nexus

Submission Category: Structural Systems

Date: 12 November 2012

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Summary Narrative

The Elementary School project for the Reading School District requires a structural system that meets client goals and meets requirements presented by site conditions and by the conditions of the project. The client goals and the project team goals were considered in making each decision. These goals include, building and site security, low life-cycle cost, energy and environmental concousness, a felixble building layout, intergration across all disiplines, and to produce a good learning environment.

The project structural team was able to produce a structure that is not only efficient, but also helps the team and other disciplines reach their goals. By using innovative materials, such as Insulated Concrete Forms, we were able to produce an innovative structural design. Also, by using good engineering practices, a very efficient structure was produced. This is evident by the reduction of the number of columns by using long spans in our building and in turn reducing the number of piles for our foundation.

The team was able to meet the goals of the client, the goals of the project team and the requirements associated with the project.

Project Goals / Requirements

The goals of the Reading School District along with the goals of the project team were all taken into consideration when developing the structural system for the Reading Elementary School Project. In addition to those goals, there were some natural obstacles that the structural system had to be designed to withstand.

The goals of the Reading School District are to design a school that is secure, has a low life-cycle cost, is energy efficient, and environmentally conscious. The School District also wanted a school that is accessible, functional, promotes a productive school environment, and has a flexible lay-out to accommodate future advances in technology.

The goals of the Nexus design team were to produce a design that is very energy efficient, is integrated across all building disciplines, and produces an environment that is a learning tool itself.

The biggest obstacle that the structural system had to be designed for was the site conditions itself. According to the geotechnical report, the site is located in a karst topography area and the presence of sink holes are very likely. Because of this, the geotechnical report suggest three options for a foundation system: driven piles and pile caps, compaction grouting, and excavation and compaction.

Another situation that had to be considered for design of the structural system was the fact that the school floor plan needs to be flexible in case of future redesign of the interior layout of the building. In order to meet this, the building structural system needed to be as non-intrusive as possible. So, the system was designed to leave as much floor space open as possible, which will be discussed in the description of systems section of this report. The school district also suggested the need for a community shelter in the event of a natural disaster or a power outage. This criterion was considered in the design of the gymnasium. One smaller obstacle in the design of the structural system was the cantilevered rooms on the second floor. The Nexus project team had to discover a way to support this over hanging floor without adding too much structural depth to the system.

By combining all of the goals of the client and the goals of the project team, along with the requirements presented by the project, Nexus believes that the result was not only a structural system that meets these goals, but an integrated building that meets these goals in all disciplines.

Narrative Description of Systems / Solutions

The Nexus design team took all of the aforementioned goals and requirements to create an integrated solution for all disciplines. The structural system was designed to work with all of the other building systems and meet the project requirements. In this section of the report each component of the structural system will be explained and in the next section the rationale will be given for the selection of the system.

Foundation System

As mentioned before, the soil conditions of the project site are not favorable. After considering the recommendations of the geotechnical report, it was decided that the best solution would be to use driven piles and pile caps under the columns in our building and to use driven piles and strip footings under bearing walls in our building.

Columns

Because of the dimensions of our building we found that it would be possible to support our building with an exterior concrete bearing wall and very few columns within the building. By doing this we left the interior of the building very open because of the fact that there are fewer columns in the floor plan. Also because of this we were able to reduce the number of piles needed. It was recommended in the geotechnical report that three piles per column would be needed and two piles at every pile cap under strip footings. Despite the higher load produced on the columns from only having one row of columns in most of the building, it was found that three ten inch diameter and quarter inch thick piles filled with concrete would be sufficient under the columns.

Exterior Bearing Wall

The exterior walls of the building are six inch concrete bearing walls. This is a unique feature of our building design and it serves several purposes. First, in order to achieve our team goal of producing an energy efficient design, we decided to explore the use of Insulated Concrete Forms (ICFs). ICFs are leave in place concrete forms made out of two pieces of insulation held together by plastic bridging. ICFs provide very good insulation, are very air tight, and can cut down construction time. Second, contribute to the structural system in more than one way: It supports the floor system, it provides backing for the façade, and it acts as a shear wall to resist lateral forces.

Floor system

The floor system consists of composite steel beams and girders along with a three inch slab on a three inch composite metal deck. The floor system was chosen largely on the desire to use as few columns as possible. Composite steel beams were able to provide the long spans that were required to achieve this, while still providing a manageable structural depth. The three inch slab on three inch deck was chosen to prevent unacceptable deflection caused by the long spans.

Roof System

The roof system over the pool and gymnasium are long span steel joists with roof deck over the pool and three inch non-composite deck and three inch slab over the gym which will be discussed in the next section of the report. The roof system over the classrooms consists of non-composite beams with roof deck. The biggest concerns for the roof were snow loads and snow drift loads.

Gymnasium/Shelter

Because the community determined their may be a need for a shelter, the feasibility of letting the gym double as a shelter was investigated and it was determined that it could be done with little added cost to the project. The gym structure was designed according to the FEMA document P-361, Design and Construction Guidance for Community Safe Rooms. Since the exterior walls are six inch concrete bearing walls, they meet the FEMA projectile requirements. The end 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, it was decided to use a three inch concrete slab on a three inch non-composite steel deck. The roof joists were then upsized accordingly in order to support the added weight. The only major additions that had to be done to the structural system in order to qualify the gym as a shelter was add the slab to the roof and added size to the roof joists.

Lateral Force Resisting System

As mentioned before, the exterior concrete walls are used as shear walls to resist lateral forces. It was determined that because of the added extra weight of the building from the exterior concrete walls, earthquake lateral forces controlled over wind forces. It was also determined that due to the asymmetry of the building, it was advantageous to isolate the building into three separate parts to prevent torsional irregularities and join them with construction joints. The west structure consists of the pool, the gym and the community areas and the lateral force resisting systems in include the concrete shear walls and concentrically braced frames. The central structure consists of the main lobby and classrooms and the lateral force resisting systems are concrete shear walls in one direction and concentrically braced steel frames in the other direction. Because of the cantilevered second floor in this part of the building, the concrete bearing walls were not able to be used and therefore shear walls had to be added in the middle of the building in order to resist lateral loads in one direction and eccentrically braced frames were added in the other direction. In the east wing the lateral force resisting systems are the exterior concrete walls in both directions.

