UNION STATION EXPANSION AND RESTORATION

WASHINGTON DC

TECHNICAL REPORT I

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Structural Option

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In this technical report, the overall objective is to analyze the existing conditions of the expansion to Union Station in Washington DC and to gain practical knowledge of the procedures used in the structural design of the building.

Within the body of the report, a description of each structural system, required design codes, materials, and gravity and lateral loads have been summarized through description as well as diagrams. At the end of the report, three appendixes are located regarding wind loads, seismic loads, and spot checks. Spot checks consist of a slab, beam, and a column check.

It is important to know that the expansion to Union Station was designed back in 2004 and was constructed between the months of April 2005 and August 2006. For the wind and seismic calculations determined in the report, ASCE 7-05 was used for this report. There is a 2.31% difference in the calculations between the ones determined in the report to the results determined by the engineers. The main reason behind this difference in the wind and seismic loads is ASCE 7-02 was used to design the forces for Union Station. Some variables differ from each edition and different values were selected by the writer of this report.

In regards to the spot checks done on Union Station, the slab check done in the report came close to the calculations done by the professional engineers. For the beam and column, the size and steel reinforcement from the actual project were used. The writer of the report determined the amount of load each can carry based on only gravity loads. Since the beams, girders, and columns are part of the lateral system, the results found were significantly lower than what the designers obtained since no lateral forces were considered in the checks of the members. For more information regarding about this topic, refer to the spot check section found on page12.

STRUCTURAL SYSTEMS

Foundation:

Union Station's expansion main foundation system consists of concrete piles and supportive columns. On the Track Level, the foundation is visible for passengers traveling on a locomotive or waiting on the platforms to notice. Each of the concrete piles and columns sit on spread footers.

The columns and piles are located between the eight locomotive rail ways that are part of Union Station. Typical diameter size of the columns and the piles are 1 ½' and are spaced 22'-0" from each other (in a straight line between the rails).

The net soil bearing capacity for the site is 1000 PSF and each column and pile was designed to carry a typical load of 250 kips. Fine to coarse sandy clay fill is the typical soil located on the site for Union Station. Bearing capacity for this type of soil is calculated to be 100 psf. Since the owner of Union Station wanted to have 5 levels above grade (not including the track level), light weight concrete was used to achieve the goal. All systems rest upon spread footers and either have a dimension of 6'-0" or 12'-0".

Floor System:

The typical floor system for the expansion to Union Station 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 (See Figure 2). Since the tracks running through Union Station had to be considered in the design as well as the parking levels, the use of long spans was concluded as the best approach for the design. 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. Typical bay sizes in Union Station are 63'-0" x 24'-4". 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.

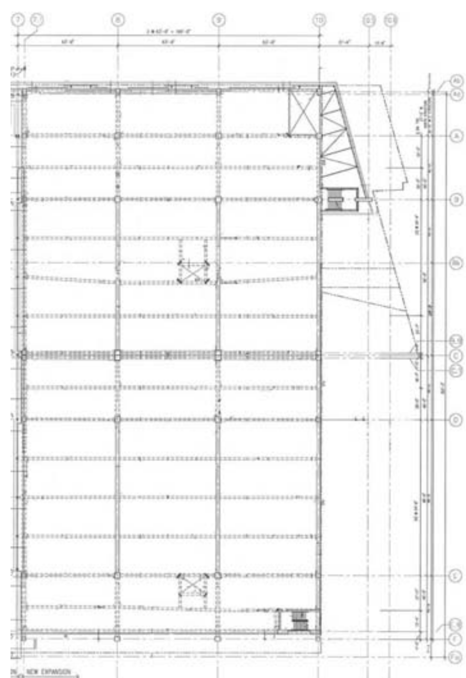


Figure 2: Typical Structural Plan

For the Ground Level, a 6 ½" concrete slab was used as well as a composite design located along the west elevation. The composite slab was used for part of the floor to give the ground floor extra support due to the locomotives located directly below the west elevation (See Figure 2 regarding the composite portion of the ground floor). 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". ¾" x 4 ½" shear studs were used in the composite floor design. The typical member size for the beams is W27x84 which span 63'-0" and tie into a W33x118 girder. The girders tie into the concrete columns that are part of the foundation system.

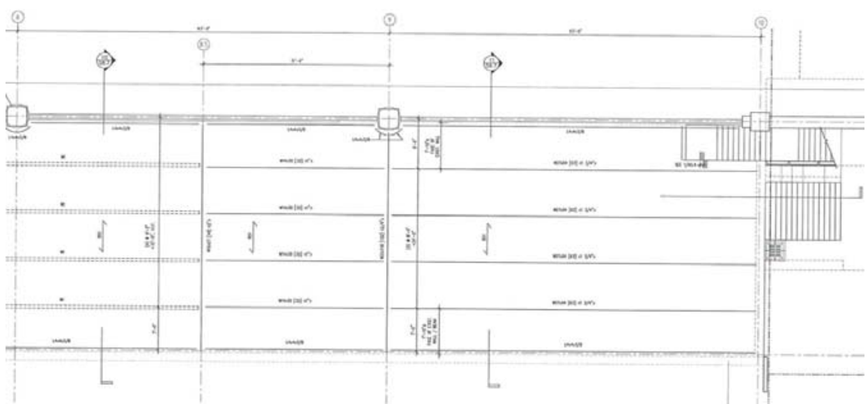


Figure 2: Composite Design for Ground Level

Roof System:

The roof system of Union station is a 7" thick post-tension cast-in-place slab. The reason for this is the roof of the Union Station expansion has parking located on it. Because of the parking located on the roof, live loads from not only rain and snow, but as well as cars had to be considered in the design. Sufficient drainage was required in the design to allow water to drain from the roof. A total eight drains are located on the roof of Union Station. Waterproofing was used to protect not only the roof, but the other levels from any damaged that could take place.

Columns:

Each floor of the Union Station expansion has about 20 cast-in-place columns. From the ground floor to the roof, some of the columns taper in size while others are uniform throughout the building. The column sizes range from 15" x 15" up to 28" x 40". The concrete compressive strength for the columns is f'_c = 8000 psi.

Lateral System:

The lateral load system for the expansion to Union Station is composed of an ordinary reinforced concrete moment frame (See Figure 3 below for a portion of the lateral system). The 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 piles and columns take all the loads into the spread footers. It is important to note that the existing structure and the addition of Union Station do not share a lateral system. The existing structure to Union Station uses steel chevrons. The expansion sits on a separate column line from the existing structure and an expansion joint was placed between column lines 7 and 7-1 (See Figures 4 and 5 for a visual representation).

