AEI Team #04-2013

February 22, 2013

Structural System Design

ASCE | STUDENT COMPETITION

Our one true aim is to enhance the quality of the communities we work with through innovative ideas and an integrated design approach

Ingenuity | Quality | Enjoyment | Integrity

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Elementary School Front view from Amity Street

Elementary School and Pool – View from Baseball Field

1 Introduction

Project Requirements The challenge of this project is to address the design issues that must be considered for the structural systems of an Elementary School to be located in the urban setting of Reading, PA. As shown in Figure 1, Reading is a city in southeastern Pennsylvania with a population of approximately 88,000; making it the fifth largest city in the state of Pennsylvania. According to the 2010 census, Reading has the largest share of citizens living in poverty in the nation at approximately 33%.[1] The team must respond to the environment and setting in which this project takes place, and provide a school that enhances the entire community. Per the AEI competition rules, this submittal addresses the following:

Figure 1 - Location of Reading, Pennsylvania (Image courtesy of www.city-data.com)

1. Construction and design issues related to a high-performance building that meet the needs of both the school district and community. In the Energy Independence and Security Act of 2007[2], section 401, a high performance building is defined as follows:

The term 'high-performance building' means a building that integrates and optimizes on a life cycle basis all major high performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations.

2. As requested by the school board, the new building is to achieve LEED certification under the LEED 2009 for Schools New Construction and Major Renovations[3].

3. A budget is provided for the school district for the design and construction of the project focusing on both the short term and lifecycle cost-benefits of the design solution. See the Construction Management submittal for details on the budget for this project.

The submitted program for the new Elementary School provides creative solutions for a natatorium and 24-hour clinic open to the community, a multi-purpose space, and a green roof. This submittal narrates the design process and results of the foundation, gravity, and lateral systems of the structure. As requested by the competition guidelines, the design addresses emerging technologies by creating adaptable spaces that may change use in the future. The design also addresses security concerns that would arise with the sharing of student and community spaces. In anticipation that the school will be used as an emergency shelter facility, the building was designed as Category IV occupancy.

Project Goals Before beginning the design process, the team developed one central goal: *to create an innovative, high-performance environment in a way that stimulates involvement in both education and the community.* To achieve this main goal, detailed project goals were developed to guide the design process and major team decisions. These three project goals are Functionality, Efficiency and Appeal which interact around the ultimate goal Community as illustrated in Figure 2.

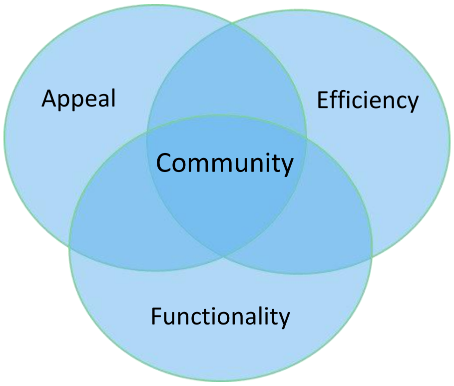


Figure 2- Project goals

The first goal was to design all building systems and components to best serve their specific functions within the building. This was achieved by breaking down the building into smaller packages which have distinct, unique and identifiable functions which drove the design of the building systems within each package. The structure was involved in every package, although many of the specific functions of the structural systems overlapped between packages. The team defined the most critical roles of each of these packages, and made sure to revert back to this definition whenever design issues or questions came about. These ideas were manifested in the design goal of functionality.

The next goal was to create a building which is affordable and long lasting, allowing the community to get optimal use out of the building. This was achieved by designing and engineering building systems which will best serve the building's inhabitants over an extended period of time. Analysis of all systems using life cycle cost assessments and sound engineering judgment also led to the accomplishment of this goal. These ideas were manifested in the design goal of efficiency, which was an important factor considered when choosing building materials and a foundation system.

The third and final goal was to create an iconic building design which attracts people to it both inside and out of the community. By creating this icon, students, families and faculty will be more inclined to be a part of this positive learning environment. This was achieved by creating a visually appealing and comfortable environment that accommodates all occupants. These ideas were manifested in the design goal of appeal. This goal to create an iconic building was the driving factor behind the design of the structural system for the natatorium.

Project Goals To achieve the project goals stated above and develop an innovative design for the structural system of the elementary school, the team made extensive use of Building Information Modeling (BIM). Organization, planned deliverables, and tracking progress were also extremely important in the success of the team as a whole. These ideas resulted in the team developing a BIM Execution Plan, which defined how exactly BIM tools would be used throughout the project. Table 1 outlines how various BIM tools were used in the design of the structural system. For details on the BIM Execution Plan, refer to the Project Delivery Goals section of the Integration submittal.

Table 1- BIM software uses

Symbol	Software	BIM Applications
	Bentley RAM	Gravity and Lateral System Design
	ETABS	Lateral System Design
	Autodesk Revit	3D Modeling, Coordination with MEP
	Autodesk Navisworks	3D Coordination, 4D Modeling

As decisions on the design of the structural system were finalized, elements were added to a Revit model central file which include architecture, topography, mechanical systems, and electrical equipment along with the structure. This model was then imported into Navisworks where a series of clash detections were run throughout the duration of the project in order to identify problem areas and possible construction issues. Independent of the Revit model, RAM and ETABS models were developed for load analysis and the sizing of members.

To illustrate the entire process and proposed solutions for the project, the remaining sections of this submittal include a specific objective for various structural elements, a list of design criteria that were considered, a narrative description of the design process, and the resulting systems chosen.

2 Site

The Reading Elementary School project is located at the intersection of 13th and Amity Street as shown in Figure 2. This location was chosen based on the surrounding buildings found in the area. By placing the elementary school in this location, it is near other public buildings and a local church and also be conveniently located in between two public bus stops.

Figure 2 - Ariel view of proposed site on North 13th Street (Image courtesy of www.bing.com)

Objective

Create a welcoming environment and an efficient site layout that is easily accessible for all occupants. Provide a safe and secure place for students that also accommodates 24-hour access to community spaces.

Criteria

- Maximize usable outdoor space in a semi-urban location
- Consider the effects of snow, seismic, and wind in the layout and placement of the building
- Consider proximity of parking to community spaces and main entrance
- Security, accessibility, and school bus traffic flow
- Soil conditions

Process

Considerations included space for a possible geothermal field, parking lot locations, vehicular and pedestrian traffic flow, recreational space, and the existing elementary school which would remain on site. Each team member individually developed a site plan. The team then compared plans and combined ideas in order to create the ideal layout on the existing site. The team considered benefits and disadvantages to flipping or rotating the building floor plan as well as moving the new elementary school to different positions within the boundary of the site. Wind and seismic loads were calculated to consider the effects on the structure of the building. Through the calculations of overturning moment and base shear, seismic loading was found to control in all directions. Flipping, rotating, or moving the building to different locations within the site did not have any major negative effects due to wind loading.

Result

The site layout is configured based upon the central idea to flip the entire footprint of the building along the north-south axis. Figure 4 depicts the changes made to the existing site plan in Figure 3. Arrows depict the direction of traffic flow. The main reason for this change was to position the multipurpose spaces (gymnasium, auditorium, and cafeteria) in the school next to the planned parking lot on the east end of the property. Also, the building has been oriented to maximize open outdoor space and the opportunity to harvest the benefits of daylight while still minimizing the effects of increased cooling loads from southern exposure. The existing elementary school in the south east corner of the site will be repurposed for use as the 24 hour clinic, public pool, and administrative space. This portion of the design will be covered in more detail in Section 8 of this submittal.

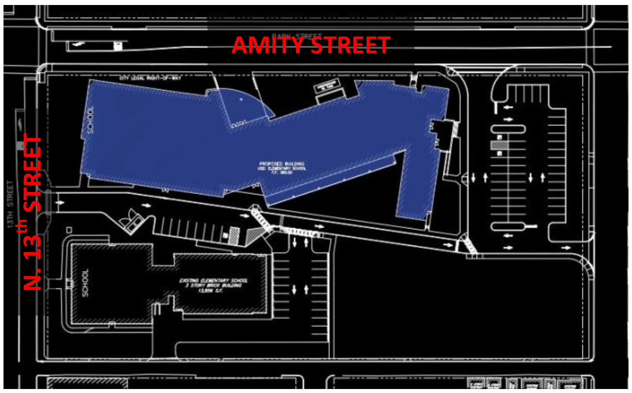


Figure 3 - Existing site plan

Figure 4 - Proposed site plan

3 Foundation

Objective

Develop a foundation system that is economical and properly responds to the site conditions.

Criteria

- Adapt to existing soil conditions including the possibility of sink holes
- Consider overall cost, and how predictable the total foundation cost will be
- Constructability and schedule
- Consider sustainable solutions

Process

A subsurface investigation was performed on site and a geotechnical report with recommendations for a foundation system was provided by the investigating engineers. The proposed location of the elementary school is in a sinkhole prone area, and subsurface conditions are characterized as fill materials overlying native soils overlying limestone bedrock. The average depth to bedrock over the fourteen boring test holes was found to be 33.5 feet, and the groundwater depth was observed to be over 35 feet below grade and is not expected to have any significant impact on the construction or performance of the proposed building.

Several foundation systems were suggested in the geotechnical report including compaction grouting, total excavation, and micro piles. Working with the team's construction specialists, a preliminary cost estimate was performed for each foundation option. Based on these numbers and further research, compaction grouting proved to be too unpredictable of a method considering the uncertainty of sink hole locations on site. Excavation was found to be one of the more expensive options, and also would not address the sinkhole problem if one were to form within the building footprint. Of the three suggested options, micro piles were found to be the best option based on cost and discussion with industry professionals. This option is also appropriate for all types of ground conditions, including the unsuitable soils found on site.

Upon further research and consultation, another option of using a rammed aggregate pier foundation system was brought up. In order to decide on the ideal system, advantages and disadvantages were considered for each. Table 2 below shows the positives and negatives considered for each system.

Table 2- Foundation system comparison

	Micro Piles	Rammed Aggregate Piers
Pros	• Can penetrate most obstacles • Low noise and vibration during installation • Certainty in stability	• Uses local and recyclable aggregate • Can increase strength of soil from 1500 psf to 7000-10000 psf. • Installed at a rate of 30 to 60 piers per day
Cons	• Labor intensive • Expensive • Ground water infill can be an issue	• Increased quality control requirements • Requires multiple mobilizations • Possible uneven settlement issues

Result

After looking at the advantages and disadvantages of each the rammed aggregate pier system and micro pile system and discussing with the construction managers, it was decided to use the rammed aggregate pier system for the school. A depiction of rammed aggregate pier system is shown Figure 5. The rammed aggregate piers will support spread footings ranging in sizes from 4'x4'x1.5' to 11'x11'x2' with the most commonly utilized spread footing size of 8'x8'x1.5'. Spread and continuous footings were sized using RAM Structural Systems software. The piers extend to a depth of 30 feet.

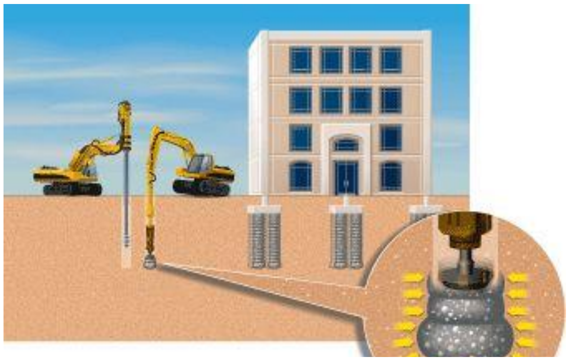


Figure 5 - Rammed aggregate pier construction (Image courtesy of www.buildinggreen.com)

The cost of this system was calculated to be approximately $150,000 less the micro pile system. A cost estimate for the micro pile and rammed aggregate pier systems can be found in the Construction Management submittal. The estimate for the rammed aggregate pier system was developed using the support of Farrell Inc. literature[4] and a feasibility study performed by a student for a project in Hershey, Pennsylvania[5]. A detailed calculation can be found in Appendix C of the supporting documentation. In the case that a sinkhole is encountered within the footprint of the building, additional piers would be installed in the surrounding area to support the load. The main reasons the team chose a rammed aggregate pier system over a micro pile system were lower cost, sustainable qualities, and faster speed of installation.

4 Gravity System

Objective

Create a system that minimizes costs, provides unobstructed space, is innovative yet practical, accommodates all systems of the building, and is modular with evenly spaced bays.

Criteria

- Consider placement of expansion joints
- Adapt to the architecture of the building plans provided
- Integrate with mechanical, electrical, and lighting engineers to accommodate all elements in the plenum space
- Constructability and schedule

Process

The first step in designing the gravity system was to determine all dead, live, snow, wind, and seismic loads to be used in calculations. See Appendix B in the supporting documents for loads, calculations, and additional assumptions. To adhere to the project design goals and select the ideal system based on the given conditions, a comparison was conducted of a concrete system versus steel system. As part of this assessment, a comparison of a frequently occurring three story frame within the building was performed to compare costs. Each member was sized and costs were compared based on material, labor, schedule, and constructability. Table 3 below illustrates the pros and cons of each system.

Table 3- Building material comparison for structural frame

	Reinforced Concrete	Steel
Pros	• Utilizes local resources and materials • Does not require additional fire proofing • Explosion/impact resistant	• Lighter weight • Uses recycled material • Shorter schedule
Cons	• Requires larger foundation to accommodate weight • Greater CO_2 emissions compared to steel	• Needs additional fire proofing

A column layout was developed based on the provided architectural plans and suggested column locations. Several minor adjustments were made to the provided column layout in order to accommodate the specific demands of our design goals. The addition of clerestories in third floor classrooms added a minor slope to some areas of the roof. Gravity loads were determined using ASCE7-05. An editable Microsoft Excel spreadsheet was created to calculate preliminary sizes of columns. Once the column locations were finalized and sizes estimated in the Excel document, a beam layout was developed. Beam spans were chosen based on the most economical and logical span direction of the floor deck. Preliminary beams were also sized using an Excel spreadsheet and used for a preliminary cost estimate for the entire gravity system. See the Construction Management submittal for a final detailed cost estimate of the gravity system.

It was decided by the team that classroom spaces would have exposed ceilings. This adhered to the project goal of creating an appealing space that is also an educational tool. Beams were limited to a reasonable and economical depth to accommodate mechanical equipment and fire protection in classrooms and corridors. The original floor to floor height given as 14 feet provided an opportunity for possible savings. At this point during design the team debated the benefits of a two foot reduction in floor to floor height, and the coordination challenges that would have to be addressed. However as the design progressed, the team found that the savings achieved by reducing the floor to floor height to 12 feet were not as high as originally expected, and the plenum space was overcrowded with many conflicts between systems.

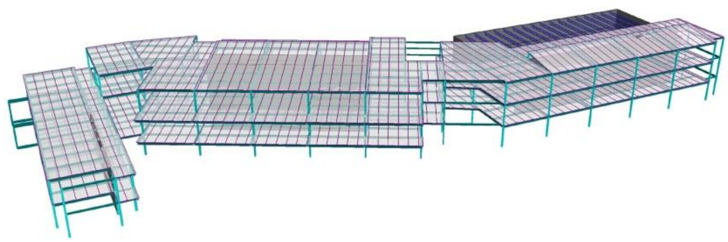


Figure 6 - 3D RAM model of gravity system

Next, a Bentley RAM Structural System model was created to finalize all beam and column sizes. They were then compared to previous Excel calculations for consistency. See supporting documentation for a sample of the Excel spreadsheet used to find preliminary sizes. The RAM model utilized is depicted in Figure 6 above. A cost estimate of the entire gravity system was based on these member sizes. When member sizes were finalized, all members were modeled in the Revit central file which was then imported into Navisworks for clash detection.

Result

The final design of the elementary school is based on a typical bay size of 28 feet by 30 feet, which is the size of a typical classroom. Based on the comparison of a steel system versus a concrete system, a steel system was chosen on the basis that aligned more with the project goals of functionality and efficiency. The typical layout of the beams is shown in Figure 7 below. Typical columns are W10x33's and W14x61's spliced at the third level (at 28 feet). A two floor tier is the most efficient during erection and provides overall smoother constructability based on OSHA[6] guidelines for steel erection.

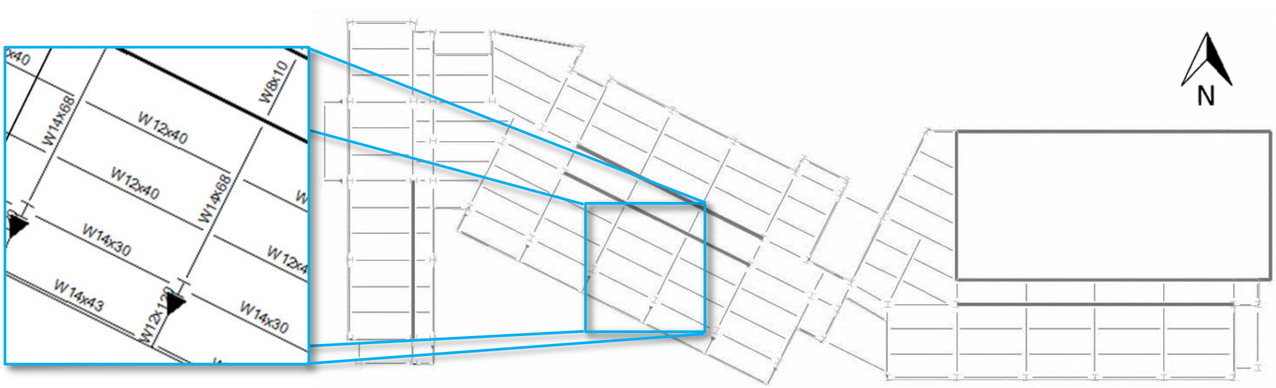


Figure 7 - Typical beam layout with details of typical first floor classroom beam sizes

Beam depths were limited to 8 inch depths for corridors, 12 inch depths in beams that span across a typical classroom, and 16 inches for classrooms in the west wing of the building which supports the green roof on the second level. Beam spacing typically ranged from 8 feet to 11 feet with a maximum camber of ¾". Beam weights ranged from the lightest of 10 pounds per foot to the heaviest of 88 pounds per foot. The team decided on exposed ceilings in classrooms, which would allow space for a 6 foot plenum with 14 foot floor-to-floor height. While 12 foot floor-to-floor height was considered, it proved to not be enough space to fit all of the systems within the plenum. The Vulcraft manufacturer deck catalog[7] was used for the selection of floor and roof assemblies. Specified decking can be seen below in Table 4 below. For detailed structural plans with all member sizes refer to Drawing S2.

Table 4 - Typical Deck Types

Decking Types			
Typical Floor	2VLI20	4.5" Composite Deck w/o studs	2.5" topping
Typical Roof	1.5BA20	Metal Non-composite	
Multipurpose Space Roof	2VLI18	5.5" Composite Deck w/o studs	3.5" topping
Green Roof	1.5BA16	Metal Non-composite	

The main roof system is composed of acoustical metal deck attached directly to the steel frame structure. Acoustic perforations are located in the vertical webs of the deck where the load carrying properties of the steal are barely affected. Sound absorbing fiberglass is placed in the rib openings which can absorb up to 60% of sound striking the deck[7]. The majority of the roof is flat except for two areas with clerestories which were added to the design in order to increase natural light in several classroom wings. With the addition of clerestories additional snow drift loads had to be considered. The slopes of these roof areas are 1:4 and 1:12. Figure 8 below depicts some key elements of the roof. See Drawing S7 for several isometric views of the roof.

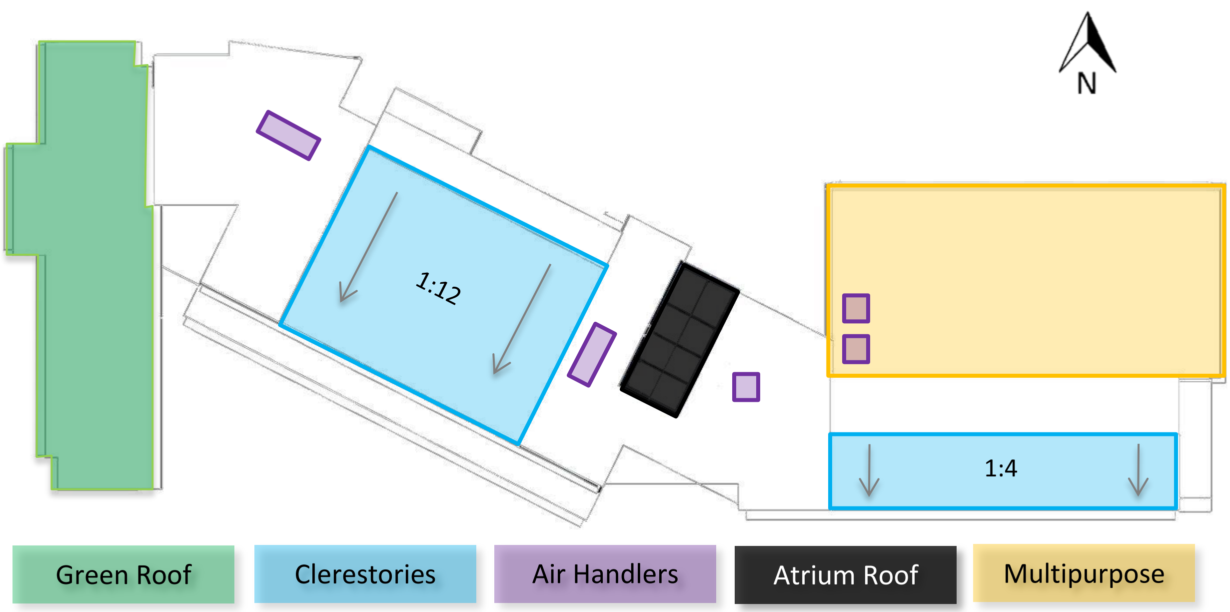


Figure 8 – Roof plan outlining roof elements

The multipurpose room design provided a challenge of coordination between the structure, mechanical, electrical, and plumbing systems. Structural, electrical, and mechanical engineers worked together to reach an ideal layout to accommodate trusses, skylights, duct work, and electric lights. Trusses 32 inch deep spaced at 7 feet span the fully grouted reinforced masonry walls which act as part of the gravity and lateral systems of the multipurpose room. Figure 9 on the following page shows all systems in a reflected ceiling plan of the multipurpose space.

