UNION STATION HISTORY

Located in the heart of Washington DC's commercial and manufacturing district, Union Station was built in the mid 1980's as one of first major public transportation buildings in the United States. One can purchase an Amtrak ticket to travel nationally on the railroad or ride a greyhound bus to travel to the desired location. The DC metro also travels through the station allowing local pedestrians and tourists to travel around our nation's capital.

Since the completion of Union Station, other renditions of the building have been designed and built in other major cities throughout the United States (Dallas, St. Louis, Los Angles, etc.). Each building was given a unique style of architecture to highlight the building in the city it resides in. For the original building of Union Station, a grand Glass Curtain wall is located along the west elevation of the building. This architectural feature allows guest and workers within the building to look at the sites of Washington DC while either riding up in the elevators or the escalators, taking the stairs, working in the office spaces, or sitting in the lobbies waiting to travel by means of one of the transportations offered.

Figure i: Union Station's Glass Curtain Wall

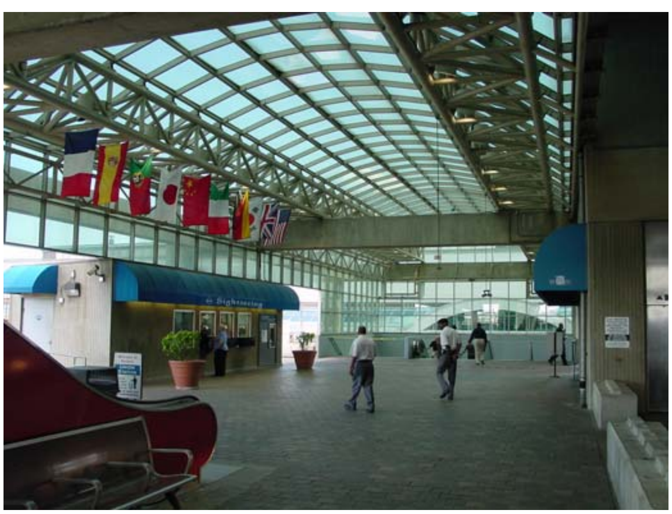


Figure ii: View Within Curtain Wall

EXISTING STRUCTURAL SYSTEM

Foundation:

Union Station's expansion main foundation system consists of concrete piles, which carry the load from the train track stations to the soil and supportive columns for all the levels above the track level. Each one rests upon a square footer that is either six feet or twelve feet in length and width, with a height of two feet.

All the piles are located between the eight locomotive rail ways that are part of Union Station. Maximum diameter size of the columns and the piles are 1 ½' and are spaced 22'-0" spanning in the north-south direction of the building between the railroads.

From the provided geotechnical report, the net soil bearing capacity for the site is 2000 PSF, which is considered weak for the soil. Fine to coarse sandy clay fill is the soil designation on the site for Union Station.

Existing Floor System:

Union Station's typical floor system is a two-way post-tension cast-in-place concrete slab with a thickness of 7". All the beams and girders are post-tension cast-in-place as well. In Union Station, the beams span a length of 63'-0". The girders located in the expansion, carry the load from the beams to the columns and have a typical span of 24'-4" throughout the expansion. The concrete compressive strength for the slabs, beams, and girders is f'_c = 5000 psi while the columns supporting the floors are cast-in-place with a compressive strength of 8000 psi. It is to be noted that the floor systems for the expansion and the existing structure for Union Station do not connect with each other.

For the Ground Level, a rigid 6 ½" concrete slab was used for majority of the floor. A composite design located along the west elevation was utilized to help reduce the weight within the weakest are of the site. A 5" light weight concrete slab over 1 ½" gage LOK-Floor was used which makes the ground floor total thickness to be 6 ½". Shear studs sized at ¾" x 4 ½" were used in the composite floor design. Typical member size for the beams is W27x84 which span 63'-0" and tie into a W33x118 girder. Each girder ties into the concrete columns that are part of the foundation system.

There are two typical bay sizes located in the expansion of Union Station, 63'-0" x 27'-6" and 63'-0" x 40'-0". Since the tracks running through Union Station were the major consideration in the design as well as the bus terminal, the use of long spans was concluded as the best approach for the design.

Lateral System:

Union Station's lateral load system is composed of ordinary reinforced concrete moment frames (See Figure 1 to the right). Lateral loads, as well as the gravity loads, reach the foundation of Union Station by first traveling through the beams, then carry through the girders which connect to the columns. From there, all loads travel down in the columns to the ground level and then the columns take all the loads into the foundation. Not all beams and girders take part of the lateral system in Union Station. The highlighted members within Figure 1 represent the beams and girders that act as part of the lateral system. Intermediate beams and girders are indicated as the black and white members within the figure.

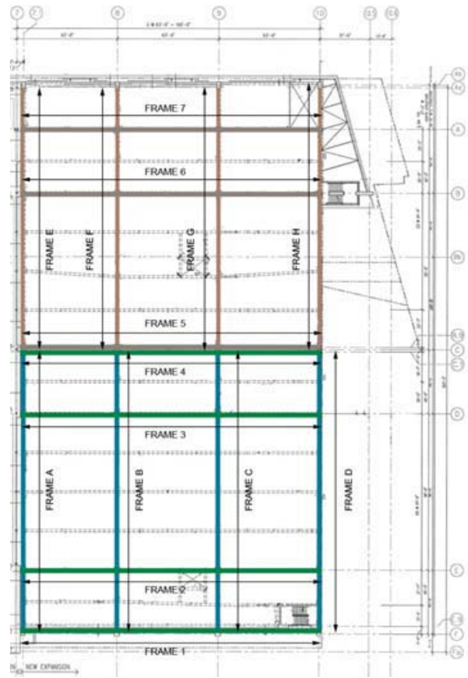


Figure 1: Moment Frames in Union Station Expansion

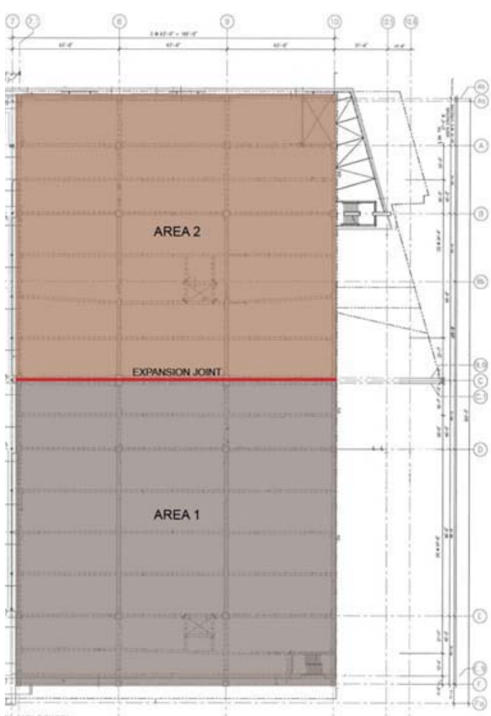


Figure 2: Expansion Joint within Expansion

An expansion joint was placed between column lines 7 and 7-1 is located between the existing structure and the expansion to Union Station (Refer to Figure Figure 2). As stated in the addendum, there is also an expansion joint within the expansion. This joint is used to create two separate structures that can move independent of each other due to forces acting upon the building.

PROBLEM STATEMENT

From Design Firm's View:

From the very start of the design for the expansion to Union Station, two major concerns for the building were used as a starting point. First, there had to be large open spaces with a minimum amount of columns for the track, ground, and mezzanine level. This is due to having a bus terminal located on the ground floor since and the owner wanted an open feeling for the mezzanine level. Second, the weight of the building should be at a minimum since the soil located on the site is considered poor. These two considerations lead to the use of the post-tension floor system and above average column sizes throughout the entire building.

From Author's View:

While the author agrees with the concerns the design firm came up with for the expansion to Union Station, another issue should have been addressed as well. While trying to create a building expansion that was cost-savings and fit within the two major concerns, there was no major attempt to create a signature expression for the expansion to Union Station. The author believes that even though the glass curtain wall of the existing structure stands out as an expression of architecture, the expansion to Union Station should have its own architecture feature since it is own building as well.

THESIS CRITERIA GOALS

Using the areas of concern from the design firm as well as the author's own point of view, the following criteria was established in order to complete the over goals of this thesis.

1.) Redesign floors mezzanine through third with a new structural system.
2.) Design a one of a kind transfer level that is located on the ground floor while incorporating the style of the king post truss.
    a. While the trusses act as the transfer system, create an architectural expression with the trusses by using different shapes and connections that show the trusses were solely made of the expansion to Union Station.
    b. Ignore the cost of how much the custom trusses and new floor system will cost since the author believes how important it is to have an architectural expression.
3.) Incorporate brace frames as the new lateral system for the expansion to Union Station.
4.) Verify the foundation of Union Station can support the new structure.
5.) Determine the vehicular circulation of the buses will not be affected by the truss designs.
6.) Incorporate the waiting/lobby area on the ground floor with the architecture of the trusses.
7.) Incorporate two new lighting layouts:
    a. Create a custom lighting scheme that will now only illuminate the trusses but highlight them to looking aesthetically pleasing.
    b. Replace the existing luminaries within the bus terminal with new, energy efficient ones.

All seven goals will be attempted by the author in order to give the expansion to Union Station not only to meet the goals of the owner, but to make the people who work and step into the expansion remember the one of a kind structural and architectural feature.

STRUCTURAL DEPTH

Location of Trusses:

Before any redesigning of the upper levels was started, the first task at hand was to determine where the transfer trusses would be placed on the ground floor. Keeping in mind there will be buses traveling and parking on the ground level, the trusses had to be placed where there would be minimal impact. The author concluded the best location for the trusses would be where the existing columns are located on the ground floor. Figure 3 below indicates where the king post trusses would be located (blue lines indicate the trusses while the red line represents the expansion joint).

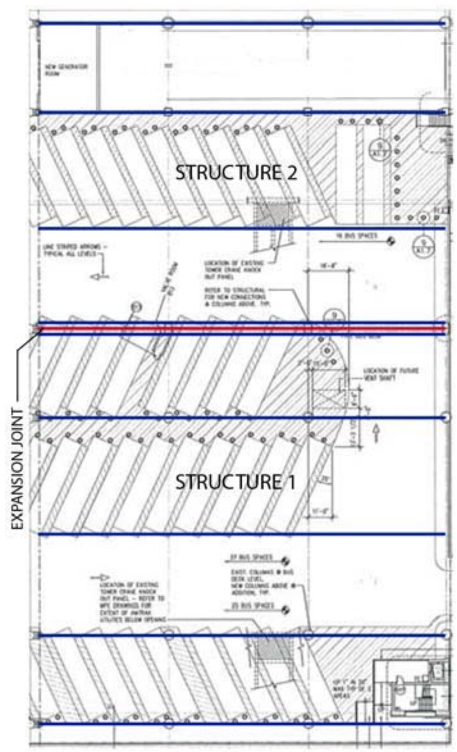


Figure 3: Location of Transfer Trusses on Ground Floor

Five trusses would be located within Structure 1 of the expansion to Union Station and four would be in Structure 2. Each truss would span the north-south length of the building which is 189’-0” and would be a height of 18’-0”. Visual inspection of Figure 3 shows that some of the trusses will be located where buses must turn and park (Refer to the Architectural Breadth portion). Since the location of the king post trusses has been determined, the next step was to design a new structural floor system for the mezzanine level through the third floor.