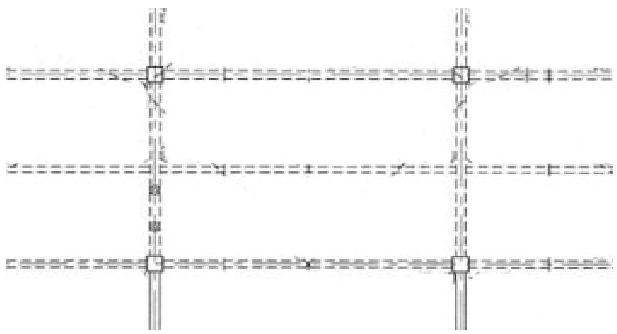


Figure 3: Portion of Lateral System

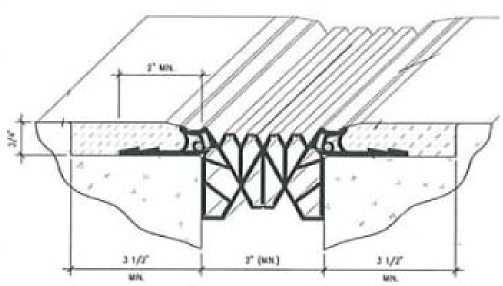


Figure 4: Expansion Joint

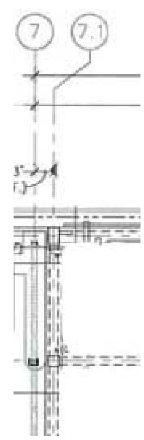


Figure 5: Location of Expansion Joint

CODE AND DESIGN REQUIREMENTS

Codes and References:

“DC Building Code 2003”

“International Building Code 2000” (as amended) – International Code Council

“DC Building Code Supplement 2000” (DCMR 12A)

“Building Code Requirements for Structural Concrete (ACI 318-02)” – American Concrete Institute

“ACI Manual of Concrete Practice 2003” – American Concrete Institute

“CRSI Handbook”, 2002 Edition – Concrete Reinforcing Steel Institute

“PCI Design Handbook, Fifth Edition” – Precast/Prestressed Concrete Institute

“PTI Design Manual, Fourth Edition” – Post Tensioning Institute

“Manual of Steel Construction” – American Institute of Steel Construction, Inc.

“ASCE 7-05”, Minimum Design Loads for Buildings and Other Structures – American Society of Civil Engineers

MATERIALS

Cast–In–Place Concrete:

Foundation Walls	f'_c = 4000 psi
Slab-On-Grade	f'_c = 5000 psi
Post Tension Beams	f'_c = 5000 psi
Post Tension Girders	f'_c = 5000 psi
Post Tension Slab	f'_c = 5000 psi
Stair/Elevator Walls	f'_c = 5000 psi
Columns	f'_c = 8000 psi

Precast Concrete:

Wall Panels	f'_c = 5000 psi
Spandrels	f'_c = 5000 psi

Structural Steel:

Wide Flange Shapes	f'_y = 50 ksi
High Strength Bolts	f'_y = 92 ksi
Anchor Bolts & Connection Steel	f'_y = 36 ksi
Steel Pipes	f'_y = 35 ksi
Structural Tubes	f'_y = 46 ksi
Cold Formed Steel	f'_y = 33 ksi
Welding Electrodes	E70xx

GRAVITY AND LATERAL LOADS

The following gravity loads were determined from ASCE 7-05

Dead Loads:

Construction Dead Load

Lightweight concrete	120 pcf
Steel	490 pcf
M.E.P.	10 psf
Finishes & Misc.	5 psf

Live Loads:

Office	50 psf
Stairs	100 psf
Landings	100 psf
Lobbies	100 psf
Mechanical	150 psf
Parking	50 psf

Wind Loads:

Wind loads were calculated in accordance with ASCE 7-05, Chapter 6. To examine the lateral wind loads in the North/South direction as well as the East/West direction, the analytical method was used. The south direction was evaluated even though it is next to the existing structure of Union Station. The reason is the addition is expected to be standing as long as the original part of Union Station will be. In the near future, a building will be constructed along the east elevation. The wind pressures for the expansion to Union Station were calculated based on the absence of this building. Union Station is categorized as Exposure B due to the urbanization surrounding the building. The length of the North/South direction is 353'-2" and the East/West length is 189''-0". Thus the wind will control along the North/South direction. It is also important to note the wind loads are higher than normal because since there are levels of parking with openings in the walls and the track level does not have a façade, the GC_{pi} factor used in the design process was ±0.55. Figures 6 and 7 represent the wind pressures on each floor of Union Station. Appendix A contains all wind variables, criteria, and detailed spread sheets.