After the first clash detection was performed in Navisworks, a relatively large number of clashes were detected between structure and architecture. The majority of these were between beams and interior walls. Logically it made sense to address a specific issue one time, rather than many throughout the building. Therefore the team decided to focus on three specific spaces to resolve clashes; a typical classroom, the first floor corridor, and the multipurpose space. Once constructability issues in one classroom were resolved, these fixes could be applied to all classrooms within the building. Figure 10 depicts the typical classroom floor assembly. See Appendix C for typical shear connection calculations.

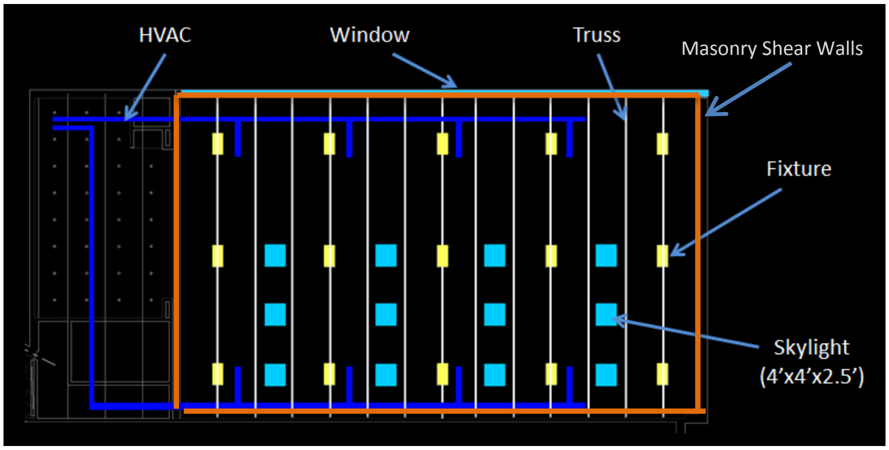


Figure 9 - Reflected ceiling plan of multipurpose space

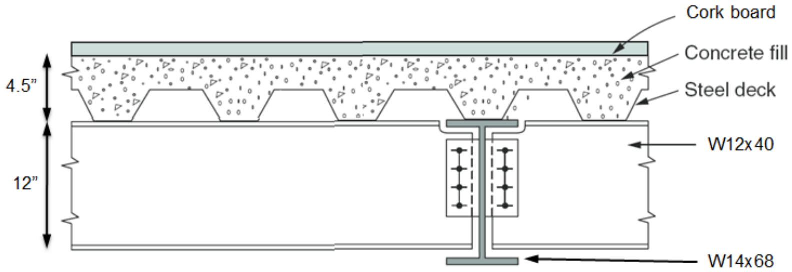


Figure 10 – Section of typical classroom floor assembly

5 Lateral System

Objective

Create a system that effectively resolves wind and seismic forces and works with the layout of the gravity system.

Criteria

- Minimize torsional effects
- Adapt to the architecture of the building plans provided
- Integrate with mechanical and electrical engineers on element obstructions such as ducts
- Provide redundancy
- Consider diaphragm to diaphragm boundaries to size joints

Process

Before the design of the lateral system, extensive research was done on different types of lateral systems and materials such as braced frames, moment frames, and shear walls. Based on the irregular geometry and differing number of stories of the building, it was logical to split the building into separate lateral systems that acted independently. Provided floor plans were investigated for locations where lateral resisting elements would best resist loads without obstructing usable space. Based on the modular layout of the elementary school, interior walls between classrooms and parallel to corridors provided ideal locations for these elements.

Next a wind load and seismic load analysis were performed, and it was found that seismic forces controlled over wind for all buildings in this project. Lateral load calculations can be found in Appendix B of the supporting documentation. Using these results, a trial and error method was used to find the required stiffness and most economical layout, while minimizing torsional effects. Structural modeling programs including RAM Element and ETABS were used to obtain forces in members for each of these trials. Using the forces obtained in these programs, elements were verified accordingly through hand calculation.

Throughout this process, possible system and material choices were discussed with all team members to address potential conflicts.

Result

The resulting lateral system that was designed consists of a combination of concentrically braced frames and masonry shear walls, which are depicted in Figure 12. The building was divided into four smaller buildings acting with independent diaphragms separated by expansion joints for the design of the lateral system: the west green roof wing, central wing, east wing, and multipurpose space. Two braced frames with fixed bases and hollow steel sections within the classroom dividing walls in one direction were utilized for the first three buildings. Figure 11 depicts one of the frames used in building 1. These were paired with concrete masonry shear walls parallel to corridors. Braced frames and floor diaphragms were modeled in ETABS to find forces to size members. Each shear wall was modeled in RAM Element with openings for doors and mechanical equipment to find the required rebar. Lengths of shear walls were based on the required lateral resistance as well as aesthetic appeal within the corridors. The multipurpose space acts as its own independent structure, with 10 inch reinforced masonry walls that act as both the lateral and gravity system.

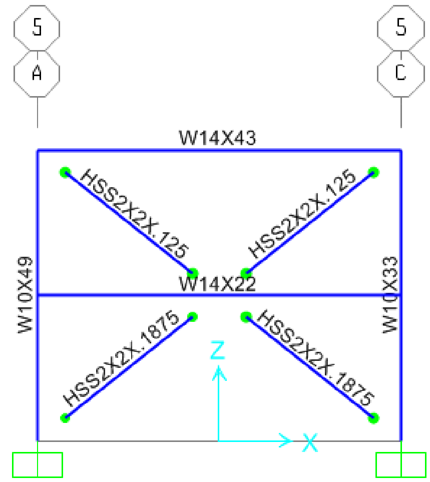


Figure 11 – Braced frame #1 in Building 1

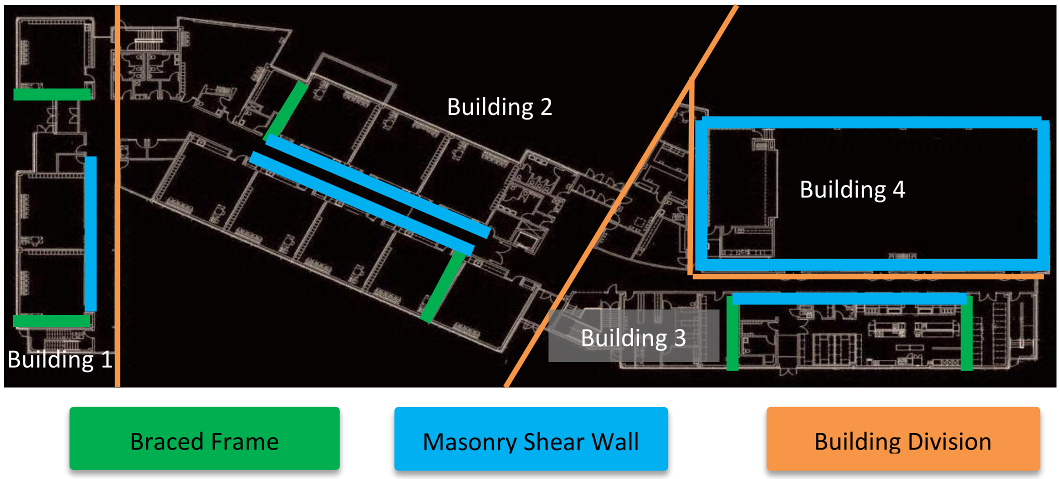


Figure 12 – First floor plan with lateral system elements highlighted

6 Enclosure

Objective

Create a functional barrier from exterior elements while maintaining aesthetic appeal and interior comfort.

Criteria

- Consider surrounding architecture
- Possibly utilize prefabricated assemblies
- Resist lateral loads
- Efficient connection to steel structure
- Constructability and schedule

Process

The design of the façade for the elementary school involved coordination among all disciplines. The team decided that the use of a precast panel would be ideal for constructability as well as other chosen systems. Several factors that drove the assembly selection were ASHRAE required U Values, window placement and spacing, required size and span of panels, and connection to the steel frame.

Result

The façade material chosen is a nonloadbearing precast panel composed of two concrete wythes separated by polystyrene insulation as shown in Figure 13. The insulated panel is primarily reinforced with 3/8 inch prestressed strands and rebar, and transversely reinforced with welded wire fabric (ASTM A 185). The typical size of each panel is 28' long by 14' high and weighs approximately 35,000 pounds. The panels are three-hour fire rated and connections are typically bolted at the centers. This lightweight product allows for larger panel sizes and a smaller dead load on the structure. The durability of precast concrete allows for a long life-cycle and low maintenance. Local fabricators are available which coincides with the team goal of using local materials and resources. The crane size was chosen based on the largest precast panel. Refer to the Construction Management report for more details on the precast panel erection plan.

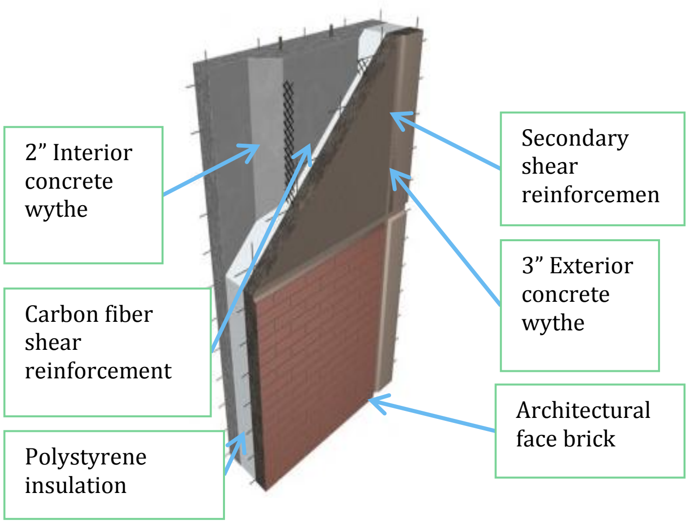


Figure 13 - Typical Precast Panel Section (High Concrete Group LLC

A typical bay spacing of 30 feet is used to accommodate interior spaces and to allow for sufficient uninterrupted window areas and achieve daylighting goals. See the Electrical and Lighting Systems submittal for more details on window area design.

7 Atrium

Objective

Create an attractive and secure entrance space to welcome students, faculty, and guests.

Criteria

- Consider aesthetics of exposed structural members
- Develop a creative solution to support overhanging walkways
- Address safety concerns inherent to a three story atrium space
- Provide structural redundancy

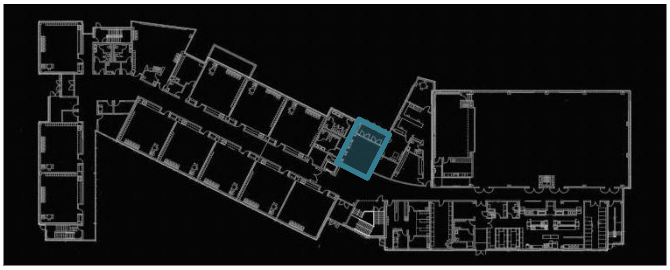


Figure 14 - Location of atrium space on first floor plan

Process

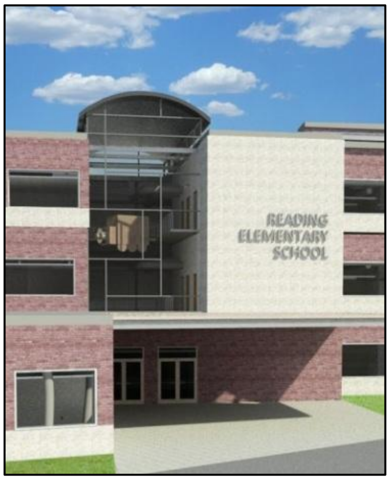


Figure 15 - Revit model view of north entrance

To add to the project goal of appeal, the team added an atrium space at the main north entrance to the architectural plans provided. Figure 14 highlights the location of the atrium on the first floor plan. The front facing façade of this space would feature a large glass curtain wall. Cantilevered walkways on the second and third floor provide access to bathrooms above the open lobby space. Inspiration for the structural system to support these walkways came from existing buildings that featured similar atrium spaces. Beam sizes for this area were modeled within the gravity system RAM model. When sizing members, additional load was considered in anticipation that artwork will be suspended within the atrium space.

Figure 16 - Revit model geometric section of atrium space

Result

The final design for the atrium space includes a curtain wall façade over the main entrance which is suspended from the steel frame. The roof of this space was originally also designed to be glazed, but due to excessive mechanical loads it was changed to solid precast concrete. For more details about the curtain wall façade see the Electrical Systems submittal. The two walkways are supported by 5'6" cantilevered W14x38 beams. Figures 15 and 16 depict the designed atrium space.

8 Clinic and Natatorium

Objective

Create a recreational and functional building to encourage healthy living and community involvement while also utilizing existing site resources.

Criteria

- Create an iconic building that the community can be proud of
- Make use of existing elementary school that will remain on site
- Develop a creative solution to spanning the large pool space

Process

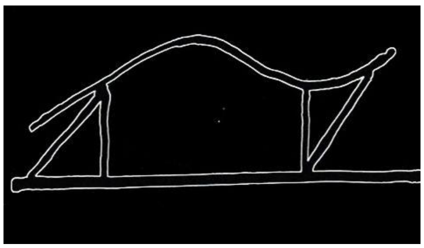


Figure 18 - Preliminary sketch of natatorium structure

The team evaluated different options on the best way to utilize the existing elementary school which will no longer have the same use upon completion the new elementary school. Based on the assumption that this building was not designed to house an indoor pool, the team decided that the east wing of the building could be demolished and rebuilt to house the indoor pool, locker rooms, and stadium style seating. The west wing of the existing elementary school would be repurposed for use as the 24-hour clinic and administrative space. No information about the existing structural system for this building was provided. Therefore, reasonable assumptions were made in order to move forward with the design. These assumptions include that the building is steel framed with modularly spaced bays utilizing moment frames for lateral resistance.

Research was done to investigate structural systems used in similar buildings that could span the 75-foot space. A schematic plan was developed for the structure which involved a curved roof to span the indoor pool. This brought up several important design concerns including how to deal with ponding, drainage, and snow build up in the concave areas of the roof. Loads were calculated and SAP2000 was used to determine forces in proposed members. These results were used to develop preliminary sizing.

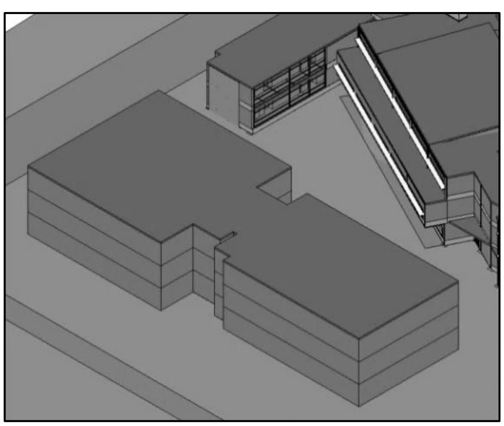


Figure 19 - 3D model of existing elementary school

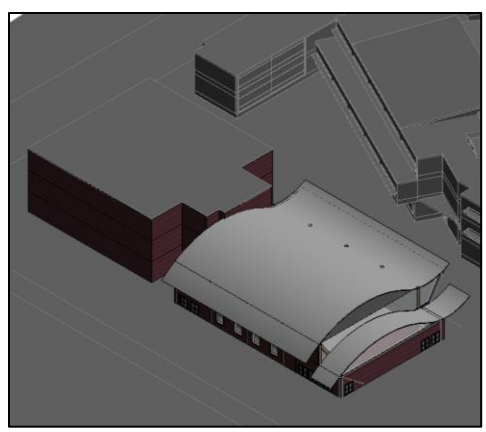


Figure 20 - 3D model of proposed addition

Result

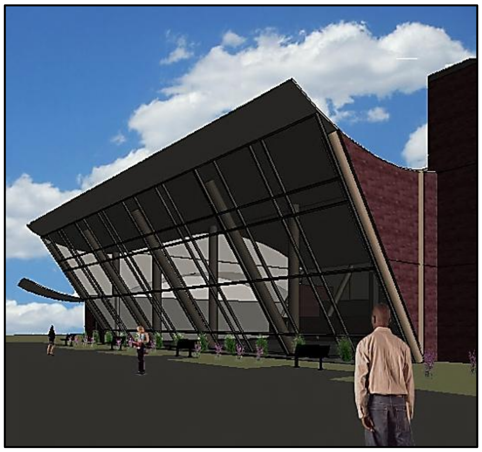


Figure 21 - Rendering of natatorium

Figures 19 and 20 on the previous page illustrate before and after views of the repurposed existing elementary school. The initial inspiration for the design of the natatorium spawned from the sketch in Figure 18 on the previous page. This natatorium design involves a curved roof supported by W21x147 rolled girders and W12x30 for purlins. The roof system made of prefabricated insulated metal deck panels supported by both vertical PIPE10 and slanted PIPE5 hollow circular steel columns. As shown in Figure 21 and 22, the slanted columns on the north side of the building also support a glass curtain wall allowing indirect natural sunlight into the building. Water from melted snow and rain will be evacuated through drains placed in the sloped valley of the curved roof. The enclosure will utilize the same precast panels as the new elementary school. For further details on the architecture of the clinic and natatorium see Drawings 8 and 9.

This sophisticated design involves higher costs which may not be feasible for the Reading school district. In order to accommodate financial limitations, a less expensive option was explored. This alternative design would not include the curved roof system or angled columns; and would instead utilize standard composite roof deck supported by wide flange members.

Allocating a larger amount of the school district's budget for the original curved structure design could be justified by the added architectural appeal. This design decision was driven by the team's project goal of appeal and to create an iconic building which attracts people to it both inside and out of the community.

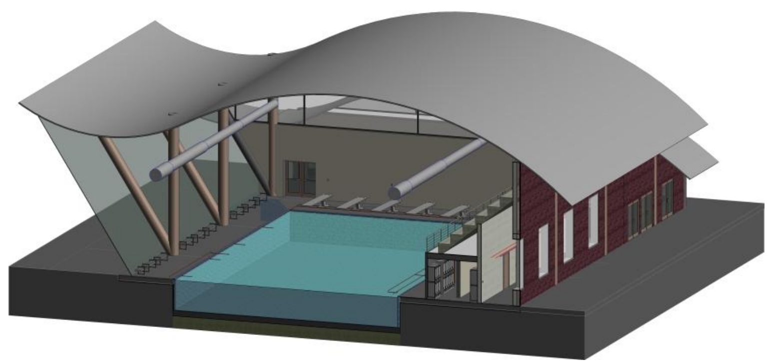


Figure 22 – Isometric section of natatorium

9 Sustainability

By designing a building that exemplifies sustainable ideas, the new elementary school can be an example to the community, educate students in a learning environment through features such as the green roof, and increase awareness of the benefits to sustainable design methods. In conjunction with the main project goal of providing a high-performance energy efficient building, each system design strived towards achieving LEED certification for Schools New Construction and Major Renovation[3]. The project as a whole anticipates achieving 51 LEED points to achieve LEED Silver certification. Along with LEED certification, the team also worked towards providing a sustainable building through design decisions that are not reflected in LEED criteria.

Some specific structural design choices made that reflect these goals include the following:

- Rammed aggregate pier foundation system uses natural local aggregate and minimizes required excavation

- Green roof used for energy savings as well as a teaching tool
- Fly ash replacement used in concrete
- Steel frame which utilizes over 90% recycled material
- Minimized excavation
- Local material vendors and suppliers
- Repurpose existing building rather than complete demolition
- Exposed ceilings used as educational tool

10 Conclusion

Figure 23 - Rendering of north facade

The most appropriate measure of success in our structural design would be an evaluation of whether our project goals were achieved, which in turn would result in a successful team goal.

Functionality was achieved through typical bay spacing based on classroom and corridor size. Lateral force resisting elements were placed between classroom walls and along corridors as not to obstruct space. Exposed ceilings were utilized in the classrooms to minimize on finish costs as well as to act as a teaching tool for the students. Utilizing local materials allowed for minimizing financial and environmental costs from transportation as well as to support local businesses.

Efficiency was achieved through utilizing prefabricated panels for the façade. Splicing columns at the 3rd floor speeds the construction process and lowers the required number of connections. The natural architecture of the building was utilized to place the lateral force resisting elements. The rammed aggregate pier system is efficient in its speed of installation as well as its use of recycled materials. Irregular angled connections were limited to reduce difficulty and cost of construction.

Appeal was achieved with a modified site plan which better utilizes the space provided. The community natatorium is a unique structure which will be an icon to the community. The redesigned open school atrium with cantilevered beams provides the school with an architectural attraction at the main entrance for all occupants to experience. Brick prefabricated panels used for the façade blend with the architecture of the surrounding community. The exposed classroom ceilings and green roof add interest as well as act as excellent teaching tools to the community.

Our team can confidently say that in successfully achieving these three project goals, we have accomplished our overarching team goal of *creating an innovative, high-performance environment in a way that stimulates involvement in both education and the community.* The structural ideas and designs presented in this submittal provide a strong response to the AEI program while working in harmony with the other systems of the building.

Supporting Documentation

Appendix A Codes and Standards

The city of Reading, Pennsylvania has adopted the latest version of the statewide building standards known as the Uniform Construction Code. The UCC has currently adopted the following codes for use:

International Building Code 2009

- Chapter 30 (Elevators) is not adopted
- Chapter 11 requires that buildings also comply with the requirements in the *ICC/ANSI A117.1-2003 Accessible and Usable Buildings and Facilities*

International Existing Building Code 2009

Other codes and standards either referenced by the International Building Code 2009 Edition or used in the design of the structural systems of the elementary school include the following:

ASCE/SEI 7-05 – *Minimum Design Loads for Building and Other Structures*

AISC – Steel Construction Manual *14th Edition*

ACI 318-05 – *Building Code Requirements for Structural Concrete*

International Swimming Pool and Spa Code *Version 1.0*

Appendix B Design Criteria, Methodology, and Assumptions

Based on the codes and standards currently in place in Reading and the assumptions made about the project, the following properties and loads were used in the design of the structural systems.

