				
Case 2 (MLFRS)						
Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)	
	14.12	-4.02	-6.81	-9.60	-4.02	-1.23

C&C	$p=qh [(GCpf)-(Gcpi)]$	Positive Internal				
Case 2 (MLFRS)						
Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)	
	8.21	8.21	8.21	8.21	8.21	8.21

C&C	$p=qh [(GCpf)-(Gcpi)]$	Negative Internal				
Case 2 (MLFRS)						
Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)	
	-8.21	-8.21	-8.21	-8.21	-8.21	-8.21

Wind Load Study: Safe Room

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

Velocity Pressure
 $qz = 0.00256KzKztKdV^2$

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

Kz	Case 1 (C&C) Case 2 (MLFRS)		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

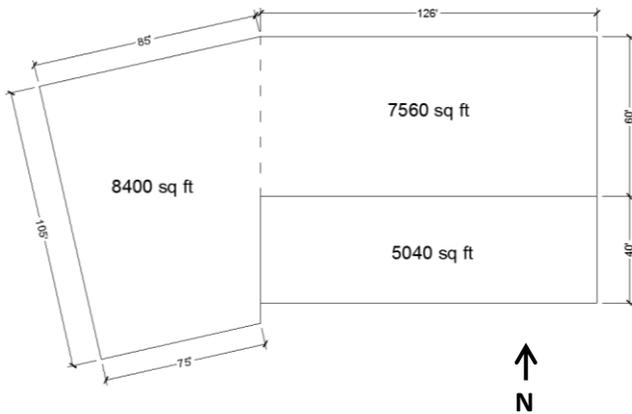
MWLRs	$p=qh [(GCpf)-(Gcpi)]$	Negative Internal	
Case 2 (MLFRS)			
Windward	Lee	Side	
	63.8	6.5	-2.3

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

West Wing



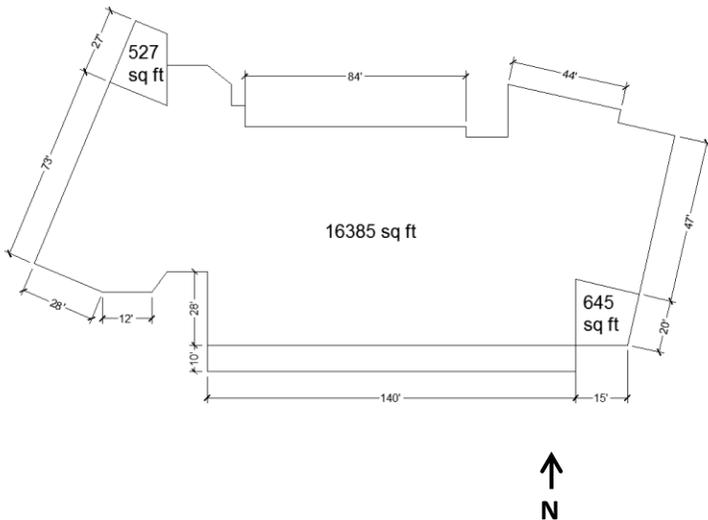
Loads:

Roof Dead:	30 psf	
Floor Dead:	60 psf	
ICF Walls:	125 psf	(elevation)
Curtain Wall:	50 psf	(elevation)

		Trib Area (ft ²)	Weight (k)	
Roof Level:	Roof	5040	151.2	
	Floor	0	0.0	
	ICF	882	110.3	
	Curtain Wall	1162	58.1	
	Total =			319.6 kip
3rd Floor:	Roof	15960	478.8	
	Floor	5040	302.4	
	ICF	4501	562.625	
	Curtain Wall	1162	58.1	
	Total =			1401.9 kip
2nd Floor:	Roof	0	0	
	Floor	5565	333.9	
	ICF	7238	904.75	
	Curtain Wall	0	0	
	Total =			1238.7 kip

W = 2960.1 kip

Central Wing



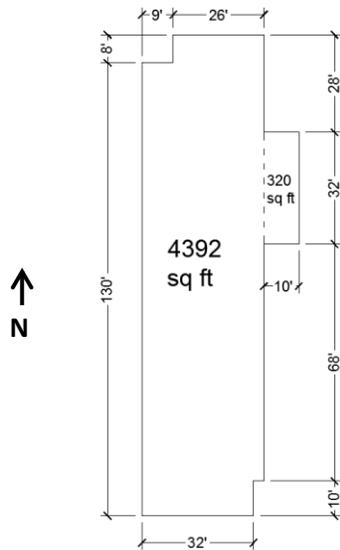
Loads:

Roof Dead:	30 psf	
Floor Dead:	60 psf	
ICF Walls:	125 psf	(elevation)
Curtain Wall:	50 psf	(elevation)

		Trib Area (ft ²)	Weight (k)	
Roof Level:	Roof	16345	490.4	
	Floor	0	0.0	
	ICF	2310	288.8	
	Curtain Wall	1582	79.1	
	Total =			858.2 kip
3rd Floor:	Roof	527	15.8	
	Floor	17745	1064.7	
	ICF	4795	599.4	
	Curtain Wall	2233	111.7	
	Total =			1791.5 kip
2nd Floor:	Roof	645	19.4	
	Floor	16872	1012.3	
	ICF	4690	586.3	
	Curtain Wall	2289	114.5	
	Total =			1732.4 kip

W = 4382.1 kip

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



East Wing

Loads:		Roof Dead:	30 psf	
		Floor Dead:	60 psf	
		ICF Walls:	125 psf	(elevation)
		Curtain Wall:	50 psf	(elevation)
			Trib Area (ft ²)	Weight (k)
Roof Level:	Roof	5048	151.4	
	Floor	0	0.0	
	ICF	1750	218.8	
	Curtain Wall	364	18.2	
				Total = 388.4 kip
2nd Floor:	Roof	0	0.0	
	Floor	5048	302.9	
	ICF	3500	437.5	
	Curtain Wall	784	39.2	
				Total = 779.6 kip
				W = 1168.0 kip

To more easily determine the seismic loads on the building, the structural team broke down each independent building structure and analyzed the loads based on tributary area. The floor plans on pages 18 and 19 show the approximate areas and dimensions for each structure. These areas were used to determine the contribution of dead weight from the floor slabs and roofs. Additionally, the seismic weight accounts for the exterior walls of the building. To determine the contribution of wall weight to each floor level, it was assumed that each floor sees weight from half the wall above and half the wall below (i.e. the roof only sees a 7-foot tributary height of wall while the floors typically see a 14-foot tributary height). The tributary height of the wall and the perimeter of wall at the floor level were used to find the total tributary area of wall load to each level.

Additionally, the calculation accounts for the somewhat significant difference in weight between the exterior ICF bearing walls that are used for most of the building perimeter and the hung curtain wall system that is used where construction of ICF walls is not feasible (most notable on the south face of the central wing where the second floor overhangs the first floor by 10 feet). These calculations help to show the significant amount of weight that is added to the structure when the ICF walls are used. The comparison of structural systems in Figure 10 of the document utilized these calculations as well as the following seismic calculations to explore the results discussed.

EARTHQUAKE LOAD CALCULATION SPREADSHEET

According to Provisions of ASCE 7-05

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	Time Period (from ETABS)
T _L = 6	R (N-S)= 4	= 0.289 s
	R (E-W)= 4	

S_{D5}= 0.417

S_{D1}= 0.140

T₀= 0.067

T_L= 6

T_S= 0.336

T_a= 0.289

S_a= 0.417

N-S:

R= 4

C_s= 0.1302

C_s= 0.1514

E-W:

R= 4

C_s= 0.1302

C_s= 0.1514

C_s= 0.1302	C_s= 0.1302
------------------------------	------------------------------

Loads:	Trib Areas:
Roof dead= 30 psf	Roof= 0 ft ²
Floor dead= 60 psf	Roof Level Floor= 0 ft ²
ICF Walls= 125 lbs/per sf wall area	ICF Wall= 0 ft ²
Curtain Walls= 50 lbs/per sf wall area	Curtain Wall= 0 ft ²
	3rd Floor Roof= 5048 ft ²
	Level Floor= 0 ft ²
	ICF Wall= 1750 ft ²
	Curtain Wall= 364 ft ²
	2nd Floor Roof= 0 ft ²
	Level Floor= 5048 ft ²
	ICF Wall= 3500 ft ²
	Curtain Wall= 784 ft ²



EARTHQUAKE LOAD CALCULATION SPREADSHEET (CONT.)

According to Provisions of ASCE 7-05

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

In order to determine the design base shear and distribution of equivalent forces for seismic loads in the building, the structural team developed the spreadsheet shown above. The areas highlighted in green indicate the cells for user input. With this spreadsheet, the team can easily determine the design forces for each level of each independent wing of the building in the N-S direction and E-W direction. The spreadsheet was also a helpful tool for comparing different types of lateral force-resisting systems by changing the values for R and the relevant weights of structural components.

The spreadsheet sample above shows the forces for the east wing of the building. As the final result shows, the forces in the N-S and E-W directions are the same since this wing of the building uses the same lateral force-resisting system (the exterior ICF walls) in both directions. The resulting forces are used in the ETABS analysis described on Page 27 of the supporting documentation. Therefore, these forces are critical to determining the required thickness of the walls, the strength of the floor diaphragms, and the size of the construction joints that exist where separate wings of the building meet each other.