Rationale for System Selections and Solutions

Each decision that was made in designing the structural system was made with the team and project goals in mind. In addition to these goals, the need to have an integrated project guided a lot of the decisions, especially ones made in some key areas. This section of the report will go through the previously discussed parts of the structural system and give the rational in making this decision and give the reason for choosing the system over other options

Foundation System

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 and pile caps. Because of our decision to use as few columns as possible, choosing a foundation system became a critical part of the design because of the large loads that were going to be on the columns. Excavation and compaction was originally ruled out after discussing with our construction management team members and determining that this option would cost the most and take the most time. Compaction grouting was looked at and considered, but it was determined that this option, though feasible, was more risky because of the unknown soil conditions.

Driven piles and pile caps seem to be the best option because of the unknown soil conditions and the large loads on the columns. Because our building uses fewer columns, driven piles are a very economical option because our system uses fewer piles. The piles chosen to use were the same as the suggested size in the geotechnical report, ten inch diameter HSS Tubes with quarter inch thickness. Three piles per column will be used because of the three hundred and eighty nine kip capacity of each pile and considering a ten foot un-braced length in case a large sink hole would be encountered. Another reason piles were chosen is that driven piles are the most common method of deep foundations in this type of Pennsylvania topography

Columns

Because of the client goal to have a flexible building layout, our team decided that one way to achieve this was to use as few columns as possible and to use larger spans. Our team was able to achieve this and it is evident especially in the central classroom corridor where there is only one row of columns down the middle and the beams span forty feet in each direction. To use the central corridor as an example, the size column that will be needed will be a W12x87 for a strength capacity of 925 kips at an un-braced length of fourteen feet.

Exterior Bearing Wall

The exterior bearing walls, as mentioned before will serve several purposes. For simplification the wall was considered in seven foot strip because this is the width between windows, so it is the uninterrupted width of the exterior walls. The bearing capacity of these seven foot widths of wall using a moderate amount of reinforcement is one thousand seven hundred kips in compression which is more than enough capacity. The thickness of the walls is six inches, which is a good size because it is the most common size available for the Insulated Concrete Forms. Also mentioned before, the big advantage of using the Insulated Concrete Forms is how the exterior façade acts as a whole. The wall is a good insulator since there is three inches of rigid polystyrene insulation and the wall is also very air tight since it is a continuous concrete wall all the way around. These two properties of the wall help meet our energy efficiency goals in our mechanical system.

Floor System

Achieving long spans with our floor structural system were critical in order to reach our goals of having an efficient structural system and having an open and flexible floor plan. We chose composite steel over a concrete system for two reasons. First, the concrete system would weigh significantly more than a composite steel system. Second, with the composite steel system we were able to achieve the long spans we were aiming for, up to forty two feet at the most. All this while maintaining a manageable structural depth; a maximum of twenty four inches under the beams and thirty inches under the girders. Taking the central classroom wing again as an example, the floor composite beams are W18x46 sections, which is large for a floor beam but reasonable considering the beams are forty two feet long and have a nine foot four inch spacing. The composite girders are W24x68 sections, but since there is only one row of columns in the central classroom wing, there is only one row of girders so the structure is less imposing.

Originally, our team designed the floor system with a four and a half inch slab on three inch deck in order to achieve a two hour fire rating. After investigating the International Building Code more thoroughly, it was determined that our building would not need a fire rating as long as the entire building had a sprinkler system. Our team decided to go with this option and as a result, the slab thickness was reduced to a three inch slab on three inch metal deck. This size slab was chosen in order to prevent excessive deflection and to prevent vibration issues.

It was a concern for us that floor vibrations could be an issue in our floor system do to the long spans of our beams and the nine foot spacing of our beams. Our team investigated the issue by reviewing a document on office floor vibrations (*Preliminary Assessment for Walking-Induced Vibrations in Office Environments,* Hanagan & Kim). After reviewing this document we determined that our assumptions were correct in preventing floor vibrations, by using a larger slab thickness and a thicker deck there is a much less chance of having floor vibration problems.

Roof System

Long span steel joists were chosen to be used in the pool and gym areas not only because of the long spans, but also because of the availability of the concrete bearing walls to be used. Since we would not have to put in any columns, we could space the joist at whatever distance that would be needed.

The roof over the classrooms is supported by steel beams and roof deck. This was chosen over using roof joists in order to keep a reasonable structural depth. The biggest concern pertaining to roof loads throughout the building were the snow loads and snow drift loads. A local provision of thirty five 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 was forty nine pounds per square foot. This was used when designing the roof system for all of the two story roofs.

Gymnasium/Shelter

FEMA document P-361: Design and Construction Guidance for Community Safe Rooms, 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 roof deck to a three inch slab on three in inch non-composite deck in order to prevent uplift. The steel long-span joists were enlarged in size in order to support the added weight of the roof. No windows or skylights were put into the gymnasium. While this isn't ideal for a normal gymnasium, it is ideal for a hurricane shelter to prevent projectile penetration through windows. It was determined by the project team that it made more sense to not have to use projectile resistant windows and just not have day lighting in the gym, which is typically artificially lit anyways. The concrete exterior walls are helpful for creating a shelter as well.

Lateral Force Resisting System

At a certain point in our design phase we realized that though we would be able to use our concrete walls as shear walls, they did add weight to the building and because of this it caused earthquake loads to control our lateral loads. From this we also saw that because earthquake loads controlled the lateral loads, the building layout was irregular and produced an irregular lateral loading. In order to prevent this, the design team decided to split the building into three parts and connect them with construction joints.

The west structure includes the community areas, the gym and the pool. The lateral load resisting system in one direction is concrete shear walls. The Lateral system in the other direction includes both exterior and the interior shear walls provided for the gym and eccentrically braced frames. The period of this section of the building determined through an ETABS model is 0.3312 seconds which is close to what would be expected by rule of thumb.

The central classroom wing of the building, in one direction, uses the exterior concrete walls as shear walls on the north side, but on the south side insulated concrete forms will not be able to be used because of the enlarged classroom on the second floor. So in order to prevent torsional irregularity, concrete shear walls were added along the column line of the wing. In the other direction eccentrically braced frames were used in a chevron pattern. This system was chosen in this direction by the project team because of its ease of construction and because it fit well with the mechanical system of the building. The period of this section of the building according to our ETABS model is 0.4168 seconds which is also close to what would be expected by rule of thumb.