Material Properties		
Structural Steel		
Wide flanges	ASTM A992 Grade 50	
HSS Members	ASTM A500 Grade B	
Roof Deck	ASTM A653	
Angles & Plates	ASTM A36 Grade 36	
Reinforcing Steel	ASTM Grade 60	
Concrete		
Pile Caps and Grade Beams	f'c = 4000 psi	
Slab on Grade	f'c = 3000 psi	
Concrete on Steel Deck	f'c = 3000 psi	
Foundation Walls and Footings	f'c = 4000 psi	
Note: all concrete is normal weight (145 pcf)		
Masonry		
Typical Shear Wall	10" stacked block, f'c = 1500 psi	
Multipurpose Room	10" stacked block, f'c = 1500 psi	
Decking		
Typical Floor	2VLI20	4.5” Composite Deck w/o Studs
Typical Flat or Sloped Roof	1.5BA16	Metal Non-composite
Green Roof	2VLI18	5.5” Composite Deck w/o Studs
Multipurpose Room Roof	1.5BA20	Metal Non-composite

Load Combinations (ASCE7-05)
1) 1.4D
2) 1.2D + 1.6(L + H) + 0.5(Lr or S)
3) 1.2D + 1.6(Lr or S or R) + (L or 0.8W)
4) 1.2D + 1.6W + L + 0.5(Lr or S)
5) 1.2D + 1.0E + L + 0.2S
6) 0.9D + 1.6W + 1.6H
7) 0.9D + 1.0E + 1.6H

Dead Loads (psf)			
Enclosure	Exterior Brick Wall Panel	45	
	Glass Curtain Wall	15	
Roof	Gym Roof	15	
	Flat Roof	15	
	Sloped Roof	15	
	Green Roof	200	
Floor	Composite Deck	45	
	Superimposed (ceiling, lights, MEP, etc.)	15	
	Total for Typical Floor	60	
Mechanical	Large Air Handling Unit	4000	lbs
Equipment	Small Air Handling Unit	2000	lbs

Live Loads (psf) (ASCE7-05)	
Assembly area movable seats/Gym	100
Corridor on 1st floor	100
Corridor above 1st floor	80
Lobbies	100
Library Stacks	150
Library Reading Room	60
School Classroom	40
Offices	50
Stage Floors	150
Stairs/exit ways	100
Ordinary flat/pitched/curved roof	20
Roof used for garden/assembly	100
Walkway/elevated platform	60

Snow Loads (psf)		
Ground	p_g =	30.0
Flat Roof	p_f =	22.7
1:12 sloped roof	p_{s1}=	22.7
1:4 sloped roof	p_{s2}=	22.7
Curved roof	P_{s3}=	25.0

Snow Load Analysis

A snow load analysis was performed using Chapter 7 as ASCE7-05. After considering the exposure of the roof, the importance factor, and the thermal factor the snow loads were determined for each section of the roof. Snow drift loads were considered on the multipurpose space roof which includes a parapet, changing roof elevations, and against the vertical wall of clerestories. See Drawing S7 for location of clerestories and roof elevation changes.

$\gamma = 0.13p_g + 14 = 17.9$ psf

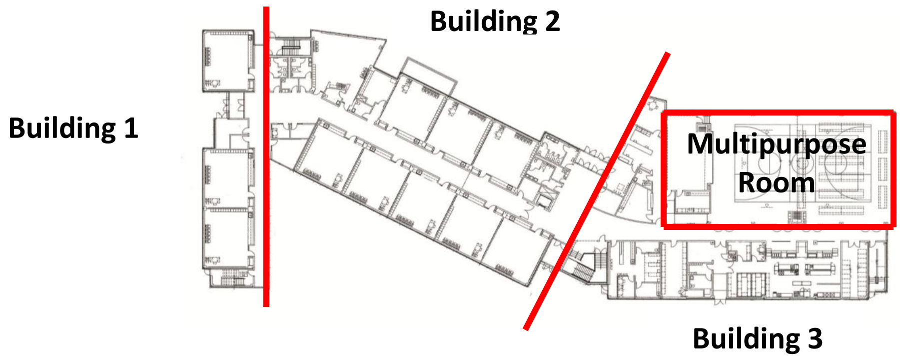
max intensity of drift surcharge load = $p_d = h_d\gamma$

h_d determined from Figure 7-9 in ASCE7-05

$hc_{clerestory}$ = 4’ l_u = 100 w_{max} = 8h = 32’
h_d = 4’
$w=4h_d$ = 16’
p_d = 71.6 psf

$hc_{parapet}$ = 1.5’ l_u = 50 w_{max} = 8h = 12’
h_d = 2’
$w=4h_d^2/h$ = 10.67’
p_d = 35.8 psf

hc_{story} = 14’ l_u = 50 w_{max} = 8h = 112’
h_d = 2’
$w=4h_d$ = 8’
p_d = 35.8 psf



Building Weight

Building 1			
	Unit Weight (psf)	**Quantity Per Floor (SF)**	**Weight (k)**
Level 1			
Composite Floor	39	5040	196.56
Superimposed	10	5040	50.4
Walls (SF Wall)	45	3480	156.6
Level 2			
Green Roof	200	5040	1008
Walls (SF Wall)	45	1740	78.3
Superimposed	10	5040	50.4
Total Building Weight (k)			1540.26

Building 2			
	Unit Weight (psf)	**Quantity Per Floor (SF)**	**Weight (k)**
Level 1			
Composite Floor	39	13224	515.736
Superimposed	10	13224	132.24
Walls (SF Wall)	45	5736	258.12
Level 2			
Composite Floor	39	13224	515.736
Walls (SF Wall)	45	5736	258.12
Superimposed	10	13224	132.24
Level 3			
Roof	60	13224	793.44
Superimposed	10	13224	132.24
Walls (SF Wall)	45	2868	129.06
Total Building Weight (k)			1812.192

Building 3			
	Unit Weight (psf)	Quantity Per Floor (SF)	Weight (k)
Level 1			
Composite Floor	39	6200	241.8
Superimposed	10	6200	62
Walls (SF Wall)	45	2424	109.08
Level 2			
Gym Roof	60	7500	450
Walls (SF Wall)	45	2424	109.08
Superimposed	10	13700	137
Composite Floor	39	6200	241.8
Level 3			
Roof	60	6200	372
Superimposed	10	6200	62
Walls (SF Wall)	45	1212	54.54
Total Building Weight (k)			1108.96

Wind Load Analysis

Building 1		
Occupancy	IV	
Exposure	B	
V (mph)		90
Kd		0.85
Kz		0.76
Kzt		1
I		1.15
N/S	B (ft)	36
	L (ft)	140
	H (ft)	24
E/W	B (ft)	140
	L (ft)	36
	H (ft)	24

Building 1 Wind Pressure			
N/S	Windward	13.2	psf
	Leeward	-5.4	psf
E/W	Windward	13.2	psf
	Leeward	-9.3	psf

	Total Base Shear (k)	Overturning Moment (k-ft)
N/S	16.0	445
E/W	75.6	2100

Building 2		
Occupancy	IV	
Exposure	B	
V (mph)		90
Kd		0.85
Kz		0.76
Kzt		1
I		1.15
N/S	B (ft)	152
	L (ft)	87
	H (ft)	36
E/W	B (ft)	87
	L (ft)	152
	H (ft)	36

Building 2 Wind Pressure			
N/S	Windward	13.2	psf
	Leeward	-9.3	psf
E/W	Windward	13.2	psf
	Leeward	-6.7	psf

	Total Base Shear (k)	Overturning Moment (k-ft)
N/S	123	3444
E/W	62	1730

Building 3		
Occupancy	IV	
Exposure	B	
V (mph)		90
Kd		0.85
Kz		0.76
Kzt		1
I		1.15
N/S	B (ft)	184
	L (ft)	106
	H (ft)	30
E/W	B (ft)	106
	L (ft)	184
	H (ft)	30

Building 3 Wind Pressure			
N/S	Windward	13.2	psf
	Leeward	-9.3	psf
E/W	Windward	13.2	psf
	Leeward	-6.7	psf

Total Base Shear (k)			
Classrooms		Gym	
N/S	149	N/S	67.5
E/W	33	E/W	29.0

Overturning Moment (k-ft)			
Classrooms		Gym	
N/S	4200	N/S	1890
E/W	924	E/W	812

Seismic Load Analysis

Seismic Design Factors and Categories	
S_s	0.261g
S_1	0.06g
F_a	1.5
F_v	2.4
S_{ms}	0.3915
S_{m1}	0.144
S_{Ds}	0.261
S_{d1}	0.096
I	1.5
Seismic Design Category	C
R (Masonry)	2
R (Concentrically Braced Frames)	3.25
Cs	0.0533

SEISMIC CALCULATIONS

1/2

SEISMIC USE GROUP: IV

SITE CLASS: D

SPECTRAL RESPONSE ACCEL. SHORT $(S_s) = 0.261g$ (USGS)

SPECTRAL RESPONSE ACCEL. LONG $(S_1) = 0.06g$

SITE COEFFICIENT $(F_a) = 1.5$

$(F_v) = 2.4$

SOIL MODIFIED ACCEL: $S_{ms} = F_a S_s$
$= (1.5)(0.261g) = 0.3915g$

SOIL MODIFIED ACCEL: $S_{m1} = F_v S_1$
$= (2.4)(0.06g) = 0.144g$

DESIGN SPECTRAL RESPONSE, SHORT: $S_{DS} = 2/3\, S_{ms}$
$= 2/3(0.3915) = 0.261g$

DESIGN SPECTRAL RESPONSE, LONG: $S_{D1} = 2/3\, S_{m1}$
$= 2/3(0.144)g = 0.096$

RESPONSE MODIFICATION FACTORS:

MASONRY SHEAR WALLS: $R = 2$

STEEL CONCENTRICALLY BRACED: $R = 3.25$

IMPORTANCE FACTOR (I_e): 1.5

SEISMIC DESIGN CATEGORY (SDC): D

APPROX FUNDAMENTAL PERIOD

$T_a = C_p h_n^x$ WHERE $C_p = 0.02$, $x = 0.75$ FROM TABLE 12.8-2

BLDG 1	BLDG 2	BLDG 3	GYM
$T_a = 0.02(24)^{0.75} = 0.2169$	$T_a = 0.2939$	$T_a = 0.2939$	$T_a = 0.2169$

$C_u = 1.7$ [UPPER LIMIT MODE VIBRATION AFTER MODAL ANALYSIS

$T = C_u T_a = T_b$

BLDG 1	BLDG 2	BLDG 3	GYM
$T_b = 0.3687$	$T_b = 0.4996$	$T_b = 0.4996$	$T_b = 0.3687$

2/2

SEISMIC CALCULATIONS

C_s | $S_{DS}/(R/I)$
For $T \le T_L$: $S_{D1}/(T \cdot R/I)$

BLDG 1

BRACED FRAMES

$C_s = \frac{0.261}{(3.25/1.5)}$ OR $\frac{0.0960}{(0.3687 \cdot \frac{3.25}{1.5})}$

$= 0.1205$ $\quad = 0.1202$

MASONRY WALLS

$C_s = \frac{0.261}{(\frac{2}{1.5})} = 0.1958$

BLDG 2

BRACED: 0.0887

MASON: 0.1441

BLDG 3

BRACED = 0.0887

MASON = 0.1441

GYM

MASON = 0.1953

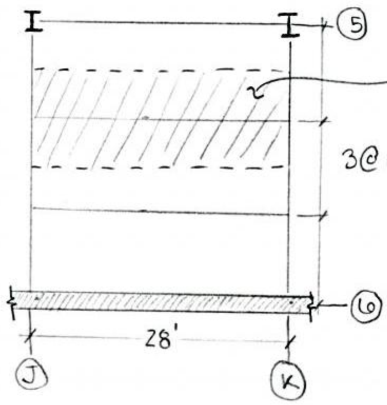
BASE SHEAR

$V_b = C_s W$

BLDG 1	BLDG 2	BLDG 3
W = 1540k	W = 1812 k	W = 1108k
BRACED: $V_b = 0.1202(1540)$ $V_b = 185k$	BRACED: $V_b = 160k$	BRACED: $V_b = 98k$
MASONRY $V_b = 300k$	MASON: $V_b = 261k$	MASON: $V_b = 160k$

Appendix C Design Calculations

Typical Beam Spot Check



Dead Load:

Slab = 45 psf

sup. = 15 psf

Live Load:

classroom = 40 psf

280 SF < 400 SF ∴ no LL reduction

* assume 1.2D+1.6L will control for gravity analysis

total DL = (45+15)(10) = 600 plf

total LL = (40)(10) = 400 plf

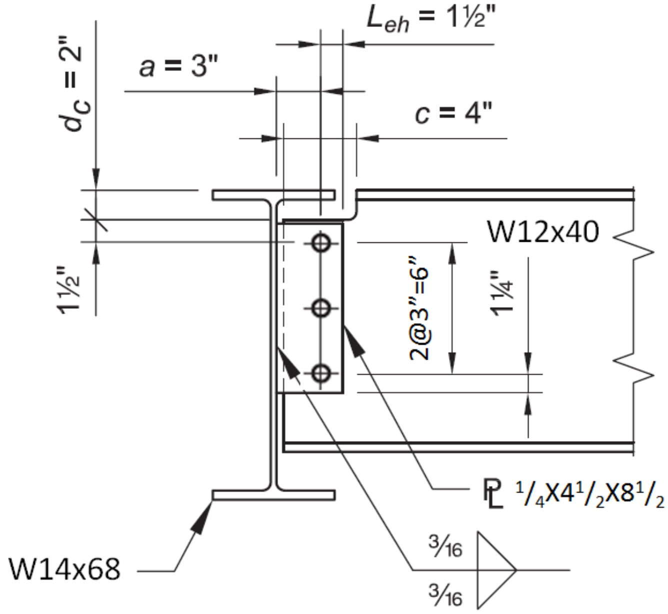
$w_u = 1.2(.6) + 1.6(.4) = 1.36 \text{ klf}$

$V_u = \frac{w_u l}{2} = \frac{(1.36)(28)}{2} = 19 \text{ kip}$

$M_u = \frac{w_u l^2}{8} = \frac{(1.36)(28)^2}{8} = 133 \text{ ft-kip}$

Typical Beam to Girder Web Shear Connection

Connections between beams and girders will be single-plate connections with the beam top flange coped 2” deep by 4” long, use ¾” ASTM A325-N bolts in standard holes, 70-ksi electrode welds, and an ASTM A36 plate.



Column Design

In order to determine preliminary sizes for the steel columns and to later on double check the computer program output, an excel sheet was created to determine all column sizes. Tributary areas were determined for each column and multiple load combinations were considered. Sizes were chosen using the ASCE Steel Manual. The similar spreadsheet was also used for preliminary beam sizing.

LEVEL 2 COLUMNS														
Column #	Height (ft)	Trib Area (sf)		Loads (psf unless otherwise notes)										
				Dead (unfactored)						Live				
		2nd L. Roof	Floor	Roof	Floor	Façade Weight: Width (ft)	Façade Weight: Wt / 1ft	Façade Weight: Weight (lb)	Above col. self (lb)	Unred. Roof L	K_{LL}	Reduced Roof L	Unred. Floor L	Reduced Floor L
AA1	14	80	0	200	49	21	630	13230		100	4	100.00		0.00
AA2	14	80	0	200	49	21	630	13230		100	4	100.00		0.00
A1	14	216	0	200	49	29	630	18270		100	4	100.00		0.00

COLUMNS											
				Load Combos			Pu (kip)	Mu (ft-kip)	Peq	Column	
d. L	Reduced Floor L	Factored L (lbs)	Unfact. Snow (psf)	1.2D + 1.6L + 0.5S	1.2D + 1.6Lr + L	1.2D + 1.6L + 0.5Lr				Size	Weight (lb/ft)
	0.00	12800.00	22.7	48784.00	55876.00	51876.00	55.88	50.00	175.88	W10x33	33.00
	0.00	12800.00	22.7	48784.00	55876.00	51876.00	55.88	50.00	175.88	W10x33	33.00
	0.00	34560.00	22.7	110775.60	129924.00	119124.00	129.92	50.00	249.92	W10x33	33.00

Composite Metal Deck

Composite metal floor deck → Level 2

deck depth: 2"

gage: 20

topping thickness: 4.5"

weight of concrete: 145 pcf

self wt.: 1.97 psf

SDI Max unshored clear span = 10' 7" for 3 span

10' 7" > 10' ∴ ok

Superimposed live load for 10' clr span = 112 psf

112 > 55 ∴ ok

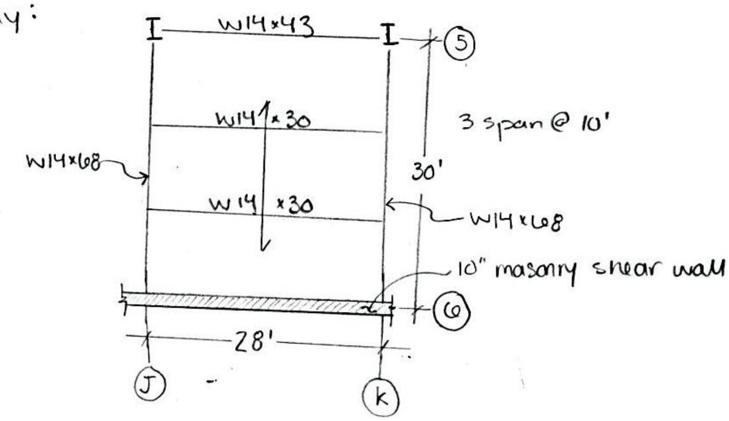
Typical classroom bay:

Floor Loading

L.L. = 40 psf

S.D.L. = 15 psf

total = 55 psf



Gravity System Summary

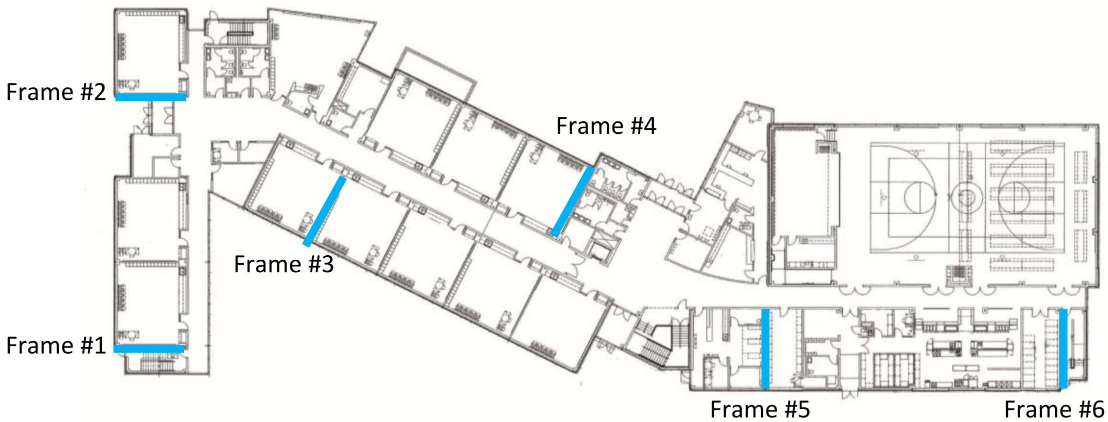
TOTAL STRUCTURE GRAVITY BEAM TAKEOFF			
Size	Quantity	Total Length	Weight
		(ft)	(lbs)
W8X10	82	931.09	9378
W8X24	2	24.54	591
W8X13	11	100.27	1310
W8X31	2	34.07	1057
W10X33	2	44.00	1454
W10X12	17	190.16	2291
W10X39	2	48.00	1878
W10X49	9	254.71	12481
W10X17	3	60.00	1019
W10X88	8	208.00	18331
W12X14	26	443.76	6282
W12X40	67	1842.00	73335
W12X16	5	100.26	1607
W12X45	3	78.00	3477
W12X53	1	30.00	1593
W12X19	16	360.29	6829
W12X58	5	154.00	8908
W12X120	8	80.00	9609
W12X136	1	32.00	4345
W14X22	31	724.35	15996
W14X43	40	1133.75	48609
W12X152	5	160.00	24337
W14X30	20	520.57	15677
W14X48	8	235.27	11288
W14X26	18	459.09	12013
W14X53	7	198.00	10511
W14X61	20	570.48	34748
W14X34	10	266.11	9055
W14X90	3	97.97	8834
W16X26	16	426.58	11148
W16X40	2	60.14	2415
W14X68	44	1246.79	84851
W16X67	2	60.00	4022
W21X48	2	20.00	960
		Total Weight =	460239

TOTAL STRUCTURE COLUMN TAKEOFF			
Size	Quantity	Total Length	Weight
		(ft)	(lbs)
W10X33	91	1332.5	44027
W10X39	12	288	11270
W10X45	1	24	1086
W10X49	4	96	4704
W12X53	1	12	637
W14X53	1	12	637
W14X61	5	72	4385
W12X65	1	24	1560
W12X79	1	24	1895
W14X82	6	144	11760
		Total Weight =	81961

Final beam and column sizes for the gravity system were taken from the RAM Structural System model. See Drawing S2 for beam framing layout and Drawing S3 for column layout.

Braced Frames

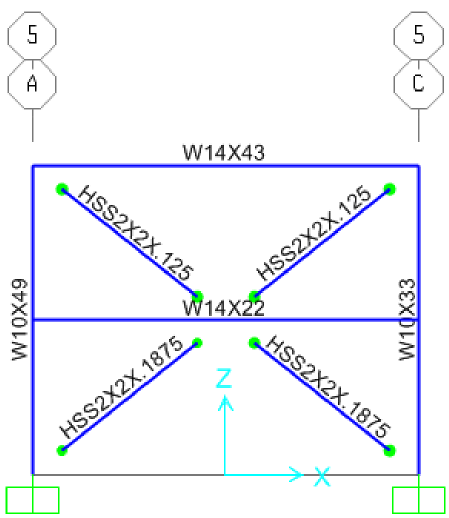
Throughout the elementary school six braced frames were used as part of the lateral system in the short direction in Buildings 1, 2, and 3. The following first floor plan shows the location of each frame. Braces were assumed to be tension only.