Composite Steel Floor System [Preliminary Sizes]:

Since one of the major concerns for the expansion for Union Station was having large open floor plans on the ground and mezzanine level, the design team that created the building decided to keep the open plan on each level. On the upper floors however, a large open space is not necessarily required since there is only office space and parking. The author believes the use of a composite steel floor system is a valuable alternative structural gravity system to the post tension slab. A composite system not only can provide long spans, but also can reduce the slab thickness as well giving each level a higher floor to ceiling height.

Starting with the existing floor plans, a new column grid and beam layout for the gravity system was created. Figure 4 on the right shows a typical plan for levels one through three and the roof as well. In the north-south direction of the expansion, each column is spaced at 31'-6" while there are multiple spans in the east-west direction (49'-0" is the longest span for the east-west direction for both structures). Since the mezzanine level is shorter in length in the east-west direction, the only difference in the layout is the short span of 20'-0" located at the very top of structure two (Refer to Figure 5 for a visual representation). To view each typical floor with column markers, see Appendix A, Figures 1 & 2.

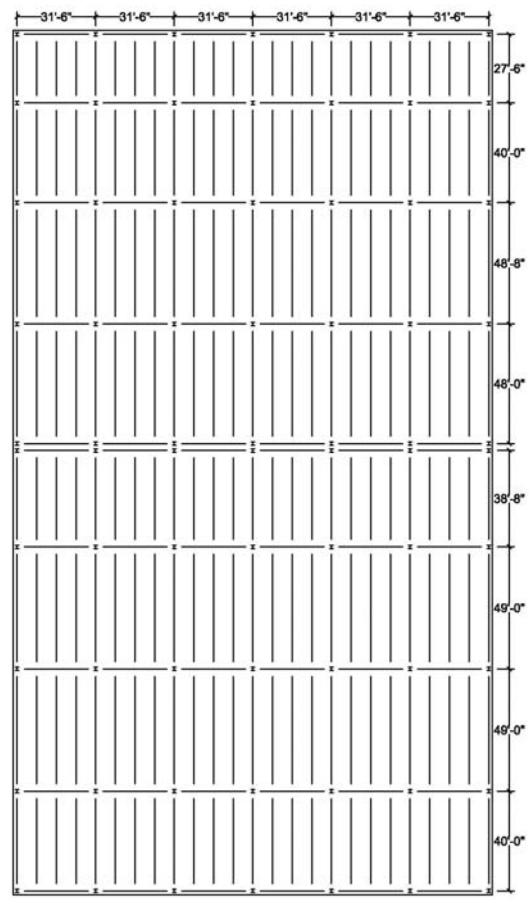


Figure 4: Composite System (Levels 1 -Roof)

The first step the author took in designing each beam and girder for the gravity system was determining the required loads for each floor per structure. Table 1 on page 13 of this report shows the dead and live loads used in accordance with ASCE 7-05. For this thesis project, no live load reductions were taken into account.
The author wanted to calculate the worst case scenario.

Each beam and girder for levels mezzanine to the roof was designed by hand using LRFD in conjunction with a calculation method learned in the advanced steel design course at The Pennsylvania State University. The bay size of 31'-6" x 49'-0" will be used as the example throughout this portion of this thesis as a guide to show the process of how the final members were selected.

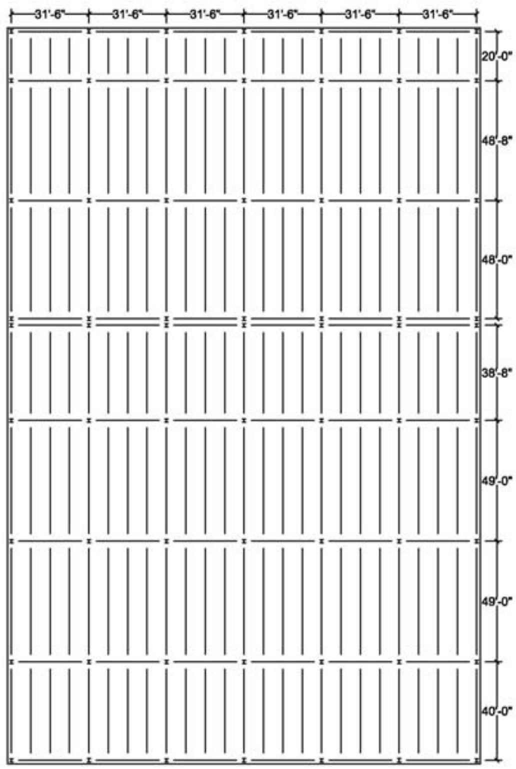


Figure 5: Composite System (Mezzanine Level)

DEAD LOADS						
Level	Roof	3	2	1	Mezzanine	Ground
Light Weight Concrete	110 pcf	110 pcf	110 pcf	110 pcf	110 pcf	110 pcf
Steel	490 pcf	490 pcf	490 pcf	490 pcf	490 pcf	-
M.E.P.	10 psf	10 psf	10 psf	10 psf	10 psf	10 psf
Finishes & Misc.	5 psf	5 psf	5 psf	5 psf	5 psf	5 psf

LIVE LOADS						
Level	Roof	3	2	1	Mezzanine	Ground
Landings	100 psf	100 psf	100 psf	100 psf	100 psf	100 psf
Lobbies	-	-	100 psf	100 psf	100 psf	100 psf
Mechanical	-	-	-	-	-	150 psf
Office	-	-	50 psf	50 psf	50 psf	-
Parking	50 psf	50 psf	50 psf	50 psf	-	-
Partition	-	-	10 psf	10 psf	10 psf	-
Stairs	100 psf	100 psf	100 psf	100 psf	100 psf	100 psf

Table 1: Gravity Loads from ASCE 7-05

Before the beams and girders were designed, a metal deck had to be selected for the composite steel floor system. Using the Vulcraft Steel Roof & Floor Deck catalog, a 2VLI16 metal deck with a 4.25" thick concrete slab was selected giving the total thickness to be 6 ¼" . Since original post-tension slab on the mezzanine to the roof was 7 ½", the floor thickness of the expansion of Union Station was increased by 1 ¼". Lightweight concrete was selected for the slab to help reduce the overall weight of the building and since the intermediate beams are spaced at 7'-10½" which is less than the maximum spacing of 12'-6" (To view the criteria designated to select the 2VLI16 metal deck can be found in Appendix B, Figure 1). The metal deck will span in the north-south direction of the expansion to Union Station, which is indicated by the arrow located on Figure 6.

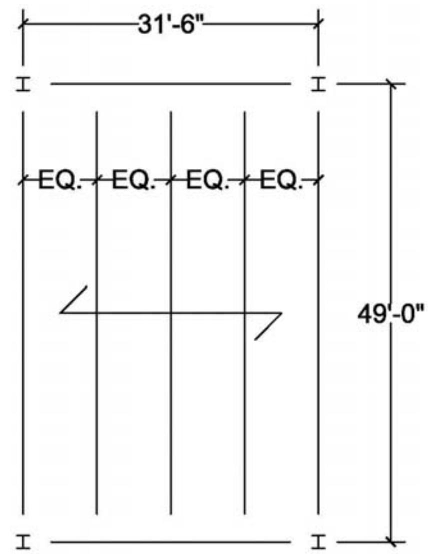


Figure 6: 31'-6" x 49'-0" Bay

Running in the 49'-0" direction of Figure 6 (See above) are the beams and the girders are the members that are 31'-6". The author selected members that would meet the construction, live load, and total deflection criteria set by the American Institute of Steel Construction (AISC). Using partial composite design, the number of shear studs required to transfer the loads from the concrete to the steel members was calculated as well by the requirements by AISC. Table 2 below shows the beam and girder member sizes calculated. To view the calculations for the beams and girders located in Table 2, see Appendix B, Calculations 1 through 10.

31'-6" x 49'-0" Interior Bay Beams: Strucutre 1 [Preliminary Calculations]					
Level	Roof	3rd	2nd	1st	Mezz.
Member	W24x55 <40>	W21x55 <24>	W21x55 <24>	W21x55 <24>	W21x55 <24>
31'-6" x 49'-0" Interior Bay Girders: Strucutre 1 [Preliminary Calculations]					
Level	Roof	3rd	2nd	1st	Mezz.
Member (G)	W24x94 <42>	W24x94 <42>	W24x94 <42>	W24x94 <42>	W24x94 <42>
Member (H)	W24x76 <46>	W24x76 <46>	W24x94 <42>	W24x94 <42>	W24x94 <42>

Table 2: Preliminary Typical Beam & Girder Sizes

Composite Steel Floor System [RAM]:

Using the same loads from Table 1, dimensions for bays in Figures 4 & 5 and now having the openings in the plans for the stairs and elevators, RAM Structural System was used to calculate the composite members to determine what sizes will be used. Figure 7 is the plan used for the roof, third, second, and first floor plan while Figure 8 is the plan for the mezzanine level. The location of the stairs and elevators are not the same as the existing expansion to Union Station. For more details on why the author moved some of their locations, refer to the Architecture Breadth portion of this thesis located on page 32.

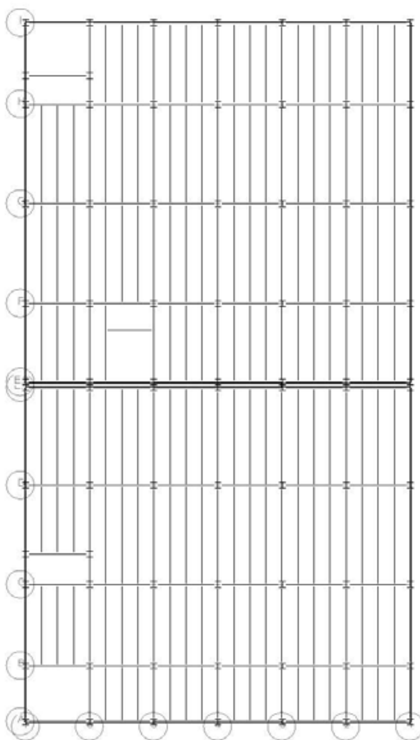


Figure 7: Roof, Third, Second, First Floor Plan

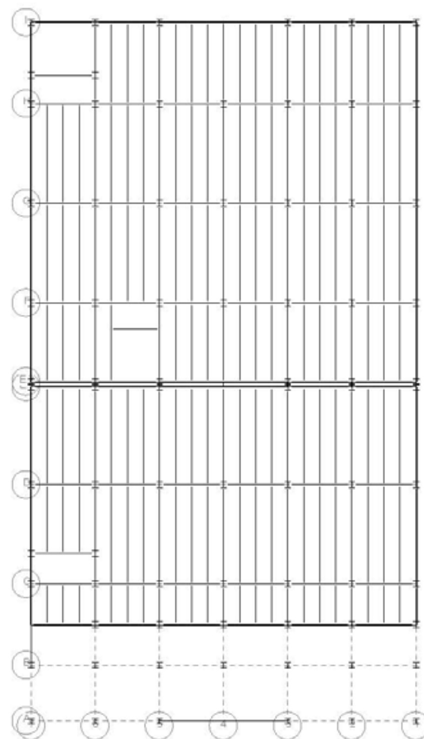


Figure 8: Mezzanine Floor Plan

After inputting all the loads, including a wall load of 35 psf, RAM Structural System was used to determine the member sizes and number of shear studs for both the composite beams and girders. Using the same interior as the one in the preliminary size section of the structural depth, Table 3 shows the sizes RAM determined were adequate for the expansion to Union Station.