The east classroom wing uses the concrete walls as shear walls in both directions, no extra lateral force resisting system components had to be added. The period of this section of the building according to an ETABS model was 0.2889 seconds, which is again close to expected.

<u>Look-ahead</u>

The main areas we will be focusing on for the rest of the competition will be refining and perfecting what we have at this time. One of these things is refining our ETABS model, which will be a big area for us to look at. We will also look into modeling our structure in RAM. Another big area for us to look at will be detailing our structure. Because of the nature of this type of group project the big picture problems all get looked at and resolved but smaller discipline specific problems don't get as much attention. For use this includes detailing connections of the steel beams to the concrete bearing wall, also, detailing the reinforcing in the concrete walls for compression and for lateral shear. These last few weeks we will also look for problems within our building and continue to work with the group to perfect our design.

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COMPOSITE BEAM DESIGN SPREADSHEET

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

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

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

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

V_U	M_U
27.0 kips	269.7 kip-ft

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

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

Pick Section From Steel Manual — W 14 x 48

I (Non-Composite)	ϕM_P
510 in^4	249 kip-ft

I	$\sum Q_n$
484 in^4	260 kips

# of studs	Economy
32	2240

Δ

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

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

$\Delta_{wet\ concrete}$	$w_{wet\ concrete}$
2.34186	0.6 klf

Check Self-Weight	a
5.1 psf	0.68 in.

Camber
1.25 in

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COMPOSITE GIRDER DESIGN SPREADSHEET

*Add 1 kip to each point load for beam self weight

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

Span	Spacing	b'
28 ft	40.00 ft	42 in

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

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

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

Pick Section From Steel Manual

W	24	x	68

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

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

# of studs	Economy
24	2144

Δ Checks

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

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

$\Delta_{wet\ concrete}$	I_{minWC} (From $\Delta_{TL\ Allowable}$)
1.2951074	1693

Check Self-Weight	a
OK	0.88 in.

Camber
1.25 in

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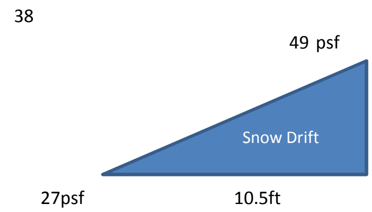
ROOF/SNOW LOAD CALCULATION SPREADSHEET

Snow Load

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



Roof Live Load

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

Superimposed DL
15 psf

Total Load

146 psf   1167.68
70060.8

Roof Deck

		Capacity	3-Span-Max Span
3C22	56 psf	87 psf	6'11"

Joist

TL= 1.28 klf   24K6   10.1 plf

Joist-Girder

TL= 18.0

60' span   G10N60   41 plf

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WIND LOAD CALCULATION SPREADSHEET

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

Velocity Pressure
qz=0.00256KzKztKdV^2I

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

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

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

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

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

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

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
8.2091232	-9.93304	-12.72414096	-15.51524285	-9.93303907	-7.141937184

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

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
14.1196919	-4.02247	-6.813572256	-9.604674144	-4.02247037	-1.23136848

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

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
8.2091232	8.209123	8.2091232	8.2091232	8.2091232	8.2091232

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

Windward	Lee	Side	Roof (0-h)	Roof (h-2h)	Roof (>2h)
-8.2091232	-8.20912	-8.2091232	-8.2091232	-8.2091232	-8.2091232

Wind Load Study: Safe Room

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

Velocity Pressure
qz=0.00256KzKztKdV^2I

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

	Kz			qh (psf)	
	Case 1 (C&C)	Case 2 (MLFRS)		Case 1 (C&C)	Case 2 (MLFRS)
0-15	0.7	0.57	0-15	44.843008	36.5150208
20	0.7	0.62	20	44.843008	39.7180928
25	0.7	0.66	25	44.843008	42.2805504
30	0.7	0.7	30	44.843008	44.843008
40	0.76	0.76	40	48.6866944	48.6866944
50	0.81	0.81	50	51.8897664	51.8897664

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
6.745669632	-50.5925	-59.41378253

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

Windward	Lee	Side
63.82441267	6.486221	-2.335039488

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

Roof (0-h)	Roof (h-2h)	Roof (>2h)
-58.96855552	-43.7219328	-36.09862144

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

Roof (0-h)	Roof (h-2h)	Roof (>2h)
-9.64124672	5.605376	13.22868736

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EARTHQUAKE LOAD CALCULATION SPREADSHEET

C_S Coefficient Calculation

Spectral Response Acc. (from ASCE 7-05)		Building Data			Story Heights		
S_s=	0.25	Total Height:	28	ft	Roof	42	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:	1.5				
T_L=	6	R (N-S)=	3.25				
		R (E-W)=	4				

S_{DS}=	0.417
S_{D1}=	0.140
T_0=	0.067
T_L=	6
T_S=	0.336
T_a=	0.243
S_a=	0.417

N-S:		E-W:	
R=	7	R=	4
C_s=	0.1923	C_s=	0.1563
C_s=	0.2654	C_s=	0.2157
C_s=	**0.1923**	**C_s=**	**0.1563**

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EARTHQUAKE LOAD CALCULATION SPREADSHEET

Earthquake Load Calulations

Loads:

Roof dead=	30	psf
Floor dead=	60	psf
ICF Walls=	200	psf
Curtain Walls=	50	psf

Trib Areas:

Roof Level	Roof=	16345	ft^2
	Floor=	0	ft^2
	ICF Wall=	2310	ft^2
	Curtain Wall=	1582	ft^2
3rd Floor Level	Roof=	527	ft^2
	Floor=	17745	ft^2
	ICF Wall=	4795	ft^2
	Curtain Wall=	2233	ft^2
2nd Floor Level	Roof	645	ft^2
	Floor	16872	ft^2
	ICF Wall	4970	ft^2
	Curtain Wall	2289	ft^2