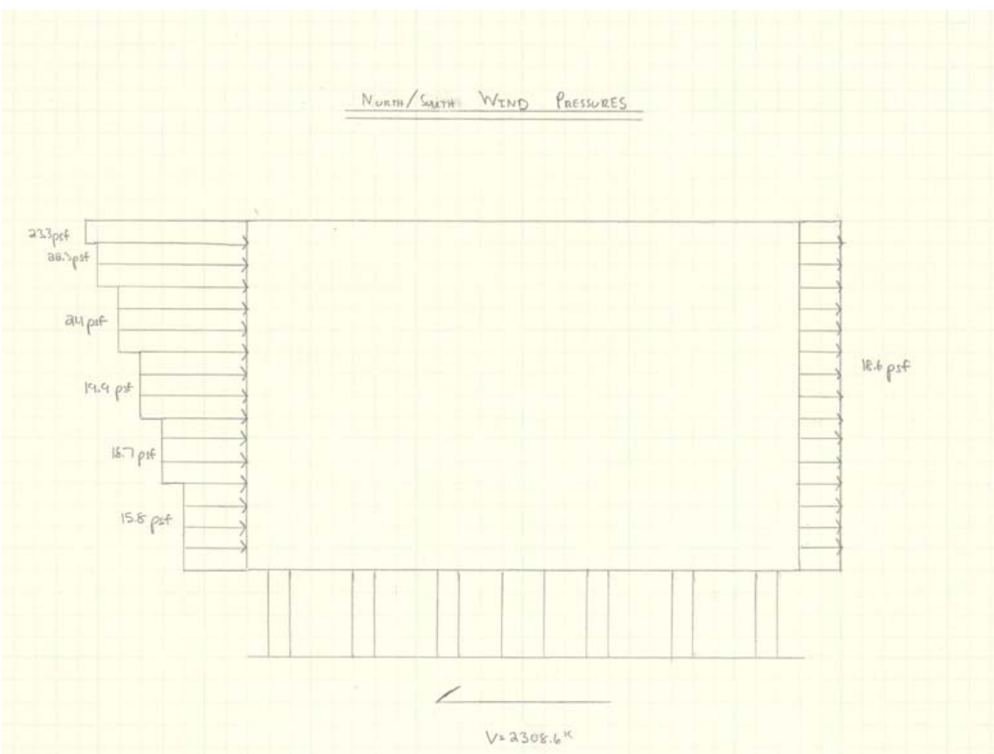


Figure 6: North/South Wind Pressure

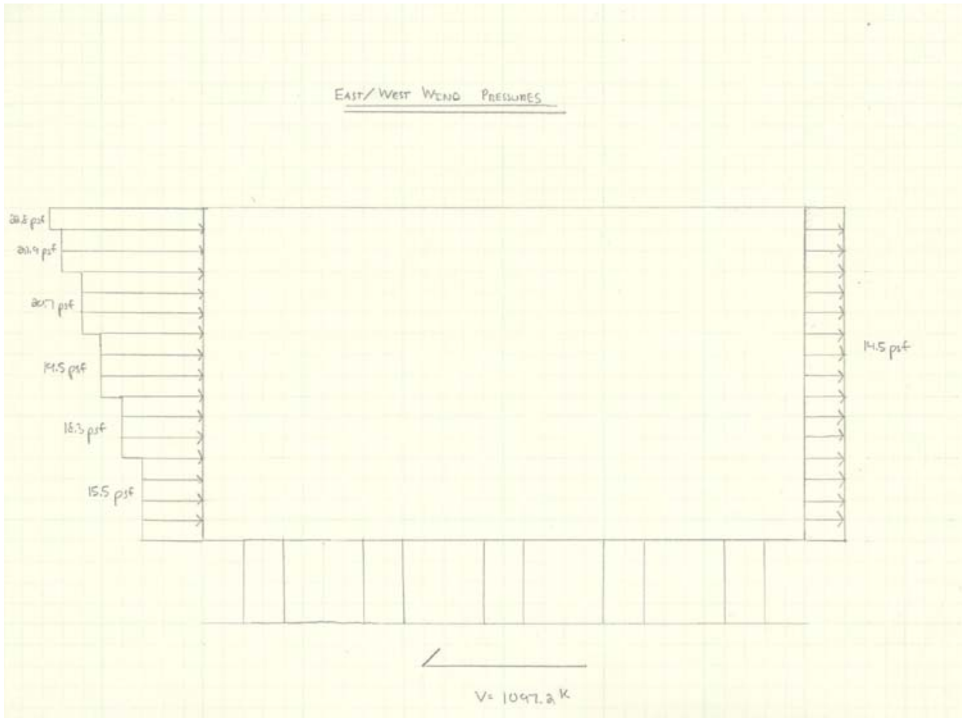


Figure 7: East/West Wind Pressures

Seismic Loads:

Seismic loads were calculated in accordance with ASCE 7-05, Chapter 12. Upon investigating the geotechnical report, the expansion to Union Station falls under the Site Class D. S_s and S_1 were calculated from the United States Geological Surveying's (USGS) website. Figure 8 represent the seismic forces on the expansion to Union Station. Appendix B contains all seismic variables, and detailed spread sheets.

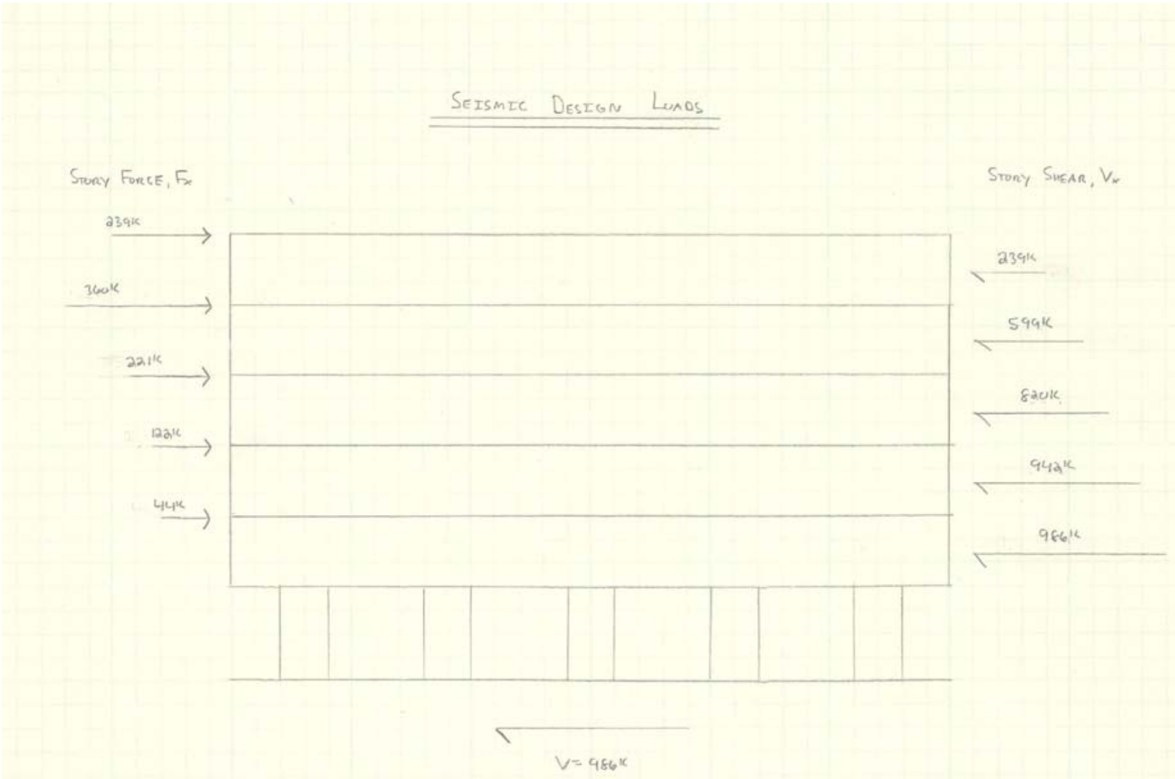


Figure 8: Seismic Design Loads

Spot Checks:

A total of three spot checks were completed for this report. The first spot check performed was on the typical 7" post-tension cast-in-place floor (See figures in Appendix C for location of each spot check). The objectives of this sport check was to determine the number of tendons and the effective force (P_{eff}) used in this portion of the slab. After completing the calculations, nineteen tendons were determined to resist a force of 509 kips in the area of the slab checked. From the drawings, a w_{bal} of 4 k/ft was used while a value of 3.18 k/ft was determined for this report. The amount of tendons determined is therefore on the low side. One reason for this could be a different load was considered for this area than the one used in the calculations

The second spot check was done on a typical beam located in Union Station (Refer to Figure 9 for the selected beam being checked). The dimensions from the drawings were used as well as the reinforcement as a starting point to determine the load the beam can carry. It is important to note that the load determined is lower than the value from the drawings which makes the beam over seized. Since the beam carries lateral load as well as gravity loads, the absence of the lateral forces explains why the beam is over designed from the hand calculations.