31'-6" x 49'-0" Interior Bay Beams: Strucutre 1 [RAM]					
Level	Roof	3rd	2nd	1st	Mezz.
Member	W18x40 <53>	W18x40 <26>	W18x40 <40>	W18x40 <40>	W18x40 <40>
31'-6" x 49'-0" Interior Bay Girders: Strucutre 1 [RAM]					
Level	Roof	3rd	2nd	1st	Mezz.
Member (G)	W27x84 <48>	W27x84 <38>	W27x84 <38>	W27x84 <38>	W27x84 <38>
Member (H)	W24x76 <66>	W24x76 <34>	W24x76 <48>	W24x76 <48>	W24x76 <48>

Table 3: RAM Beam & Girder Sizes

Comparing the preliminary sizes to the ones calculated by RAM, one can see the beams used in RAM are smaller and lighter than the ones in the preliminary section. The reason for this is RAM used fully composite design instead of partial (as the author used in the hand calculations). Also, the RAM members have a larger camber than the members done by the author. The W18x40 beams have a camber of 2 ¼" while the W21x55 only have a ¼" camber. Since determining whether having a larger camber would cost more than a deeper and heavier beam was not part of this thesis, the author will use the beam sizes that were determined by RAM since they are smaller in depth and lighter in weight.

For the girders, the sizes are almost identical except the members in the G column line are deeper and heavier in RAM than the preliminary sizes. Since RAM could have another method of deterring the girders, the author will accept the values from RAM and use them as the final members for the expansion to Union Station.

Columns on Mezzanine through Third Floor:

After the beams and girders were designed in RAM, the columns that will transfer the gravity loads from each level had to be determined. RAM Structural System was used to calculate the member sizes for the columns. Looking at the same interior bay used as the example in this portion of this thesis (Figure 6 located on page 14), Table 4 on the following page shows the sizes of the columns used along grid lines G and H.

Column Line G				
Level	3rd	2nd	1st	Mezzanine
Member	W14x61	W14x82	W14x109	W14x132
Interaction	0.68	0.85	0.82	0.91
Column Line H				
Level	3rd	2nd	1st	Mezzanine
Member	W14x53	W14x74	W14x99	W14x176
Interaction	0.83	0.85	0.82	0.61

Table 4: Member Sizes along Grid Lines G & H

Location of Trusses [Additional Discussion]:

Once the composite steel gravity system was designed, the author went back to make sure where the original locations of the trusses were would line up with the proposed new column line. After investigating the floor plans, the trusses are directly below each column line of the composite steel system. Placing the trusses below the column makes the transfer system much more efficient. Figure 9 shows the trusses (blue hatching symbol) on top of the column line (black solid squares).

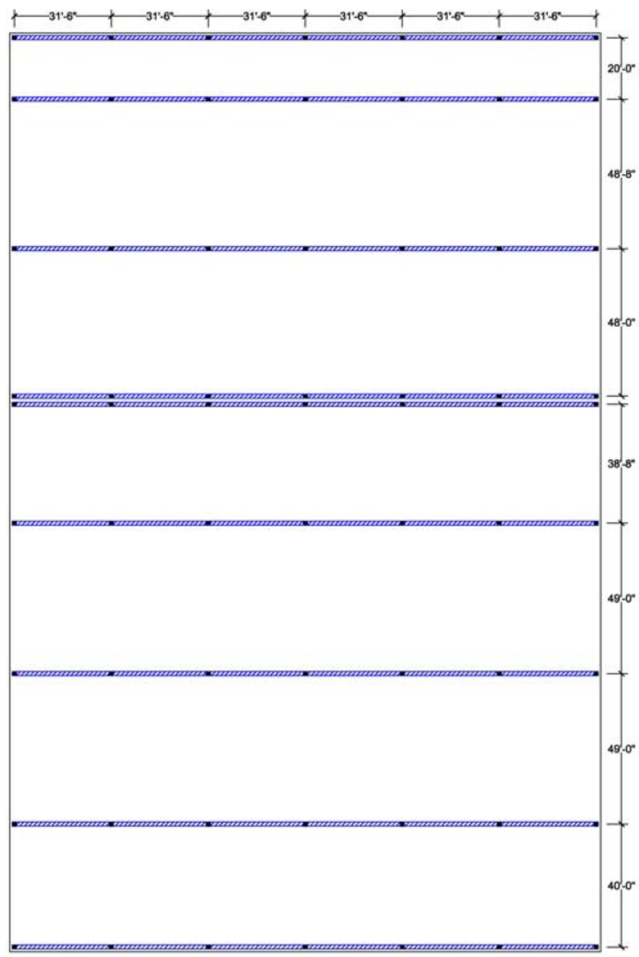


Figure 9: Column Line over Location of Trusses

Forces within Truss Members:

Before continuing on with the truss portion of this thesis, the author would like to make a statement to the reader. Since this portion of the thesis deals with the structural analysis of the trusses, all the architectural criteria the author used can be found within the Architectural Breadth portion. Also, since there is a total of nine trusses being designed for the expansion to Union Station, the author will use only two throughout this portion of the thesis because they are all similar to each other. It should be noted that all trusses were designed by the author. Truss 1 and 2, which is noted on Figure 10, will be the designated trusses used.

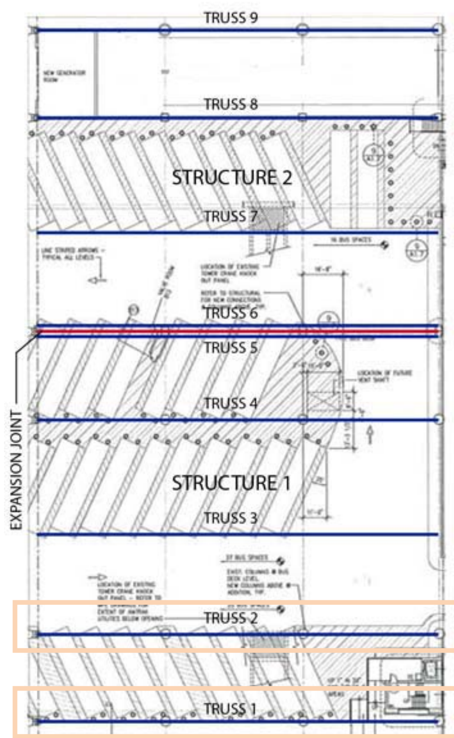


Figure 10: Location of Truss 2

To begin determining the forces within each truss member, the loads acting on the trusses from the four levels above the ground floor had to be resolved. Using RAM Structural, the point loads from Table 5 were figured from the columns on the mezzanine level. By inspection of the values from Table 5, the forces that are acting upon Truss 2 are significantly large. This makes sense because there are four levels the trusses must support and transfer the loads down to the track level then to the foundation.

Truss Point Loads Within Structure 1							
Truss 1							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	337.90	578.80	578.80	578.80	578.80	307.83	72.64
Truss 2							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	669.69	1125.06	1125.06	1125.06	1125.06	835.23	388.98
Truss 3							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	739.67	1186.48	1186.48	1186.48	1186.48	1186.48	739.67
Truss 4							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	900.71	2115.88	2115.88	2115.88	2003.01	2044.84	900.71
Truss 5							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	300.22	501.36	501.36	501.36	302.57	381.97	300.22

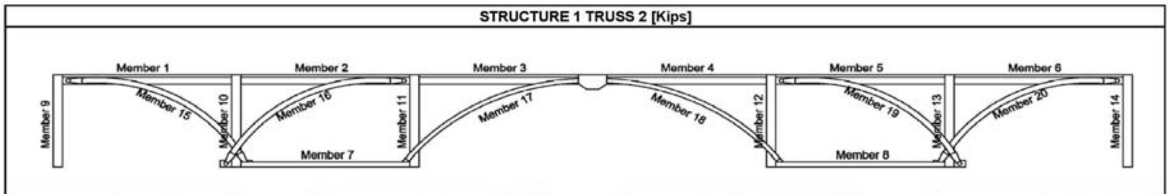
Truss Point Loads Within Structure 2							
Truss 6							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	372.47	622.94	622.94	622.94	622.94	622.94	372.38
Truss 7							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	728.85	1169.08	1169.08	1169.08	1169.08	1056.81	613.60
Truss 8							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	667.22	1120.94	1120.94	1120.94	1120.94	761.28	320.18
Truss 9							
Column Line	1	2	3	4	5	6	7
Loads (Kips)	48.78	72.17	72.17	72.17	72.17	72.17	48.78

Table 5: Loads to Trusses From Above Levels

Using the loads from Table 5, a detailed spread sheet was used to determine the forces within each member for the trusses as well as the support reactions from the columns located on the track level. In addition to the spreadsheet, STAAD Pro was used to verify the forces in the members as well as the reaction values. Since the members for the trusses are unknown as well as the area, the author inputted a one square foot area in STAAD, the values came out to be within 1% of the spreadsheet calculations. To view the spreadsheet and STAAD Pro report of Truss 2, turn to Appendix C, Calculations 1 through 13.

Table 6 below shows the forces within each member of Truss 2. The reader should realize the image used is not the final image of the truss used, but as the design at the time when the loads were determined (See the Architectural Breadth of the thesis to learn more about the design of the trusses). After each load in Table 6 are the directions how the loads act within the members. Tension is represented as [T] and [C] means compression.

STRUCTURE 1 TRUSS 2 [Kips]

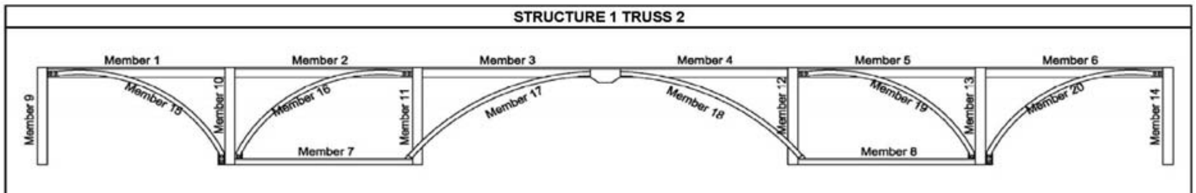


Member 1	860.13 [C]	Member 6	634.45 [C]	Member 11	1759.81 [C]	Member 16	1280.73 [T]
Member 2	860.13 [C]	Member 7	253.38 [T]	Member 12	1598.63 [C]	Member 17	1171.56 [C]
Member 3	253.38 [C]	Member 8	196.32 [T]	Member 13	835.23 [C]	Member 18	1093.17 [C]
Member 4	196.315 [C]	Member 9	1160.00 [C]	Member 14	750.64 [C]	Member 19	956.32 [T]
Member 5	634.45 [C]	Member 10	1125.06 [C]	Member 15	990.06 [T]	Member 20	730.29 [T]

Table 6: Loads in Truss 2 Members

Determination of Preliminary Member Sizes for Trusses:

STRUCTURE 1 TRUSS 2



Member 1	WT15x130.5	Member 6	WT15x130.5	Member 11	W14x176	Member 16	(2) HSS10x0.50
Member 2	WT15x130.5	Member 7	W16x31	Member 12	W14x176	Member 17	(2) HSS10x0.50
Member 3	WT15x130.5	Member 8	W16x31	Member 13	W14x176	Member 18	(2) HSS10x0.50
Member 4	WT15x130.5	Member 9	W14x176	Member 14	W14x176	Member 19	(2) HSS10x0.50
Member 5	WT15x130.5	Member 10	W14x176	Member 15	(2) HSS10x0.50	Member 20	(2) HSS10x0.50

Table 7: Preliminary Sizes for Truss 2

Following the criteria set by AISC, the author used the thirteenth edition of the steel to determine the preliminary sizes of the member for the king post trusses. Each column and top chord of each truss was selected using Part 4 of the manual by taking the un-braced length in the y-axis and making sure $\Phi P_n \geq P_u$. Since both the columns and top chords are in compression, Part 4 of the manual looks at members in compression. Both bottom chords were determined by using Part 5 of the manual since this part looks at members in tension. For the four curved bracing members in tension (Members 15, 16, 19, & 20), the preliminary sizes were selected from Part 1 of the manual by calculating the required I needed for the load then looking up a member that had a greater I. The two bracing members in compression were determined by the same method as the bracing members in tension. Table 7 shows the preliminary member sizes selected for Truss 2. A variety of shapes were selected for the trusses, which is explained in the Architectural Breadth of this thesis. To view the calculations for determining the preliminary sizes in Truss 2, refer to Appendix D, Calculations 1 through 7.