Roof Level Load
W= 1031.5 kips

3rd Floor Load
W= 2151.2 kips

2nd Floor Load
W= 2140.1 kips

Total W= 5322.73 kips

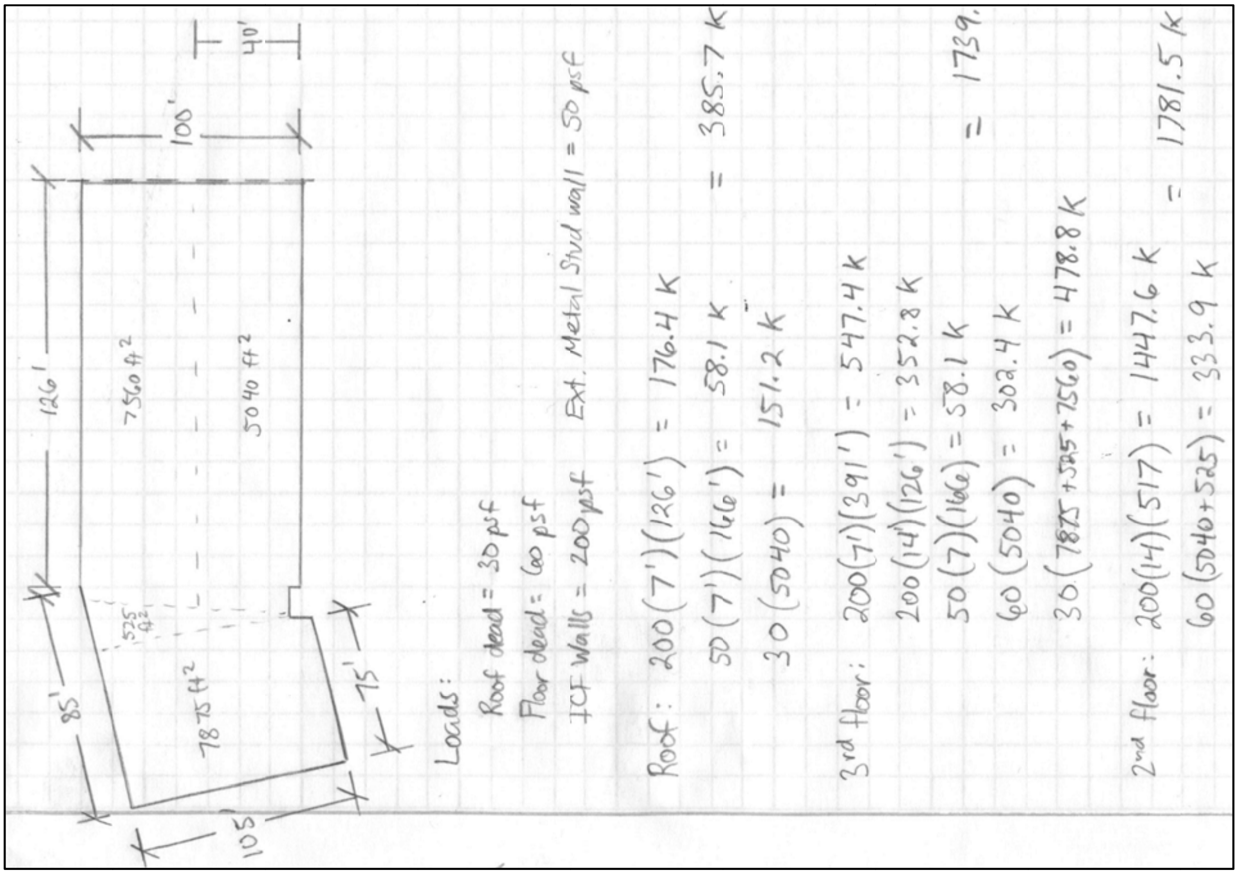
Load Distributions:

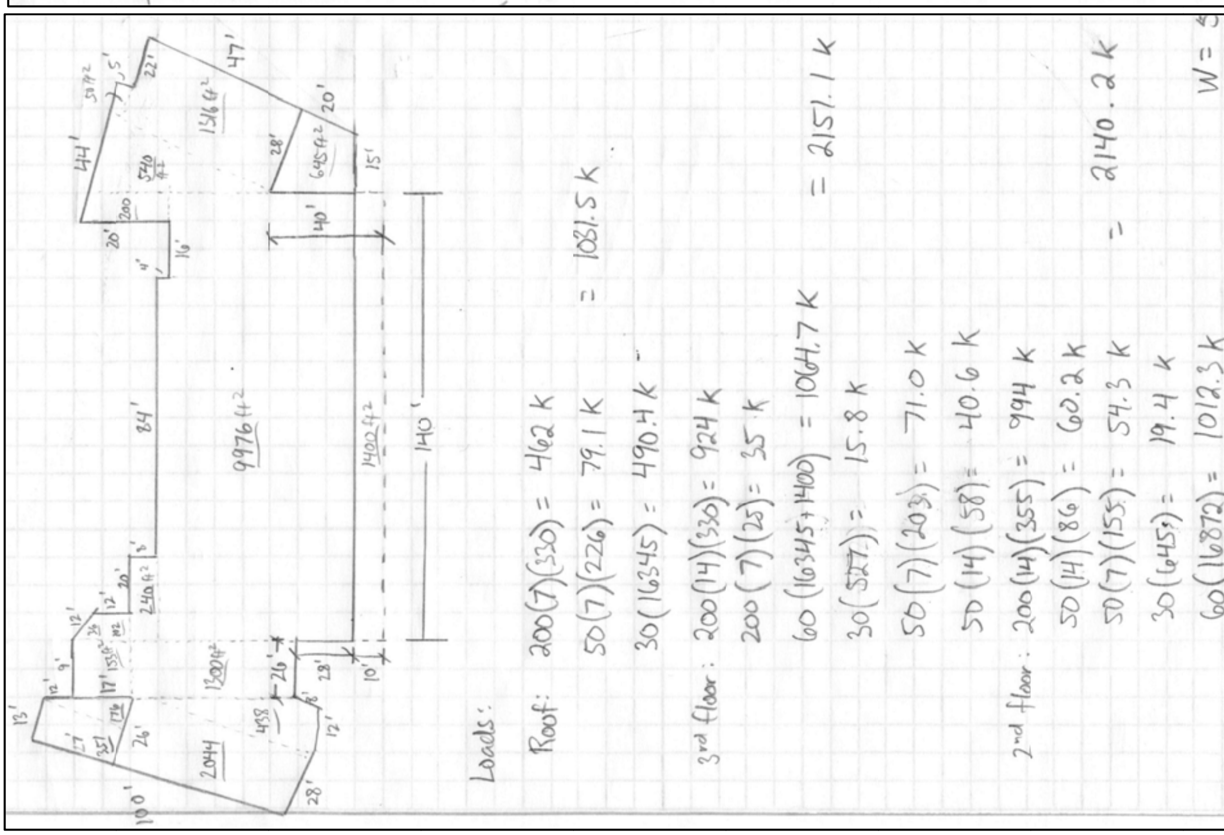
N-S:		E-W:	
Base Shear=	1023.6 kips	Base Shear=	831.7 kips