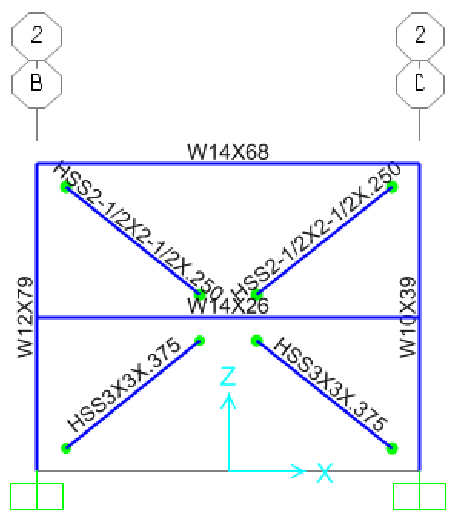
First floor plan showing location of each braced frame

Building 1 Details

Label	Force (k)	Frame Section	Tensile Capacity (k)
D1	35.84	HSS2x2x3/16	38.8
D2	34.69	HSS2x2x3/16	38.8
D3	19.26	HSS2x2x1/8	27.4
D4	20.23	HSS2x2x1/8	27.4
D5	81.15	HSS3x3x3/8	96.1
D6	81.41	HSS3x3x3/8	96.1
D7	42.19	HSS2.5x2.5x1/4	64.4
D8	42.45	HSS2.5x2.5x1/4	64.4



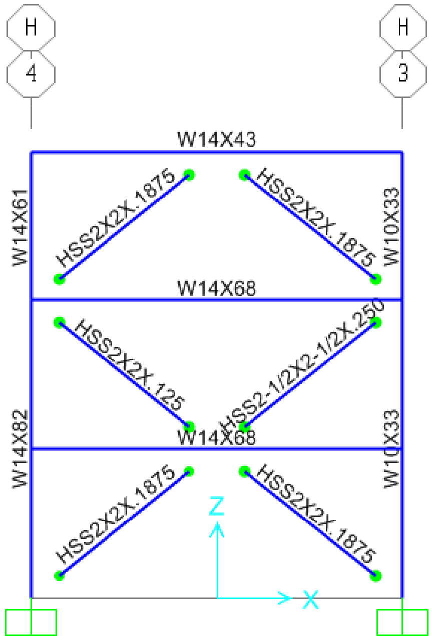
Frame #1 Building 1



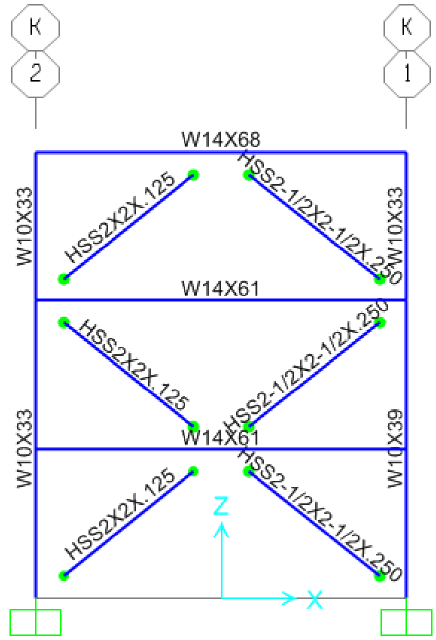
Frame #2 Building 1

Building 2 Details

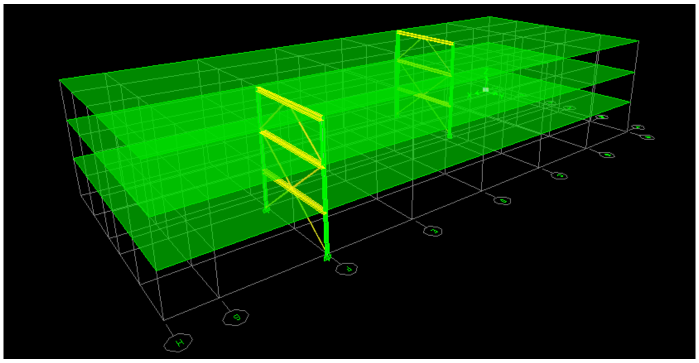
Label	Force (k)	Frame Section	Tensile Capacity (k)
D21	16.98	HSS2x2x1/8	27.4
D22	50.83	HSS2.5x2.5x1/4	64.4
D23	16.98	HSS2x2x1/8	27.4
D24	50.83	HSS2.5x2.5x1/4	64.4
D25	33.91	HSS2x2x3/16	38.8
D26	33.91	HSS2x2x3/16	38.8
D27	15.98	HSS2x2x1/8	27.4
D28	46.35	HSS2.5x2.5x1/4	64.4
D29	16.17	HSS2x2x1/8	27.4
D30	49.13	HSS2.5x2.5x1/4	64.4
D31	32.86	HSS2x2x3/16	38.8
D32	31.33	HSS2x2x3/16	38.8



Frame #3 Building 2



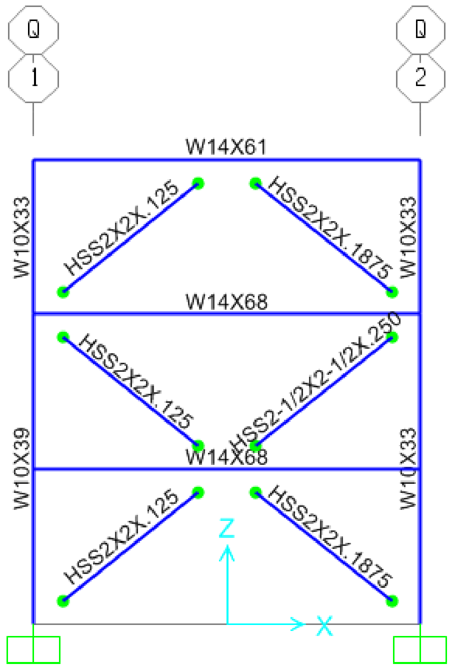
Frame #4 Building 2



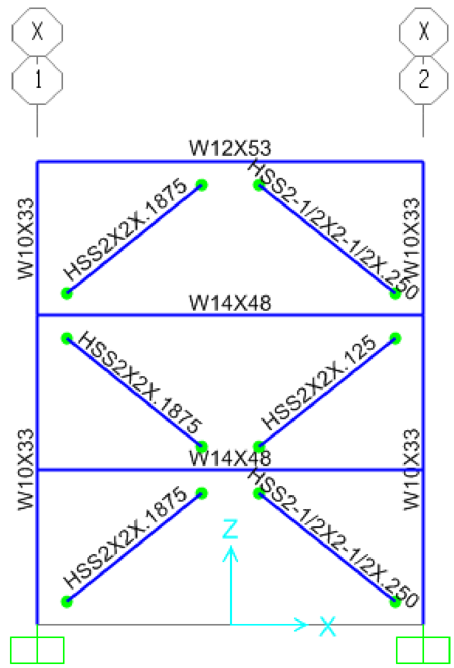
ETABS model of building 2 with masonry walls hidden to illustrate the braced frames

Building 3 Details

Label	Force (k)	Frame Section	Tensile Capacity (k)
D33	18.34	HSS2x2x1/8	27.4
D34	54.07	HSS2.5x2.5x1/4	64.4
D35	36.57	HSS2x2x3/16	38.8
D36	18.34	HSS2x2x1/8	27.4
D37	54.07	HSS2.5x2.5x1/4	64.4
D38	36.57	HSS2x2x3/16	38.8
D39	14.27	HSS2x2x1/8	27.4
D40	42.06	HSS2.5x2.5x1/4	64.4
D41	28.45	HSS2x2x3/16	38.8
D42	14.27	HSS2x2x1/8	27.4
D43	42.06	HSS2.5x2.5x1/4	64.4
D44	28.45	HSS2x2x3/16	38.8



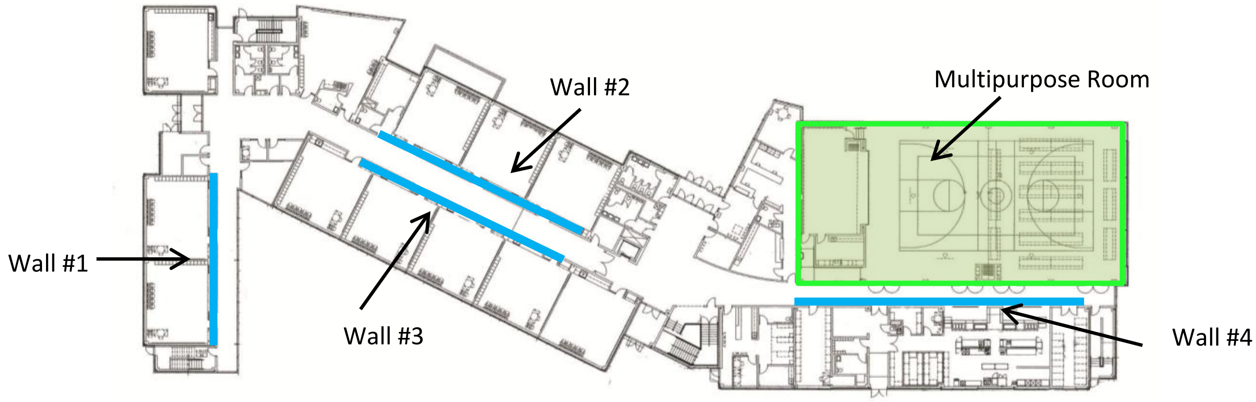
Frame #5 Building 3



Frame #6 Building 3

Masonry Shear Walls

Ten inch reinforced masonry shear walls were used as part of the lateral system in the long direction in Buildings 1, 2, and 3. The multipurpose room which acts as its own independent structure is also composed of load bearing reinforced masonry. The following first floor plan shows the location of each masonry wall in the elementary school. See Drawing S6 for masonry wall elevations and details.



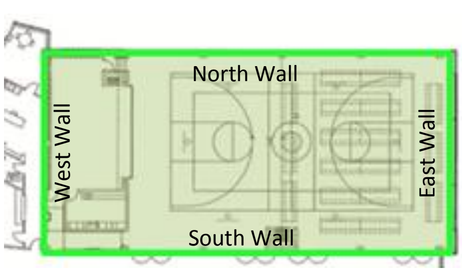
Reinforcement Requirements for Masonry Shear Walls		
Wall	**Bar #**	**Total Length (ft)**
1	8	72
	4	1190
	3	18
2	8	180
	4	404
	3	63
3	8	180
	4	404
	3	63
4	8	240
	4	516
	3	168

Multipurpose Room Masonry Wall Reinforcement

Location		Bar	Length (LF)
South Wall	Vertical	#3	459
	Openings	#5	98
North Wall	Vertical	#3	653
		#4	25.5
		#10	24
	Openings	#7	336

Multipurpose Room Masonry Wall Loads

Location		Type	Load	
North/South Walls	Vertical	Dead	450	plf
		Roof Live	600	plf
		Snow	680	plf
		Air Handler	2	kip
	Lateral In-Plane	Wind	396	plf
	Lateral Out-of-Plane	Wind	13.2	psf
East/West	Vertical	Dead	923	plf
		Roof Live	1230	plf
		Snow	1396	plf
	Lateral In-Plane	Wind	396	plf
	Lateral Out-of-Plane	Wind	13. 2	psf



Rammed Aggregate Piers

From Farrell Inc.:

-30” Diameter

-12’ Deep

-Medium Clay

-Capacity: 120kips

Our Building:

-Each spread footing will be supporting approximately 250kips.

F.S.=1.8

250x1.8=450kips

450k/120k= 3.75 – 4 Piers/ Spread Footing

50 Spread Footings x 4 =200 Piers

-Continuous Footings will need to support approximately 3k/ft.

872 feet on continuous footing

F.S.=1.8

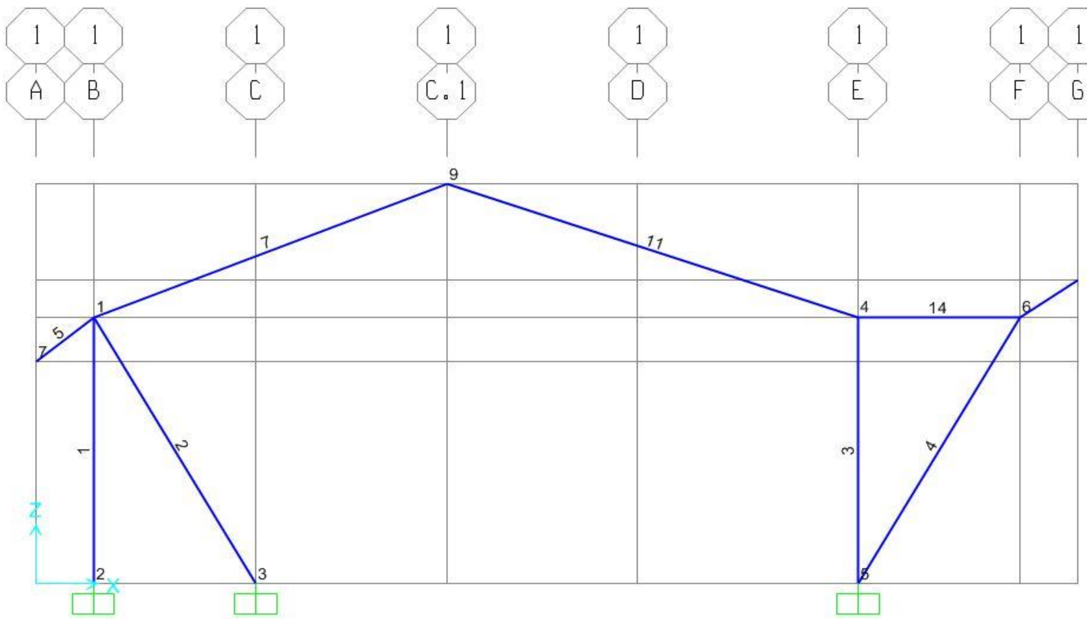
(3k/ft x 872 ft. x 1.8)/120= 40 Piers

200+40= 240

240 Piers

Natatorium

See Drawings S8 and S9 for plans and more details on the clinic and natatorium.



SAP2000 Model

TABLE: Element Forces - Frames				
Frame	Station	P	V2	M3
Text	in	Kip	Kip	Kip-in
1	0	-242.897	32.466	6168.041
1	144	-243.167	32.466	1492.92
1	288	-243.436	32.466	-3182.201
2	0	71.511	24.08	5321.473
2	166.709	71.241	24.238	1293.928
2	333.419	70.971	24.395	-2759.866
3	0	-242.822	-82.432	-10823.04
3	144	-243.092	-82.432	1047.152
3	288	-243.361	-82.432	12917.345
4	0	-22.676	-25.808	-7229.378
4	166.709	-22.406	-25.651	-2940.047
4	333.419	-22.137	-25.493	1323.037
5	0	4.547E-12	-1.54E-12	-3.64E-12
5	38.419	9.645	12.056	-231.593
5	76.837	19.29	24.112	-926.371

6	0	-2.91E-11	3.39E-12	-7.28E-12
6	38.419	9.645	12.056	-231.593
6	76.837	19.29	24.112	-926.371
7	0	-146.272	-116.948	-12415.89
7	196.655	-117.337	-43.405	3351.162
7	393.309	-88.402	30.138	4655.645
11	0	-87.002	-33.97	4655.645
11	224.84	-115.937	51.629	2670.376
11	449.68	-144.872	137.229	-18561.02
14	0	-10.867	-66.428	-7737.978
14	24	-10.867	-56.783	-6259.458
14	48	-10.867	-47.138	-5012.417
14	72	-10.867	-37.493	-3996.856
14	96	-10.867	-27.848	-3212.774
14	120	-10.867	-18.203	-2660.172
14	144	-10.867	-8.558	-2339.05
14	168	-10.867	1.087	-2249.407

Beams: W21x147

Purlins: W12x30

Columns: PIPE 10: t=0.465 in.

PIPE5: t=0.699in.

Appendix D **References**

1. United States Census Bureau (2013). *Reading (city) QuickFacts from the US Census Bureau*. Fall 2012. Web. <http://quickfacts.census.gov/qfd/states/42/4263624.html>.
2. U.S. Congress (2007). *Energy and Independence Security Act*. Fall 2012. Web. <http://en.wikisource.org/wiki/Energy_Independence_and_Security_Act_of_2007>.
3. Leadership in Energy and Environmental Design (2008). LEED 2009 For Schools New Construction and Major Renovations. Fall 2012. Web. <http://www.usgbc.org/ShowFile.aspx?DocumentID=5547>.
4. Farrell Design-Build Companies, Inc. (2012). *Rammed Aggregate Pier System.* Fall 2012. Web. <http://www.farrellinc.com/media/impact_pier_2012.pdf>.
5. Voros, Chris. (2007). *Intermediate, Geopier-reinforced Mat Slab versus Deep Micropile Foundation System.* Fall 2102. Web. < http://www.engr.psu.edu/ae/thesis/portfolios/2007/CAV138/>.
6. United States Department of Labor (2012). *Occupancy Safety and Health Administration: Construction*. Fall 2012. Web. <http://www.osha.gov/about.html>.
7. Nucor Vulcraft Group. (2008). *Vulcraft Deck Catalog.* Fall 2012. Web. <http://www.vulcraft.com/products/catalogs/>.

Software Used

Revit 2013

- Used to model all structural elements
- Collaborate with architecture, mechanical systems, lighting, and electrical systems

RAM Structural System

- Used to design beams and columns and compare output to hand calculations
- Used to design concrete retaining walls and compare output to hand calculations

RAM Element

- Used to design masonry shear wall reinforcement and compare output to hand calculations

ETABS

- Used to design braced frame elements and compare output to hand calculations
- Used to determine story drifts

Other Resources

AISC – "Manual of Steel Construction" *14th Edition*

Fisher, James M. S.E. (2005). The Steel Conference. *Expansion Joints: Where, When and How*. North American Steel Construction Conference.

Geopier Foundation Company (2012). *Geopier Rampact System.* Fall 2012. Web. <http://www.geopier.com/Geopier-Systems/Rammed-Aggregate-Pier-System/Rampact-System>.

Building Green, Inc. (2013). *Geopier Rammed Aggregate Pier System*. Fall 2012. Web. <http://www.buildinggreen.com/auth/productDetail.cfm?PRODUCTID=4847>.

GENERAL NOTES

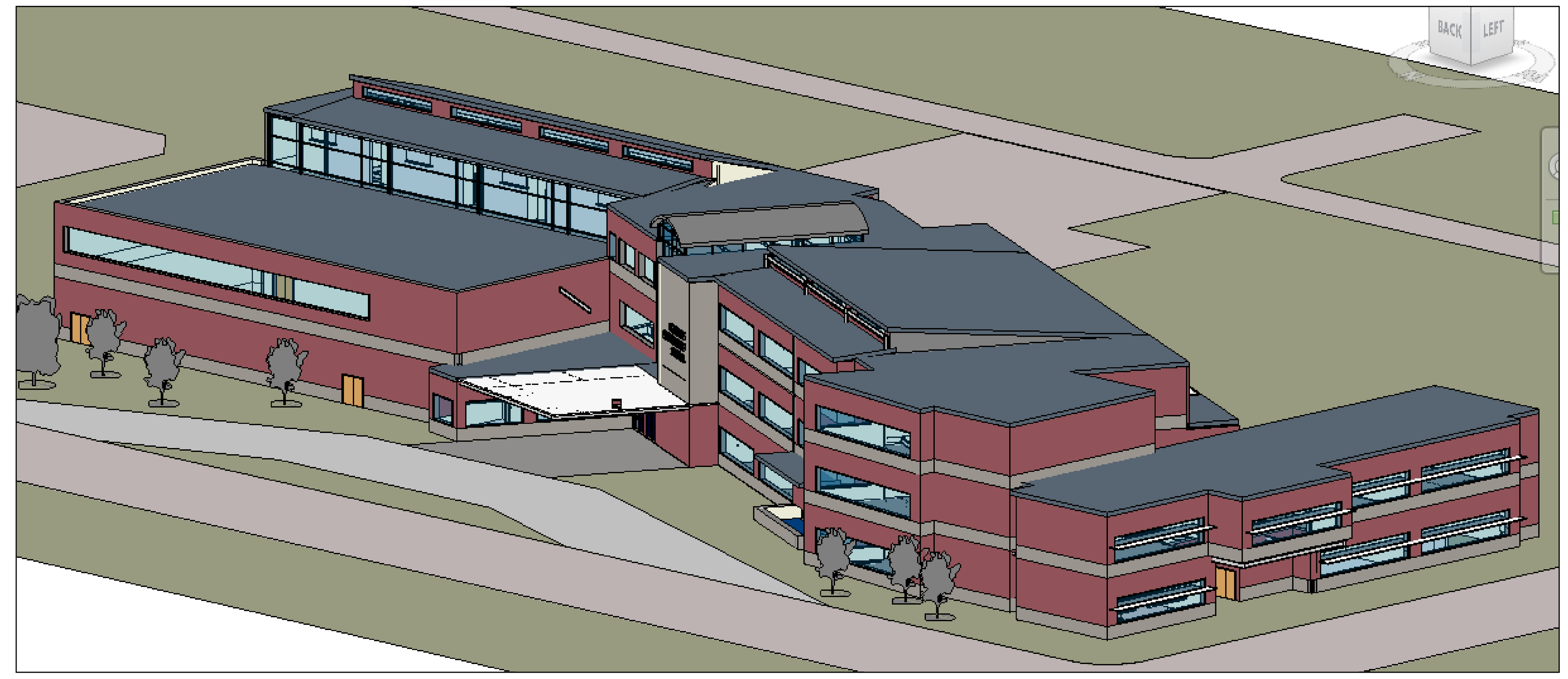
1. CONCRETE WORK WILL ADHERE TO LATEST EDITION OF ACI 318 REQUIREMENTS.
2. CAST IN PLACE CONCRETE SHALL DEVELOP A STRENGTH OF 3,000 PSI FOR SLAB ON GRADE, CONCRETE DECK AND 4,000 PSI FOR PILE CAPS, GRADE BEAMS, RETAINING WALLS, FOOTINGS.
3. SEE DRAWINGS IN INTEGRATION SUBMITTAL FOR ARCHITECTURAL PLANS.