Curved Tension Members In Trusses:

Using curved tension members in the trusses, each one must be looked at to make sure that the moment created by the forces within the member will not cause the shape to go into a compression state. Taking the preliminary HSS sizes, the author created the curved members within STAAD. By making twenty-six increments along the radius of the arced shape as Figure 11 shows on the left, this allows to examine where the maximum moment will occur.

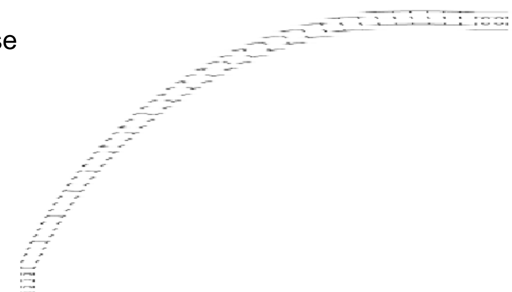


Figure 11: Segments Used For Tension Members

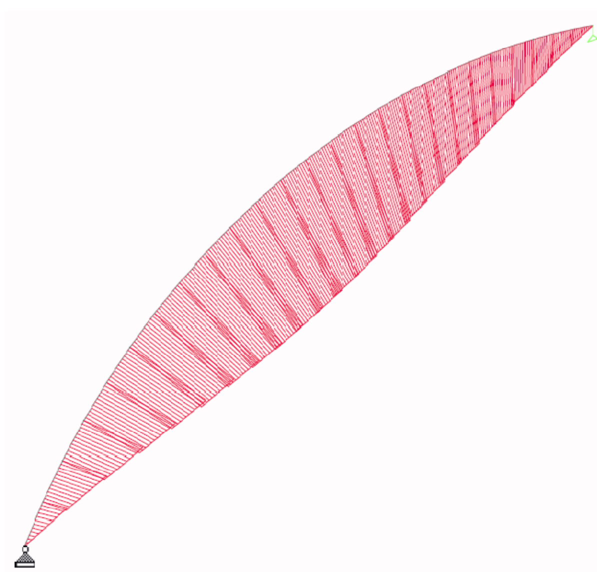


Figure 12: Moment within Tension Member 19

Once each section off the HSS members was modeled in STAAD as well as the forces causing the member to be in tension, an analysis was run on the worse tension member in Truss 2 which is Member 19. The reason for doing the worst case scenario is if the selected HSS member passes, then each tension chord in Truss 2 will pass as well. Figure 12 on the left shows the moment diagram created by the member after the analysis was done it STAAD. One can see how the moment diagram is the shape of a parabola acting in compression. This shows how the moment wants to cause the member to bend into a compression due to tension.

A closer inspection of the STAAD results also shows that the maximum moment occurs within the eleventh segment from the pin connection at the bottom of the member, which can be viewed in Appendix E. To determine the reaction force, R, the maximum moment was divided by the lever arm in the y-direction (Refer to Figure 13). This determined the force within the x-direction (R_x) and taking this value and dividing it by the angle created by the two ends points of the member, 30°, the value R is determined.

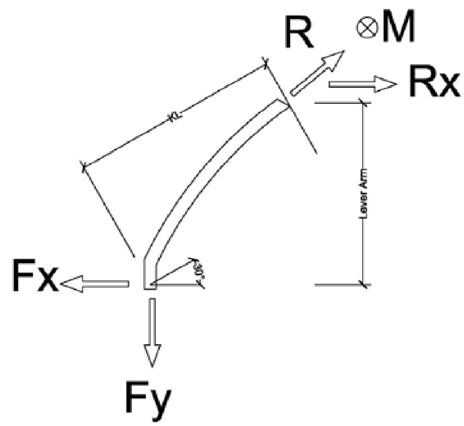


Figure 13: Determination of R

Going into the AISC Steel Manual and using Table 4-5, the ΦP_n can be determined by using the KL length where R is located. For Member 19 of Truss 2, the un-braced length is 23.42 ft and after interpolation within Table 4-5, ΦP_n comes out to be 343 Kips which is greater than 313 Kips for R. Therefore the preliminary size HSS10.0x0.500 can be used for the curved tension member throughout Truss 2. To view the calculations for ΦP_n, turn to Appendix E, Calculation 1.

Lateral Resisting System:

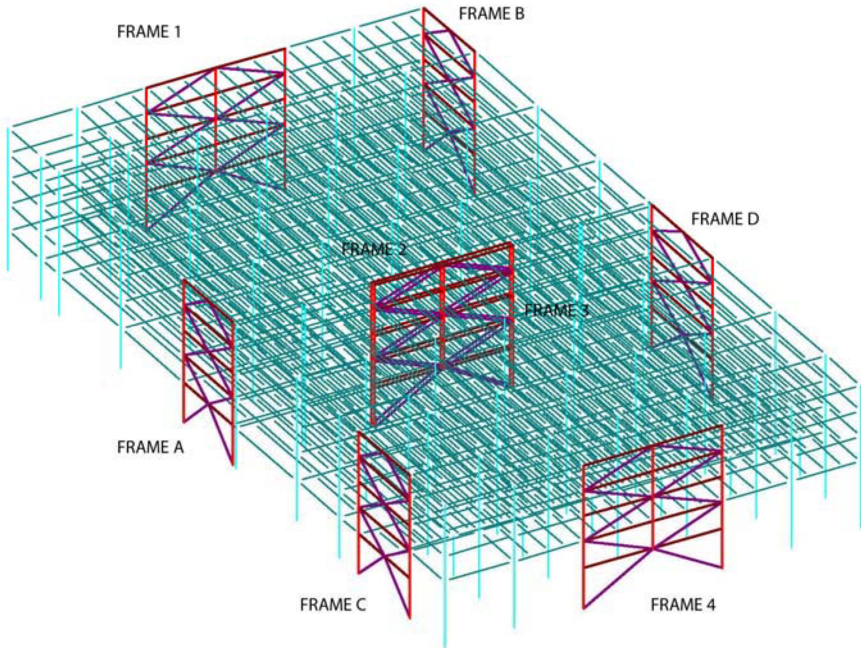


Figure 14: Isometric View of Lateral Resisting System

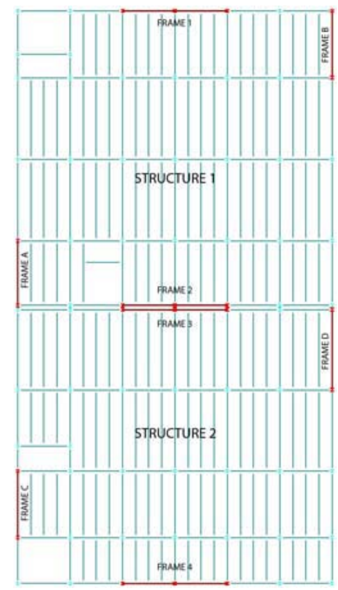


Figure 15: Plan View of Brace Frames

With a composite steel floor system being used instead of the post-tension system, a new lateral system was incorporated into the expansion of Union Station. Steel brace frames with a response modification factor (R) of 3.25 were selected to replace the existing concrete moment frames (R =3). A total of eight brace frames, four in each structure (two in the north-south direction as well as the east-west), were placed within the expansion. Figure 15 shows the frames in plan view and Figure 14 above shows an isometric view of the expansion to Union Station. From Figure 14, the bottom of the columns is where the ground floor is located. Therefore the ground level and the brace frames is shown in the view. One can then observe from Figure 10 (Page 18) that Frames 1, 2, and 3 are part of Trusses 1, 2, and 6. Each of the trusses with the brace frames as part of them as well as the remaining five frames had to be analyzed to determine if each frame can withstand the forces from wind and seismic. For this portion of the report, Frame 1 which is part of Truss 1 will be looked at in depth. All other Frame calculations can be found in Appendix F.

Selecting preliminary sizes that the author believed could withstand the lateral forces were modeled in RAM Frame and then the members that were undersized were replaced with members that met design requirements. After getting the member sizes for the frames, the author used SAP2000 to determine the required stiffness for each frame. Figure 16 shows the member sizes selected for Truss 1 and Frame 1. Within the truss, the two braces on the ground floor are W14x257. Since these members have to carry both gravity and lateral loads, this is the reason for having such heavy members. Going up the brace frame, the majority of the braces are W14x99. The author wanted to keep the same shape as much as possible throughout Frame 1 and all the others. Going down each level, the columns increase in weight to take more loads from the level above them.

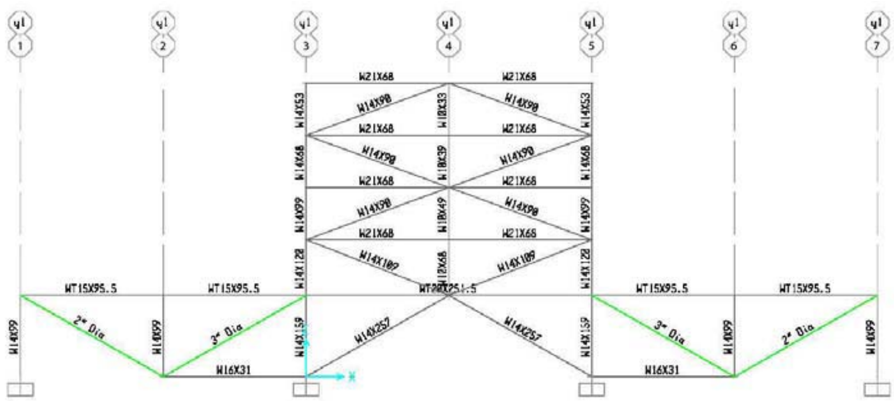


Figure 16: Member Sizes for Brae Frame 1

After the relative stiffness of each frame was determined, center of rigidity, direct, torsional, and net forces due to wind and seismic loads were calculated using RAM and also by hand as well. To understand what each of the previously mentioned definitions are, review technical report three written by the author. All calculations regarding the definitions are located within Appendix F.

Once the net forces due to wind and seismic were determined, each load for both forces was placed on each frame in SAP. Then each frame was analyzed one at a time to verify the serviceability of each frame. Tables 8 and 9 on the following page represent the allowable drift criteria for each floor and the entire expansion as well as the calculated drifts done by SAP. Looking at both tables, one can see that the seismic drift controls from the roof to the first level and the mezzanine level drift is controlled by the wind. These results are almost identical to what was happening in the expansion to Union Station when the ordinary concrete moment frames were being used. Since the response modification factor difference is 0.25 between the two systems, the values obtained are reasonable.