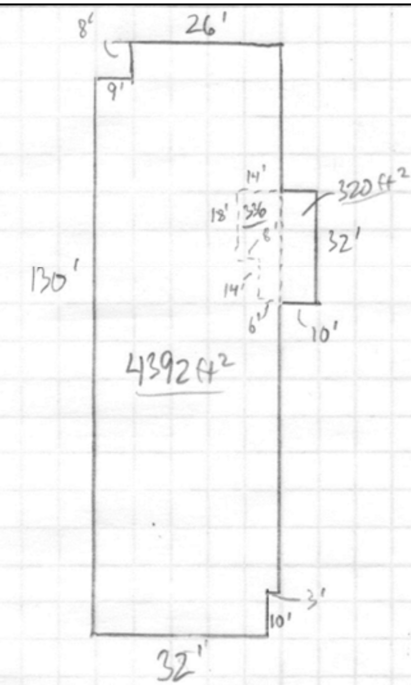
k= 1
C_{VR}= 0.3245
C_{V3}= 0.4511
C_{V2}= 0.2244

Roof	**332.1** kips	Roof	**269.8** kips
3rd Floor	**461.8** kips	3rd Floor	**375.2** kips
2nd Floor	**229.7** kips	2nd Floor	**186.6** kips

ROOF, WALL, AND FLOOR AREA CALCULATIONS







Loads:

Roof: $200(7)(250) = 350\ k$

$50(7)(52) = 18.2\ k$ $\quad = 520\ k$

$30(5048) = 151.4\ k$

2nd floor: $200(14)(250) = 700\ k$

$50(7)(52) = 18.2\ k$

$60(5048) = 302.8\ k$ $\quad = 1042\ k$

$50(7)(60) = 21\ k$

Structural Engineering Division
Patrick Allen
Brad Frederick

EXTERIOR BEARING WALL DESIGN SPREADSHEET

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

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

Empirical Design Method

Wall Dimensions

0.50	x	7	504
			(A_g)

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

h	l_c	f_c'
12	504	4

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

Compression Members

A_{st}	A_g	f_y	f_c'
14	504	60	4

ϕ	$\phi P_{n,Max}$
0.85	1704.08

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

Shear in Walls

$$V_s = A_v f_y d/s$$

λ	f_c'	h	d	ϕ
1	4000	6.00	67.2	0.75

V_c	V_s	s	A_v	bar#
51.00121	49.28	18	0.22	3

ϕV_n
75.21091

Structural Fire Protection Evaluation

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

As outlined in Figure 1, we looked at the options for an "E" classified building (education), and sought to satisfy the requirements for a Type II B construction, which does not require any structural fireproofing. According to the code table, the school would have to be limited to a height of two stories and 14,500 square feet of area per floor. However, the code allows for height and area modifications if an approved sprinkler system is added to the building. The addition of the sprinkler system allows for one additional story to be added to the building, meaning that our three-story design is allowed. Also, the automatic sprinkler increase outlined in Figure 2 allows for an additional 200% increase in the allowed square footage per floor. This increase results in a new allowable area of 43,500 square feet per floor. Our school's first floor, which has the largest area of any floor, is just under 40,000 square feet. Therefore, the addition of an approved sprinkler system means that we will be allowed to use Type II B construction for the building.

According to the code table outlined in Figure 3, the use of Type II B construction requires no fireproofing for any structural members of the building. In conclusion, this makes the addition of an approved sprinkler system a logical choice for our design. The sprinkler system provides added fire safety to the building, but it also allows us to achieve our design goals for the classroom spaces.

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

Figure 1

SECTION 506
BUILDING AREA MODIFICATIONS

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

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

where:

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

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

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

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

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

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

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

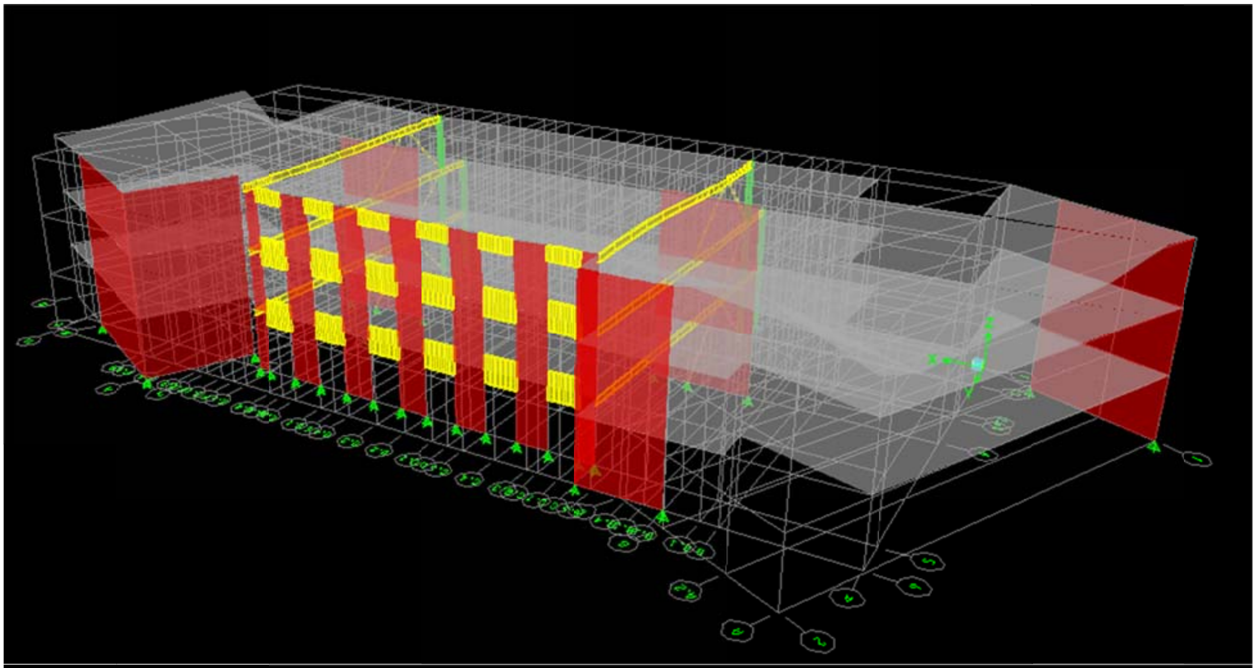
1. The *automatic sprinkler system* increase shall not apply to *buildings* with an occupancy in Group H-1.
2. The *automatic sprinkler system* increase shall not apply to the *building area* of an occupancy in Group H-2 or H-3. For *buildings* containing such occupancies, the allowable *building area*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