FOUNDATION NOTES

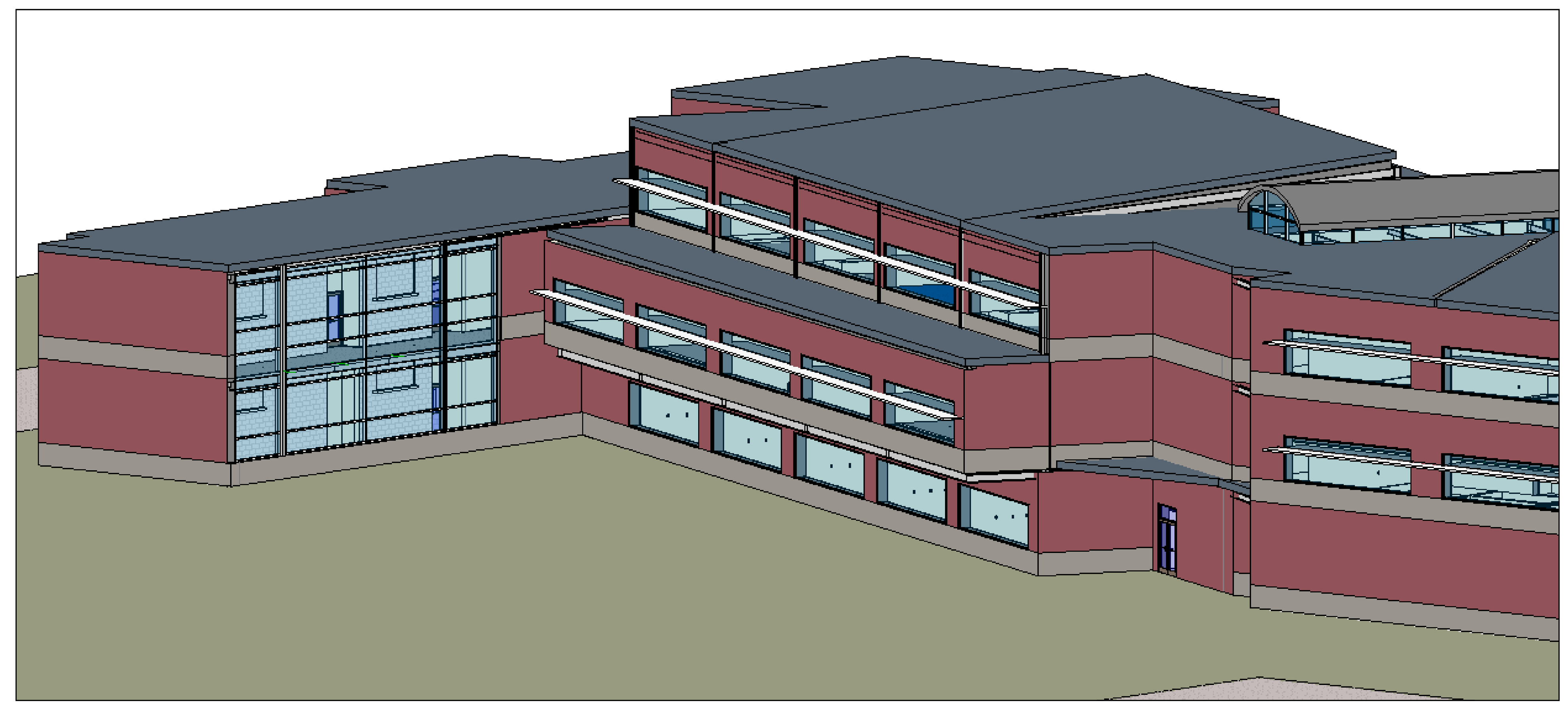
1. BACKFILL IN EXCAVATED AREAS WILL BE PLACED IN 6" LAYERS TO REQUIRED COMPACTION.
2. MATERIAL USED IN RAMMED AGGREGATE PIERS WILL BE PLACES IN 12" LIFTS AND COMPACTED WITH HYDRAULIC HAMMER.
3. 5" SLAB ON GRADE.
4. SEE APPENDIX C IN SUPPORTING DOCUMENTATION FOR FOUNDATION CALCULATIONS.

N

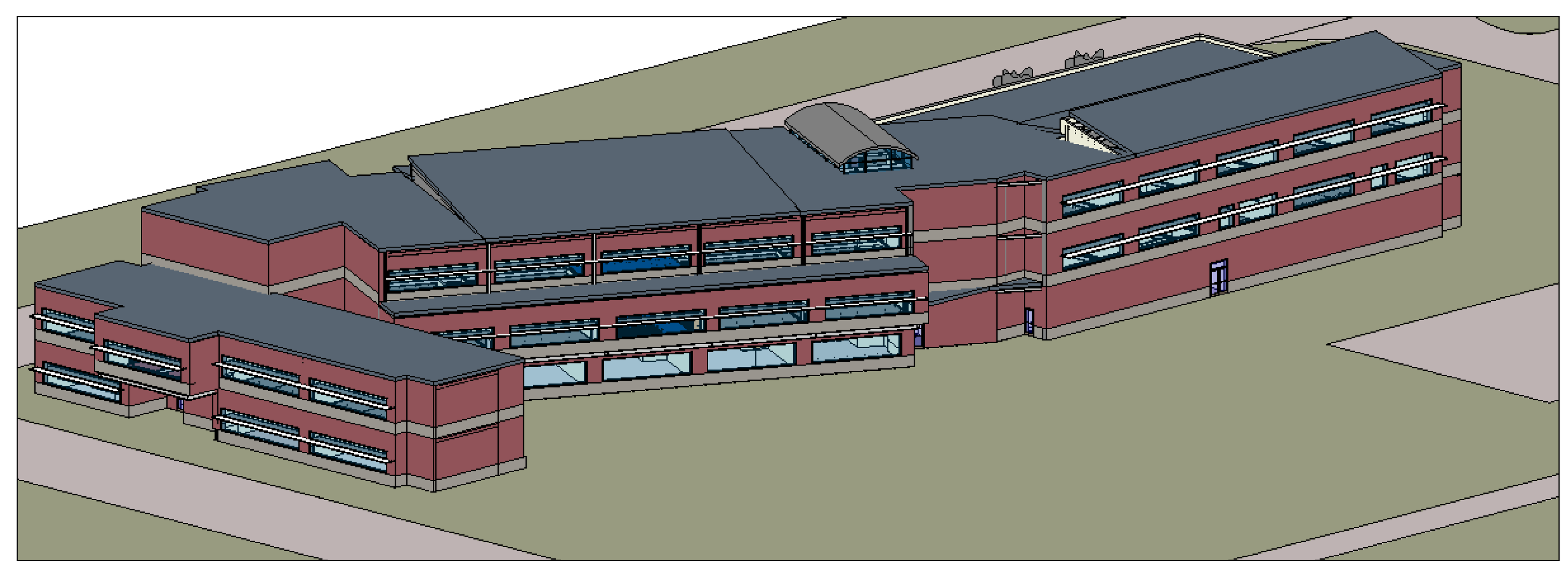
SITE PLAN



3D VIEW OF ELEMENTARY SCHOOL



3D VIEW OF ELEMENTARY SCHOOL



3D VIEW OF ELEMENTARY SCHOOL

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#04-2013

Project

Reading Elementary School

Reading, Pennsylvania

Sheet Title

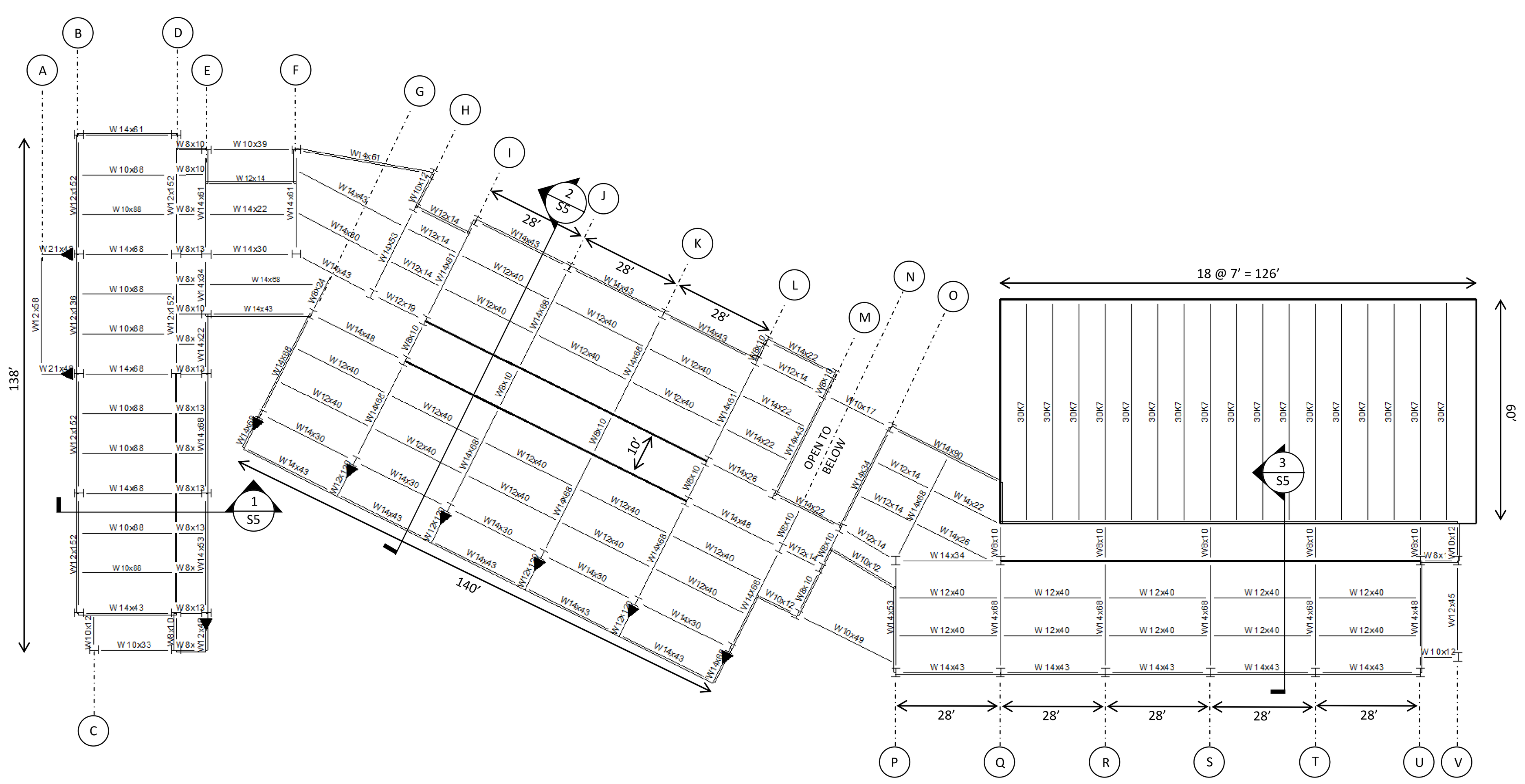
Site

S1

LEVEL 1 BEAM LAYOUT

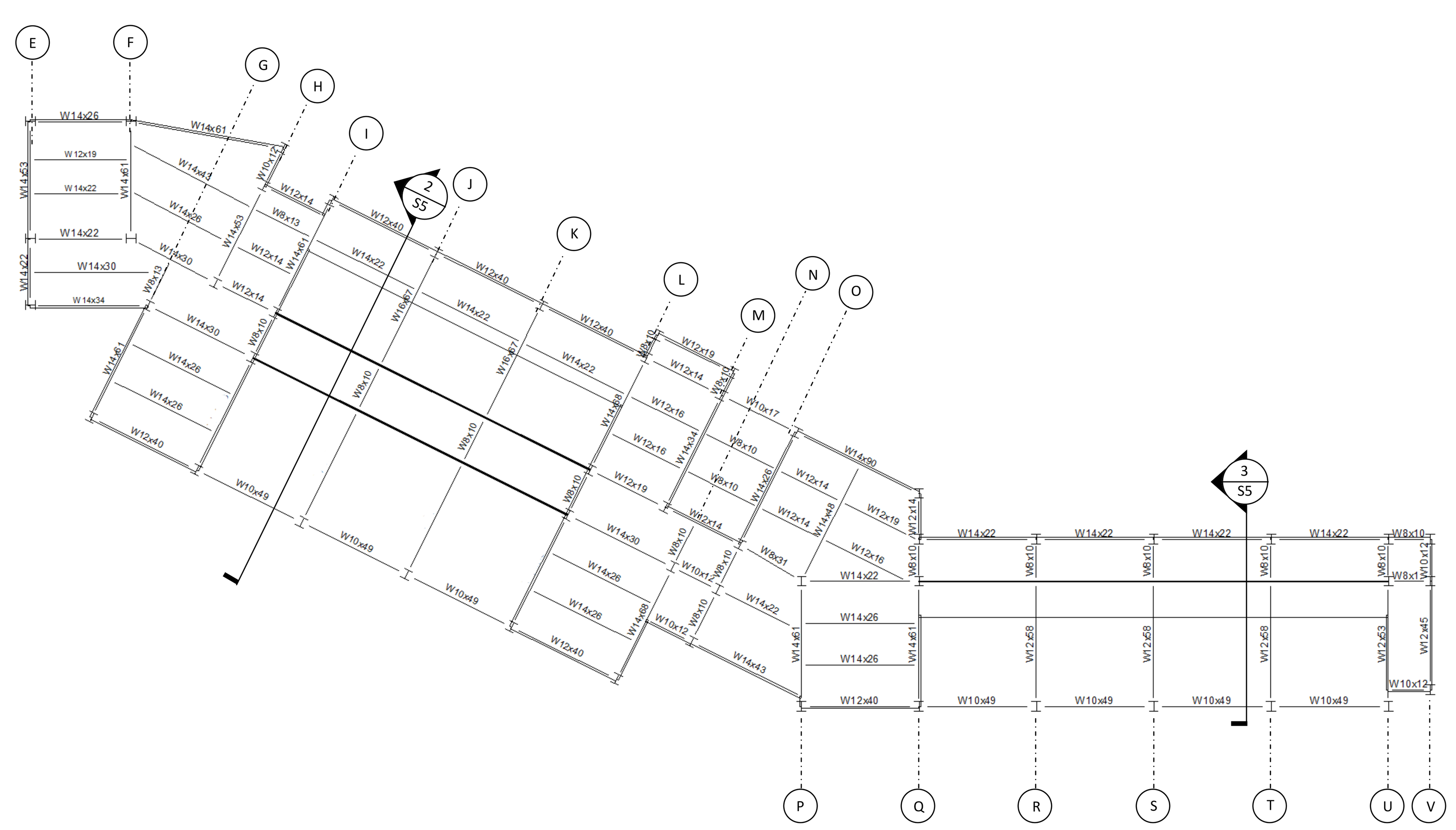
GENERAL FRAMING NOTES

1. ALL WIDE FLANGES ASTM A992 GRADE 50 STEEL.
2. 5. SEE APPENDIX B IN SUPPORTING DOCUMENTATION FOR DEAD AND LIVE LOADS USED IN DESIGN.
3. SEE APPENDIX B IN SUPPORTING DOCUMENTATION FOR WIND, SNOW, AND SEISMIC LOAD ANALYSIS.
4. ALL BOLTS 3/4" A325



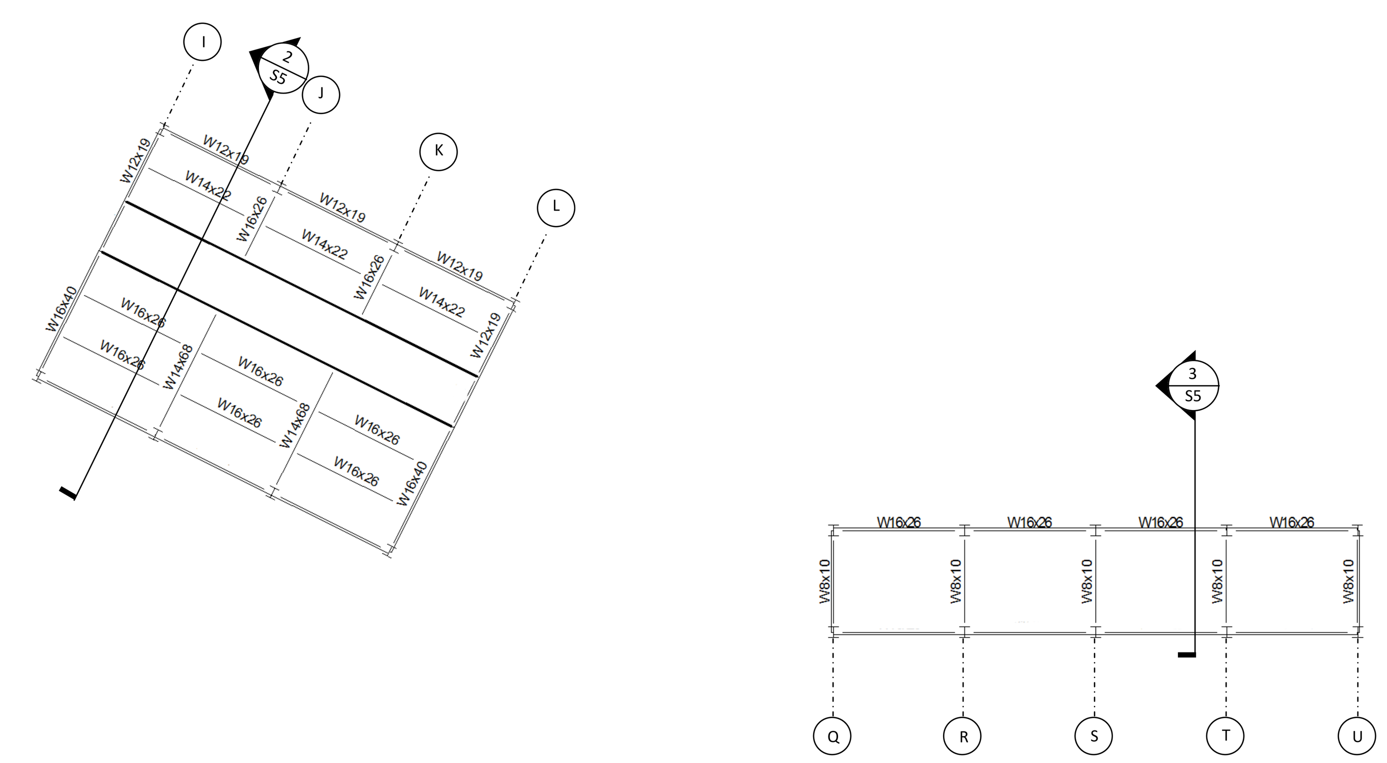
LEVEL 2 BEAM LAYOUT

NOTE: SOME GRID LINES ELIMINATED FOR CLARITY



ROOF BEAM LAYOUT

NOTE: SOME GRID LINES ELIMINATED FOR CLARITY



CLERESTORY BEAM LAYOUT

NOTE: SOME GRID LINES ELIMINATED FOR CLARITY

0 10' 20' 40'

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#04-2013

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Reading Elementary School

Reading, Pennsylvania

Sheet Title

Framing Plans

S2

COLUMN SCHEDULE

"BUILDING" 1

COLUMN NUMBER	B 2	B 3	B 4	B 6	B 8	C 1	D 1	D 2	D 4	D 6	D 8	E 2	E 3	E 4	E 5	E 6	E 7	F 6	F 7
CLERESTORY																			
THIRD FLOOR																			
SECOND FLOOR / FIRST FLOOR	W10X49	W10X39	W14X82	W14X82	W10X49	W10X33	W10X33	W10X33	W10X49	W10X39	W10X49	W12X79	W10X33	W10X33	W10X33	W10X33	W10X33	W10X33	W10X45
ANCHOR BOLT SIZE	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"
BASE PLATE (INCHES x INCHES)	12X12	12X10	16.5X12.25	16.5X12.25	12X12	11.75X10	11.75X10	11.75X10	12X12	12X10	12X12	14.5X14.25	11.75X10	11.75X10	11.75X10	11.75X10	11.75X10	11.75X10	12.25X10.25
COLUMN NUMBER	B 2	B 3	B 4	B 6	B 8	C 1	D 1	D 2	D 4	D 6	D 8	E 2	E 3	E 4	E 5	E 6	E 7	F 6	F 7