EXTERIOR BEARING WALL DESIGN SPREADSHEET

	P_u
1st Floor	47.2
2nd Floor	41.2
3rd Floor	41.2
Roof	17.6

$$\phi P_n = 0.55 \phi f'_c A_g [1 - (k l_c / 32h)^2]$$

Empirical Design Method

		Wall Dimensions			
Total	147.2	0.50	x	7	504
x2	294.4	(A_g)			

$\rho_{min\ vert}$	$\rho_{min\ horiz}$	s	k
0.0015	0.0025	12	1
h	l_c	f'_c	
12	504	4	

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

Compression Members

A_{st}	A_g	f_y	f'_c
6.16	504	60	4
ϕ	$\phi P_{n,Max}$		
0.85	1402.334		

$$V_c = 2 \lambda f'_c \lambda^{1/2} h d$$

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				



EXTERIOR WALL REINFORCEMENT DESIGN

ρ_{min} vert : 0.0012 for reinforcing bar not larger than #5
 0.0015 for all other bars
 0.0012 for welded wire mesh not larger than W31 or D31

ρ_{min} horiz : 0.002 for reinforcing bar not larger than #5
 0.0025 for all other bars
 0.002 for welded wire mesh not larger than W31 or D31

bar #	8	$f'_c =$	3000 psi	$P_u =$	7.30 kip
$f_y =$	60 ksi	$E_c =$	3122019 psi		
$E_s =$	29000000 psi	$\beta =$	0.85		
b =	12 in	Spacing:	12 in		
d =	3 in	A_s per ft =	0.79 in ² /ft		
h =	6 in	$l_c =$	168 in		

a = 1.55 in
c = 1.82 in

$M_{ua} =$ 0.445 ft-k

$I_{cr} =$ 36.0 in⁴

$M_u =$ 7.17 ft-k

$\phi M_n =$ 7.91 ft-k **OK**

A detailed analysis of the exterior wall design showed that out-of-plane bending due to eccentric loads controls the design of vertical reinforcement of the exterior walls. This spreadsheet sample shows the calculations for a unit one-foot strip of a typical three-story wall segment that is found in the building. The structural team wanted to use a single layer of reinforcement in the wall for purposes of cost and constructability. Additionally, the 6-inch wall thickness was also set to provide the desired R-value for the building envelope. Using these parameters, the final design uses a single layer of #8 bars spaced at 12 inches on center. This configuration satisfies requirements for strength and for code-mandated minimum reinforcement ratios. Finally, the design of the horizontal reinforcement is controlled by the code-determined minimum reinforcement ratios. In the horizontal direction, #4 bars at 15 inches on center are used.



COMPOSITE BEAM DESIGN SPREADSHEET

<u>LL</u> 27 psf	<u>Reduced LL</u> 22 psf	<u>K_{LL}</u> 2		
<u>Superimposed DL</u> 15 psf	<u>Deck depth</u> 3 in.	<u>Slab depth</u> 3 in.	<u>Total depth</u> 6 in.	
<u>Span</u> 40 ft	<u>Spacing</u> 9.33 ft	<u>Deck and Slab DL</u> 56 psf	<u>Beam Self Weight Assumption</u> 5.2 psf	
<u>W_{DL}</u> 0.71 klf	<u>W_{LL}</u> 0.3 klf	<u>W_{UL}</u> 1.35 klf	<u>Concrete strength</u> 4 ksi	
<u>V_U</u> 27.0 kips	<u>M_U</u> 269.7 kip-ft			
<u>b'</u> 56 in	<u>b_{Eff}</u> 112 in. interior 56 in. exterior	<u>Q_n</u> 17.2 kips	<u>Δ_{LL Allowable}</u> 1.33 in.	
<u>I_{min} (From Δ_{LL Allowable})</u> 375.39 in ⁴	<u>a (assumed)</u> 2 in.	<u>y₂</u> 5 in.		
<u>Pick Section From Steel Manual</u>	<u>W</u> 18 x 46	<u>I (Non-Composite)</u> 712 in ⁴	<u>φM_p</u> 340 kip-ft	
<u>I</u> 1220 in ⁴	<u>ΣQ_n</u> 239 kips			
<u># of studs</u> 28	<u>Economy</u> 2120			
<u>Δ</u>				
<u>Δ_{TL Allowable}</u> 2 in.	<u>I_{min} (From Δ_{TL Allowable})</u> 957	<u>LL_{Construction}</u> 20 psf		
<u>W_{Unshored}</u> 0.82 klf	<u>M_{unshored}</u> 165 kip-ft			
<u>Δ_{wet concrete}</u> 0.92581	<u>W_{wet concrete}</u> 0.6 klf			
<u>Check Self-Weight</u> 4.9 psf	<u>a</u> 0.63 in.			
<u>Camber</u> 1 in				



COMPOSITE GIRDER DESIGN SPREADSHEET

P_D 28.448	P_L 10.08	P_U 51.266	Concrete strength 4 ksi	Deck and Slab DL 56 psf
Span 28 ft	Spacing 40.00 ft	b' 42 in		
b_{Eff} 84 in. 42 in.	interior exterior	V_U 51.3 kips	M_U 478.5 kip-ft	
I_{min} (From $\Delta_{LL Allowable}$) 504.53 in ⁴	$\Delta_{LL Allowable}$ 0.93 in.			
Q_n 21 kips	a (assumed) 2 in.	Y_2 5 in.		
Pick Section From Steel Manual				
W 24 x 68		I (Non-Composite) 1830 in ⁴	ϕM_p 664 kip-ft	
I 2970 in ⁴	ΣQ_n 251 kips	ϕM_n 916 kip-ft		
# of studs 24	Economy 2144			
<u>Δ Checks</u>				
$\Delta_{TL Allowable}$ 1.4 in.	I_{min} (From $\Delta_{TL Allowable}$) 1286	$LL_{Construction}$ 20 psf		
$P_{Unshored}$ 43.53 kips	$M_{unshored}$ 406 kip-ft			
$\Delta_{wet\ concrete}$ 1.295107	I_{minWC} (From $\Delta_{TL Allowable}$) 1693			
Check Self-Weight OK	a 0.88 in.			
Camber 1.25 in				



BEAM VIBRATION CHECK SPREADSHEET

According to Provisions of AISC 11 Design Guide

$$a_p/g = p_o^{-0.35f_n}/\beta W$$

$$a_p/g < a_o/g$$

Design Criteria:

$P_o = 65$ lbs
 $\beta = 0.03$
 $a_o/g = 0.5$ %
 $C_j = 2.0$

Beam Properties:

Weight = 46 plf
 $A = 13.5$ in²
 $I_x = 712$ in⁴
 $d = 18.1$ in

Slab Properties:

Deck Depth = 3 in
 Topping = 3 in
 $f'c = 4000$ psi

Loading:

Floor DL = 60 psf
 Misc. = 10 psf

Spans/Spacing:

Beam Span: 504 in
 Beam Spacing: 112 in

$$E_c = 3674 \text{ ksi}$$

$$n = 5.85$$

$$y = 1.077 \text{ in. below top of deck}$$

$$I_j = 2337 \text{ in}^4$$

$$w_j = 699 \text{ plf}$$

$$\Delta_j = 0.722 \text{ in}$$

$$f_j = 4.16 \text{ Hz}$$

$$D_s = 15.6 \text{ in}^4/\text{ft}$$

$$D_j = 250.4 \text{ in}^4/\text{ft}$$

$$B_j = 41.96 \text{ ft}$$

$$503.5 \text{ in}$$

$$W_j = 198.1 \text{ k}$$

$$a_p/g = 0.25 \text{ \%} \quad \text{OK}$$

The structural team believes that an important serviceability aspect of the building will be the effect of vibrations induced by walking in the halls and classrooms. Since the team decided to modify the structural grid, the building has two bays where the beams cross spans of 40 feet and 42 feet. Therefore, the structural team knew that vibrations may be a concern for the long-span beams. Even if the original structural grid was maintained, a 40-foot bay existed anyway, so a vibration check would still probably be necessary. To evaluate the performance of the beam and slab system, the team first consulted a document on floor vibrations [6] to get an overall impression of whether the system is adequate. Since the document suggested that there likely should not be any significant vibration issues, the team consulted the AISC 11 design guide to find the proper design criteria for a school and compare the performance of the design to the recommended values. As the spreadsheet above shows, the floor beams spanning 42 feet satisfy the AISC design criteria limit. Therefore, the team feels confident that the long spans created by the modified structural grid will not have a negative impact on the school learning environment. This is important since it is reasonable to believe that many children may be running around at any given time in an elementary school.

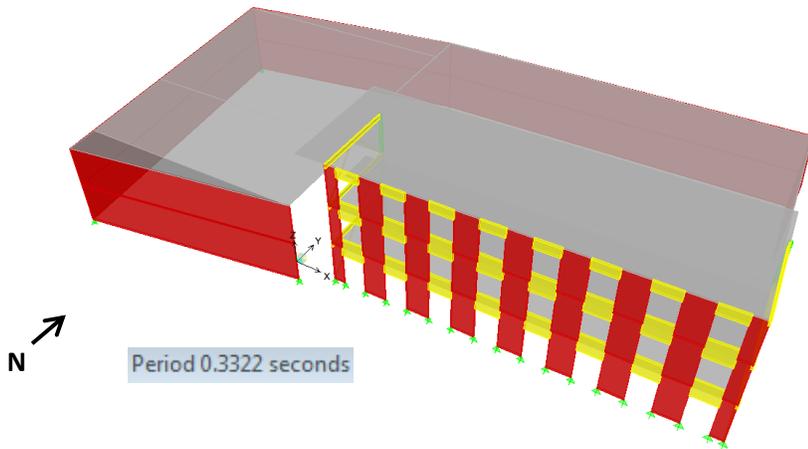


Figure A: West Wing ETABS Model and Modal Response Period

The west wing of the building contains the pool and multipurpose room/shelter area. As a result, this part of the building is designed with an importance factor of 1.5 for earthquake loads rather than the factor of 1.25 used for the rest of the elementary school. As Figure A shows, the modal response period of the structure as calculated by ETABS is 0.3322 seconds. This is consistent with what would be expected from a three story building with a relatively stiff overall lateral system.