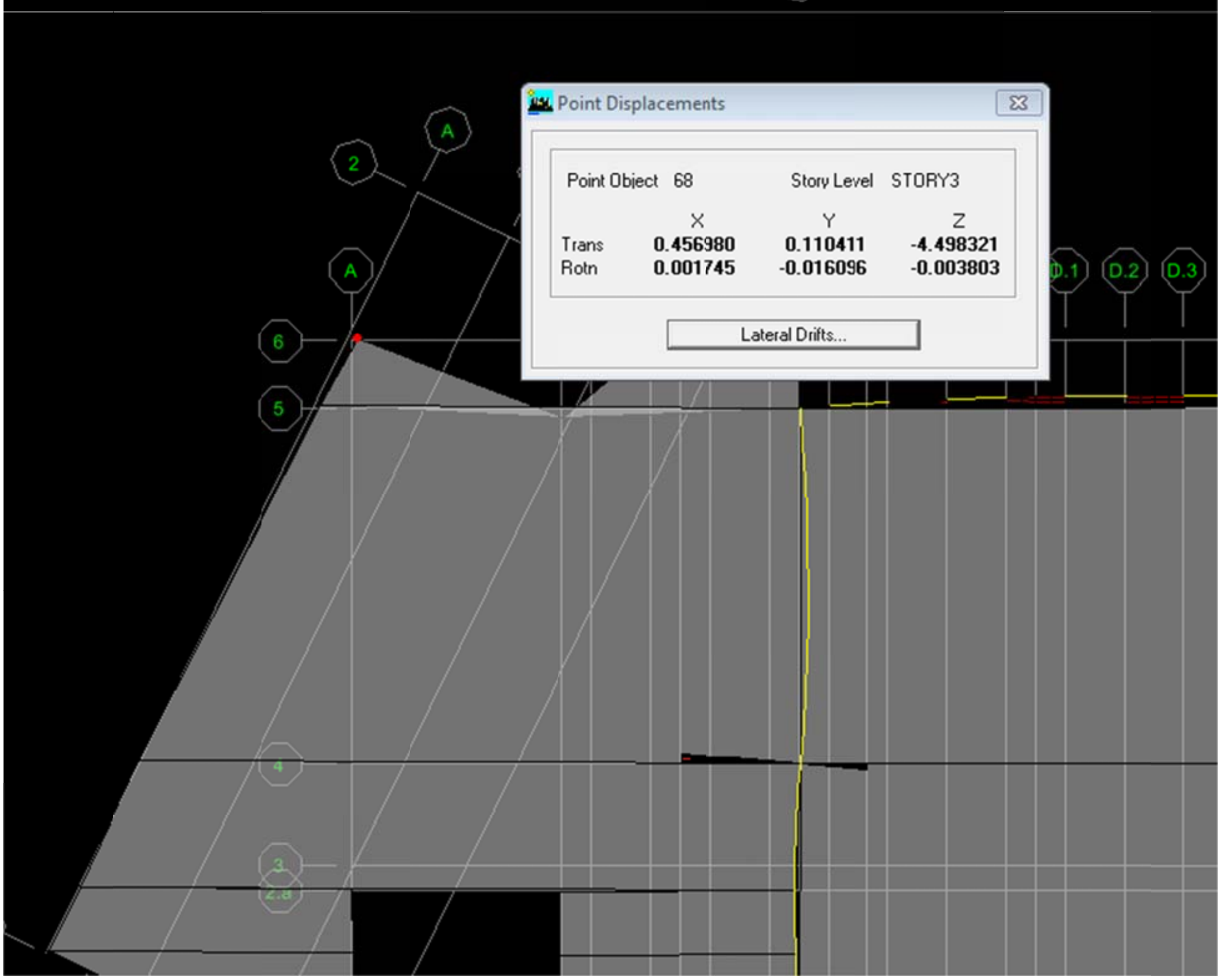
Figure 2

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

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

Figure 3





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Point Object 68