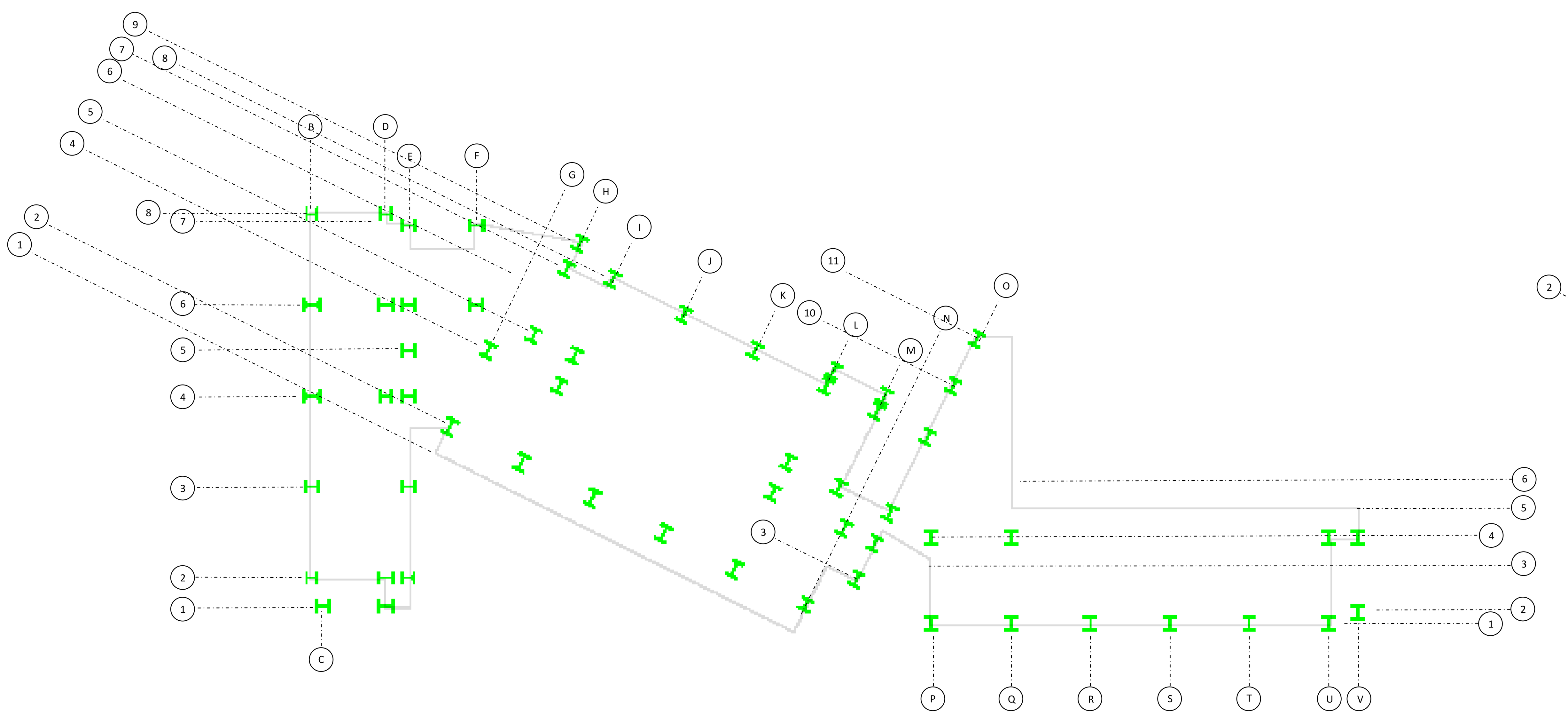
"BUILDING" 2

COLUMN NUMBER	G 2	G 4	H 5	H 7	H 9	I 2	I 4	I 5	I 6	I 8	J 2	J 6	J 8	K 2	K 6	K 8
CLERESTORY									W10X33			W10X33			W10X33	
THIRD FLOOR	W14X53	W10X33	W10X33	W10X33	W10X33	W14X61	W10X33	W10X33		W10X33	W14X61		W10X33	W14X61		W10X33
SECOND FLOOR / FIRST FLOOR	W14X61	W10X39	W10X33	W10X33	W10X33	W14X82	W10X33	W10X33		W10X39	W14X82		W10X39	W14X82		W10X39
ANCHOR BOLT SIZE	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"		3/4"	3/4"		3/4"	3/4"		3/4"
BASE PLATE (INCHES x INCHES)	16X12	12X10	11.75X10	11.75X10	11.75X10	16.5X12.25	11.75X10	11.75X10		12X10	16.5X12.25		12X10	16.5X12.25		12X10
COLUMN NUMBER	G 2	G 4	H 5	H 7	H 9	I 2	I 4	I 5	I 6	I 8	J 2	J 6	J 8	K 2	K 6	K 8

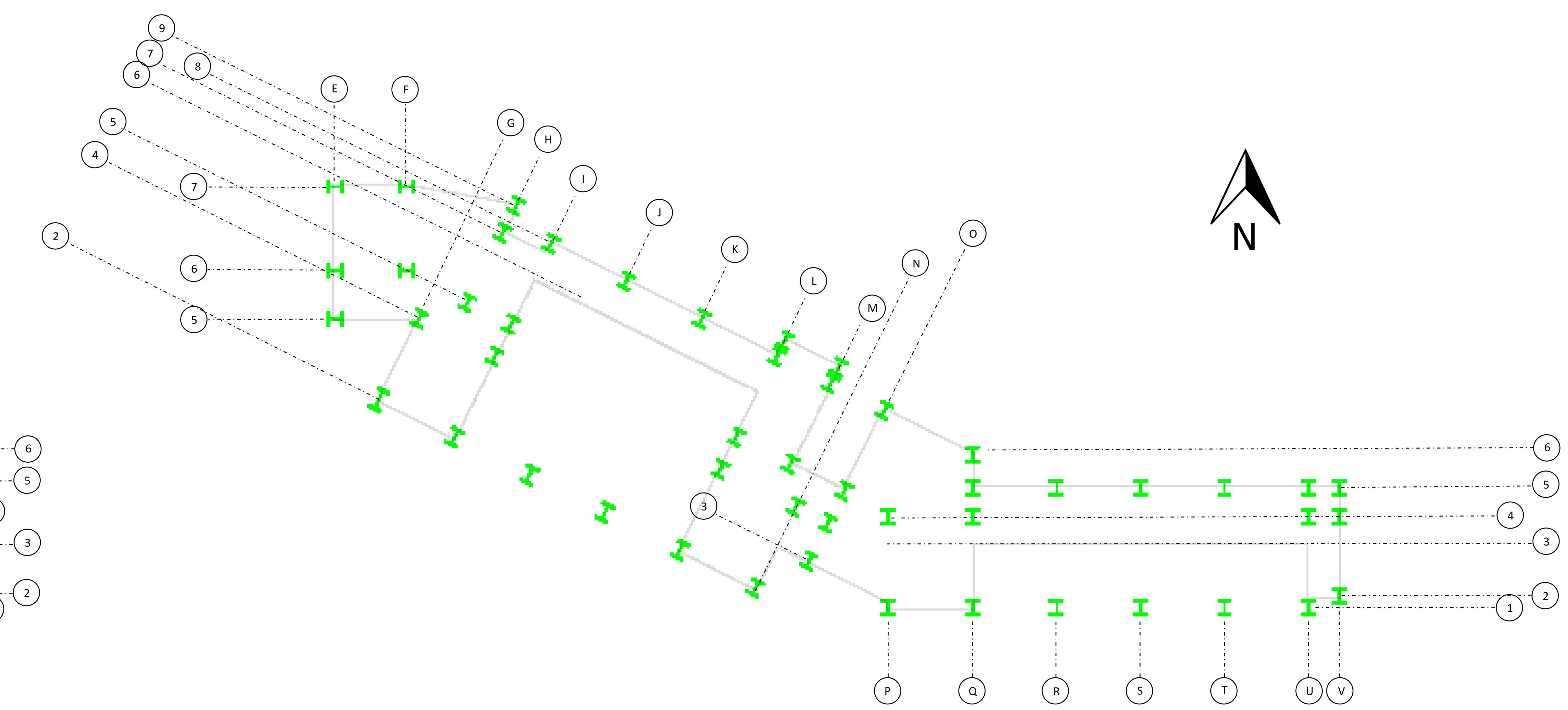
COLUMN NUMBER	L 2	L 4	L 5	L 6	L 8	L 9	M 5	M 8	M 9	N 2	N 4	O 3	O 4	O 5	O 8	O 10	O 11
CLERESTORY				W10X33													
THIRD FLOOR	W14X61	W10X33	W10X33		W10X33	W10X33	W10X33	W10X33	W10X33	W12X53	W10X33	W10X33	W10X33	W10X33	W10X33	W10X33	W10X33
SECOND FLOOR / FIRST FLOOR	W14X82	W10X33	W10X33		W10X39	W10X33	W10X33	W10X33	W10X33	W12X65	W10X33	W10X33	W10X33	W10X33	W10X33	W10X33	W10X33
ANCHOR BOLT SIZE	3/4"	3/4"	3/4"		3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"	3/4"
BASE PLATE (INCHES x INCHES)	16.5X12.25	11.75X10	11.75X10		12X10	11.75X10	11.75X10	11.75X10	11.75X10	14.25X14	11.75X10	11.75X10	11.75X10	11.75X10	11.75X10	11.75X10	11.75X10
COLUMN NUMBER	L 2	L 4	L 5	L 6	L 8	L 9	M 5	M 8	M 9	N 2	N 4	O 3	O 4	O 5	O 8	O 10	O 11

"BUILDING" 3

COLUMN NUMBER	P 1	P 4	Q 1	Q 3	Q 4	Q 5	Q 6	R 1	R 3	R 5	S 1	S 3	S 5	T 1	T 3	T 5	U 1	U 3	U 4	U 5	V 2	V 4	V 5
CLERESTORY				W10X33					W10X33			W10X33			W10X33			W10X33					
THIRD FLOOR	W10X33	W10X33	W10X33		W10X33	W10X33	W10X33	W10X33		W10X33	W10X33		W10X33	W10X33		W10X33	W10X33		W10X33	W10X33	W10X33	W10X33	W10X33
SECOND FLOOR / FIRST FLOOR	W10X39	W10X33	W10X39		W10X33			W10X39			W10X39			W10X39			W10X33		W10X33		W10X33	W10X33	
ANCHOR BOLT SIZE	3/4"	3/4"	3/4"	3/4"	3/4"			3/4"			3/4"			3/4"			3/4"		3/4"		3/4"	3/4"	
BASE PLATE (INCHES x INCHES)	12X10	11.75X10	12X10	11.75X10	11.75X10			12X10			12X10			12X10			11.75X10		11.75X10		11.75X10	11.75X10	
COLUMN NUMBER	P 1	P 4	Q 1	Q 3	Q 4	Q 5	Q 6	R 1	R 3	R 5	S 1	S 3	S 5	T 1	T 3	T 5	U 1	U 3	U 4	U 5	V 2	V 4	V 5



FIRST AND SECOND FLOOR COLUMN LOCATIONS



THIRD FLOOR COLUMN LOCATIONS

N

COLUMN SCHEDULE NOTES

1. ALL COLUMNS SPLICED AT THIRD FLOOR.
2. ALL BASE PLATES HAVE 4-HOLE ANCHOR BOLT ARRANGEMENT.
3. CAP PLATES PLACED AT LOCATIONS WHERE COLUMN ENDS AT THE TOP OF CONNECTION.
4. BASE PLATE THICKNESSES RANGE FROM 0.5" TO 1.125".

AEI Team

#04-2013

Project

Reading Elementary School

Reading, Pennsylvania

Sheet Title

Column Layout and Schedule

S3

NORTH ELEVATION OF ELEMENTARY SCHOOL

SOUTH ELEVATION OF ELEMENTARY SCHOOL

EAST ELEVATION OF ELEMENTARY SCHOOL

WEST ELEVATION OF ELEMENTARY SCHOOL

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#04-2013

Project

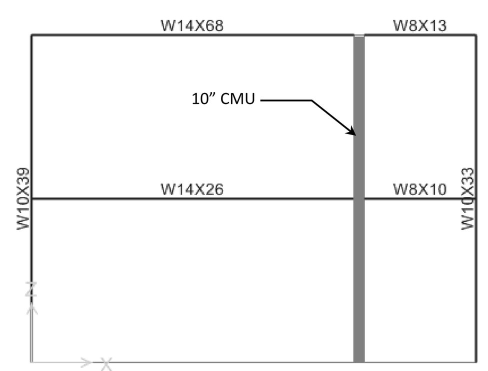
Reading Elementary School

Reading, Pennsylvania

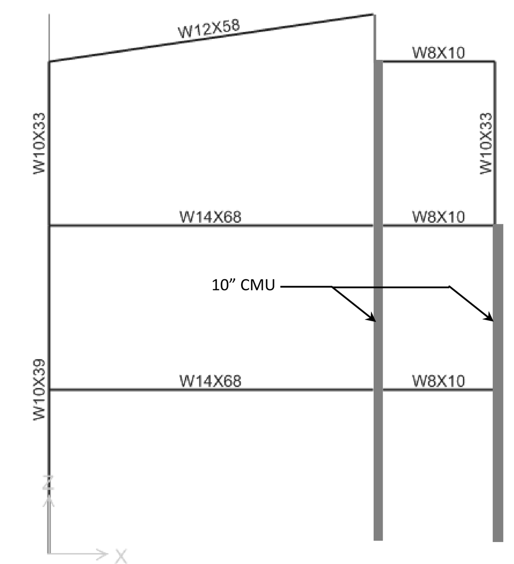
Sheet Title

Elevations

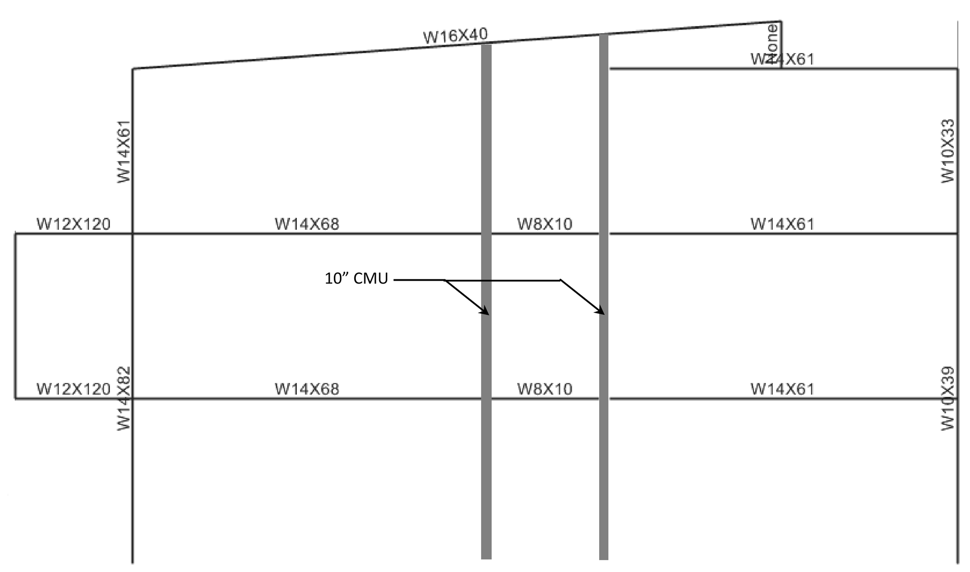
S4



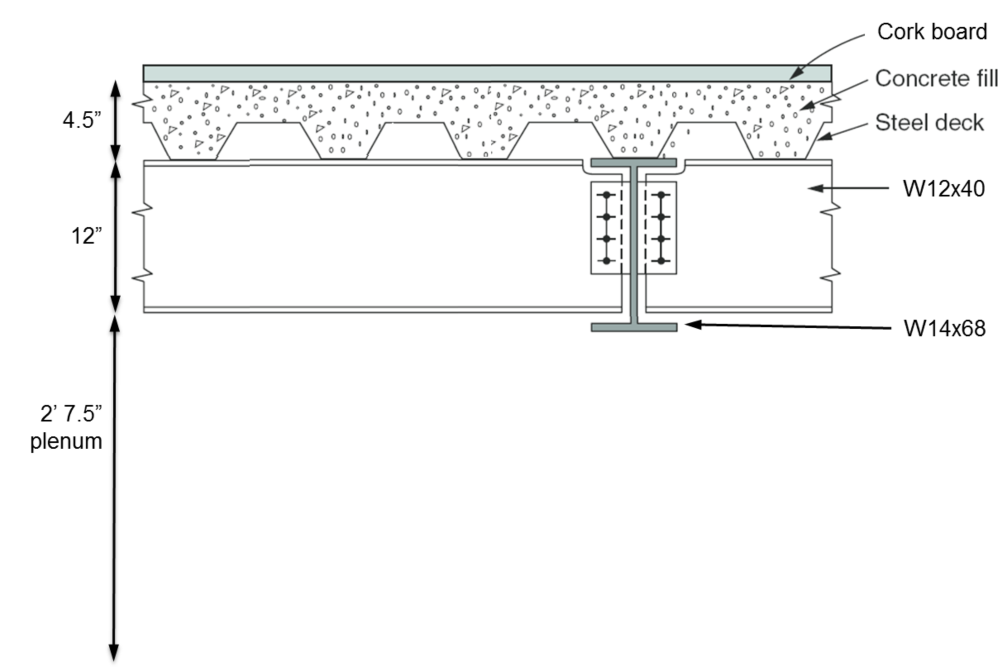
1
S7
TYPICAL FRAME IN WEST WING OF BUILDING



3
S7
TYPICAL FRAME IN EAST WING OF BUILDING



2
S7
TYPICAL FRAME IN CENTRAL WING OF BUILDING



4
S7
TYPICAL FRAME IN EAST WING OF BUILDING

0 5' 10' 20'