The final spot check was on column A/7.1 located next to the expansion joint that separates the existing and expansion of Union Station. Like the beam, the column is over sized from the calculations due to not including lateral forces. For the third technical report, a more detailed look of the lateral system will be done by computer modeling.

To view all hand calculations for each spot check, refer to Appendix C.

APPENDIX A: WIND LOAD CALCULATIONS

Basic Wind Speed (V)	90 mph
Wind Exposure Category	B
Building Category	III
Importance Factor	1.15
Wind Directionality Factor (K_d)	0.85
Topographic factor (K_{zt})	1.0

Number of Stories	5
Building Height (Feet)[1]	90.62
N-S Building Length (Feet)	353.25
E-W Building Length (Feet)	189
L/B in N-S Direction	1.869
L/B in E-W Direction	0.54

1) Height Includes Parapet On Roof

Table I: Basic Wind Pressure Parameters

Gust Factor		
Variable	Wind Direction	
	N-S	E-W
Stiffness	Rigid	Rigid
B (Feet)	189	353.25
L (Feet)	353.25	189
h (Feet)[2]	65.67	65.67
c	0.30	0.30
z (Feet)	52.9	52.9
I_z	0.291	0.291
l (Feet)	320	320
$\in$	1/3.0	1/3.0
L_z (Feet)	340	340
Q	0.81	0.77
g_Q & g_v	3.4	3.4
G	0.81	0.78

2) Considering only the part of
the building with a façade

Table II: Gust Factor Parameters

Wind Direction	C_p, Windward	C_p, Leeward	Gust Factor	GC_{pi}[3]
N-S Direction	0.8	-0.5	0.81	± 0.55
E-W Direction	0.8	-0.25	0.78	± 0.55

3) Used since there are multiple openings in the façade

Table III: C_p, Gust Factor, GC_{pi} Factors

Height (Feet)	K_z	q_z	Wind Pressures (psf) N-S Windward	N-S Leeward	N-S Total
90.62	0.96	19.46	23.31	-18.58	41.89
90	0.96	19.46	23.31	-18.58	41.89
80	0.93	18.85	22.58	-18.58	41.17
70	0.89	18.04	21.61	-18.58	40.19
60	0.85	17.23	20.64	-18.58	39.22
50	0.81	16.42	19.67	-18.58	38.25
40	0.76	15.40	18.45	-18.58	37.04
30	0.7	14.19	17.00	-18.58	35.58
25	0.66	13.38	16.03	-18.58	34.61
20	0.62	12.57	15.06	-18.58	33.64
0-15	0.57	11.55	13.84	-18.58	32.42

Height (Feet)	K_z	q_z	Wind Pressures (psf) E-W Windward	E-W Leeward	E-W Total
90.62	0.96	19.46	22.84	-14.50	37.34
90	0.96	19.46	22.84	-14.50	37.34
80	0.93	18.85	22.13	-14.50	36.63
70	0.89	18.04	21.18	-14.50	35.68
60	0.85	17.23	20.23	-14.50	34.72
50	0.81	16.42	19.28	-14.50	33.77
40	0.76	15.40	18.09	-14.50	32.58
30	0.7	14.19	16.66	-14.50	31.15
25	0.66	13.38	15.71	-14.50	30.20
20	0.62	12.57	14.75	-14.50	29.25
0-15	0.57	11.55	13.56	-14.50	28.06

Table IV: Values for Typical Wind Loads from ASCE 7-05

Wind (North-South)										
Level	Height (Feet)	Tributary Area (Feet)	K_z	q_z (psf)	Windward (psf)	Leeward (psf)	Total (psf)	Story Force (Kips)	Story Shear (Kips)	Overturning Moment (Ft-Kips)
Roof	90.62	5.75	0.96	19.5	23.3	-18.6	41.9	85.1	85.1	489.3
5	76.67	11.5	0.92	18.6	22.3	-18.6	40.9	338.4	423.5	3413.8
4	65.17	11.5	0.87	17.6	21.1	-18.6	39.7	755.5	1179.0	12628.2
3	53.67	11.875	0.82	16.6	19.9	-18.6	38.5	1350.2	2529.2	34645.9
2	41.42	15.1	0.77	15.6	18.7	-18.6	37.3	2308.6	4837.8	90266.8
Ground	23.5	10.96	0.65	13.2	15.8	-18.6	34.4	2308.6	4837.8	90266.8
Track Level	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4837.8	90266.8

Table V: Wind Load Distribution along North/South Direction of Union Station

Wind (East-West)										
Level	Height (Feet)	Tributary Area (Feet)	K_z	q_z (psf)	Windward (psf)	Leeward (psf)	Total (psf)	Story Force (Kips)	Story Shear (Kips)	Overturning Moment (Ft-Kips)
Roof	90.62	5.75	0.96	19.5	22.8	-14.5	37.3	40.6	40.6	233.3
5	76.67	11.5	0.92	18.6	21.9	-14.5	36.4	161.3	201.9	1627.4
4	65.17	11.5	0.87	17.6	20.7	-14.5	35.2	359.8	561.7	6017.7
3	53.67	11.875	0.82	16.6	19.5	-14.5	34.0	642.4	1204.1	16501.9
2	41.42	15.1	0.77	15.6	18.3	-14.5	32.8	1097.2	2301.3	42967.8
Ground	23.5	10.96	0.65	13.2	15.5	-14.5	30.0	1097.2	2301.3	42967.8
Track Level	0	0	0	0.0	0.0	-14.5	14.5	0.0	2301.3	42967.8

Table VI: Wind Load Distribution along West Direction of Union Station

APPENDIX B: SEISMIC LOAD CALCULATIONS

Seismic Parameters													
S_s	S_1	Site Class	Occupancy Category	Importance Factor	F_a	F_v	S_{MS}	S_{M1}	S_{DS}	S_{D1}	Seismic Design Category	R	C_u
0.153	0.05	D	III	1.25	1.6	2.4	0.245	0.120	0.163	0.080	B	3	1.7
T_a	T	T_s	C_s	Roof Dead Load (psf)	Floor Dead Load (psf)[1]	Snow Load (psf)	Wall Load (psf)	W_{roof} (kips)	W_{floor} (kips)[2]	W (Kips)	A (ft^2)	P (ft)	V (kips)
0.901	1.53	0.490	0.0218	75	140	21	35	6409	38840	45249	66749.13	1084.34	986

1) Floor dead loads include the weight of the slab, beams, girders, and columns
2) Total force for all levels not including roof