Controlling Wind Drift: Frame 1									
Story	Story Height (ft)	Story Drift (in)	Allowable Story Drift (in) D_{wind} = H/400			Total Drift (in)	Allowable Total Drift (in) D_{wind} = H/400		
Roof	11.500	0.041	<	0.345	Acceptable	0.509	<	1.94	Acceptable
3rd	11.500	0.049	<	0.345	Acceptable	0.468	<	1.595	Acceptable
2nd	11.500	0.140	<	0.345	Acceptable	0.419	<	1.25	Acceptable
1st	12.250	0.150	<	0.368	Acceptable	0.278	<	0.905	Acceptable
Mezzaine	17.917	0.129	<	0.538	Acceptable	0.129	<	0.5375	Acceptable

Table 8: Controlling Wind Drift for Frame 1

Controlling Seismic Drift: Frame 1									
Story	Story Height (ft)	Story Drift (in)	Allowable Story Drift (in) $D_{SEISMIC} = 0.020h_{sx}$			Total Drift (in)	Allowable Story Drift (in) $D_{SEISMIC} = 0.020h_{sx}$		
Roof	11.500	0.129	<	0.230	Acceptable	0.738	<	1.293	Acceptable
3rd	11.500	0.140	<	0.230	Acceptable	0.609	<	1.063	Acceptable
2nd	11.500	0.201	<	0.230	Acceptable	0.469	<	0.833	Acceptable
1st	12.250	0.189	<	0.245	Acceptable	0.269	<	0.603	Acceptable
Mezzaine	17.917	0.080	<	0.358	Acceptable	0.080	<	0.358	Acceptable

Table 9: Controlling Seismic Drift for Frame 1

Truss Connections [M.A.E. Criteria]:

Each of the nine trusses has twenty-six connections that are required for the selected geometry and all twenty-six connections are made up of three types; pin, heavy brace, and gusset plate. A majority of the connections are made up of pin connections from the braces within the truss as well as the top and bottom chords. The heavy brace connections are located on the three trusses that are part of the lateral system and the gusset plate connections are locate at the top in the middle of each truss. Figure 17 shows the location of each type of connections on the two different styles of trusses (Blue is Pin, Green is Heavy Braced, & Red is Gusset Plate). For this report, the typical pin connection for the tension members and the heavy brace members will be looked at.

Each of the pin connections for the tension members were designed based on the criteria set by AISC. Since there is a significant load within the members, each steel plate is A992. This is to keep the size and the thickness of each plate reasonable. For exterior trusses (Truss 1, 5, 6, & 9), a single bolt pin connections was used for the rods and a two bolt pin connection was used for the interior connections (Figures 18 & 19 show a visual of each plate). The reason for using two pins in the exterior trusses is the load on a single pin makes the diameter significantly large. Therefore using two smaller pins makes the connection look more aesthetically appealing. Dimensions a and b from Figures 18 & 19 are the minimum distance from the edge of the plate to prevent and failure from occurring. One can view the calculations for all the plates for each truss in Appendix H, Calculations 1 through 9 and Table 10 on page 26 summarizes the plates and pins used for Trusses 1 & 2.

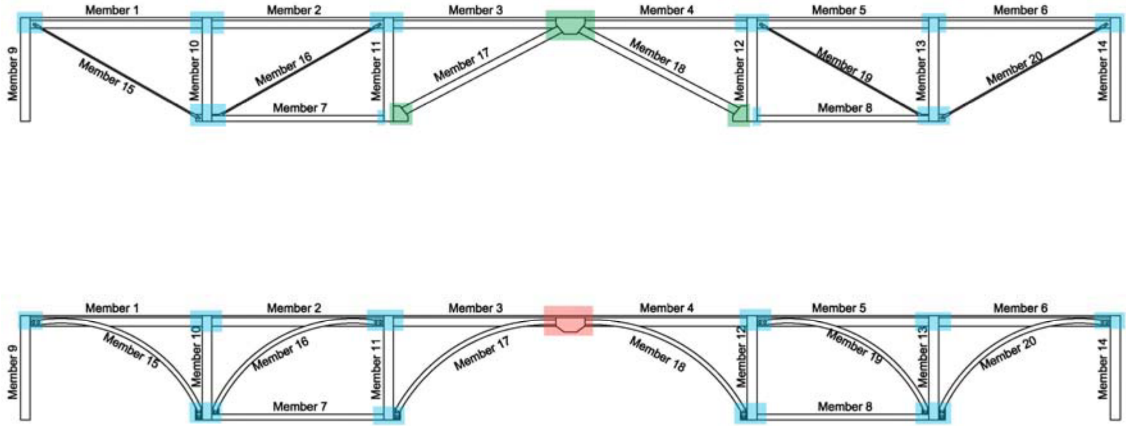


Figure 17: Types of Connections

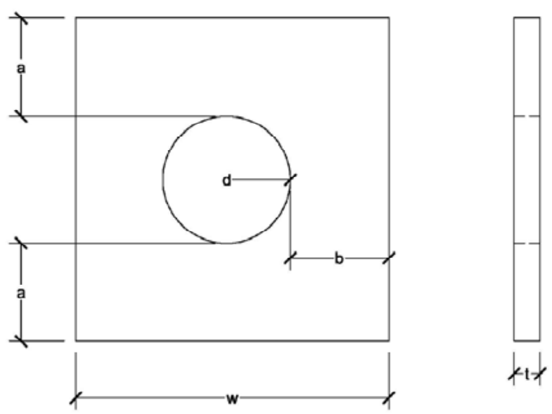


Figure 18: Single Pin Plate Design

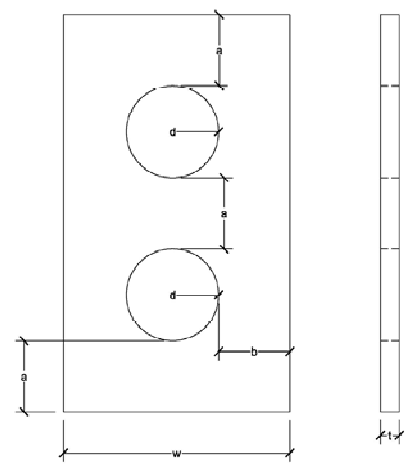


Figure 19: Double Pin Plate Design

Truss 1						Truss 2				
Member	15	16	19	20		Member	15	16	19	20
w (in)	10	10.5	10.5	10		w (in)	14	14.5	14	14
t (in)	1.125	1.25	1.25	1.125		t (in)	1.5	1.75	1.5	1.5
d_{pin} (in)	4	4	4	4		d_{pin} (in)	(2) 3	(2) 3	(2) 3	(2) 3

Table 10: Dimensions & Pin Sizes for Trusses 1 & 2

All pin plates will be connected to the columns web by using two welds along on the perimeter of the plate. Welds were used instead of bolts because the width of the plate should be at a minimum to prevent any trouble with the busses traveling near. Figure 20 on the left shows how the plates are connected to the columns of the trusses with. Each weld was designed by using Table 8-6 from AISC Steel Manual because the loads are coming in at an angle of sixty degrees off the vertical. Since the load is located at the center of the plate (Figure 21), there is no eccentricity from the load therefore the value of a within Table 8-6 is zero. Each plate weld calculation can be found in Appendix H, Calculations 10 through 18 and Table 11 below shows the size of the weld for Trusses 1 and 2.

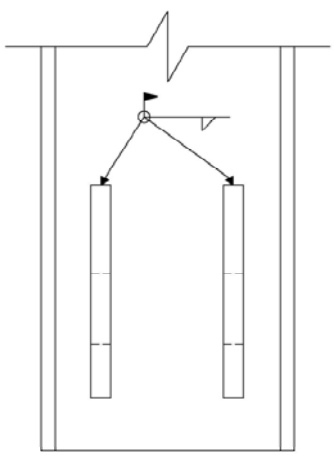


Figure 20: Weld Symbols for Plates

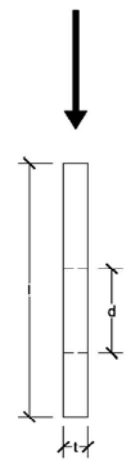


Figure 21: Location of Load

Truss 1						Truss 2				
Member	15	16	19	20		Member	15	16	19	20
Weld	Fillet	Fillet	Fillet	Fillet		Weld	Fillet	Fillet	Fillet	Fillet
Electrode	E70XX	E70XX	E70XX	E70XX		Electrode	E70XX	E70XX	E70XX	E70XX
t (in)	7/16	8/16	4/16	4/16		t (in)	9/16	11/16	9/16	7/16

Table 11: Weld Sizes for Trusses 1 & 2

All but two of the welds are fillet welds. Members 16 and 19 in Truss 4 have full penetration welds because the actual size of a fillet weld exceeds 1 inch and it is around the same cost for a fillet weld over 1 inch and a full penetration weld.

The second type of connection being looked at in this thesis is a heavy brace connection on Truss 1 which acts as part of the lateral system. To prevent any moment from occurring within the connection, the Uniform Force Method was used. Figure 22 shows the location as where the forces for the column and the beam would be located at on the plate. Since there is no beam required, due to the bottom chord at the location is a zero force member, and the connections is being attached to the column web, the only two forces acting are the shear in the column and the pull out force need in a beam. Therefore a WT7x41 was selected to handle to horizontal force from the connection.

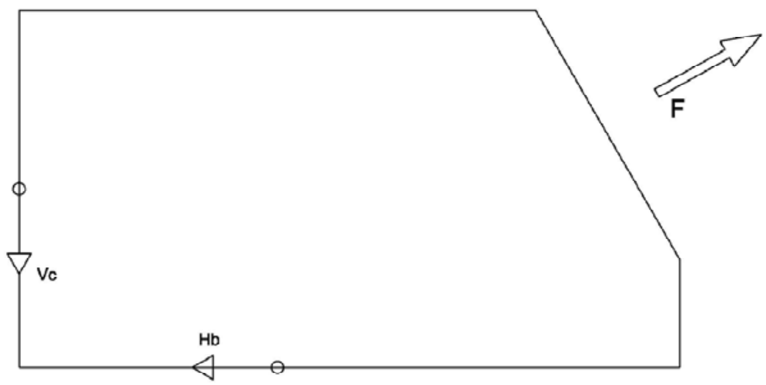


Figure 22: Column and Chord Force Distribution in Plate

All limit states for each portion of the connection were taken into detail for the heavy brace connection. On the following page of this thesis is a detailed drawing of what members, bolts, welds, and dimensions are required for brace member 17 for Truss 1. All calculations for this connection can be found in Appendix H, Calculations 19 through 22.