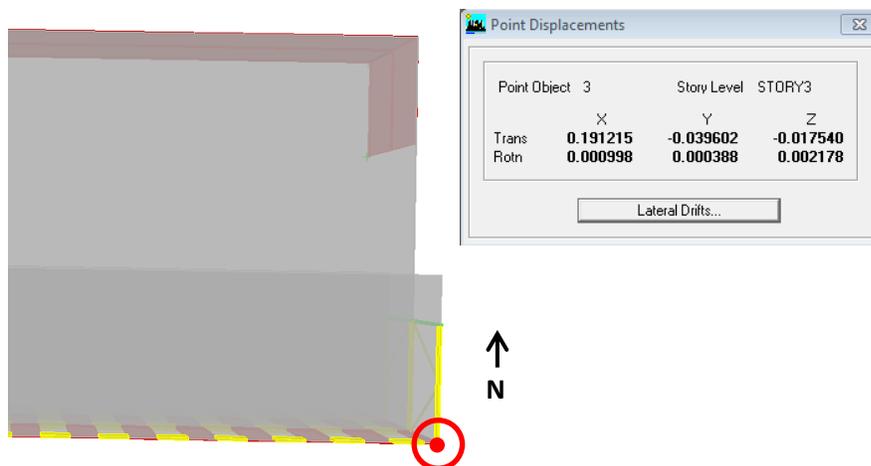


Figure B: West Wing Maximum Displacement (inches) at Expansion Joint

An important reason for performing this analysis is the result obtained in Figure B. Since the building is comprised of three isolated structures, the construction joint between each separate structure must be large enough so that they can move independent of each other. As Figure B shows, the maximum displacement of the west wing in the X-direction at the interface with the central wing is 0.19 inches. This number will be compared to the value for displacement of the central wing at this same location to determine how far apart the structures need to be placed and how large the construction joint will be.

ETABS MODELING SUMMARY (CONT.)

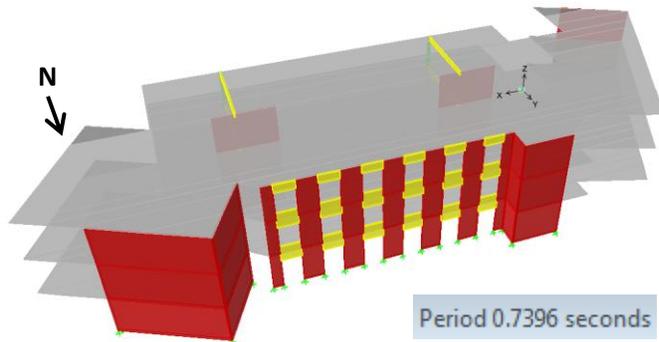


Figure C: Central Wing ETABS Model and Modal Response Period

As Figure C shows, the central wing of the building contains the largest variety of lateral systems. The exterior ICF bearing wall on the north face of the wing functions as a series of slender shear walls joined by coupling beams. Since there is no ICF wall on the south face of the wing, two 8-in thick interior shear walls provide the rest of the required lateral support in that direction. Additionally, ordinary steel concentrically braced frames provide lateral support in the N-S direction of the wing. As shown, the modal response period for the central wing is 0.7396 seconds, which is notably less stiff than the west wing.

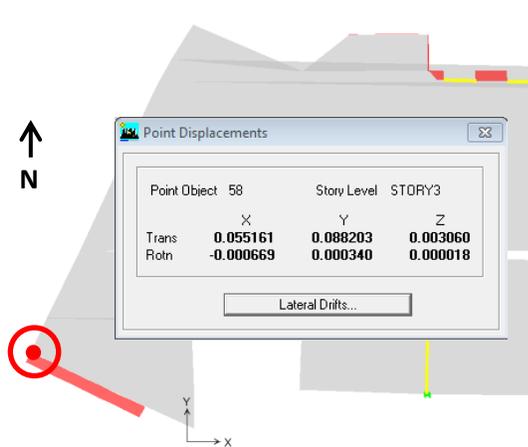


Figure D: Central Wing Maximum Displacement (inches) at West Expansion Joint

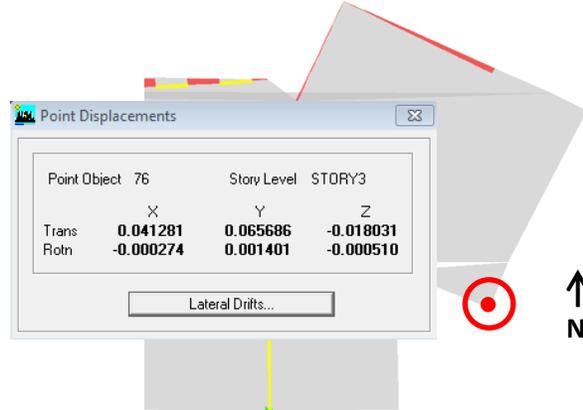
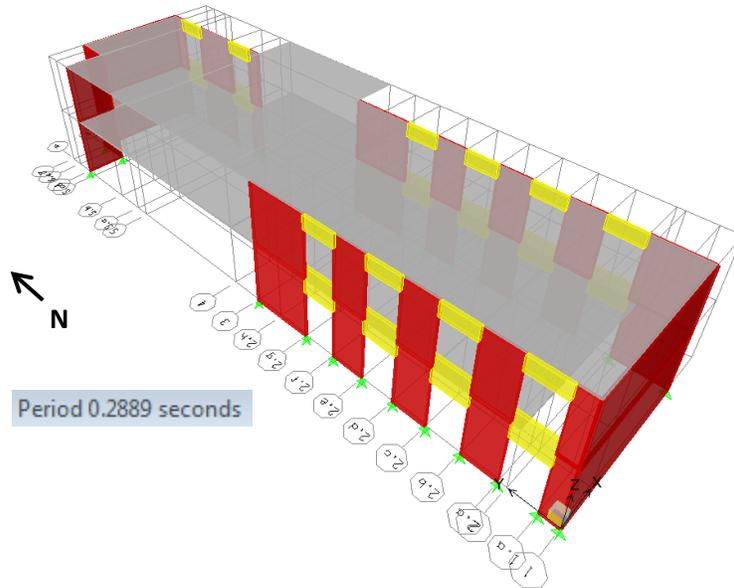


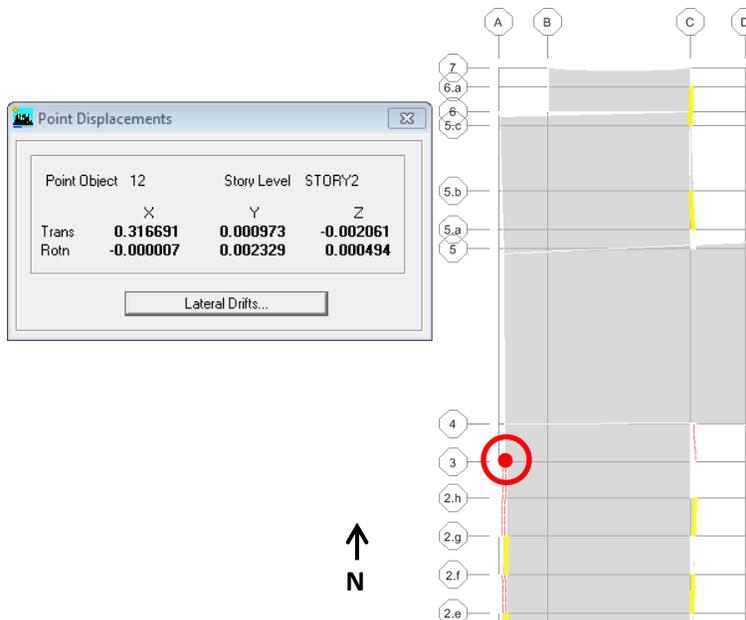
Figure E: Central Wing Maximum Displacement (inches) at East Expansion Joint

A look at the maximum displacement of the building toward the other wings shows that the apparently lower stiffness in the central wing is actually a consequence of the ordinary steel concentrically braced frames. Therefore, the stiffness is lower in the N-S direction of the structure. As Figures D and E show, the maximum obtained displacements in the X-direction are actually quite low. By combining the X and Y components of the displacements (since the axis of this wing is changed from the other two wings), it was determined that the absolute displacement of the central wing towards the west wing is 0.104 inches. Combining this with the results from the analysis of the west wing means that the structures must be separated by at least 0.29 inches. To account for construction tolerances and to use a standard unit of measurement, the team decided that a 1-in construction joint will be used between the west and central wings. Finally, the maximum absolute displacement of the central wing towards the east wing was determined to be 0.08 inches. This number will be compared to the displacement at the corresponding location on the east wing to size the other construction joint.



As shown here in Figure F, the east wing is the smallest wing of the structure in both height and floor area. This is also able to use the exterior ICF bearing walls as the entire lateral system for the wing so that no interior braces or shear walls are required. The computed modal response period of 0.2889 seconds from ETABS is again consistent with what would be expected from a two-story structure with a relatively stiff lateral system.

Figure F: East Wing ETABS Model and Modal Response Period



The design of the construction joint between the east and central wings was determined in the same way displacements were analyzed to size the construction joint between the west and central wings. Combining the obtained displacement of 0.32 inches as shown in Figure G with the displacement from the central wing indicates that the structures must be separated by at least 0.40 inches. Therefore, the design team decided that using another 1-inch construction joint will be the best option.

Figure G: East Wing Maximum Displacement (inches) at Expansion Joint

FIRE PROTECTION SYSTEM

According to Provisions of IBC 2009

Since the elementary school is being designed with exposed ceilings, structural members, and mechanical components throughout the building, one important consideration was whether or not fireproofing would be required for the structure. Knowing that fireproofing would be an aesthetic issue, the team 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, the design team 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 the proposed 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. The 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 Type II B construction is permissible 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 the design. The sprinkler system provides added fire safety to the building, but it also allows the team to achieve the outlined goals for the classroom spaces.

GROUP	HEIGHT (feet)	TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
		UL	160	65	55	65	55	65	50	40
STORIES(S) AREA (A)										
A-1	S	UL	5	3	2	3	2	3	2	1
	A	UL	UL	15,500	8,500	14,000	8,500	15,000	11,500	5,500
A-2	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-3	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-4	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-5	S	UL	UL	UL	UL	UL	UL	UL	UL	UL
	A	UL	UL	UL	UL	UL	UL	UL	UL	UL
B	S	UL	11	5	3	5	3	5	3	2
	A	UL	UL	37,500	23,000	28,500	19,000	36,000	18,000	9,000
E	S	UL	5	3	2	3	2	3	1	1
	A	UL	UL	26,500	14,500	23,500	14,500	25,500	18,500	9,500

Figure G: The 2009 IBC Table 503 showing allowed stories and square footages for each construction type and building group

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

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](#).