Table I: Seismic Parameters

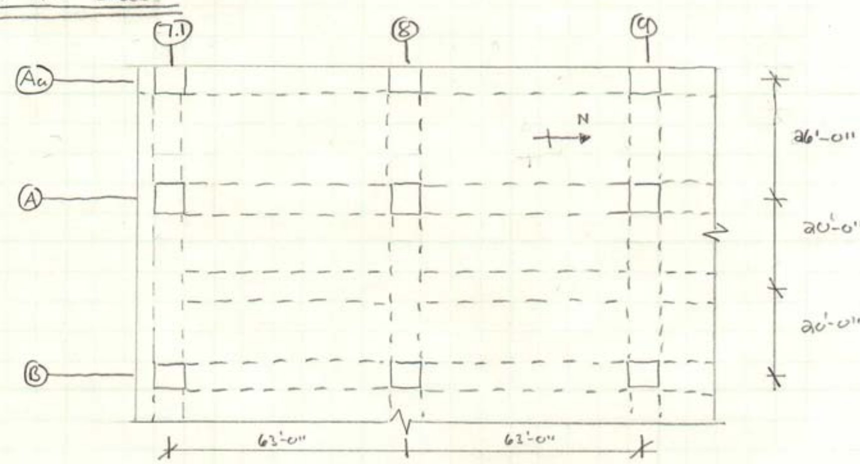
Level	Height (Feet)	Tributary Area (Feet)	C_{vx}	F_x (Kips)	Overturning Moment (Ft-Kips)
Roof	88.12	5.75	0.24	239	1376.2
5	76.67	11.5	0.37	360	6199.6
4	65.17	11.5	0.22	221	14366.1
3	53.67	11.875	0.12	122	24834.8
2	41.42	15.1	0.04	44	39397.7
Ground	23.5	10.96	1.00	986	39397.7
Track Level	0	0	1.00	986	39397.7

Table II: Seismic Load Distribution for Union Station

APPENDIX C: SPOT CHECK CALCULATIONS

UNION STATION EXPANSION | TECH. I REPORT | PAGE 1

SLAB SPOT CHECK



COLUMNS ⇒ STORY HEIGHT: 11'-6"

f'_c = 5000 psi [SLAB]
8000 psi [COLUMNS]

w = 115 pcf [SLAB]
150 pcf [COLUMNS]

f_y = 60,000 psi

f_{pu} = 270,000 psi

LL = 50 psf

DETERMINE SLAB THICKNESS:

$\frac{\text{SPAN}}{\text{DEPTH}} = \frac{L}{45}$

*SINCE BEAMS & GIRDERS ARE IN DESIGN, USE 27'-6"

$\frac{27.5ft(12)}{45} = 7.33in$ ∴ USE 7in SLAB

DESIGN OF EAST-WEST INTERIOR FRAME:

$A = bh = 20ft(12\,in/ft)(7in) = 1680\,in^2$

$S = \frac{bh^2}{6} = \frac{20ft(12in/ft)(7in)^2}{6} = 1960\,in^3$

TARGET LOAD BALANCE: $0.75\,w_{DL} = 0.75\left[\frac{7_{in}(115_{pcf})}{12_{in}/ft}\right] = 50.3\ psf$

$a_{int} = 7.0_{in} - 1.0_{in} = 6.0_{in}$ (MAX TENDON SLAG)

$a_{end} = \frac{(4_{in} + 7.0_{in})}{2} - 1.75_{in} = 3.75_{in}$ (MAX TENDON SLAG)

$W_b = 0.75\,w_{DL} = 0.75(67.1\,psf)(63\,ft) = 3170\ plf = 3.17^k/ft$

$P = \frac{w_b L^2}{8\,a_{end}} = \frac{3.17^k/ft\,(20\,ft)^2}{8(3.75_{in}/12_{in}/ft)} = 507^k$

* WILL ASSUME 14 ksi LONG TERM LOSSES AND 1/2" ϕ STRANDS

$0.153[0.7(270) - 14] = 26.8^k$

$\#\ \text{TENDONS} = \frac{507^k}{26.8^k/\text{TENDON}} = 18.9 = 19$ TENDONS

$P_{ACTUAL} = 19\ \text{TENDONS}(26.8^k/\text{TENDON}) = 509^k$

$W_b = \left(\frac{509^k}{507^k}\right)(3.17^k/ft) = 3.18\ ^k/ft$

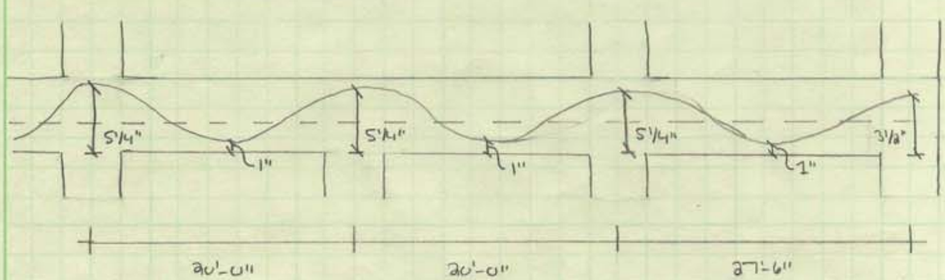
$P_{ACTUAL}/A = \frac{509^k(1000)}{1680\,in^2} = 303\ psi > 125\ psi$ $\therefore$ OKAY [ACI 318-08 18.12.4]

CHECK INTERIOR SPAN FORCE:

$P = \frac{3.17^k/ft\,(20\,ft)^2}{8(6_{in}/12)} = 317^k < 509^k$ $\therefore$ LESS FORCE REQUIRED IN INTERIOR SPAN

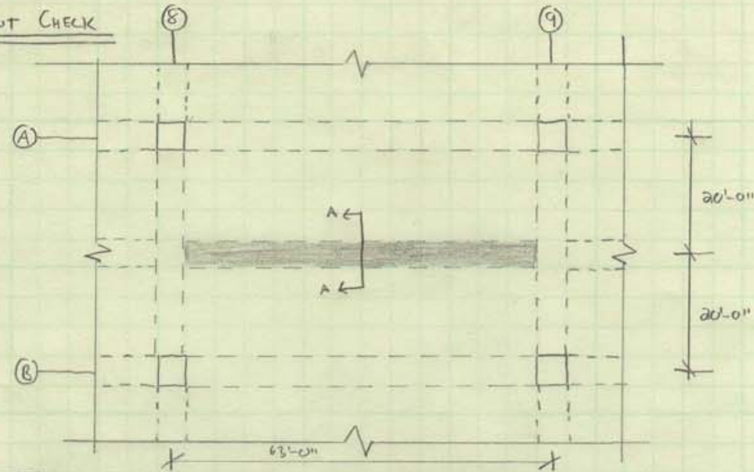
$\boxed{P_{eff} = 509^k}$

TENDON PROFILE



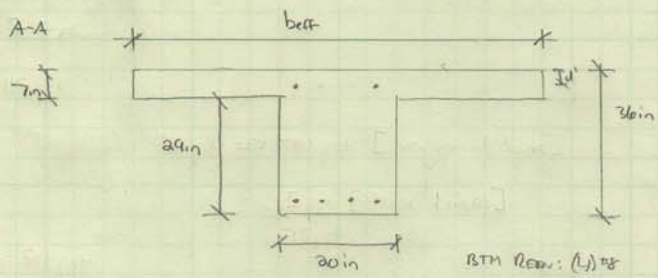
UNION STATION EXPANSION | TECH. I REPORT | PAGE 3