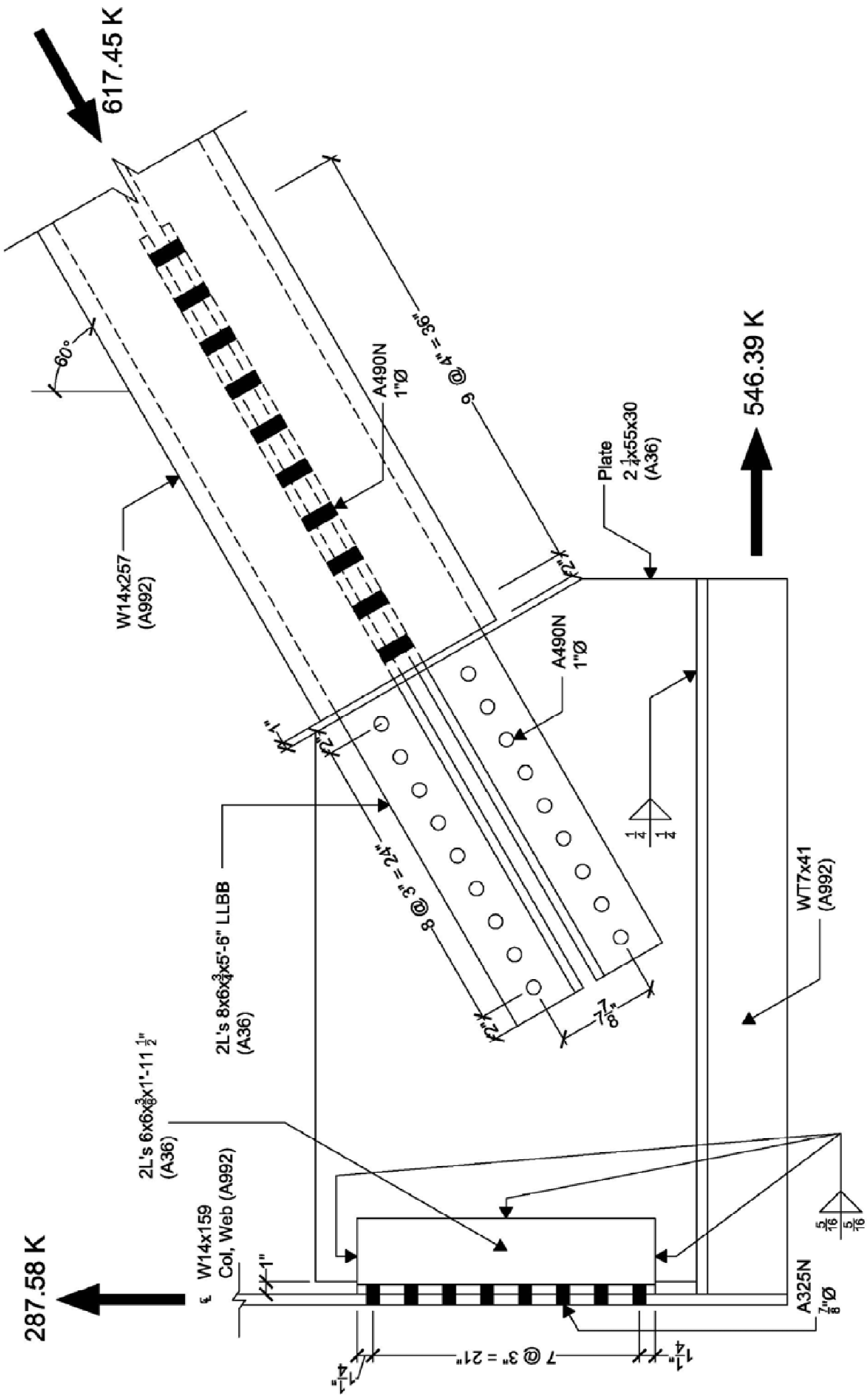
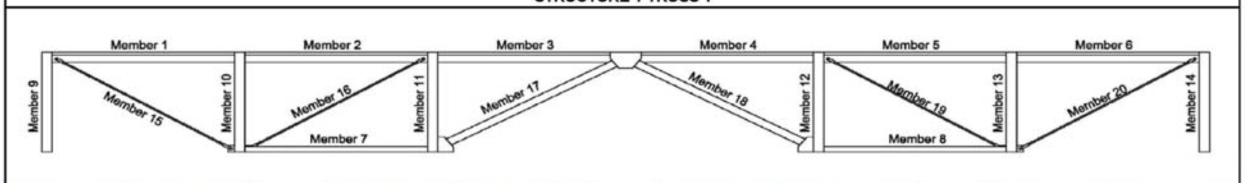


Figure 23: Detailed Connection of Heavy Brace Member

Final Members for Trusses:

After taking all the loads from the upper levels, figuring out the forces that act in all the members, performing lateral analysis, designing the connections, Table 12 and 13 shows the final members used for both Trusses 1 and 2. Appendix I, Tables 1 through 9 show all nine members with their final member sizes. As stated previously in this report, refer to the Architecture Breadth to understand why the two trusses were designed as they are.

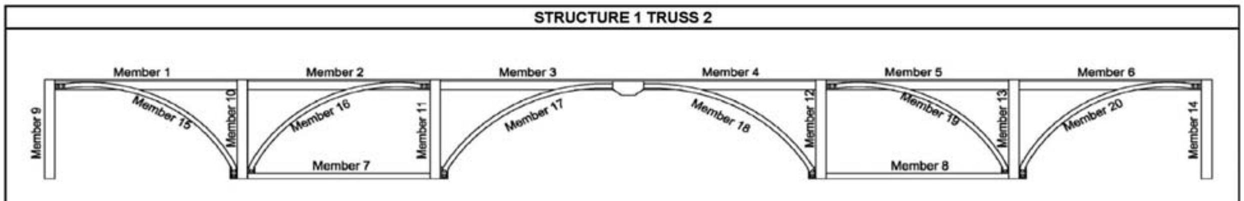
STRUCTURE 1 TRUSS 1



Member 1	WT15x95.5	Member 6	WT15x95.5	Member 11	W14x159	Member 16	(2) 3" Dia. Rod
Member 2	WT15x95.5	Member 7	W16x31	Member 12	W14x159	Member 17	W14x257
Member 3	WT20x251.5	Member 8	W16x31	Member 13	W14x99	Member 18	W14x257
Member 4	WT20x251.5	Member 9	W14x99	Member 14	W14x99	Member 19	(2) 3" Dia. Rod
Member 5	WT15x95.5	Member 10	W14x99	Member 15	(2) 2" Dia. Rod	Member 20	(2) 2" Dia. Rod

Table 12: Final Members for Truss 1

STRUCTURE 1 TRUSS 2



Member 1	WT15x130.5	Member 6	WT15x130.5	Member 11	W14x176	Member 16	(2) HSS10x0.50
Member 2	WT15x130.5	Member 7	W16x31	Member 12	W14x176	Member 17	(2) HSS10x0.50
Member 3	WT15x130.5	Member 8	W16x31	Member 13	W14x176	Member 18	(2) HSS10x0.50
Member 4	WT15x130.5	Member 9	W14x176	Member 14	W14x176	Member 19	(2) HSS10x0.50
Member 5	WT15x130.5	Member 10	W14x176	Member 15	(2) HSS10x0.50	Member 20	(2) HSS10x0.50

Table 13: Final Members for Truss 2

Foundation Verification:

Since the soil at the site for the expansion to Union Station is considered weak (Refer to Foundation Section of Existing Structural System), making sure the foundation can withstand the change from post-tension concrete to steel is important. The change of systems works as one can see from Table 14 on the following page. There is one area where there is a problem and that is located at Truss 4. The *b* designed succeeds the allowable area to put a square footer. One possibility to correct this is to have a different system as the foundation. Since the research and development of a new foundation system was not part of this thesis due to the time restriction the author had.

The second check for the foundation done was making sure overturning was not a problem. Table 15 on page 31 shows that overturning moment is not an issue to Union Station. The two checks done on the foundation verify that this new system can work on the site for the expansion to Union Station.

Spot Checks On Foundation: Structure 1				
Grid Line: Truss 1				
Member	9	11	12	14
P (Kips)	591.28	1210.00	1030.00	206.93
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	73.91	151.25	128.75	25.87
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	73.91	151.25	128.75	25.87
b (ft)	9	13	12	6
≤ 18 ft ?	Yes	Yes	Yes	Yes

Spot Checks On Foundation: Structure 1				
Grid Line: Truss 2				
Member	9	11	12	14
P (Kips)	1160.00	2340.00	2140.00	750.64
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	145.00	292.50	267.50	93.83
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	145.00	292.50	267.50	93.83
b (ft)	13	18	17	10
≤ 18 ft ?	Yes	Yes	Yes	Yes

Spot Checks On Foundation: Structure 1				
Grid Line: Truss 3				
Member	9	11	12	14
P (Kips)	1250.00	2460.00	2460.00	1250.00
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	156.25	307.50	307.50	156.25
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	156.25	307.50	307.50	156.25
b (ft)	13	18	18	13
≤ 18 ft ?	Yes	Yes	Yes	Yes

Spot Checks On Foundation: Structure 1				
Grid Line: Truss 4				
Member	9	11	12	14
P (Kips)	1820.00	4370.00	4220.00	1790.00
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	227.50	546.25	527.50	223.75
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	227.50	546.25	527.50	223.75
b (ft)	16	24	23	15
≤ 18 ft ?	Yes	No	No	Yes

Spot Checks On Foundation: Structure 1				
Grid Line: Truss 5				
Member	9	11	12	14
P (Kips)	517.32	1040.00	769.39	461.84
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	64.67	130.00	96.17	57.73
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	64.67	130.00	96.17	57.73
b (ft)	9	12	10	8
≤ 18 ft ?	Yes	Yes	Yes	Yes

Spot Checks On Foundation: Structure 2				
Grid Line: Truss 6				
Member	9	11	12	14
P (Kips)	641.03	1290.00	1290.00	641.03
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	80.13	161.25	161.25	80.13
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	80.13	161.25	161.25	80.13
b (ft)	9	13	13	9
≤ 18 ft ?	Yes	Yes	Yes	Yes

Spot Checks On Foundation: Structure 2				
Grid Line: Truss 7				
Member	9	11	12	14
P (Kips)	1230.00	2420.00	2350.00	1070.00
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	153.75	302.50	293.75	133.75
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	153.75	302.50	293.75	133.75
b (ft)	13	18	18	12
≤ 18 ft ?	Yes	Yes	Yes	Yes

Spot Checks On Foundation: Structure 2				
Grid Line: Truss 8				
Member	9	11	12	14
P (Kips)	1160.00	2340.00	2090.00	650.31
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	145.00	292.50	261.25	81.29
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	145.00	292.50	261.25	81.29
b (ft)	13	18	17	10
≤ 18 ft ?	Yes	Yes	Yes	Yes

Spot Checks On Foundation: Structure 2				
Grid Line: Truss 9				
Member	9	11	12	14
P (Kips)	79.82	149.39	149.39	79.82
# Supporting Piles For Platfroms	4	4	4	4
Tons Per Pile	9.98	18.67	18.67	9.98
σ (psf)	2000.00	2000.00	2000.00	2000.00
$A_{required}$ (ft^2)	9.98	18.67	18.67	9.98
b (ft)	4	5	5	4
≤ 18 ft ?	Yes	Yes	Yes	Yes

Table 14: Spot Checks on Foundation

Overturning Verification: Wind										
Structure 1						Structure 2				
Moment (ft-Kips)	L/2 (ft)	P (Kips)	W/2 (Kips)	Overturning Issues		Moment (ft-Kips)	L/2 (ft)	P (Kips)	W/2 (Kips)	Overturning Issues
45170	89.75	503.2869	27106.5	No		45235	83.5	541.7365	23324	No
Overturning Verification: Seismic										
Structure 1						Structure 2				
Moment (ft-Kips)	L/2 (ft)	P (Kips)	W/2 (Kips)	Overturning Issues		Moment (ft-Kips)	L/2 (ft)	P (Kips)	W/2 (Kips)	Overturning Issues
48422	89.75	539.5209	27106.5	No		46603	83.5	558.1198	23324	No

Table 15: Overturning Moment

Structural Depth Conclusion:

Designing a transfer system is no easy task for an engineer, especially when one decides to be creative and integrate the structure and architecture of the building. The hardest challenge was not to determine the loads from the above floor or figuring out the loads in the members or designing a new lateral system, but figuring out if the curved tension members selected could withstand the moment inside the member which wants to pull the member into a compression state. Making sure the foundation system could support the new structural system as well was a challenging task as well. Trying to keep in mind that the soil on the site is weak throughout the whole structural depth was at times hard.