506.3 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: Building area modifications allowed for approved sprinkler systems

SECTION 601 GENERAL

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 ^e (see Section 202)	3 ^a	2 ^a	1	0	1	0	HT	1	0
Bearing Walls									
Exterior ^{f,g}	3	2	1	0	2	2	2	1	0
Interior	3 ^a	2 ^a	1	0	1	0	1/HT	1	0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior ^c	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: Fire rating requirements for building elements depending on construction type

Penetration into Concrete

AR-15 with 5.56 mm rounds

$$P_c = \frac{56.6 \left(\frac{m}{D^3} \right)^{0.075} \bar{N} m v^{1.8}}{D^2 \sqrt{f_c}} \left(\frac{D}{c} \right)^{0.15} f_{age} + D$$

$\frac{m}{0.00356 \text{ g}}$	$\frac{D}{5.66 \text{ mm}}$	$\frac{N}{1.17}$	$\frac{f_c}{27.579 \text{ Mpa}}$
$\frac{v}{986 \text{ m/s}}$	$\frac{c}{19.05 \text{ mm}}$	$\frac{f_{age}}{1}$	

P_c= 132.5 mm

P_c= 5.22 in

5.22-in. is less than the 6-in wall thickness, so the concrete wall alone will stop an AR-15 5.56 mm round

Despite being a very somber topic, gun violence is a relevant issue in society and recent events call for increased security within schools. This ballistics calculation was done to determine if the exterior walls were adequate to provide protection against gunfire. An AR-15 is a powerful semi-automatic rifle that shoots 5.56 mm rounds, and is one of the most popular selling guns in the United States. This analysis shows that the concrete wall alone will stop a 5.56 mm round, not taking into account the brick exterior. (Note: all units are in SI units)

LEED 2009 for Schools New Construction and Major Renovations			Project Name
Project Checklist			Date
Sustainable Sites Possible Points: 24			
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	Y ? N		
<input checked="" type="checkbox"/>	Prereq 1	Construction Activity Pollution Prevention	
<input checked="" type="checkbox"/>	Prereq 2	Environmental Site Assessment	
<input checked="" type="checkbox"/>	Credit 1	Site Selection	1
<input type="checkbox"/>	Credit 2	Development Density and Community Connectivity	4
<input type="checkbox"/>	Credit 3	Brownfield Redevelopment	4
<input checked="" type="checkbox"/>	Credit 4.1	Alternative Transportation—Public Transportation Access	1
<input checked="" type="checkbox"/>	Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
<input checked="" type="checkbox"/>	Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	2
<input checked="" type="checkbox"/>	Credit 4.4	Alternative Transportation—Parking Capacity	2
<input checked="" type="checkbox"/>	Credit 5.1	Site Development—Protect or Restore Habitat	1
<input checked="" type="checkbox"/>	Credit 5.2	Site Development—Maximize Open Space	1
<input checked="" type="checkbox"/>	Credit 6.1	Stormwater Design—Quantity Control	1
<input type="checkbox"/>	Credit 6.2	Stormwater Design—Quality Control	1
<input checked="" type="checkbox"/>	Credit 7.1	Heat Island Effect—Non-roof	1
<input checked="" type="checkbox"/>	Credit 7.2	Heat Island Effect—Roof	1
<input checked="" type="checkbox"/>	Credit 8	Light Pollution Reduction	1
<input checked="" type="checkbox"/>	Credit 9	Site Master Plan	1
<input checked="" type="checkbox"/>	Credit 10	Joint Use of Facilities	1
Water Efficiency Possible Points: 11			
<input checked="" type="checkbox"/>	Prereq 1	Water Use Reduction—20% Reduction	
<input checked="" type="checkbox"/>	Credit 1	Water Efficient Landscaping	2 to 4
<input checked="" type="checkbox"/>	Credit 2	Innovative Wastewater Technologies	2
<input checked="" type="checkbox"/>	Credit 3	Water Use Reduction	2 to 4
<input checked="" type="checkbox"/>	Credit 3	Process Water Use Reduction	1
Energy and Atmosphere Possible Points: 33			
<input checked="" type="checkbox"/>	Prereq 1	Fundamental Commissioning of Building Energy Systems	
<input checked="" type="checkbox"/>	Prereq 2	Minimum Energy Performance	
<input checked="" type="checkbox"/>	Prereq 3	Fundamental Refrigerant Management	
<input checked="" type="checkbox"/>	Credit 1	Optimize Energy Performance	1 to 19
<input type="checkbox"/>	Credit 2	On-Site Renewable Energy	1 to 7
<input checked="" type="checkbox"/>	Credit 3	Enhanced Commissioning	2
<input checked="" type="checkbox"/>	Credit 4	Enhanced Refrigerant Management	1
<input checked="" type="checkbox"/>	Credit 5	Measurement and Verification	2
<input type="checkbox"/>	Credit 6	Green Power	2
Materials and Resources Possible Points: 13			
<input checked="" type="checkbox"/>	Prereq 1	Storage and Collection of Recyclables	
<input type="checkbox"/>	Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 2
<input type="checkbox"/>	Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
<input checked="" type="checkbox"/>	Credit 2	Construction Waste Management	1 to 2
Materials and Resources, Continued			
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<input type="checkbox"/>	Y ? N		
<input type="checkbox"/>	Credit 3	Materials Reuse	1 to 2
<input type="checkbox"/>	Credit 4	Recycled Content	1 to 2
<input checked="" type="checkbox"/>	Credit 5	Regional Materials	1 to 2
<input checked="" type="checkbox"/>	Credit 6	Rapidly Renewable Materials	1
<input checked="" type="checkbox"/>	Credit 7	Certified Wood	1
Indoor Environmental Quality Possible Points: 19			
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<input checked="" type="checkbox"/>	Prereq 2	Environmental Tobacco Smoke (ETS) Control	
<input checked="" type="checkbox"/>	Prereq 3	Minimum Acoustical Performance	
<input checked="" type="checkbox"/>	Credit 1	Outdoor Air Delivery Monitoring	1
<input checked="" type="checkbox"/>	Credit 2	Increased Ventilation	1
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<input checked="" type="checkbox"/>	Credit 8.1	Daylight and Views—Daylight	1 to 3
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Innovation and Design Process Possible Points: 6			
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<input type="checkbox"/>	Y ? N		
<input type="checkbox"/>	Credit 1.1	Innovation in Design: Specific Title	1
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<input type="checkbox"/>	Credit 1.3	Innovation in Design: Specific Title	1
<input type="checkbox"/>	Credit 1.4	Innovation in Design: Specific Title	1
<input checked="" type="checkbox"/>	Credit 2	LEED Accredited Professional	1
<input checked="" type="checkbox"/>	Credit 3	The School as a Teaching Tool	1
Regional Priority Credits Possible Points: 4			
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<input type="checkbox"/>	Y ? N		
<input type="checkbox"/>	Credit 1.1	Regional Priority: Specific Credit	1
<input type="checkbox"/>	Credit 1.2	Regional Priority: Specific Credit	1
<input type="checkbox"/>	Credit 1.3	Regional Priority: Specific Credit	1
<input type="checkbox"/>	Credit 1.4	Regional Priority: Specific Credit	1
<input checked="" type="checkbox"/>	55	Total	Possible Points: 110
Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110			

This table is the LEED Checklist as developed by the design team. It is proposed that the new school building will reach LEED Silver Certification. This is based on site analysis, materials and resources analysis, and innovation analysis by the construction managers. The mechanical engineers performed water efficiency, energy and atmosphere, and indoor environmental quality analyses.

List of References

- [1] *2009 International Building Code*. Washington, DC: International Code Council, 2009.
- [2] *ACI 318-08: Building Code Requirements for Structural Concrete*. Farmington Hills, MI: American Concrete Institute, 2008.
- [3] *AISC 11: Floor Vibrations Due to Human Activity*. Chicago, IL: American Institute of Steel Construction, 2003.
- [4] *ASCE 7-05: Minimum Design Loads for Buildings and Other Structures*. Reston, VA: American Society of Civil Engineers, 2006.
- [5] Design and Construction Guidance for Community Safe Rooms, P-361 (FEMA 2008).
- [6] Hanagan, Linda, and Taehoo Kim. "Preliminary Assessment for Walking-Induced Vibrations in Office Environments." *Engineering Journal* (First Quarter 2005): 15-30.
- [7] "Nudura Insulated Concrete Forms." Nudura Integrated Building Technology. Web. Fall 2012.
- [8] "Pennsylvania Uniform Construction Code." *Pennsylvania Uniform Construction Code*. Web. Fall 2012.
- [9] *Steel Construction Manual*. Chicago, IL: American Institute of Steel Construction, 2011.
- [10] *Vulcraft Steel Joists & Joist Girders*. Lawrenceville, GA: Nucor Vulcraft Group, Steel Joist Institute, 2007.
- [11] *Vulcraft Steel Roof & Floor Deck*. Lawrenceville, GA: Nucor Vulcraft Group, Steel Deck Institute, 2008.
- [12] *UFC 4-023-07: Design to Resist Direct Fire Weapons Effects*. Washington, DC: United States Department of Defense, July 2008.
- [13] *LEED 2009 for Schools: New Construction and Major Renovations*. Washington, DC: U.S. Green Building Council, 2012