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#04-2013

Project

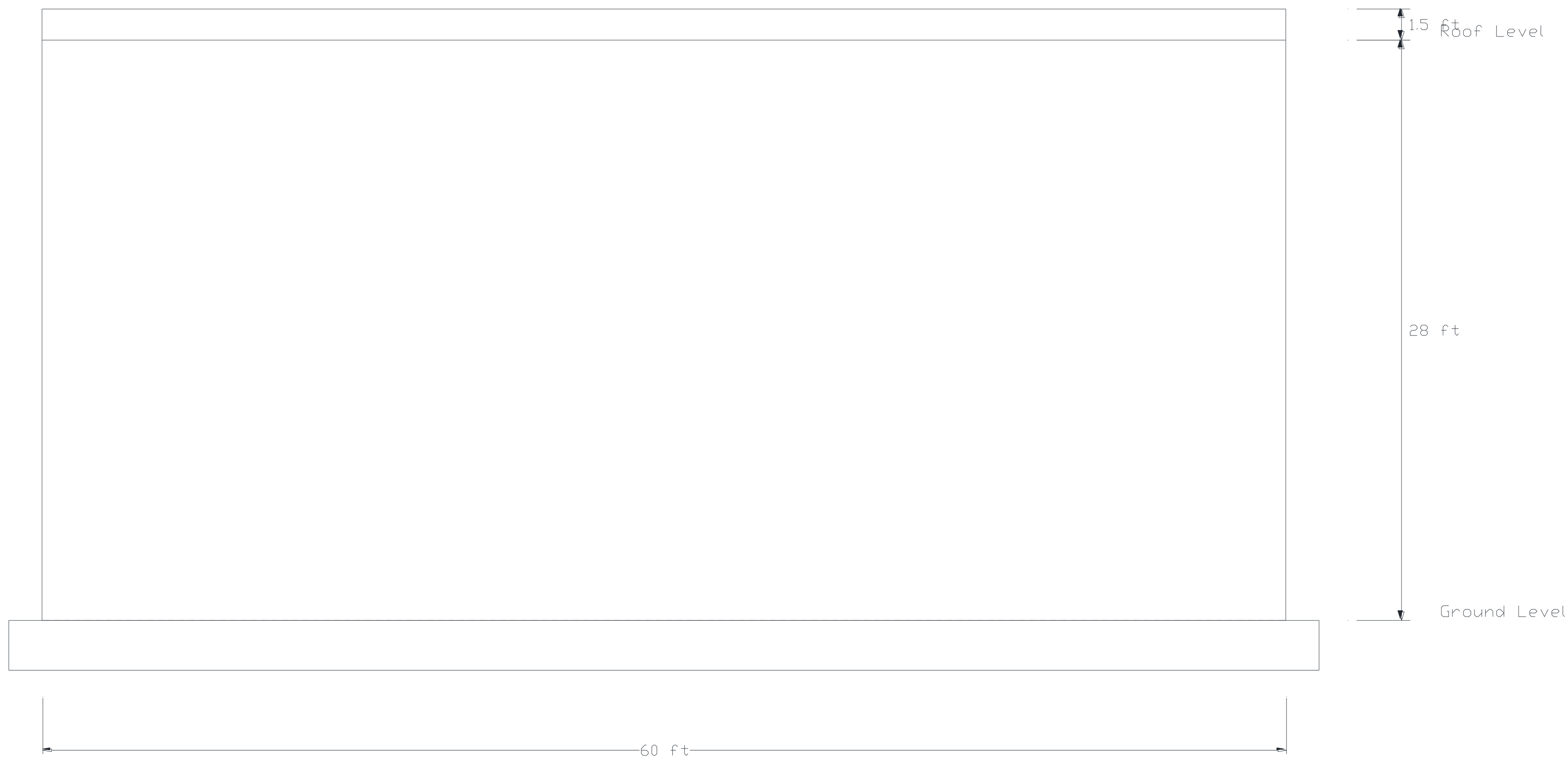
Reading Elementary School

Reading, Pennsylvania

Sheet Title

Sections

S5



EAST AND WEST REINFORCED MASONRY WALL ELEVATION

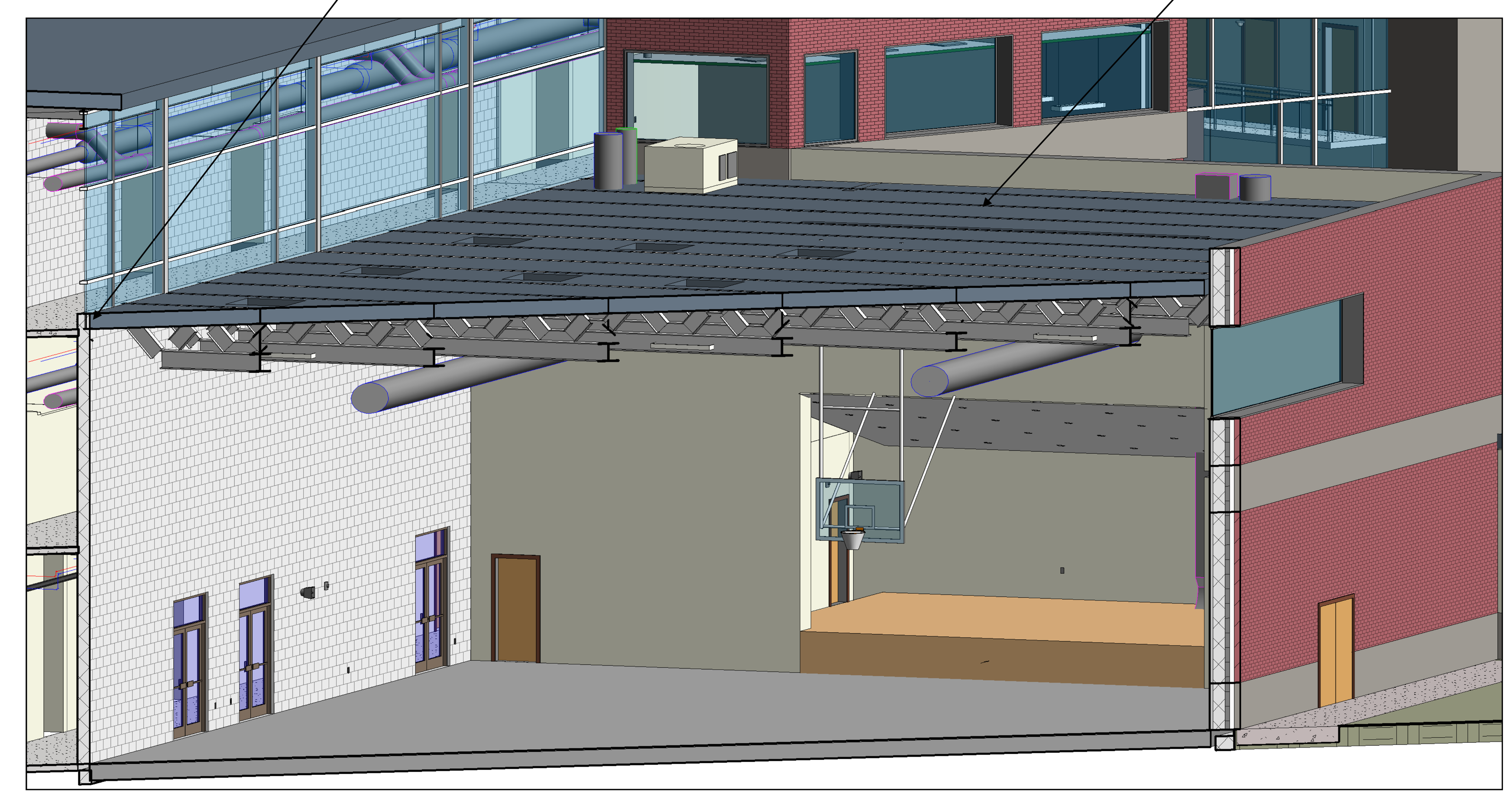
NOTE: BOTH WALLS ARE IDENTICAL AND HAVE THE SAME REINFORCEMENT

MASONRY NOTES

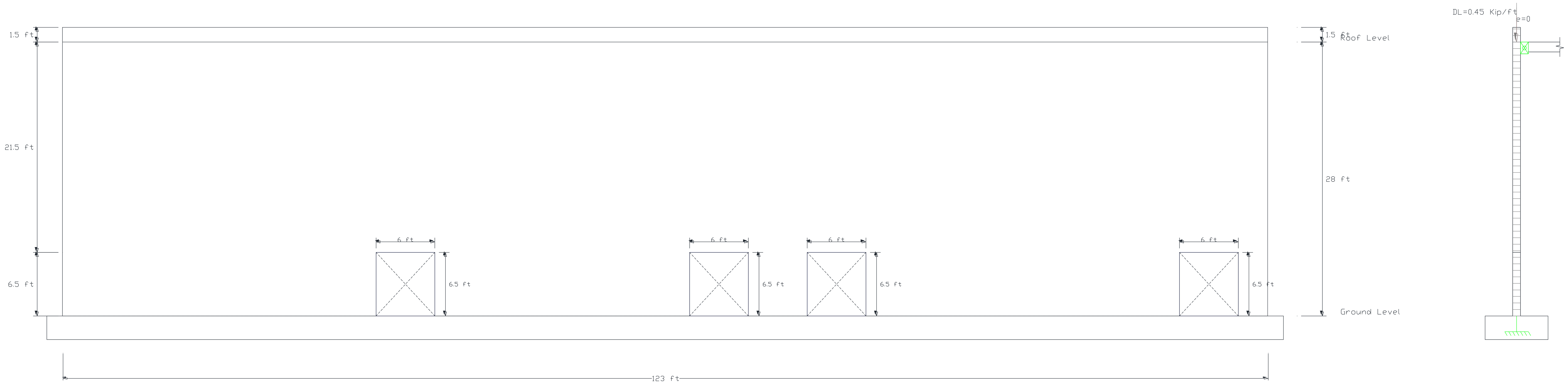
1. MINIMUM f'm WILL BE 1,500 PSI.
2. GROUT WILL HAVE A MINIMUM COMPRESSIVE STRENGTH OF 2,500 PSI, AND ALL MASONRY WALLS WILL BE FULLY GROUTED.
3. TYPE M/S MORTAR WILL BE USED.
4. ALL CMU'S WILL BE LAID IN A RUNNING BOND PATTERN AND FULLY GROUTED.
5. GRADE 60 REINFORCING STEEL WILL BE USED IN ALL MASONRY WALLS

K-SERIES JOISTS FABRICATED WITH OVERSIZED SLOTS IN TOP CHORD ANCHORED TO STEEL BEARING PLATE

INSULATED ROOF PREVENTS JOIST MOVEMENT DUE TO TEMPERATURE CHANGES

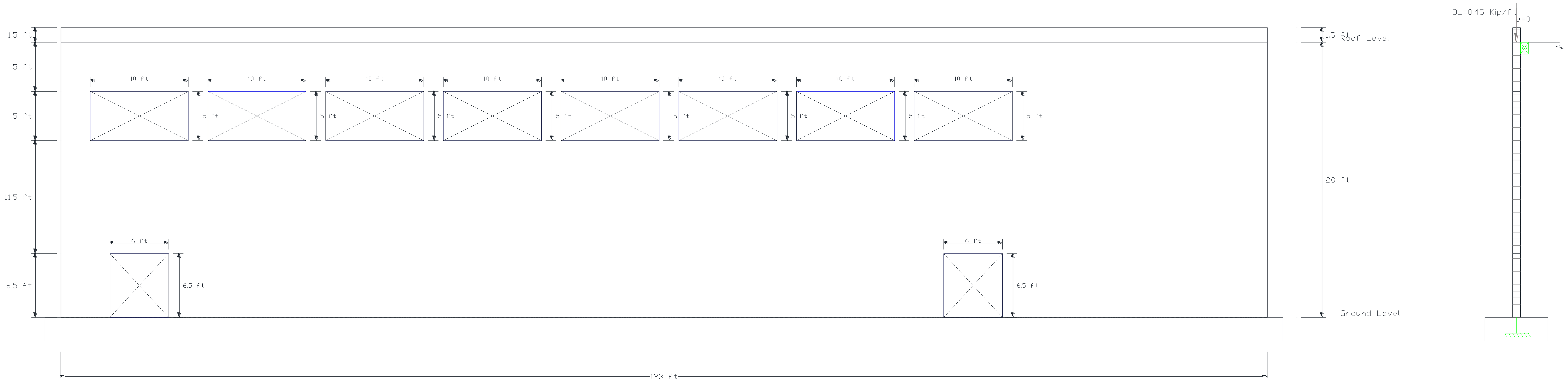


ISOMETRIC SECTION OF MULTIPURPOSE SPACE



SOUTH REINFORCED MASONRY WALL ELEVATION

PROVIDE STEEL JOIST AND BEAM BEARING PLATES AS REQUIRED



NORTH REINFORCED MASONRY WALL ELEVATION

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Multipurpose Space

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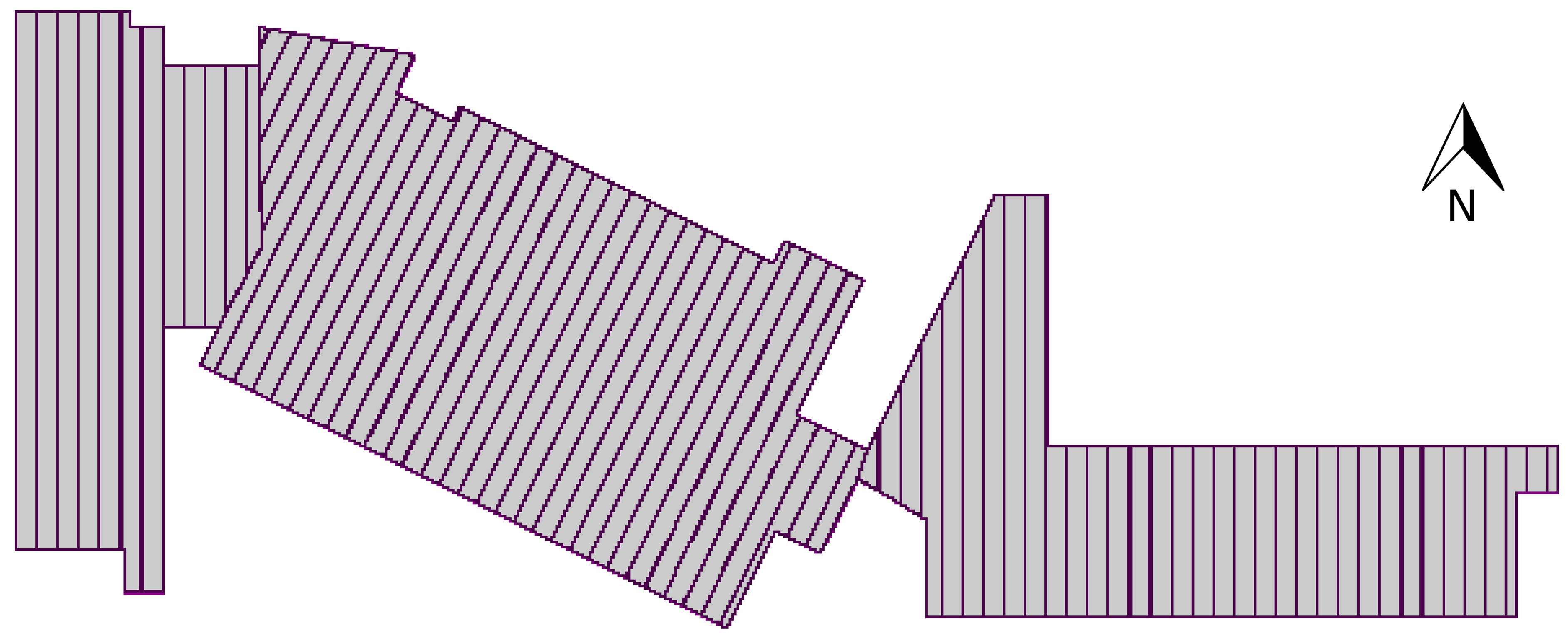
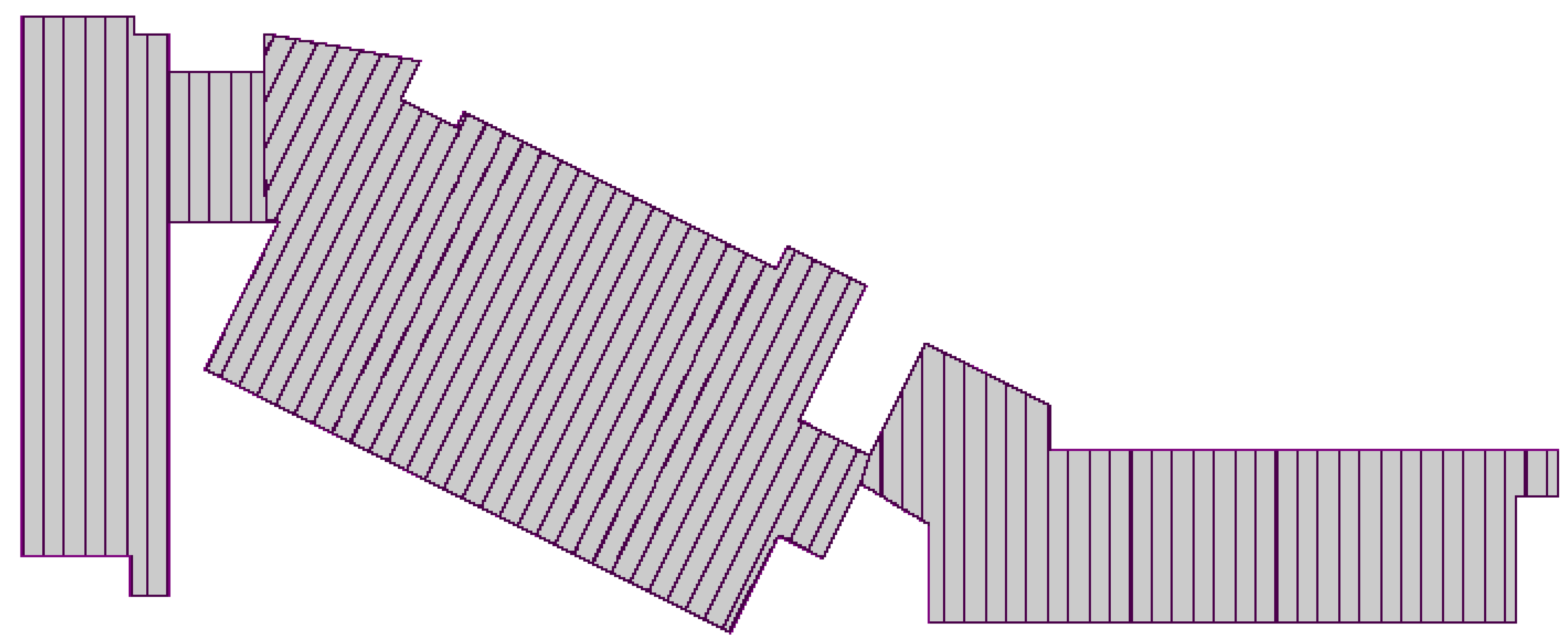
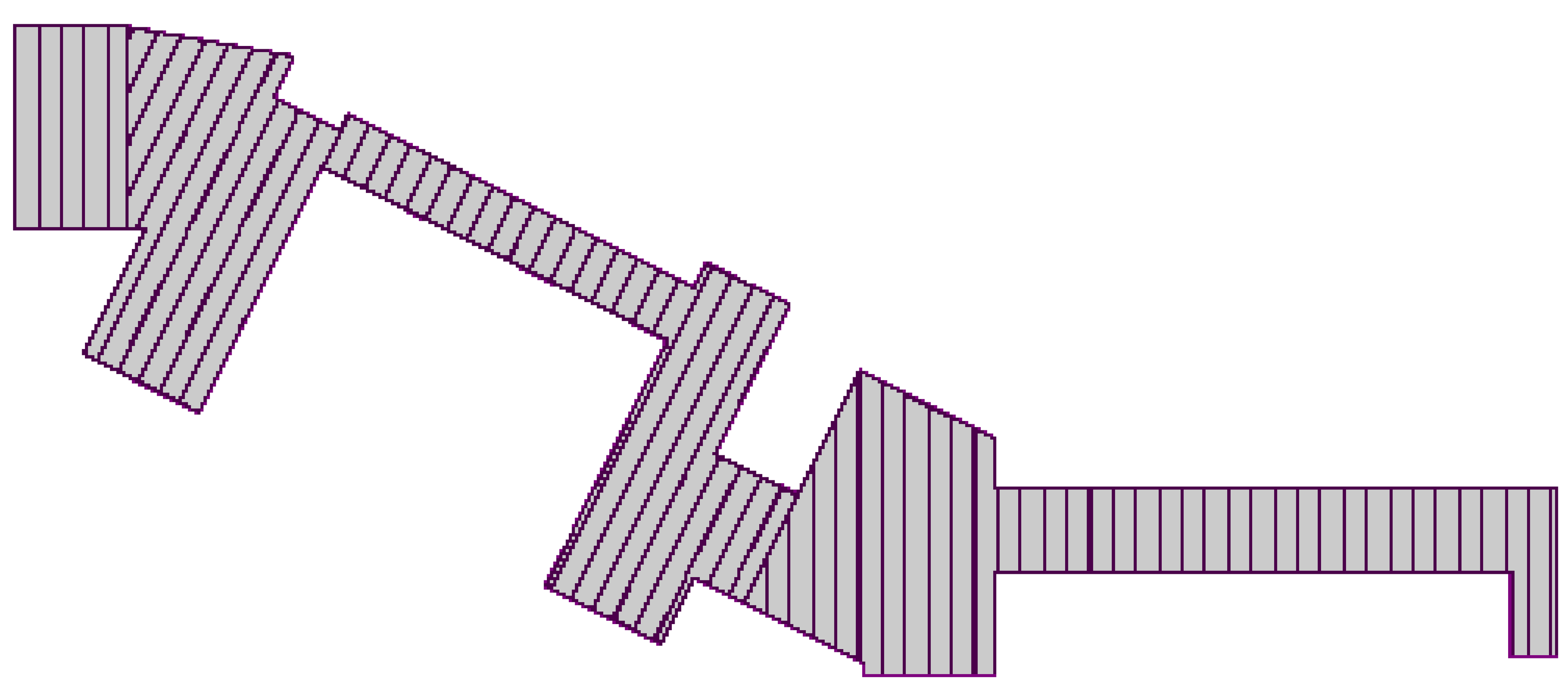


LEVEL 1 DECKING

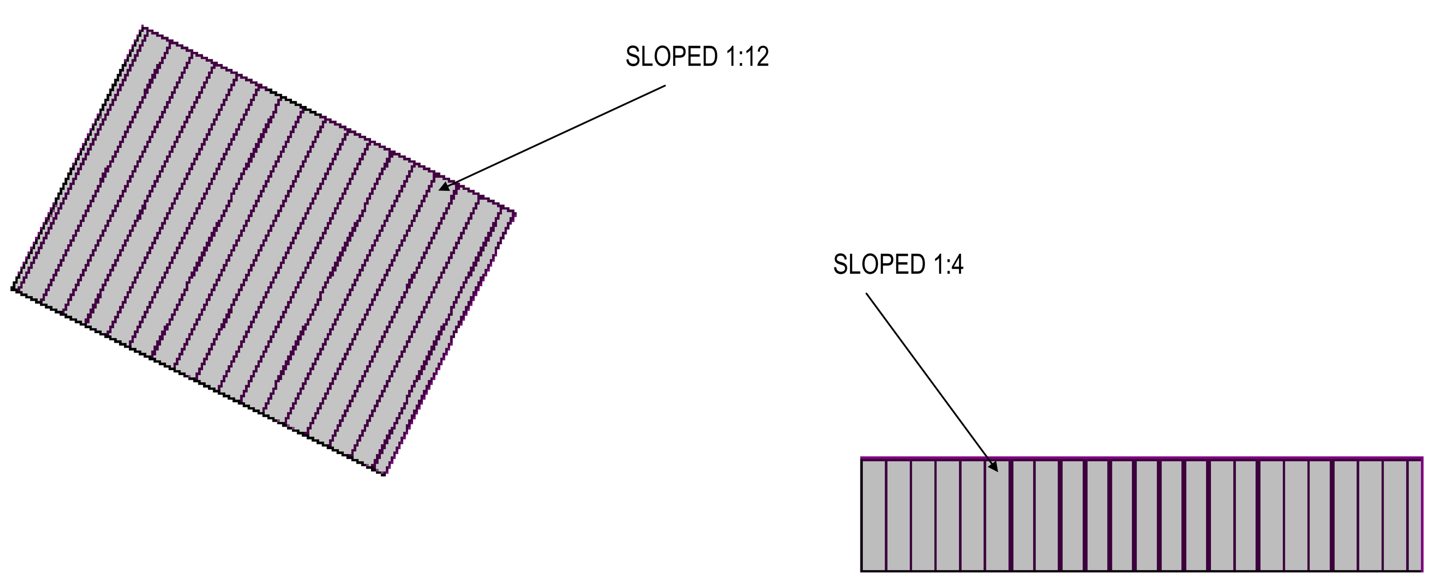


LEVEL 2 DECKING

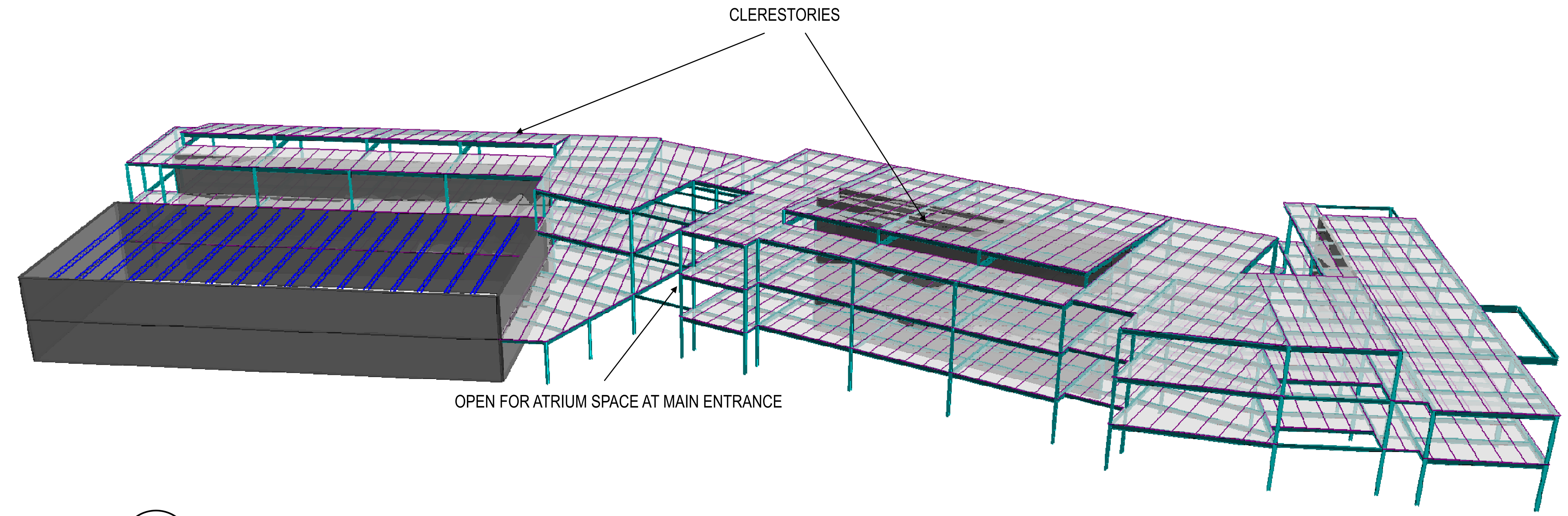
NOTE: MULTIPURPOSE SPACE ROOF DECKING NOT SHOWN



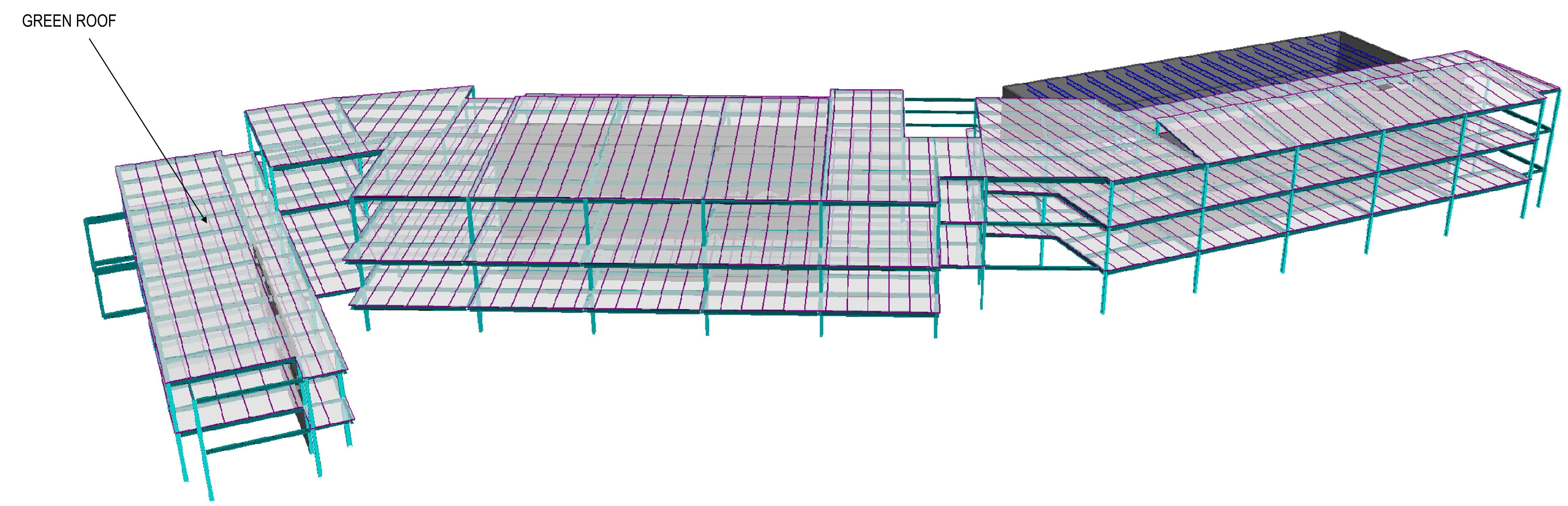
FLAT ROOF DECKING



CLERESTORY ROOF DECKING



NORTH SIDE ISOMETRIC VIEW OF ELEMENTARY SCHOOL GRAVITY SYSTEM



SOUTH SIDE ISOMETRIC VIEW OF ELEMENTARY SCHOOL GRAVITY SYSTEM

STEEL DECK NOTES

1. METAL DECK UNITS WILL HAVE A MINIMUM YIELD STRENGTH OF 33,000 PSI.

2. METAL DECK WILL BE SHORED TO SUPPORT WEIGHT OF WET CONCRETE AND CONSTRUCTION LOADS DURING CONSTRUCTION.

3. UNFRAMED OPENINGS FOR MECHANICAL, ELECTRICAL, OR PLUMPING EQUIPMENT WILL BE REINFORCED WITH 14 GAUGE FLAT METAL SHEET.