BEAM SPOT CHECK



 REPRESENTS BEAM BEING DESIGNED

SECTION A-A



BTM REIN: (4) #8
TOP REIN: (2) #8

$f'_c = 5000\text{ psi}$

$w = 120\text{ pcf}$ [LIGHT WEIGHT]

$f_y = 60\text{ ksi}$

DEAD LOAD: SLAB => $\dfrac{7\text{in}(120\text{pcf})}{12\text{in/ft}} = 70\text{ psf}$

BEAM => $\dfrac{20\text{in}(29\text{in})(120\text{pcf})}{144\text{ in}^2/\text{ft}^2} = 483\text{ plf}$

MEP/MISC => 15 psf

TOTAL DEAD LOAD = $(70\text{psf} + 15\text{psf})(20\text{ft}) + 483\text{plf} = 2183\text{ plf}$

LIVE LOAD = $50\text{psf}(20\text{ft}) = 1000\text{ plf}$

COMBINED LOAD

$1.2D + 1.6L = \dfrac{1.2(2183\text{plf}) + 1.6(1000\text{plf})}{1000} = 4.23\text{ k/ft}$

UNION STATION EXPANSION | TECH. I REPORT | PAGE 4

$$b_{eff} \le \begin{cases} \tfrac{1}{4}\text{span length} = 63ft(12)/4 = 189in \\ b_w + 16h_f = 20in + 16(7in) = 132in \\ b_w + \tfrac{1}{2}\text{span} = 14in + (20ft(12) - 14in) = 240in \end{cases}$$

$b_{eff} = 132in$

$d = 36in - 1.5in - 0.5in - \frac{1in}{2} = 33.5in \qquad d' = 2.5in$

$M_{u,a=h_f} = \phi(0.85f'_c)(h_f)(b_{eff})(d - h_f/2) = 0.9(0.85)(5ksi)(132)(7in)(33.5 - 7/2) = 8836\ k\text{-}ft$

$M_{u,a=h_f} > M_u$ ∴ No T-BEAM BEHAVIOR

+ASSUME $\varepsilon_s \ge \varepsilon_y$ & $\varepsilon'_s \ge \varepsilon_y$

$T = C$

$A_s f_y = 0.85f'_c(b)(a) + A'_s f_y$

$a = \dfrac{A_s f_y - A'_s f_y}{0.85f'_c(b)} = \dfrac{(4(0.79in) - 2(0.79in^2))60}{0.85(5ksi)(20in)} = 1.12in$

$\beta_1 = 0.85 - \dfrac{0.05}{1000}[5000 - 4000] = 0.80$

$c = a/\beta_1 = 1.12in/0.80 = 1.4in$

$\varepsilon_y = 60ksi/29{,}000 = 0.00207$

$\varepsilon_s = \dfrac{0.003(33.5in - 1.4in)}{1.14in} = 0.0845 \gg \varepsilon_y$ ∴ good

$\varepsilon'_s = \dfrac{0.003(1.4in - 2.5in)}{1.4in} = 0.000214 < \varepsilon_y$ ∴ no good

+CASE II APPLIES

$0.85f'_c(b)(\beta_1)(c) + A'_s(0.003)\dfrac{(c-d')}{c}(E_s) = A_s f_y$

$0.85(5ksi)(20in)(0.8)(c) + 2(0.79in^2)(0.003)\left(\dfrac{c - 2.5in}{c}\right)(29000) = 4(0.79in^2)(60ksi)$

$68c^2 + 137.5c - 343.7 = 189.6c$

$$0 = 68c^2 - 52.1c - 343.7$$

$$c = \frac{52.1 \pm \sqrt{(-52.1)^2 - 4(68)(-343.7)}}{2(68)} = \frac{52.1 \pm 310.2}{2(68)}$$

$$c = 2.66\,in$$

$$\varepsilon_t = \frac{0.003(d_t - c)}{c}$$

$$d_t = 33.5\,in + 0.5\,in + \frac{1\,in}{2} = 34.5\,in$$

$$\varepsilon_t = \frac{0.003(34.5\,in - 2.66\,in)}{2.66\,in} = 0.0360 > 0.005 \therefore \phi = 0.9$$

$$\phi M_n = 0.9\left[A'_s(0.003)\left(\frac{c-d'}{c}\right)(E_s)(d-d') + 0.85 f'_c (b)(\beta_1)(c)\left(d - \frac{\beta_1 c}{2}\right)\right]$$

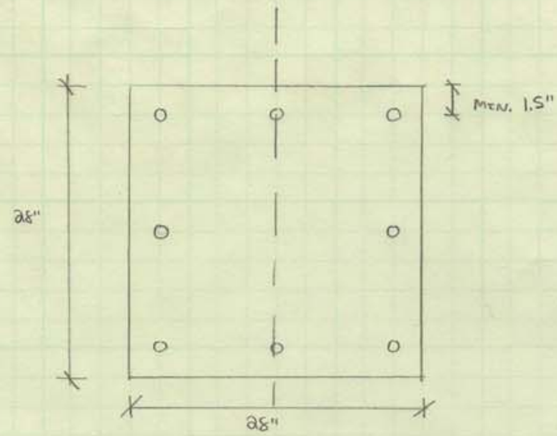
$$\phi M_n = 0.9\left[2(0.79\,in^2)(0.003)\left(\frac{2.66\,in - 2.5\,in}{2.66\,in}\right)(29000)(33.5\,in - 2.5\,in) + 0.85(5\,ksi)(20\,in)(0.80)(2.66\,in)\left(33.5 - \frac{0.8(2.66)}{2}\right)\right]$$

$$\phi M_n = 0.9\left[256\,k\text{-}in + 5867\,k\text{-}in\right] = 5511\,k\text{-}in = 460\,k\text{-}ft$$

$$\underline{\underline{\phi M_n = 460\,k\text{-}ft}}$$

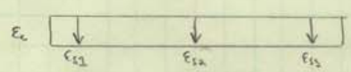
* THIS MOMENT ONLY LOOKS AT THE GRAVITY LOADS & NO LATERAL LOADS. THE BEAM IS OVER DESIGNED ACCORDING TO THE CALCS SINCE NO LATERAL LOADS WERE CONSIDERED