Structural Systems

2013 ASCE Charles Pankow Foundation Annual Architectural Engineering Student Competition

Team Registration Number:
02-2013

Structural Framing Plans

Date 22 February 2013

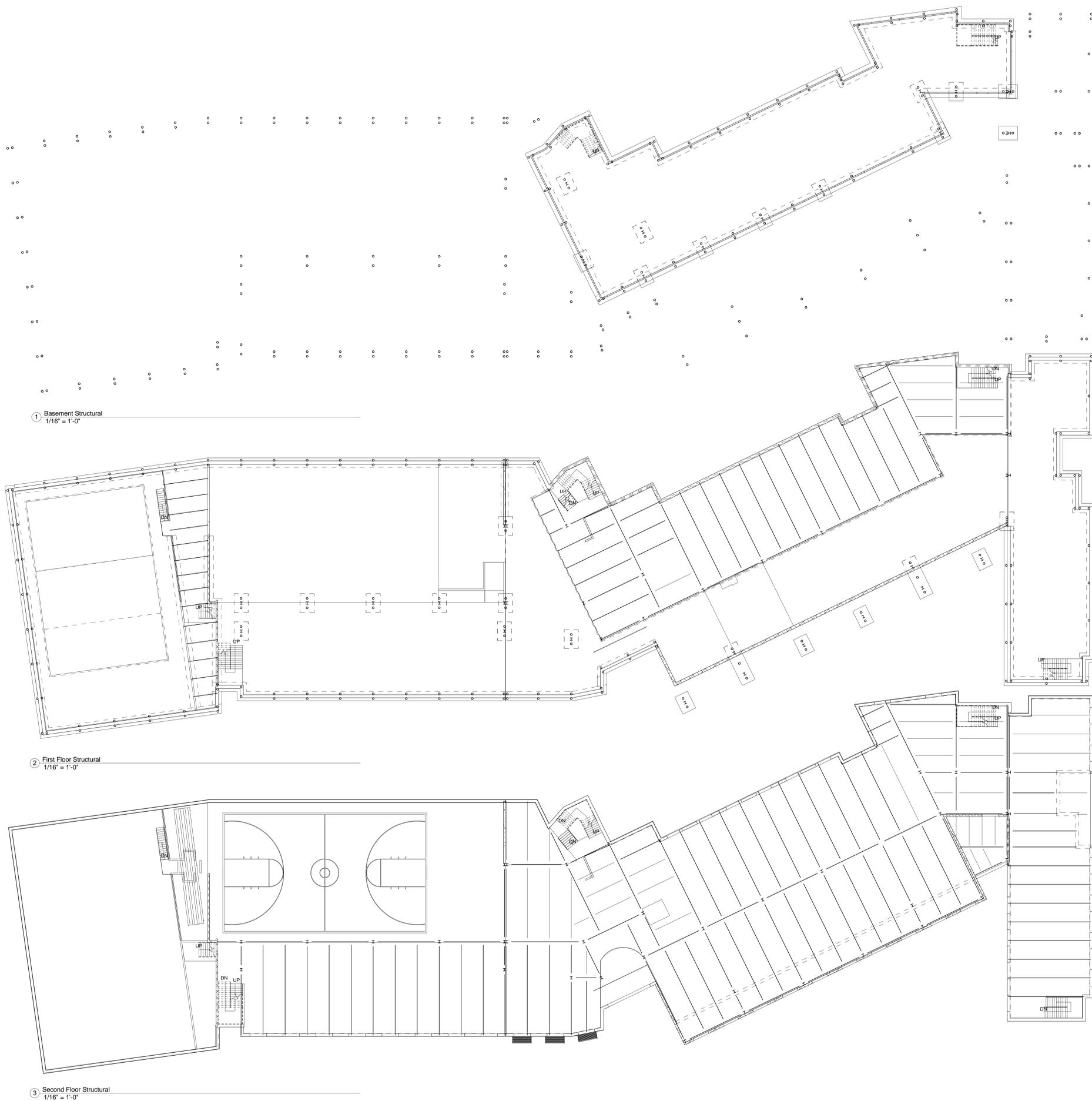
S-1

Scale 1/16" = 1'-0"

The basement level structural plan shows that the basement exists under only a small portion of the entire building footprint. The basement is accessible from two stairwells and sits 12 feet below the first floor level. As the drawing shows, the basement walls along the exterior of the building support the insulated concrete form (ICF) bearing walls from above. Piles of 10-in. diameter support the basement walls at increments of 14 feet (half the typical bay size) under a 24" thick footing that acts as the pile caps for each pile group. The basement walls under the interior of the building footprint are supported on a strip footing that is continuous with pile caps supporting the steel columns. This plan also shows the pile locations along the ICF walls around the building perimeter.

The first floor level structural plan shows steel beams supporting the floor over the basement, but most of the first floor is slab on grade. The 6-in. thick slab functions as a diaphragm to brace the pile caps shown in the west and central portions of the floor plan. Additionally, the slab is reinforced with welded wire fabric to ensure protection against cracking in the event a sinkhole forms under the slab. Most of the building perimeter features a 4-ft wide, 24-in. thick strip footing on which the ICF bearing walls sit. This footing is designed the same as the basement strip footing, and it is also supported by the same 10-in. diameter piles used throughout the project. Since the first floor slab on grade system is designed to act as a rigid diaphragm providing lateral support to the pile caps, grade beams are not needed for the foundation system.

The second floor structural plan shows more clearly the typical structural bays sizes of the building. The bays in the central wing of the building are 42 feet by 28 feet and 40 feet by 28 feet. As described in the report, this column grid layout was selected as an alternative to the original structural grid proposed by the competition guidelines. The modified grid requires fewer interior columns and foundation elements and therefore reduces cost. This structural plan also shows the overhanging second floor on the south side of the central wing. The size of these bays drove the decision to modify the structural grid. Another detail that can be noticed in this plan is the construction joint locations between building wings. A close look shows that two column lines sit immediately adjacent to each other where the building structure is split. The structure is designed with a construction joint of 1 inch to provide adequate room for deflection under maximum lateral loads.





The third floor level structural plan shows a very similar structural layout in the central wing of the building, but it also shows the support for the roofs over the west wing and east wing. The west wing houses the pool and multipurpose room. The roofs above these open spaces are supported by long span open web joists that are relatively lightweight and allow room for mechanical and electrical systems. The pool roof is supported by 5-ft deep joists and the multipurpose room by 40-in. deep joists. Additionally, since the multipurpose room is designed in accordance with FEMA regulations for an emergency shelter [5], a roof built of 3-in. concrete slab on 3-in. deck is used to provide enough weight to prevent roof uplift in a major wind storm. The roof joists are therefore designed to carry the increased dead load of the roof system which is also magnified by a larger importance factor for the emergency shelter.

The roof level structural plan shows that wide flange steel beams are used for the majority of the roof system. The structural team investigated the use of open web steel joists for the roof, but it was determined that the W18X40 beams are more economical. Since the roof joists would be required to span 42 feet, they would either need to be excessively deep or too closely spaced together to support the design snow load for Reading. At this level, snow drifts were not a concern. However, snow drifts reach as high as 49 psf on the lower roofs over the west and east wings. Additionally, a maximum snow load of 93 psf exists over the roof above a one-story space between the central and east wings. The geometry of the space and the 28-ft difference in height from the adjacent walls made this the most critical snow drift location in the building.

① Third Floor Structural
1/16" = 1'-0"

② Roof Structural
1/16" = 1'-0"

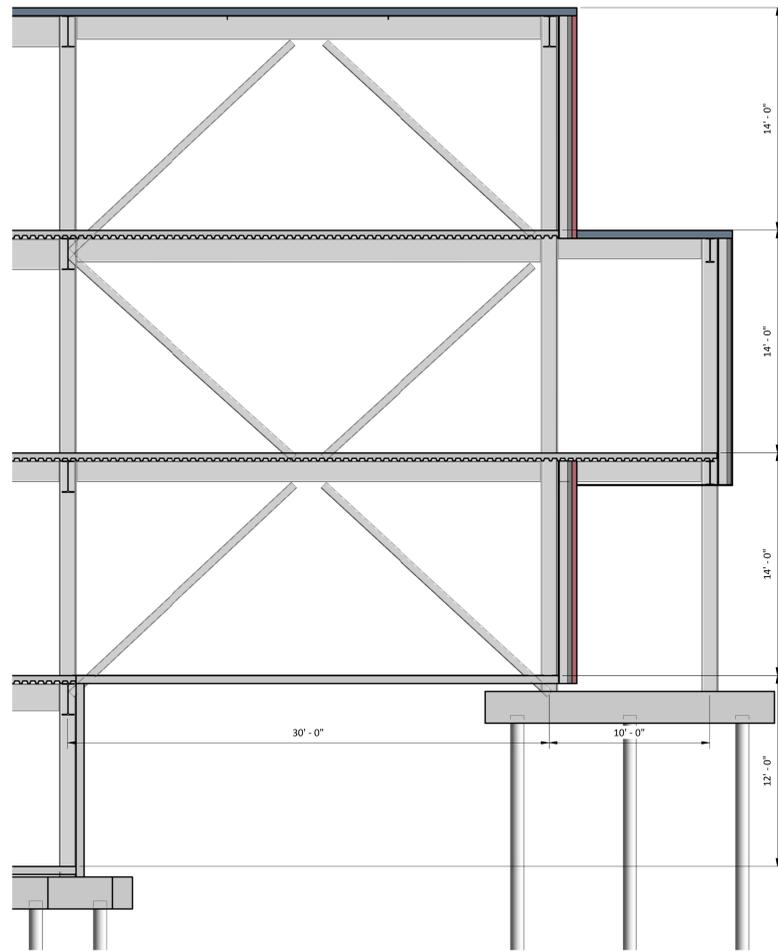
Team Registration Number:
02-2013

Structural Framing Plans

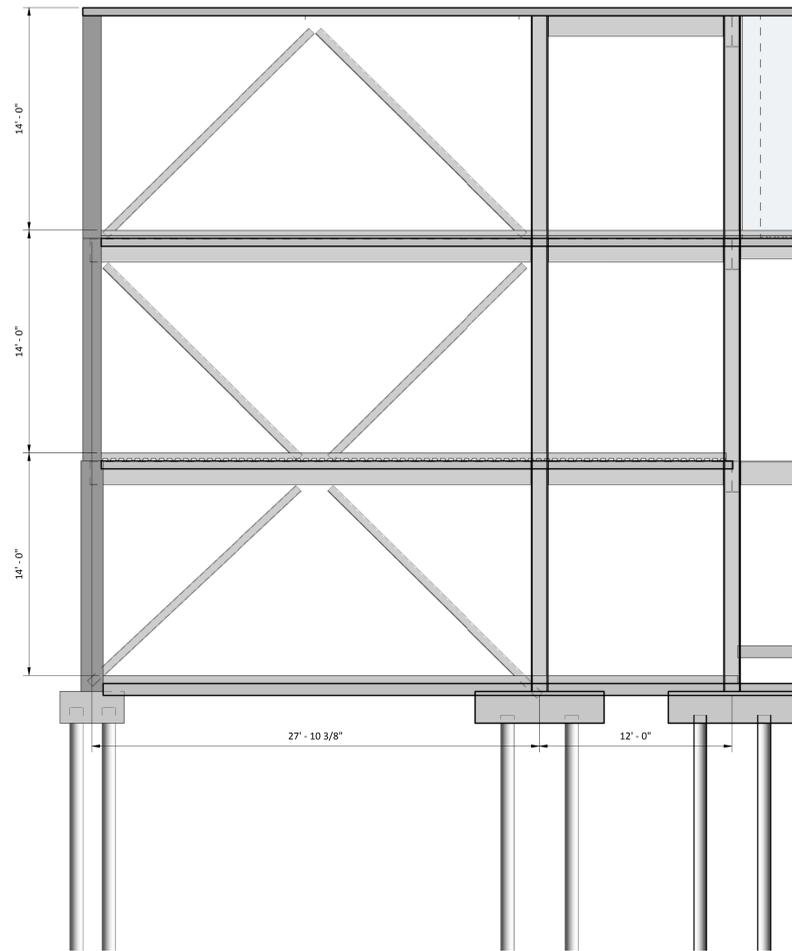
Date 22 February 2013

S-2

Scale 1/16" = 1'-0"