After all the calculations and innovative structural designing, the author believes the thesis criteria goals 1 through 4 (refer to page 10) where accomplished. Switching from a post-tension concrete to a composite steel floor system with transfer trusses can satisfy not only the goals of the design firm, but the author's as well. Each truss shows how creative an engineer can be when working with certain boundaries to follow. The only main concern the author wishes there was more time for was the foundation system. If there was time, the author would try to create a new foundation system that would work around the train tracks and give extra support to the expansion of Union Station.

ARCHITECTURAL BREADTH

Architectural Design of King Post Trusses:

To create a signature expression for the expansion of Union Station, the author believed the best way to achieve this was to use the king post trusses that act as the transfer system. In order to make the trusses look appealing to the traveler's eye, a variety of members should be used and the author wanted to make the trusses look like no other truss someone has seen. This is to make the viewer look and ask themselves the questions about the trusses.

In the beginning of the design of the trusses, sketches were drawn up for parts of the trusses. The authors started off with just having one type of truss in the expansion. Having one truss kept the concept simple but intriguing. Shown below are concepts the author originally started off with. One can see from Figure 1 that the original thoughts of the top chord was to have a built up box shape with a WT member as the bottom portion with tension rods connecting into the web of the WT member. Using HSS rectangular members as columns were thought about since it would be different having them act as columns to carry massive loads. Figure 2 shows how the bottom chord could be rotated 90 degrees where the columns rest on the web of bottom chord and the original bracing members were going to be double angles. The original design of the trusses can be found on Figure 1 (Note that the truss is not to scale).

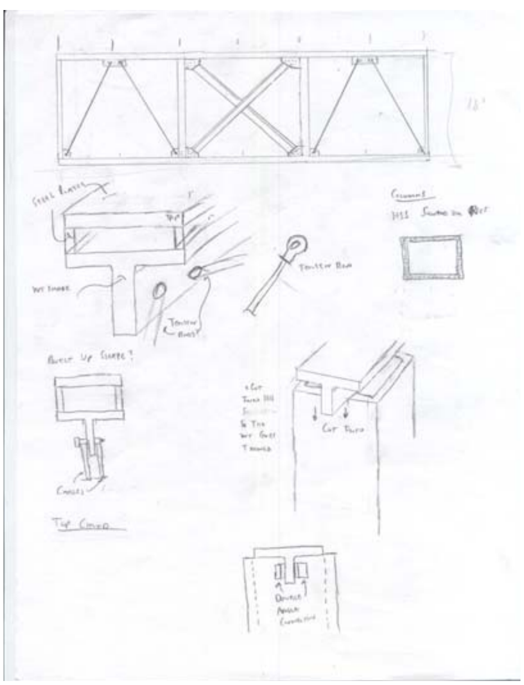


Figure 1: Top Chord & Column Concepts

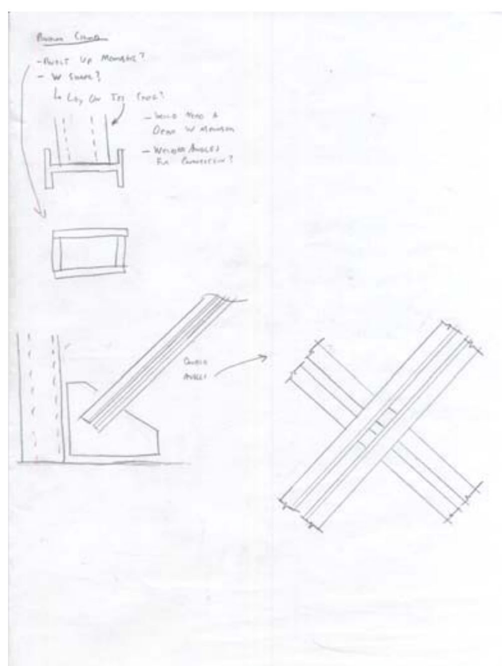


Figure 2: Bottom Chord & Brace Concepts

While the concepts and style of the truss is different than most trusses, the author felt there wasn't enough "signature" behind it. Going back and rethinking about some of the members to use, only WT members would be used for the top chords (no built up members). This is to give a more simple look to the top chords and no one would really see the built up member portion since the floor to ceiling height is 18'-0" high. Also three of the columns were removed in this design of the trusses because this would give long spans to the trusses which would help with traffic of the busses as well as make the trusses feel as if they were more related to the definition of a king post truss. Figure 3 below shows the second design of the truss for the expansion to Union Station. From here on out within this section, the truss figures are scaled correctly to the 18'-0" high by 189'-0" long.

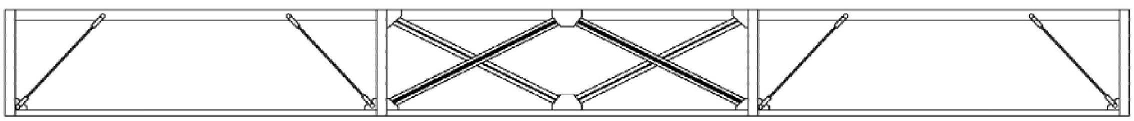


Figure 3: 2nd Design of Truss

Having long spans, tension rods, and an interesting diagonal bracing in the middle portion of the truss does make this design interesting to view. However, the author realized that problems could arise with the long spans from a structural engineering stand point. One problem is the weight from the floors above could cause a significant deflection which could lead to future problems. Another design was sketched up (Figure 4) and in this design, the three columns removed were placed back. Also the tension rods were inverted and now meet at the bottom of a truss because the author wanted to view the rods at a different perspective. Each tension rod was no longer attached to the web of the WT member at the top and a plate was used instead for the design.

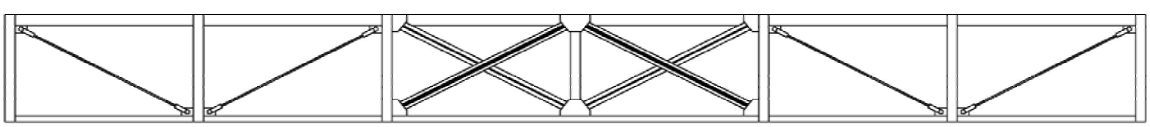


Figure 4: 3rd Design of Truss

Realizing that the tension rods look more appealing when they meet at the bottom of a column, the author finalized this portion of the trusses. When structural calculations were being done on the trusses (Refer to the structural depth portion of this report), there were three zero force members. Since those members serve no purpose, the author removed them from the truss and when that happened, the trusses became more intriguing to look at. Once this took place, the author decided to remove the center column and replace the double angles with a wide flange shape (Refer to Figure 5 below). All of the following changes started to make the truss look as if it were a signature expression for the expansion.

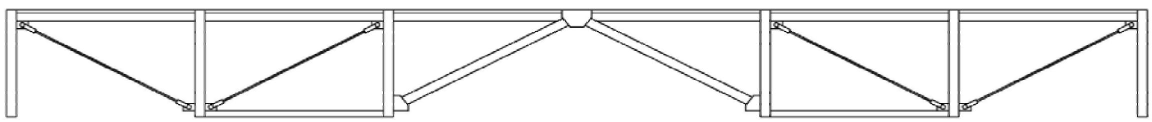


Figure 5: 4th Design of Truss

To finalize this truss, the tension rods were once again connected to the web of the WT members to make the connection seem simplified to the viewers' eye. Figure 6 shows the final design of the truss. Now that this truss was completed, the author realized that this truss would not work on the inside of the expansion since the busses must travel and park in their allowed areas. Therefore a new truss would be created for the interior and the truss already created will be used for the exterior of the building.

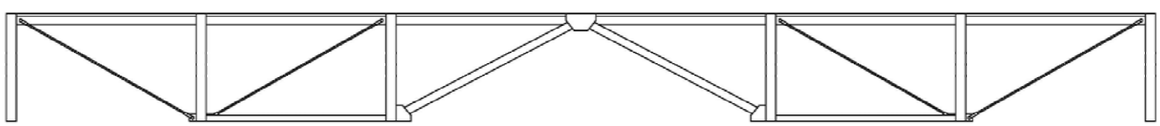


Figure 6: Final Exterior Truss Design

While thinking about what could be used in the interior truss to allow busses to travel under while making a signature expression, the idea of using curved members that create an arch would came to the author's attention. This gives the feeling of openness to the ground floor as well as drawing one's view to the trusses giving a sense of intrigue. HSS tubes were selected as the members for the curved for not only their strength they can carry but as another different steel member used in the trusses that already have multiple steel shapes within them. Figure 7 below shows the final design for the interior trusses.

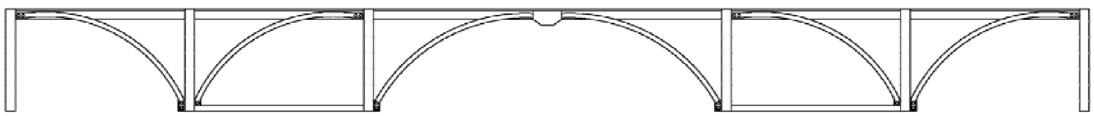


Figure 7: Final Interior Truss Design

Verification of Vehicular Circulation:

With the trusses placed at their desired locations on the ground floor, making sure the busses can travel and park to unload passengers is of high importance. From Figure 8 on the right, one can see the original circulation path used in the expansion to Union Station and where the trusses are located at. Since Trusses 5 and 6 are the exterior type due to being the ends of the two structures, this causes a problem with the original circulation. Due to the tension rods used as braces within the trusses, the busses will not be able to pass with the clearance height required as well as park under. Therefore the author proposes a change of the circulation on the ground floor and the location of the parking spaces as well.

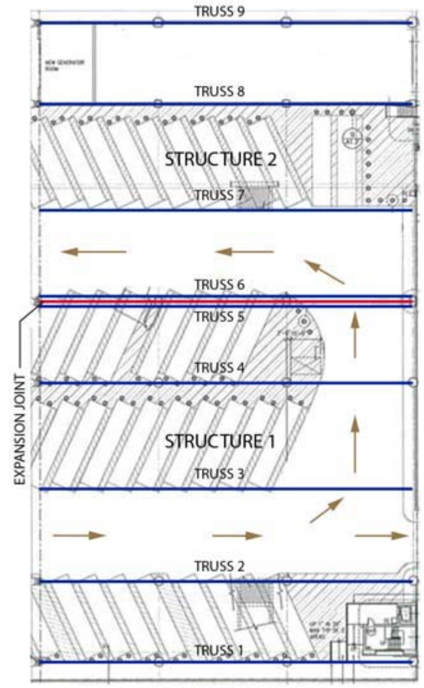


Figure 8: Existing Vehicular Circulation

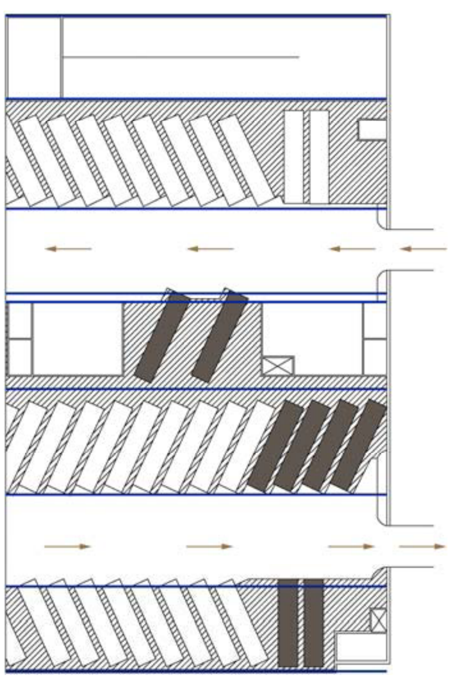


Figure 9: New Vehicular Circulation & Bus Locations

Figure 9 on the left indicates the new circulation for the expansion to Union Station. Instead of just having an exit to H-Street in Washington DC, an entrance was created as well which helps reduce the traffic at the main entrance of the entire building. Allowing an entrance in the expansion gives the busses the choice to reduce the trip around the building to their designated parking zone. As for the relocation of the busses that have issues with Trusses 5 & 6, the areas shaded gray in Figure 9 show where how six of the eight bus zones can be moved without causing major problems. At the very bottom right of the expansion, two of the buses were positioned where some of the waiting area is, but since more room was created between the trusses, the author decided to relocate the waiting terminals which are discussed on the following page.