COLUMN DESIGN: A/7.1



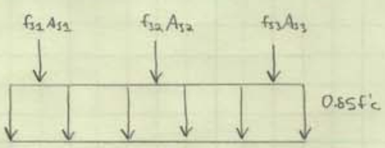
$f'_c = 8000$ psi
$f_y = 60$ ksi
(8) #11 BARS

AXIAL STRENGTH (P_o)



$\varepsilon_c = \varepsilon_u = 0.003$

$\varepsilon_{si} > \varepsilon_y = 60/29{,}000 = 0.00207$



$P_o = 0.85 f'_c \left(bh - \Sigma A_{si} \right) + \Sigma A_{si} f_{si}$

$P_o = 0.85(8)\left[28in(28in) - 8(1.56in^2)\right] + 8(1.56in^2)(60ksi)$

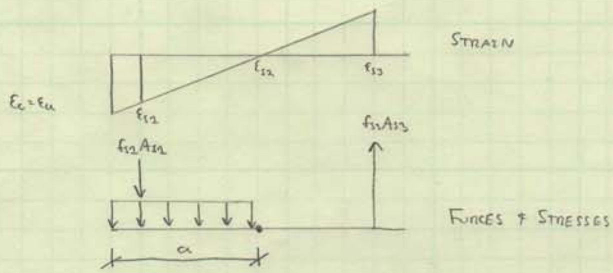
$P_o = 5995^k$

$\phi P_o = 0.65(5995^k)$

$\boxed{\phi P_o = 3897^k}$

UNION STATION EXPANSION | TECH. I REPORT | PAGE 7

BALANCED – STRAIN STRENGTH (M_b, P_b)



$\varepsilon_y = \dfrac{60\text{ ksi}}{29{,}000\text{ ksi}} = 0.00207$

$c = \dfrac{0.003}{0.003+\varepsilon_y}\,d_{imax} = \dfrac{0.003\,(26.5\text{in})}{0.003+0.00207} = 15.7\text{in}$

$\beta_1 = 0.85 - \frac{0.05}{1000}(8000-4000) = 0.65$

$a = 15.7\text{in}(0.65) = 10.2\text{in}$

$\varepsilon_{s1} = \dfrac{0.003\,(c-d_1)}{c} = \dfrac{0.003\,(15.7\text{in}-1.5\text{in})}{15.7\text{in}} = 0.00271 > \varepsilon_y$

$d_1 < a \therefore f_{s1} = 0.00271\,(29{,}000\text{ ksi}) = 78.6\text{ ksi}$

$\varepsilon_{s2} = \dfrac{0.003\,(c-d_2)}{c} = \dfrac{0.003\,(15.7-14)}{15.7} = 0.000325 < \varepsilon_y$

$f_{s2} = 0.000325\,(29{,}000\text{ ksi}) = 9.43\text{ ksi}$

$\varepsilon_{s3} = \dfrac{0.003\,(c-d_3)}{c} = \dfrac{0.003\,(15.7-26.5)}{15.7} = -0.00206 < \varepsilon_y$

$f_{s3} = -0.00206\,(29{,}000\text{ ksi}) = -59.8\text{ ksi}$ (IN TENSION)

$P_b = 0.85(8\text{ ksi})(28\text{in})(0.65)(15.7) + 3(1.56\text{in}^2)(78.6\text{ ksi}) + 2(1.56\text{in}^2)(9.43\text{ ksi}) + 3(1.56\text{in}^2)(-59.8\text{ ksi})$

$P_b = 1943^k + 368^k + 29^k - 280^k$

$P_b = 485^k$

$\phi = 0.65^k$

$\phi P_b = 485^k(0.65)$

$\boxed{\phi P_b = 315^k}$

UNION STATION EXPANSION | TECH. I REPORT | PAGE 8

$M_b = 1443^k\left(14_{in} - \frac{10.2_{in}}{2}\right) + 368^k(8_{in} - 1.5_{in}) + 29^k(0_{in}) - 280^k(14_{in} - 26.5_{in})$

$M_b = 1729\ k\text{-}in + 2392\ k\text{-}in + 3500\ k\text{-}in = 7621\ k\text{-}in$

$M_b = 635\ k\text{-}ft$

$\phi = 0.65$

$\boxed{\phi M_b = 413\ k\text{-}ft}$

PURE BENDING (M_o)

+ASSUME ε_{s1} DOESN'T YIELD
+ASSUME ε_{s2} & ε_{s3} YIELD

$f_{s1} = \frac{0.003(c - d_1)(29{,}000\ ksi)}{c} = \frac{0.003(c - 1.5)(29{,}000\ ksi)}{c} = \frac{87c - 131}{c}$

$f_{s2} = f_{s3} = -60\ ksi$

$\Sigma F = 0$

$0 = 0.85(8\ ksi)(26_{in})(0.65)c + 3(1.56_{in^2})f_{s1} + 2(1.56_{in^2})(f_{s2}) + 3(1.56_{in^2})(f_{s3})$

$0 = 124c + 4.68\left(\frac{87c - 131}{c}\right) - 187 - 281$

$0 = 124c^2 + 407c - 613 - 187c - 281c$

$0 = 124c^2 - 61c - 613$

$c = \frac{61 \pm \sqrt{(-61)^2 - 4(124)(-613)}}{2(124)}$

$c = \frac{61 \pm 555}{248}$

$c = 2.48_{in}$

+VERIFY ASSUMPTIONS

$f_{s1} = \frac{87(2.48) - 131}{2.48} = 34.1\ ksi < 50\ ksi$ ∴ okay

$f_{s2} = \frac{0.003(2.48_{in} - 14_{in})}{2.48_{in}}(29{,}000\ ksi) = -404\ ksi$ ∴ must $< 60\ ksi$ ∴ okay

UNION STATION EXPANSION TECH. II REPORT   PAGE 9

$f_{s3} = \frac{0.003\,(2.48in - 26.5in)}{2.48in}\,(29{,}000ksi) = -842\,ksi \therefore$ must use $-60\,ksi \therefore$ okay

$$M_o = 0.85f'_c(b)(\beta_1)(c)\left(\tfrac{h}{2} - \tfrac{\beta_1 c}{2}\right) + A_{s1}(f_{s1})\left(\tfrac{h}{2} - d_1\right) + \cancel{A_{s2}(f_{s2})\left(\tfrac{h}{2} - d_2\right)}^{\,0} + A_{s3}(f_{s3})\left(\tfrac{h}{2} - d_3\right)$$

$$M_o = 0.85(8ksi)(28in)(0.65)(2.48in)(14in - 1.61in) + 3(1.56in^2)(14in - 1.5in)(34.7ksi) + 3(1.56in^2)(-60ksi)(14in - 26.5in)$$