① Central Wing Lateral Bracing
1/4" = 1'-0"



② East Wing Lateral Bracing
1/4" = 1'-0"

The section cuts above show the lateral braces that are used to provide lateral support in the North-South direction of the building where the insulated concrete form (ICF) walls are not available to be utilized as shear walls. After some consultation with the mechanical systems design team, the structural team decided that ordinary steel concentrically braced frames are the most appropriate lateral system to use. A computer analysis of the building with code-determined wind and seismic loads aided the design of the braces. The HSS6X6X1/4 brace members are designed to provide adequate space for the mechanical system and to fit within the partitions between classrooms so that they do not invade classroom spaces.

One change that was required by the use of these braces was the addition of a column at each brace location. The braces from the central wing are part of an irregular cross section of the building that results from the overhanging portion of the second floor. To provide the frame for the braces, the column supporting the roof above the third floor was extended all the way to the foundation. This was done for both of the braced frames in the central wing. A similar problem was encountered with the braces in the west wing of the building. Although shear walls provide lateral support for most of the west wing, such shear walls were unavailable to support the three-story classroom space in this wing. The structural team opted to use a very similar ordinary steel concentrically braced frame system as the central wing. However, if the braces were placed between the existing columns, they would have interfered with the corridor running through each level of the building. To fix the problem, an additional column was added at each of the two braces so that they did not extend out into the corridors. HSS6X6X1/4 members also make up these braced frames, which are very similar in size to the braced frames in the central wing (the braces in the central wing cross a bay that is 2 feet wider than the bay size created in the west wing.)

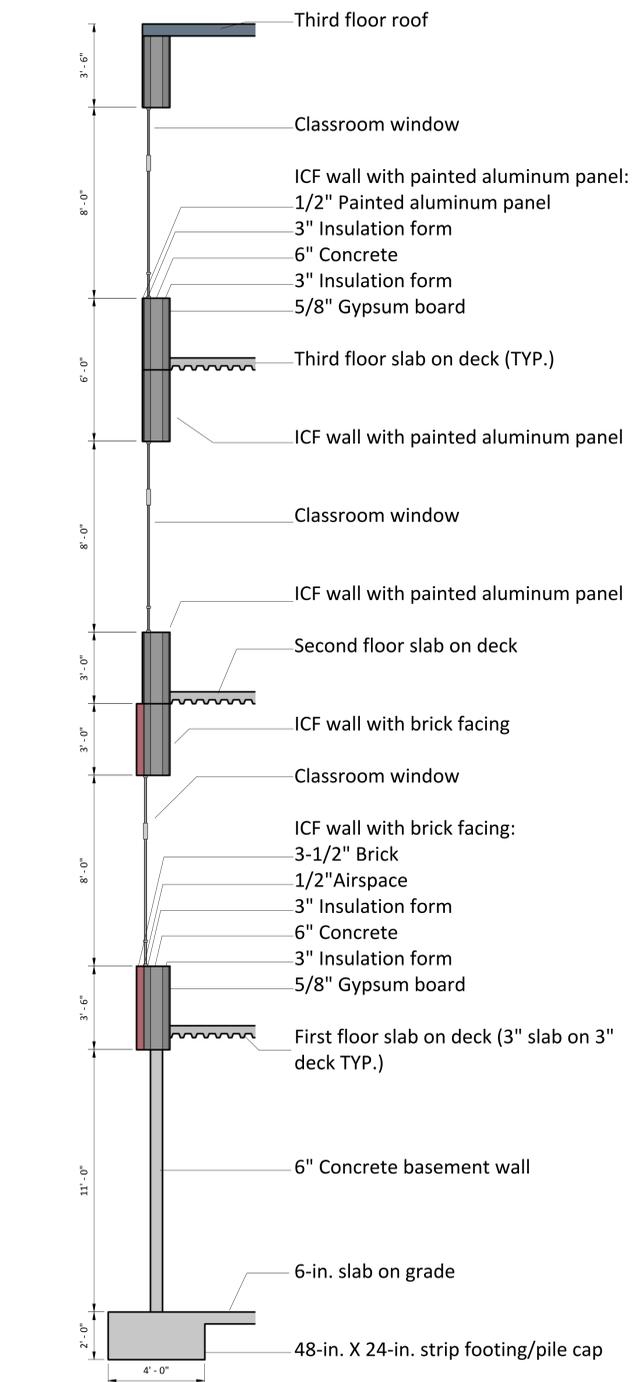
Team Registration Number:
02-2013

Lateral Bracing

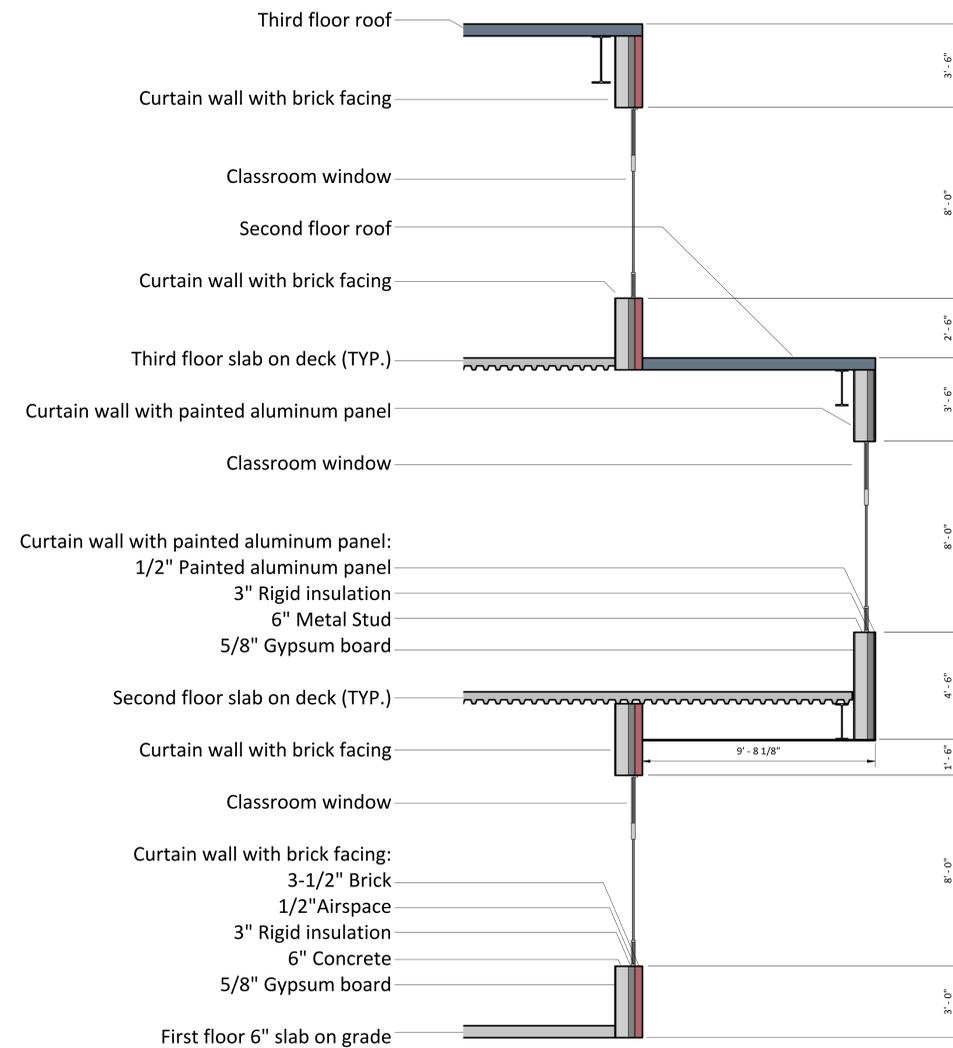
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Scale 1/4" = 1'-0"



① ICF Wall Section
3/8" = 1'-0"



② Curtain Wall Section
3/8" = 1'-0"