Story Level STORY3
X Y Z
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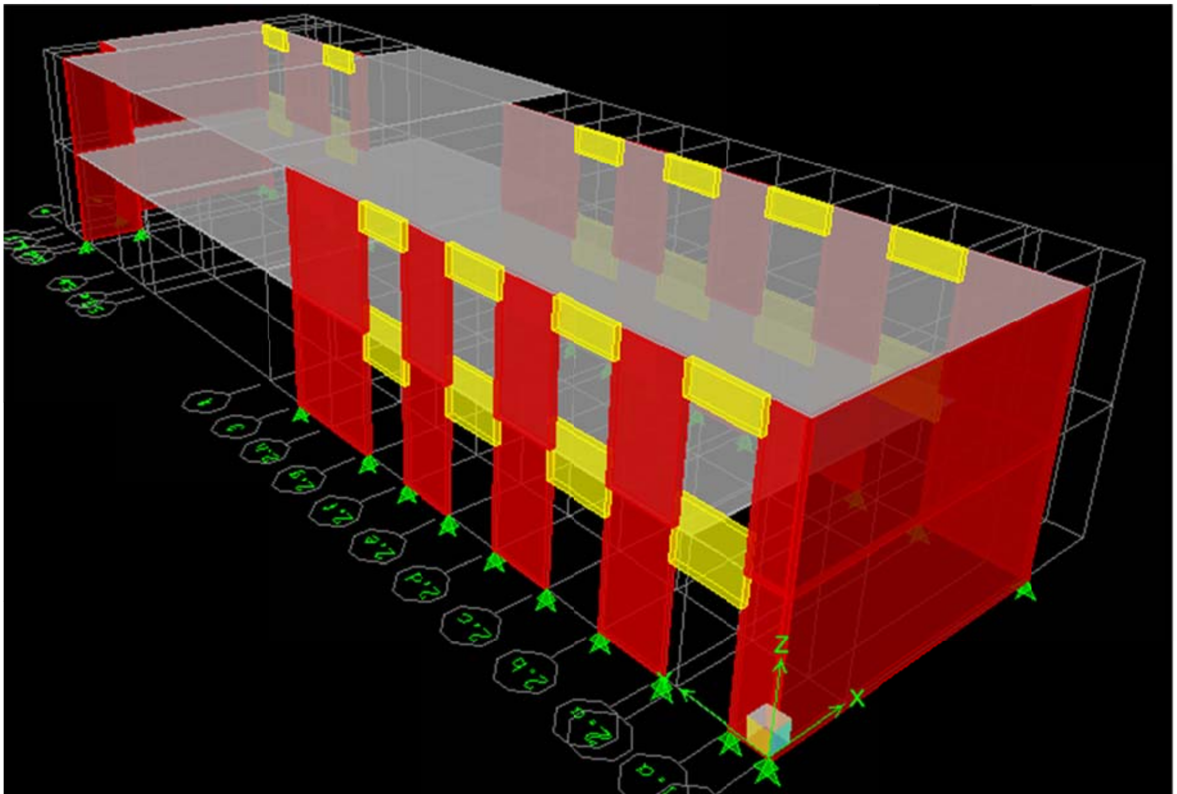
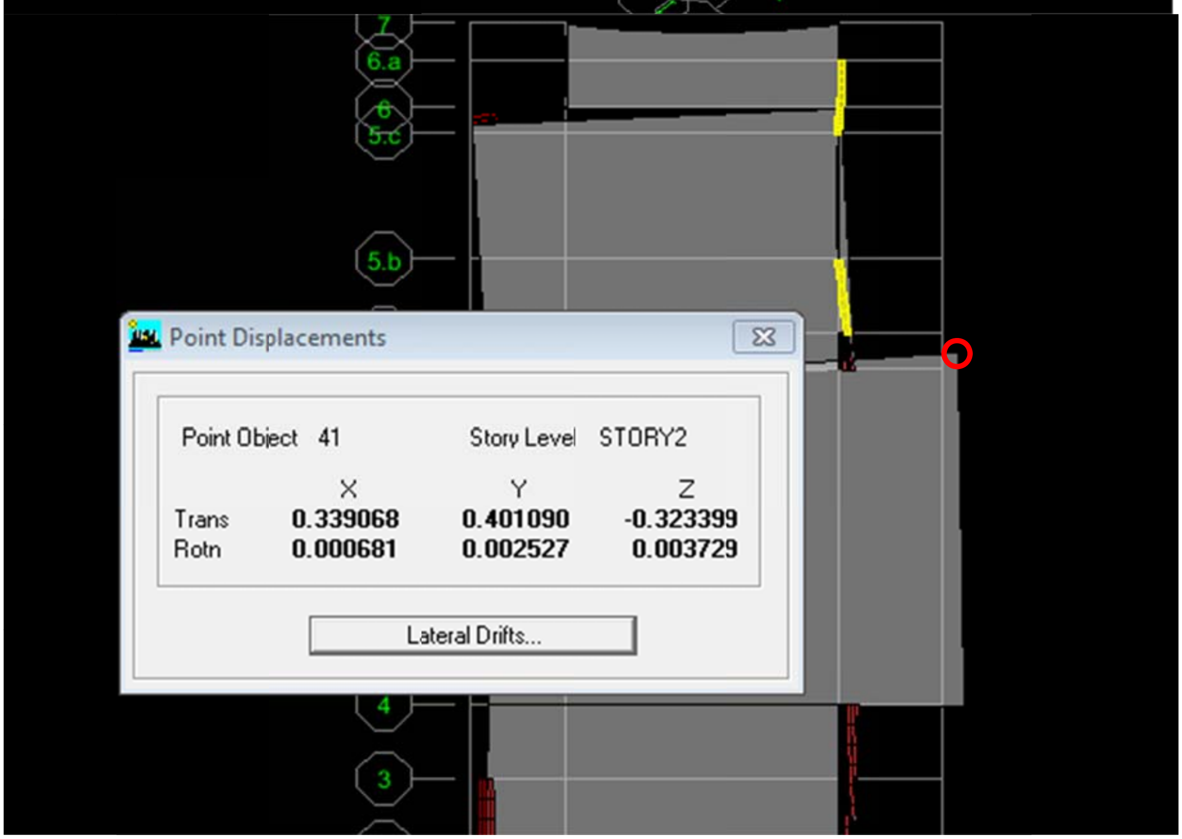
Rotn 0.001745 -0.016096 -0.003803
Lateral Drifts...
2
A
A
6
5
4
3
D.1
D.2
D.3