4. FLOOR CONSTRUCTION: 2.5” NORMAL WEIGHT CONCRETE FILL (3,000 PSI @ 28 DAY STRENGTH REINFORCED WITH WELDED WIRE FABRIC PLACED 1” DOWN FROM TOP OF SLAB) ON 2” 20 GAGE COMPOSITE METAL DECK. TOTAL SLAB THICKNESS OF 4.5”.

5. TYPICAL ROOF CONSTRUCTION: 1.5” 16 GAGE ROOF DECK.

6. GREEN ROOF CONSTRUCTION: 3.5” NORMAL WEIGHT CONCRETE FILL (3,000 PSI @ 28 DAY STRENGTH REINFORCED WITH WELDED WIRE FABRIC PLACED 1” DOWN FROM TOP OF SLAB) ON 2” 20 GAGE COMPOSITE METAL DECK. TOTAL SLAB THICKNESS OF 5.5”.

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3D Gravity System Views and Decking Layout

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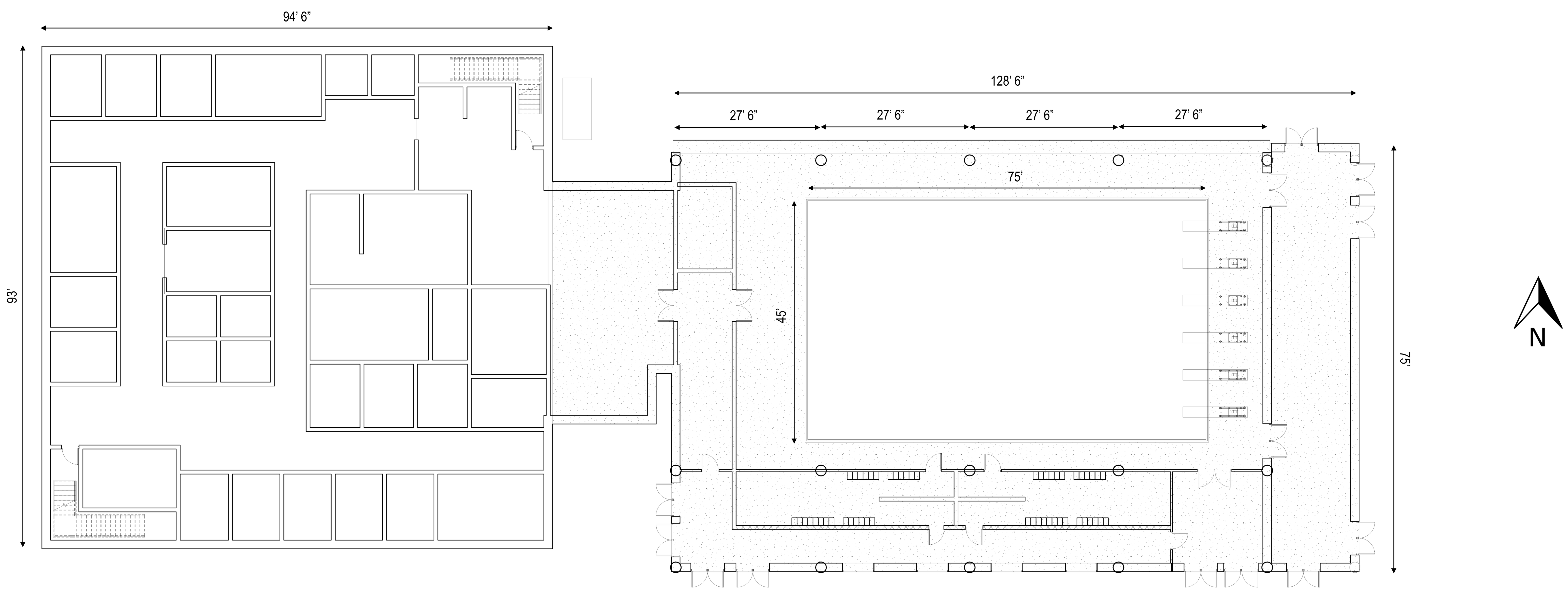
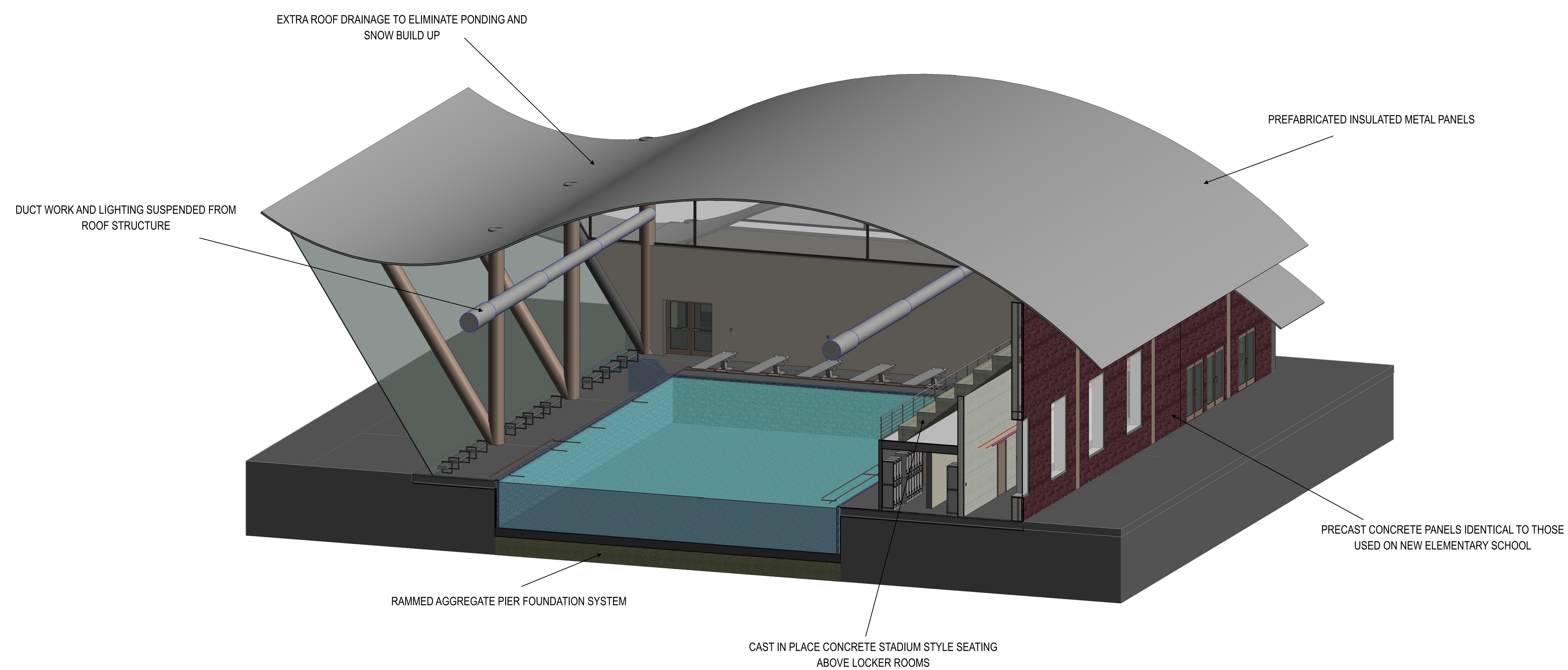
GENERAL PHASE 2 NOTES

1. SEE CONSTRUCTION MANAGEMENT SUBMITTAL FOR SCHEDULE DETAILS ON DEMOLITION, RENOVATION, AND NEW CONSTRUCTION FOR PHASE 2.
2. SEE APPENDIX A IN SUPPORTING DOCUMENTATION OF INTEGRATION SUBMITTAL FOR ASSUMPTIONS ABOUT EXISTING STRUCTURE.
3. SEE APPENDIX C IN SUPPORTING DOCUMENTATION FOR ALL MEMBER SIZES AND DESIGN CALCULATIONS.



CLINIC AND NATATORIUM FIRST FLOOR PLAN



NATATORIUM ISOMETRIC SECTION

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Natatorium and Clinic

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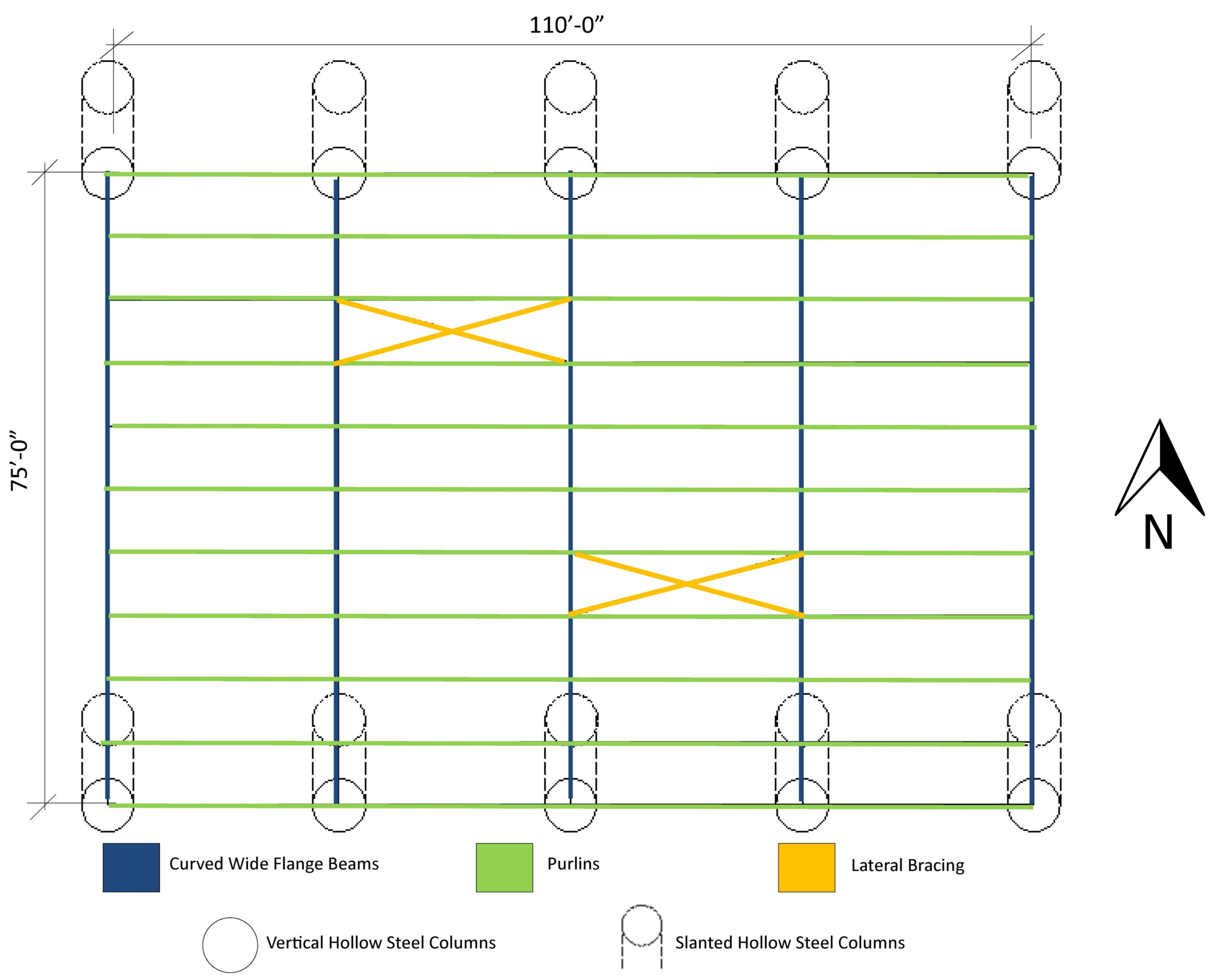
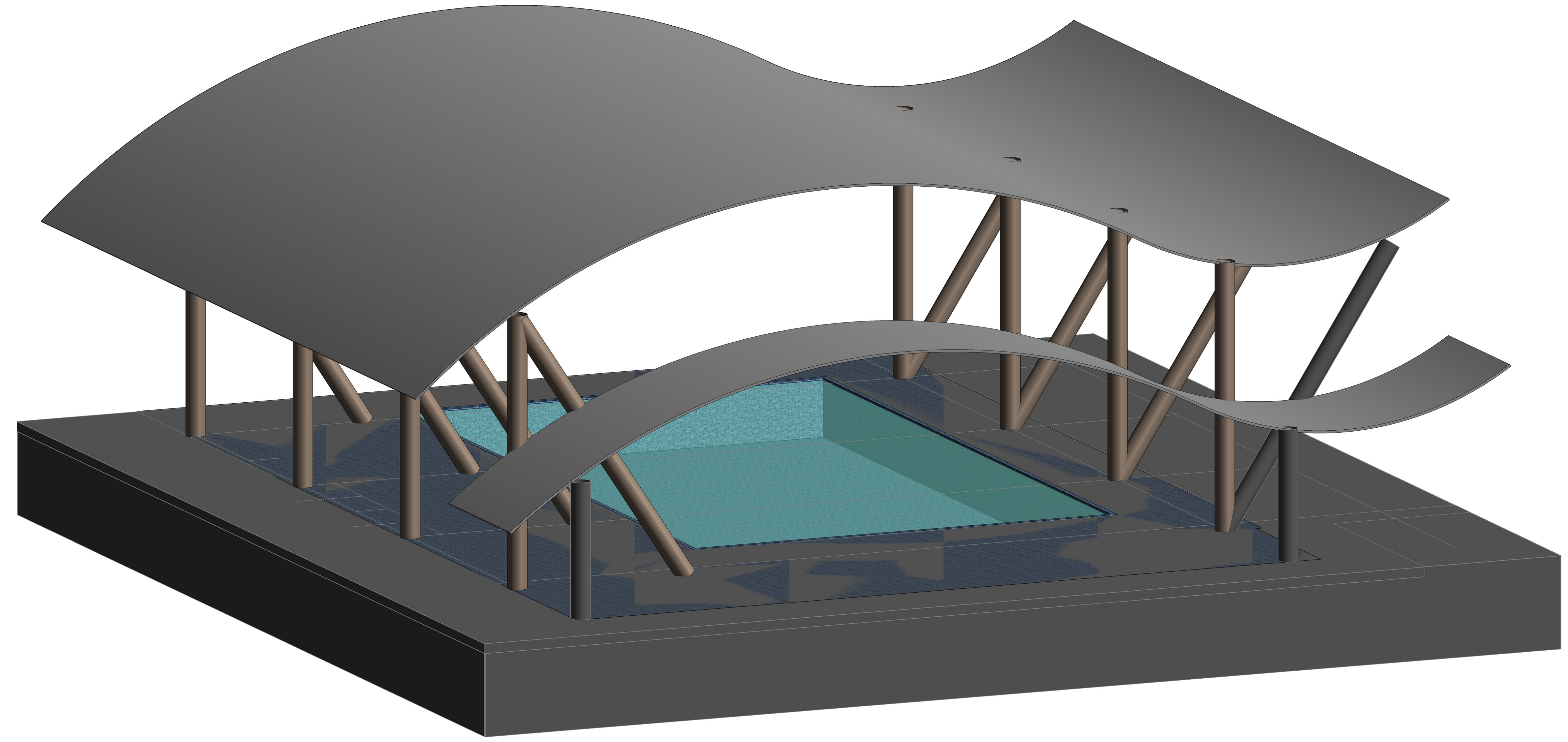


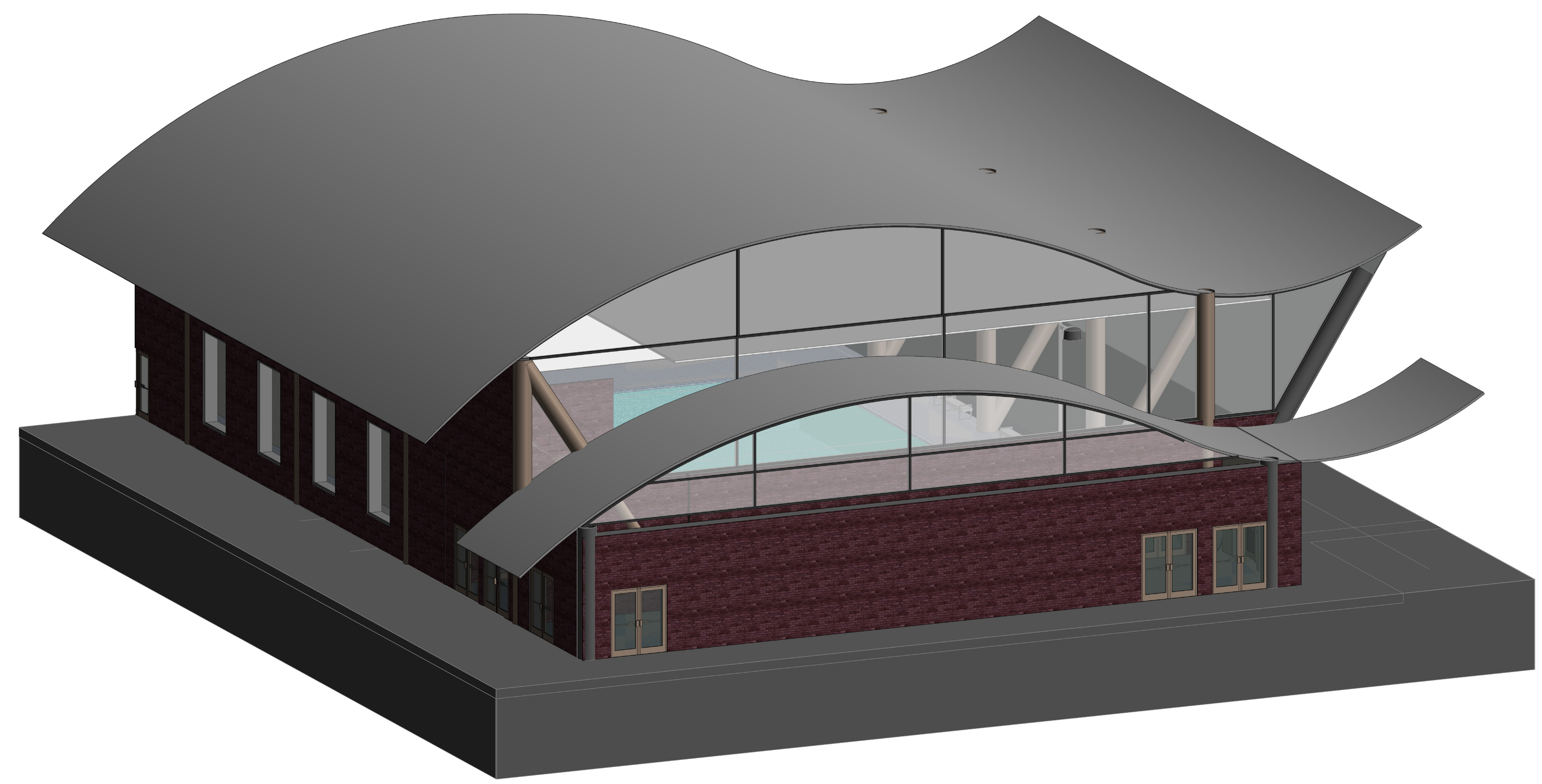
NATATORIUM ROOF FRAMING PLAN

NOT TO SCALE



NATATORIUM ROOF PANEL SYSTEM AND COLUMN ISOMETRIC

VIEW FROM SOUTH-EAST CORNER OF SITE



NATATORIUM ISOMETRIC

VIEW FROM SOUTH-EAST CORNER OF SITE

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Natatorium and Clinic

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