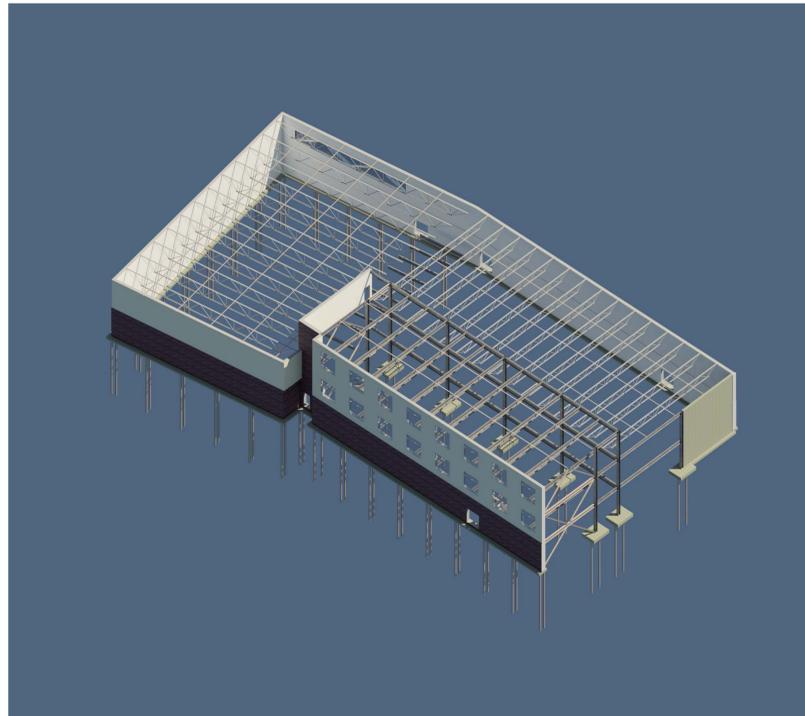
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Wall Sections

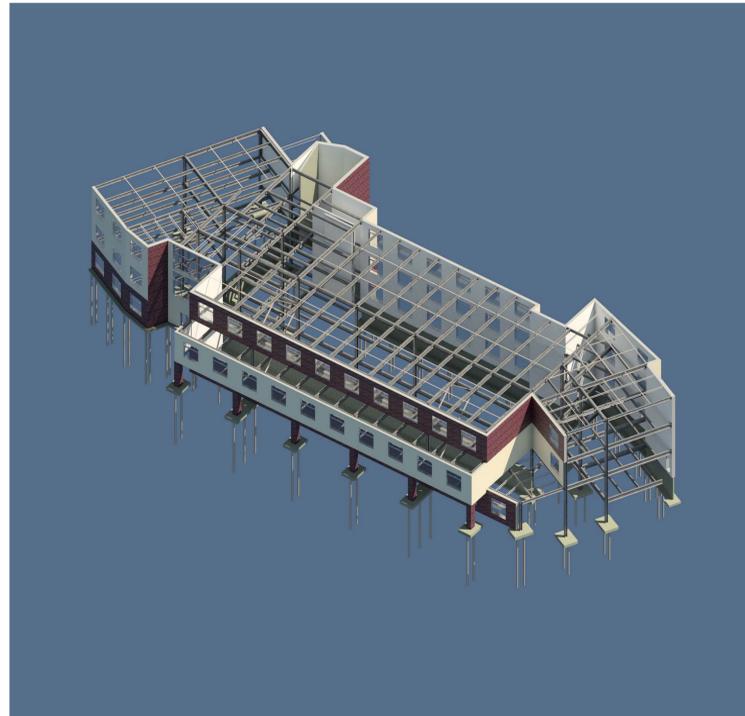
Date 22 February 2013

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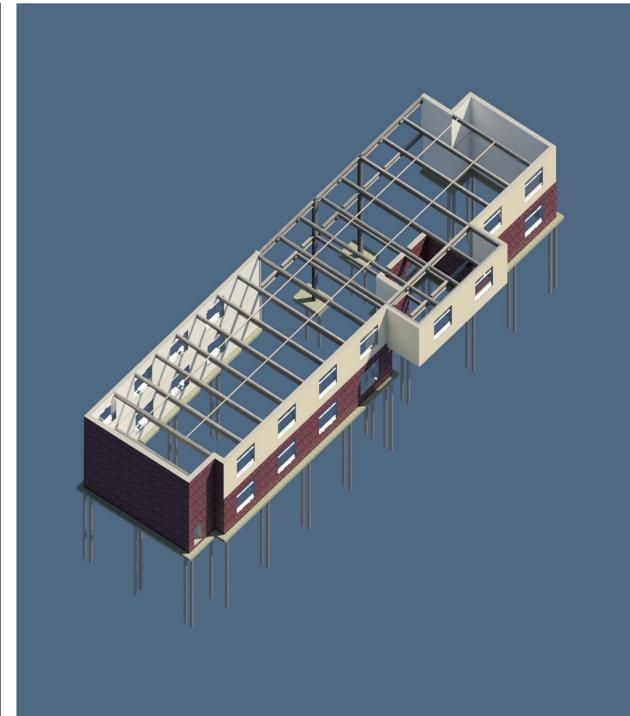
Scale 3/8" = 1'-0"



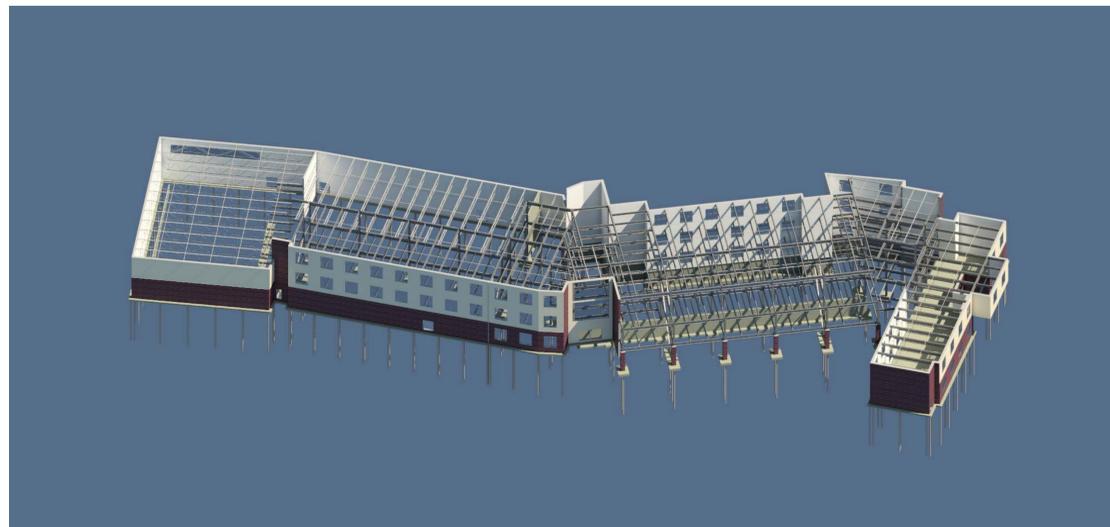
Rendered cutaway view of west wing structural elements: The west wing is supported by insulated concrete form (ICF) walls around most of the perimeter. Long span open web steel joists support the roof over the pool and multipurpose room. The lateral system primarily uses the ICF walls as shear walls, but also requires two ordinary steel concentrically braced frames and a concrete shear wall behind the multipurpose room stage.



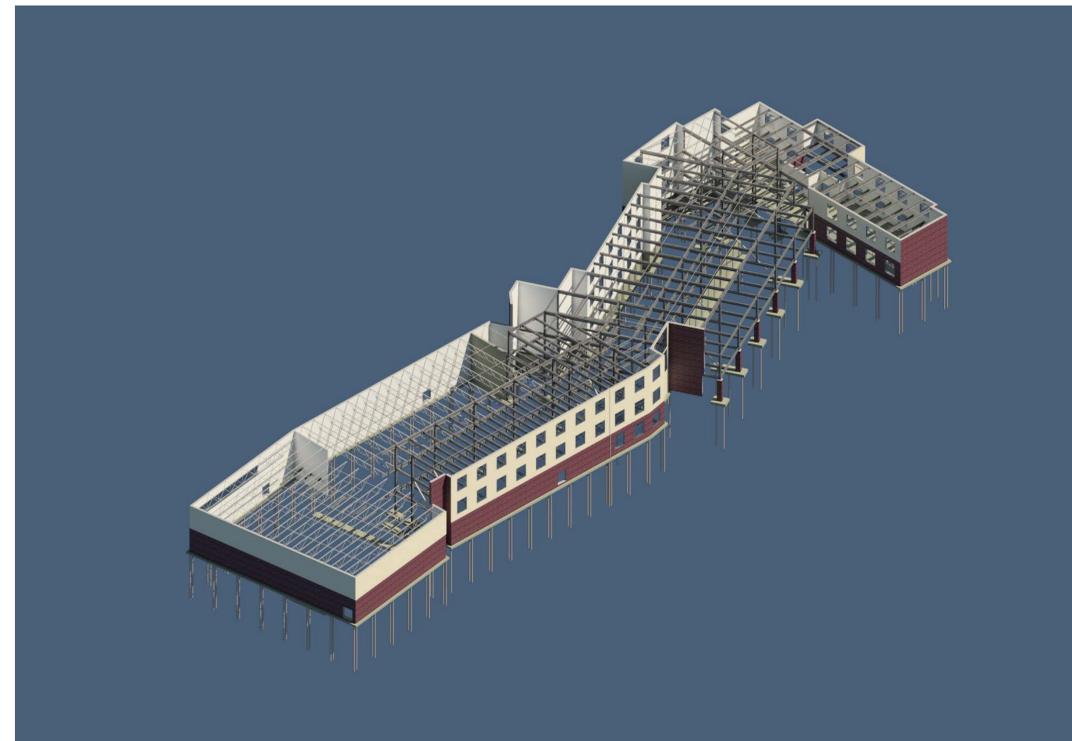
Rendered cutaway view of central wing structural elements: The central wing is supported by an ICF wall on the north and by structural steel framing in the center and on the south face of the structure. The ICF walls are used in conjunction with two interior shear walls for lateral support in the east-west direction of the structure. Ordinary steel concentrically braced frames provide lateral support in the north-south direction.



Rendered cutaway view of east wing structural elements: The east wing is the simplest portion of the building. The floors are supported by beams that transfer loads directly to the exterior ICF bearing walls. Just two columns are required where the east wing meets the central wing and exterior walls cannot be placed. The ICF walls also provide all of the lateral support for this part of the structure in both directions.



Rendered cutaway view of entire building structural elements: The image to above and the image to the right show two rendered isometric views of the structural systems for the entire building once the three wings are properly placed alongside each other. These views clearly show how the exterior ICF bearing walls dominate the structure and how they provide vertical and lateral support for most of the building.