7
6.a
6
5.c
5.b
4
3
Point Displacements
Point Object 41
Story Level STORY2
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Y
Z
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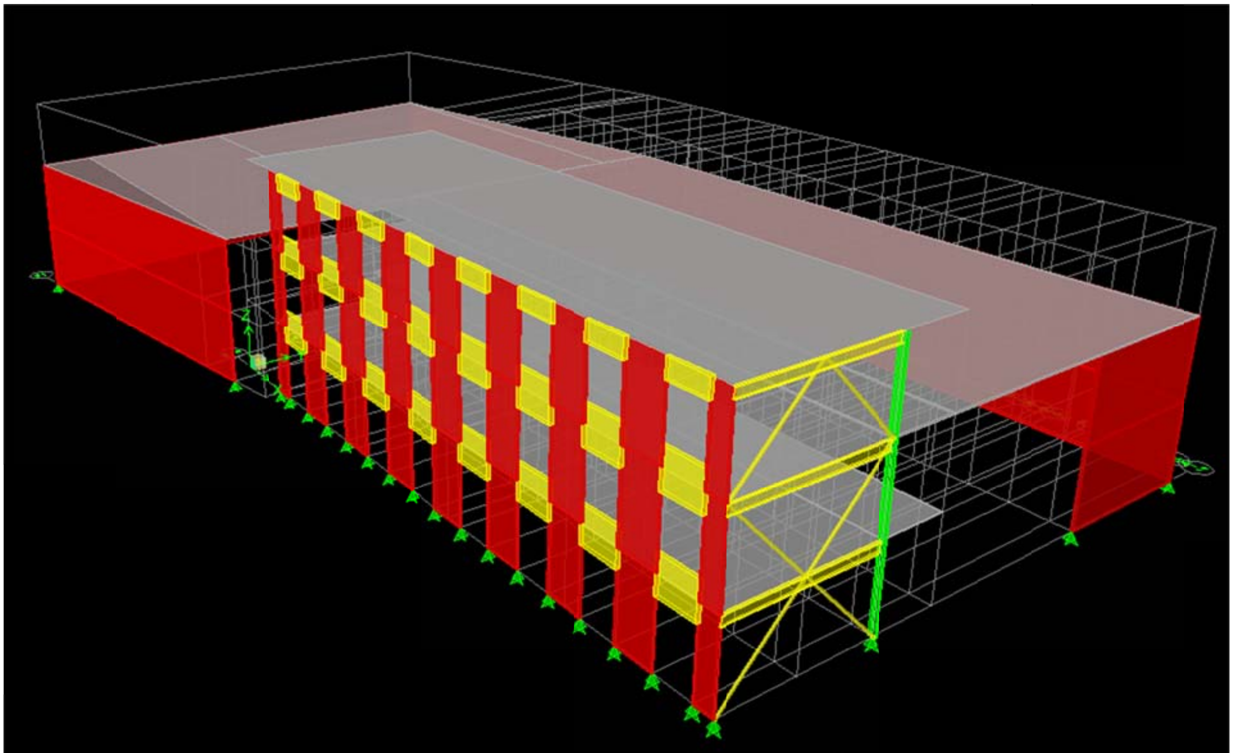
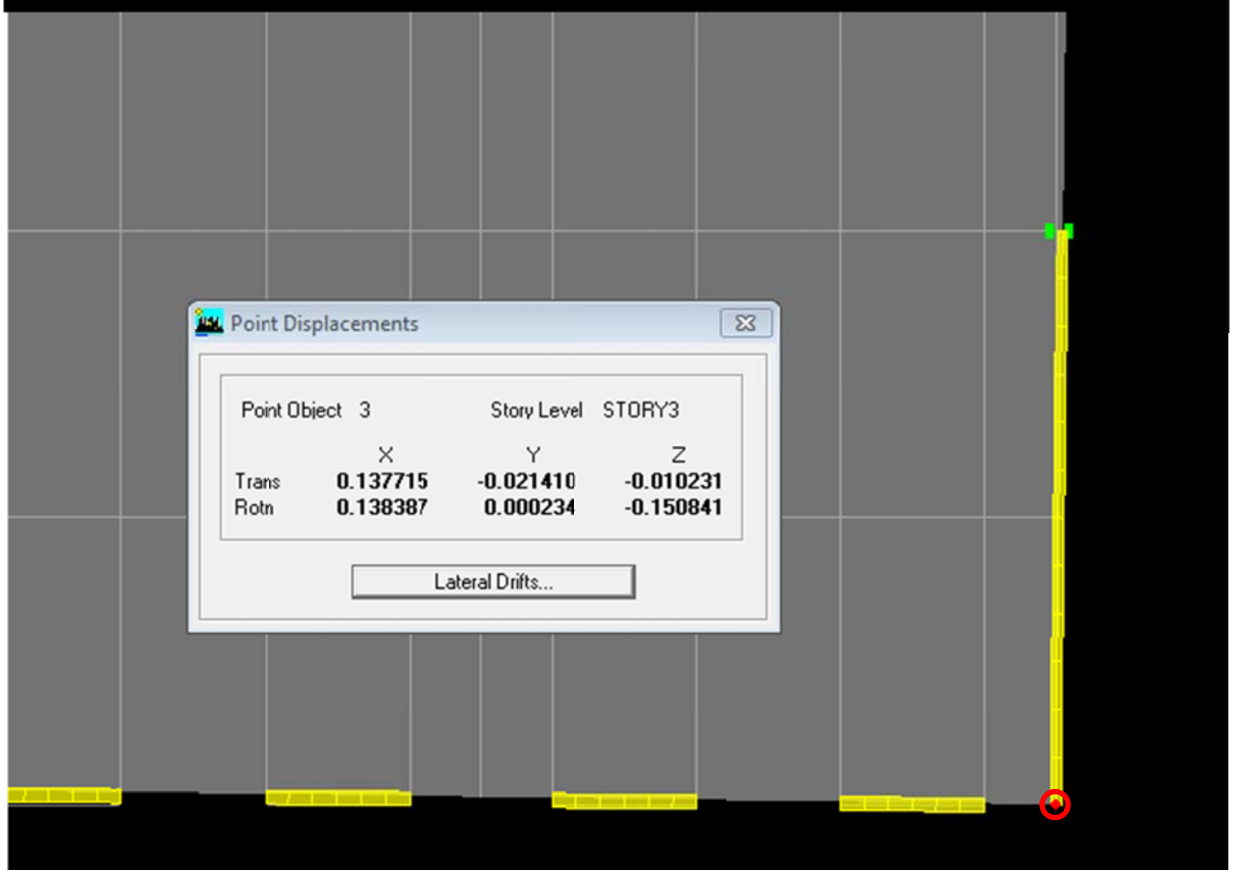
Rotn 0.000681 0.002527 0.003729
Lateral Drifts...

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Point Object 3
Story Level STORY3
X
Y
Z
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Rotn 0.138387 0.000234 -0.150841
Lateral Drifts...