Redistribution of Waiting Terminals:

Located next to the MEP Room of the expansion of Union Station (Upper left corner of Figure 8) is where all of the area for the waiting terminal is located. Now that the circulation and location for the busses has changed, the author decided to break up the one area into two parts that are now underneath the king post trusses (refer to Figure 10). This gives the trusses more of a signature expression while the crowd can notice them while they wait and stare at them through the glass walls that make up the new terminals (refer to Figure 11). The new floor plan not only helps with the expression of the trusses, but now draws travelers to want to stay inside the waiting terminals.

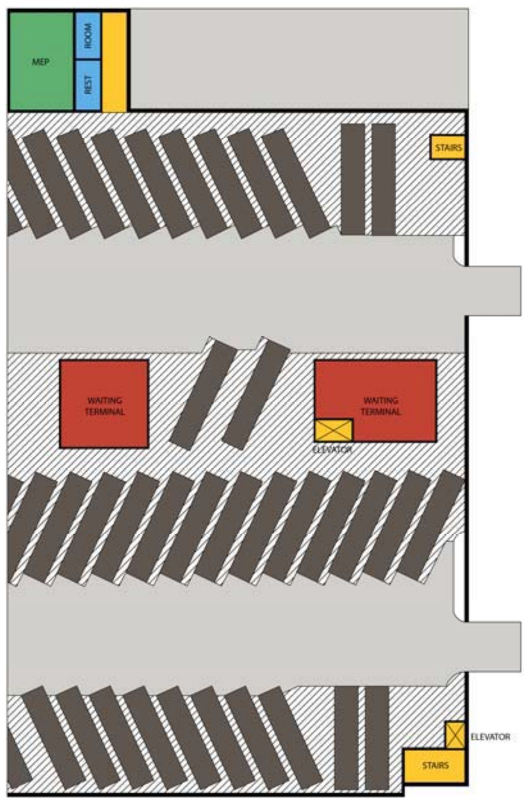


Figure 10: New Ground Floor Plan

Architectural Breadth Conclusion:

As stated in the previous page, the new floor plan of the expansion to Union Station optimizes the area while giving the signature expression of the trusses the author wanted to create. Having the waiting terminals under the trusses helps draw the attention to the trusses but also makes one to believe that this building was given a custom idea when in the design phase. If given more time for this thesis, the author would have liked to keep working on the architectural design of the trusses. While they are one of a kind for the building and do give off a signature look, there could have a better concept for the columns. One possibility could have been to have two different members act as the columns and join with a creative connection half way. To view renderings of the trusses and ground floor of the expansion to Union Station, Refer to the Renderings portion of this report located on page 44.

LIGHTING BREADTH

Selection of Luminaries to Highlight Trusses:

Acting as a signature expression for the expansion to Union Station, all the trusses should be illuminated to capture the grand impression each one gives off. Instead of using typical luminaries to highlight the trusses, the decision to use LEDs was determined by the author because not only do LEDs save energy and last for a long period of time, but they also gives off a high-performance illumination and beam quality to emphasis the structure being lit. The author selected the eW Graze Powercore Linear LED strip made by Philips. Typically the Philips eWs are used for exterior lighting to emphasis a façade or structure and since the trusses are part of the structure to Union Station, the LEDs fit the criteria where they are going to be used.

Each four foot section has forty-eight white LEDs inside that will give off five foot candles at a distance of eighteen feet (the height of the trusses). Each one of the trusses will have six of the four foot length LED strips per 31'-6" at the bottom of each one (Refer to Figure 1 to see layout). Note that the LEDs are not scaled to size in the width direction because the author wants the reader to be able to see how they will be spaced. Since the two bottom chords of all the trusses are rotate ninety degrees (resting on the web), the lights within that 31'-6" will be placed within the chord. Having indirect lighting will guide one's eyes from the ground to looking up and noticing the trusses within the expansion. Figure 2 below is a picture of the four foot strip of LEDs and to view the specifications for the lights, refer to Appendix J.

It should be noted to the reader that the LEDs will not be the main lighting system for the bus terminal area. Only will the LEDs serve the purpose of illuminating the trusses and another system shall be used to meet the requirements set forth by the IESNA for lighting the bus terminal.

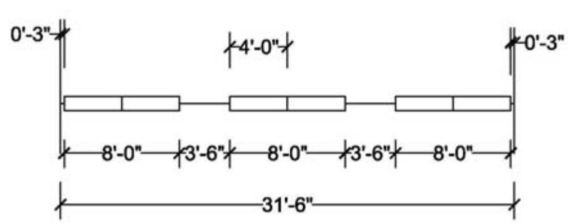


Figure 1: Typical 31'-6" LED Layout under Trusses

Figure 2: eW Graze Powercore 4' Strip

Illuminance Categories & Required Foot Candles:

Using Chapter 10 of the IESNA book, the required illuminance categories as well as foot candles were determined. Table 1 below shows each area with the requirements set forth by IESNA. The waiting terminals have a required fifty foot candles due to the fact that there will be ticket counters within the areas and according to Figure 2 in Appendix K, a minimum of fifty foot candles is required. All other remaining illuminance category requirements can be found from Figure 2 for the ground floor and Figure 1 in Appendix K shows the required foot candles for each illuminance category.

Ground Floor of Expansion to Union Station					
Area	Watiting Terminal	Restrooms	Bus Terminal	Elevators	Stairs
Category	E	B	A	B	B
Foot Candles	50	5	3	5	5

Table 1: Illuminance Categories & Foot Candles

Selection of Luminaries for Waiting Terminals:

Since the waiting terminal has been broken into two areas that are now located within the center of the expansion to Union Station, the author wanted to use different luminaries than the existing ones. The Avante recessed direct/indirect lighting luminarie was selected for each of the waiting terminals. Each luminarie consists of three T8 32 Watt lamps that create indirect light which is then reflected as direct lighting from the cover of the Avante luminarie. This luminarie is suggested using in areas where there is a work space that one has to concentrate on. Because there are ticket counters in the waiting terminals, this type of luminaire works sufficiently. Figure 3 on the right shows the design of the luminaire and the specifications can be found in Appendix L.

Figure 3: Avante 2x4 Luminaire

Lumen Method for Waiting Terminal:

From Chapter 9 of IESNA, the lumen method design approach was used to calculate the number of Avante 2x4 luminaries required for the waiting terminal on the left side of the ground floor plan (refer to Figure 10 on page 36 of the report). The cavity ratios used to determine the required ρ for the walls, floor, and ceiling were 80/60/30. These are the numbers typically used when designing for a room with its criteria. All light loss factors were determined as well based on the assumption the luminaries used are a category type VI with a clean environment and have a cleaning period of three months. The reason three months is used is staff may not clean the luminaries every week, but it is safe to assume around every three months a cleaning will take place.

After all calculations were done, the amount of luminaries required to light the 35'-0"x35'-0" waiting terminal is 10.55. Since a whole number is required, the author decided to select twelve luminaries as the number for the waiting terminal and this number falls within the ten percent tolerance allowed for the lumen method. Figure 4 below shows the waiting terminal with its relative ceiling grid, which has 2'x2' grids, and the location of the twelve Avante luminaries. One can notice that the author has spaced the luminaries evenly across the entire ceiling plan to evenly distribute the light being generated. To view all calculations, charts, and diagrams for the waiting terminal, refer to Appendix M.

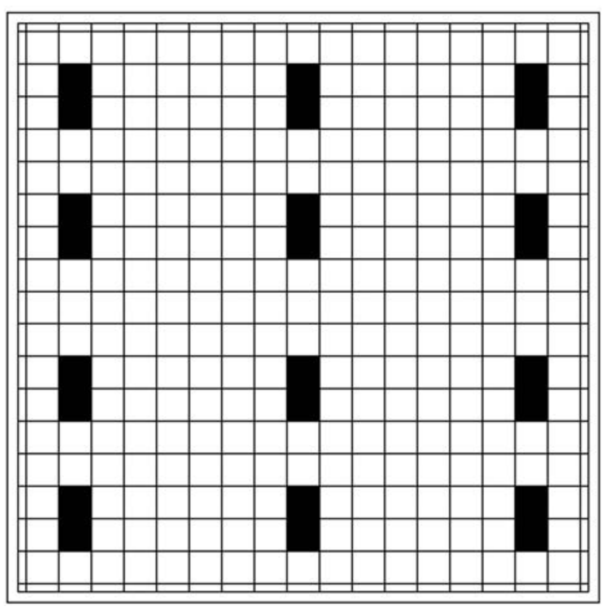


Figure 4: Lighting Layout for Waiting Terminal

Lighting Breadth Conclusion:

Giving the trusses a separate lighting system than the bus terminal creates a greater impact on how they are the signature expression for the expansion to Union Station. Using LEDs helps give more of a direct beam that shots up from the ground and invites one who is one the ground to look up and notice the trusses. Lighting up each truss gives the feeling of comfort to them as well. Instead of having a dark area where you cannot see what is happening, making it possible to see the connections and each member of the trusses make one feel safe when walking, waiting, or riding underneath the trusses.

Creating two separate waiting terminals and putting them under the trusses and giving them new lighting fixtures draws the travelers who are waiting to come to them and take a rest of this feet. Each of the new lightning schemes in the waiting terminals brighten up the center of the ground floor to the expansion of Union Station.

One can argue that the location of the LEDs on the ground could cause problem when the busses need to pass underneath and park. Recognizing this problem, the author suggests using strong plexus glass over the top of the LEDs to prevent them from being damaged by a moving vehicle.

CONCLUSION

All three topics discussed in this thesis; structural, architecture, and lighting were centered about the trusses. While other concerns were brought up in the two depths (i.e. moving the waiting terminal to a new location), they impacted on the concept of the trusses as well.

This signature expression does make a significant improvement to the expansion of Union Station and also meet all the criteria goals set forth by the author (Refer to page 10 to review the goals). As stated in the structural depth conclusion, the only concern the author has is with the foundation to the expansion. With more time, the author would have liked to try to redesign the foundation system so it would not be close to its limit.

One topic not mentioned in this thesis is the cost of creating this signature expression through trusses. The mezzanine level through the third floor’s cost would not be a concern because those floors are switching from a post-tension floor slab to a composite steel system where the composite system is cheaper (Refer back to Technical Report II done by the author). However, the trusses would need significant time for steel to be erected as well as making sure all the tension members were ready for the loads from the floors above. Also, the welds the author requested for the plates on the columns would raise the cost since an extra set of specialized workers would be needed. The author still believes even though the cost of the expansion could increase and the schedule could take a little longer due to the trusses, the benefit of having this grand expression in the building would not only mean better business for the owner, but would give the occupants and travelers something to talk about while in the expansion to Union Station.