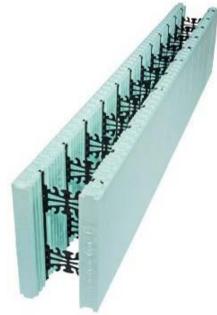
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3-D Model
Representations

Date 22 February 2013

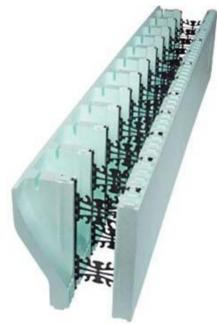
S-5

Scale



The image to the left shows a piece of typical insulated concrete form (ICF) wall. The green insulation foam is used as a stay-in-place form that saves in construction costs since forms do not need to be constructed, removed, and thrown away. The final assembly provides a nearly airtight building envelope that has important thermal advantages over a typical wall. The R-value for the 6-inch thick walls used in this project is 24, which is roughly double that for a standard wall in a similar building. The two foam panels are separated by a spacer that also serves as a chair for steel reinforcement that goes into the walls.

www.nudura.com



This particular ICF manufacturer has a number of pieces available for order and also builds custom pieces if necessary. The ICF piece shown immediately to the left is used primarily as a brick ledge for buildings with brick veneer facades much like this project. Similar pieces will be used in this project to provide seats on the wall for beams and girders to frame into the walls and transfer gravity loads. Threaded studs will be cast into the form so that the steel framing members will be securely anchored to the walls. Like all of the other ICF segments, these pieces are relatively lightweight and easy to transport. Therefore, they are an attractive option for the contractor due to ease of construction.

www.nudura.com



www.nudura.com

Another example of the available ICF pieces includes this T-form. Although an obvious use of this to perpendicularly join to walls, this piece can also be used to form a pilaster by capping the end of one leg of the T. The structural team investigated the slender walls in the pool to determine if these pilasters will be necessary to resist out-of-plane bending in the walls. As designed for the current loads, the wall has enough capacity to resist out-of-plane bending without the use of pilasters. However, the flexibility of the forms to help build these structural components was a large reason that the team believed that ICF walls would be a feasible option for construction.



www.forms.org

Insulated concrete forms are most often used in small residential construction, but they are increasingly more commonly being used for larger projects. For example the image of the building on the corner is a four-story commercial office building constructed with ICF walls. The use of ICF walls is especially beneficial because of the virtually airtight building envelope it creates. As a result, the walls have essentially no leaks and great thermal properties. This equates to large savings in energy costs. For a school district that may be using the elementary school for the next hundred years, energy efficiency of the building will be a huge concern. This is one of the most important reasons the Nexus design team opted to use ICF walls for this elementary school. The benefits of using ICF walls in reducing energy costs are outlined in more detail in the Nexus Mechanical Systems Report.



www.protrend-arrow.com



www.buildblock.com

In addition to providing an energy efficient solution, the walls also make for cheap and efficient construction. The ICF blocks are easy to assemble, and once the concrete is poured, the forms stay in place as part of the building structure. This helps reduce the time of construction and significantly reduces labor and formwork costs. The photo to the bottom left of the page shows a six-story ICF residential building under construction. Construction of a multistory building like this is certainly feasible, so construction of a three-story should be simple for a contractor with experience in ICF construction. The image on the lower right shows a two-story ICF wall that is very similar to the design proposed by Nexus. The image shows how the wall is shored before the remaining structural elements are put into place. This is the same method the construction team has developed to build the elementary school, and this process can be seen in the Nexus Construction Management Report.

Finally, the ICF walls also provide structural efficiency for the building. Properly reinforced walls of modest thickness will sufficiently carry the loads of a multistory structure as shown in the exterior bearing wall calculations of the appendix. At the same time, the walls can also function as shear walls and provide lateral support for the building. The elementary school design takes full advantage of the ICF walls as shear walls where they are available and, as a result, very few additional lateral support elements are required. The east wing of the building is a perfect example of the efficiency of the ICF walls: only two columns are required to support the floors in the east wing, and the ICF walls comprise the entire lateral force-resisting system for this wing.



Structural Systems

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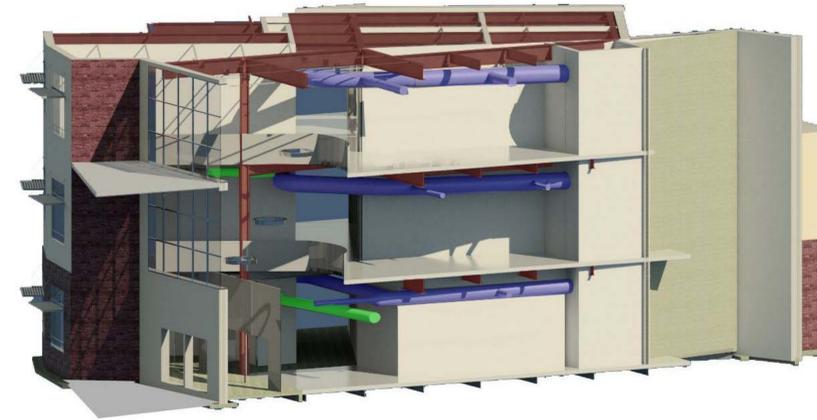
Insulated Concrete Forms

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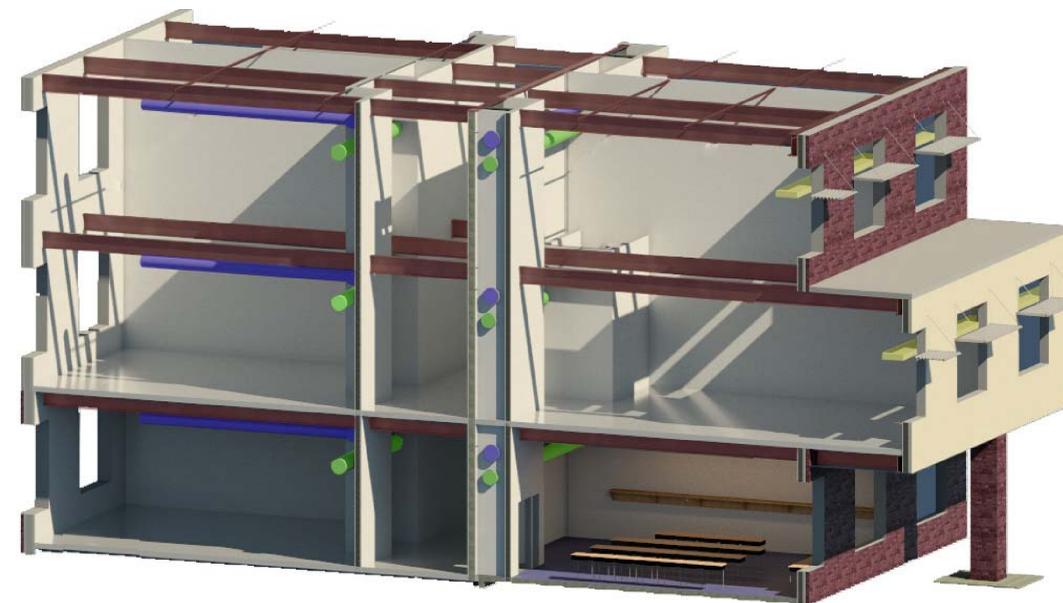
S-6

Scale

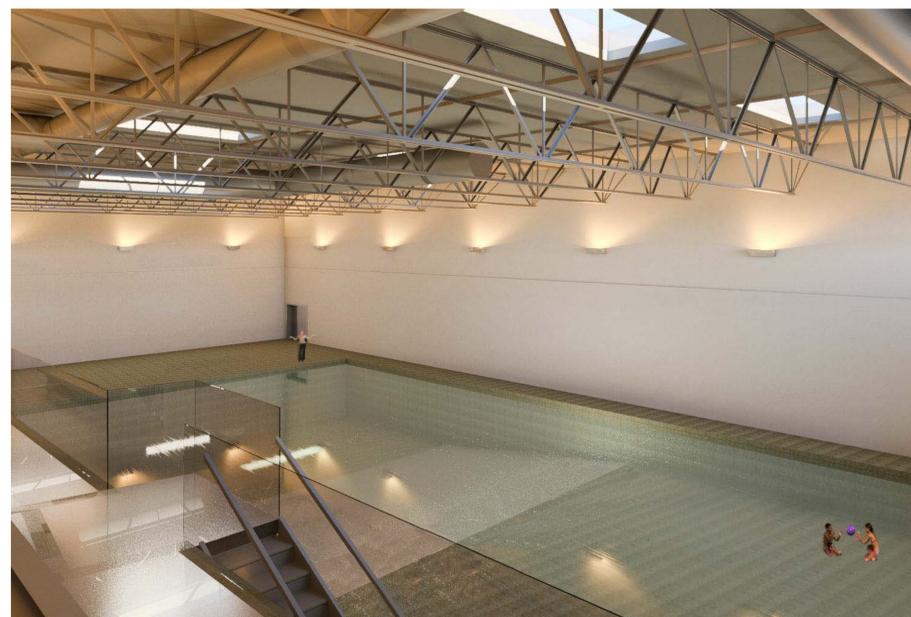
This rendering is showing a section cut of the entrance lobby. This is showing how the structural system, seen in red, functions with the other building systems. The structure was kept at a reasonable depth in order to accommodate the mechanical system, seen in purple.



This is a view from one of the classrooms, again, showing how the building systems function together. The mechanical system was designed to fit directly under the structural without being too intrusive into the space. The lighting system is located at the same elevation as the bottom of the beams, that way no shadows are cast from the lights.



This section cut shows how the systems fit together in the classrooms and the hallways. A "Horizontal Chasis" was created on either side of the hallway between the classrooms to house the main duct runs. Since there is only one row of columns on the interior in this area, there is enough room to make this "horizontal chasis" possible.



The pool area took a lot of integration to fit all of the building systems together. The joists were spaced far enough apart to accommodate skylights, which will provide good natural daylight. The joist webs also had large enough spacing to run the ducts through. All of this leaves a very open space, which is ideal for a pool.

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Integration

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S-7

Scale