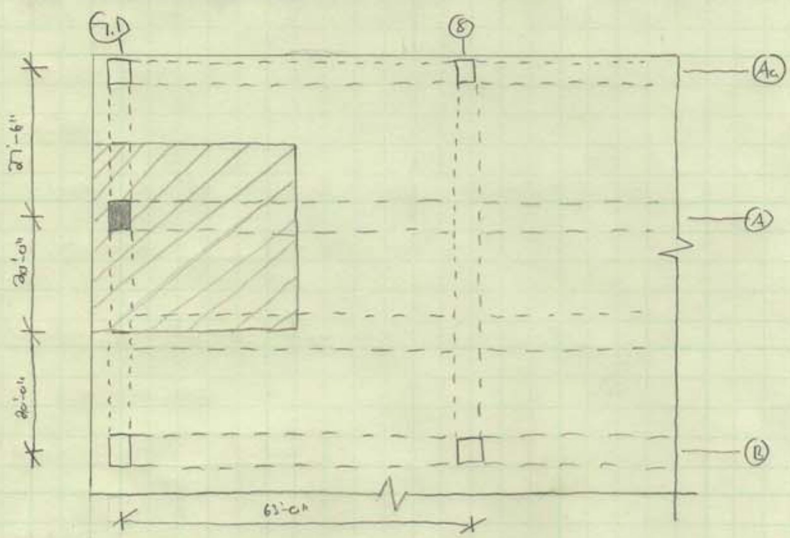
$M_o = 3803$ k-in $+ 1995$ k-in $+ 3510$ k-in $= 9308$ k-in

$M_o = 776$ k-ft

$\phi M_o = 0.9(776$ k-ft$)$

$\boxed{\phi M_o = 698 \text{ k-ft}}$

LOAD ON COLUMN FROM ROOF



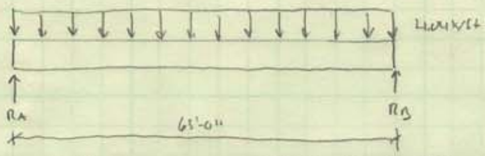
SLAB: DL $= 7/12\,(120\,psf) = 70\,psf$
$+5$ [MISC]

LL $= 50\,psf$

$1.2D + 1.6L = 1.2(75\,psf) + 1.6(50\,psf) = 170\,psf$

$\frac{170\,psf\left(\frac{27.5+20}{2}\right)}{1000} = 4.04\,k/ft$

BEAM:



$R_A = R_B = \dfrac{4.04^k/ft\,(63ft)}{2} + \dfrac{70psf\,(^{20in}/_{12})\,(63ft)}{1000\,(2)}\,(1.2)$

↳ SELF WEIGHT OF BEAM

$R_A = R_B = 127^k + 4.41^k$

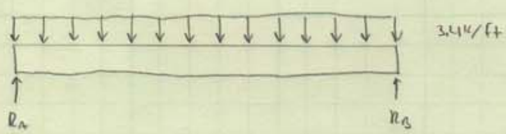
$R_A = R_B = 131^k$

GIRDER: FOR THE GIRDER ALONG AA-A COLUMN LINE, ONLY CONSIDERED SELF-WEIGHT

$\dfrac{(1.2)\,70_{psf}\,(^{21in}/_{12})\,(27.5ft)}{1000(2)} = 2.01^k$

FOR THE GIRDER ALONG A-B COLUMN LINE, MUST CONSIDERED THE LOADS FROM BEAM & SLAB

$\dfrac{170psf\,(20ft)}{1000} = 3.4^k/ft \Rightarrow$ UNIFORM LOAD ON BEAM



$R_A = R_B = \dfrac{3.4^k/ft\,(63ft)}{2} + \dfrac{(1.2)\,70psf\,(^{20in}/_{12})\,(63ft)}{1000(2)} = 107^k + 4.41 = 111^k \Rightarrow$ LOAD ON GIRDER

$111^k/2 = 55.5^k \Rightarrow$ LOAD THAT TRAVELS TO COLUMN

TOTAL LOAD ON COLUMN 7.1/A FROM ROOF:

$P = 131^k + 2.01^k + 55.5^k$

$\boxed{P = 190^k}$

- WILL NOW LOOK AT THE SAME COLUMN AT THE GROUND FLOOR

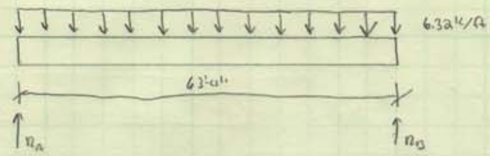
SLAB:
140 psf
10 psf [MEP]
+ 5 psf [MISC]
155 psf

$1.2D + 1.6L = 1.2(155\,psf) + 1.6(50\,psf) = 266\,psf$

UNION STATION EXPANSION | TECH. I REPORT | PAGE 11

$$\frac{266\,psf\left(\frac{47.5+40}{2}\right)}{1000} = 6.32^k/ft$$

BEAM:



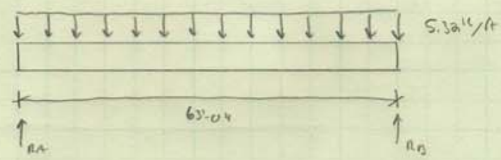
$R_A = R_B = \frac{6.32^k/ft(63\,ft)}{2} = 200^k \Rightarrow$ INCLUDES SELF-WEIGHT OF BEAM

GIRDERS: FOR THE GIRDER ALONG A4-A COLUMN LINE, ONLY CONSIDER SELF-WEIGHT

$$\frac{1.2(70\,psf)(^{2}/_{12})(27.5\,ft)}{1000(2)} = 2.01^k$$

FOR THE GIRDER ALONG A-B COLUMN LINE, MUST CONSIDER ALL LOADS FROM BEAM & SLAB

$$\frac{266\,psf(20\,ft)}{1000} = 5.32^k$$



$R_A = R_B = \frac{5.32^k/ft(63\,ft)}{2} = 168^k \Rightarrow$ LOAD ON GIRDER

$168^k/2 = 84^k \Rightarrow$ LOAD THAT TRAVELS TO COLUMN

TOTAL LOAD ON COLUMN FROM FLOOR:

$200^k + 2.01^k + 84^k = \underline{\underline{286^k}}$

TOTAL LOAD ON COLUMN (TOP TO BOTTOM):

$P = (286^k)(4) + 190^k$

$\boxed{P = 1334^k < 3847^k \therefore \text{OKAY}}$

* SINCE ALL BEAMS / GIRDERS / COLUMNS ARE PART OF LATERAL SYSTEM, NO LATERAL FORCES WERE CONSIDERED. THIS EXPLAINS WHY THIS COLUMN IS OVERSIZED