THE ODYSSEY
ARLINGTON, VA

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Structural Technical Report III

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Lateral System Analysis and Confirmation Design

Executive Summary:

The Odyssey is a 475,650 SF luxury residential complex located in Arlington, Virginia. The site features 2- 3 story townhouses adjacent to 3 levels of underground parking with adjoining skewed towers rising from the lower parking levels clad with glass curtain walls and brick facade. There are 16 stories of apartments with suites located on the top floors and retail space on the ground floors. The Odyssey is a perfect example of the latest designs for the rising market of luxury apartment and condominium construction with a structural system almost entirely composed of concrete. The floor systems are 2-way flat slabs and the lateral systems are shear walls located throughout the plan of the Odyssey and concrete slab frames.

The lateral system analysis and confirmation design report is a look into the design and interaction of lateral design elements. Lateral load cases analyzed in the Structural Concepts and Existing Structural Conditions report are distributed throughout the lateral elements by logical loading paths through stiffness. Lateral elements are then checked by strength, drift, and overturning effects from the resolved lateral load distribution.

The Odyssey consists of two lateral resisting systems integrated into the building design. An assumption that shear walls controlled the lateral design was made to check if in fact the two systems worked as dual system or were redundant. The analyses and checks provided a better understanding of individual contributions of each system. The design shear reinforcement for shear walls was inadequate to resist the full distribution of the direct and eccentric loading. The nominal strength of the shear wall would only contribute to a third of the distributed load. An overturning check revealed the requirement of the slab frame contribution to distribute moment throughout the foundation with a resulting uplift by the shear wall lateral reaction. A further analysis into the combined deflections of the dual system must be addressed to determine the interaction of each system upon one another, thereby reducing overall drift.

A general conclusion can be made that the lateral system design of the Odyssey is two systems working together to distribute lateral loading. The interaction and economical implications of a dual system may be the basis of a proposal to study and redesign the system.

Introduction:

The Odyssey is located in Arlington, Virginia adjacent to the Court district and several blocks from the commercial center of downtown Arlington. The primary use of the building is residential apartments and luxury condominiums located throughout the 1st-15th levels of the tower structure. Retail spaces are designed into the upper garage and 1st levels running along the 16th street which leads directly out of downtown Arlington.

The site for the Odyssey was chosen for its ideal location within the Arlington and proximity to the metro train with access into Washington D.C. within minutes. It is zoned under the "Special Affordable Housing Protection District" ("SAHPD") designation and requires the replacement of existing affordable residential units demolished on site to build the Odyssey. A row of multistory townhouses is incorporated into the design of the overall structure of the building on account of this zoning ordinance.

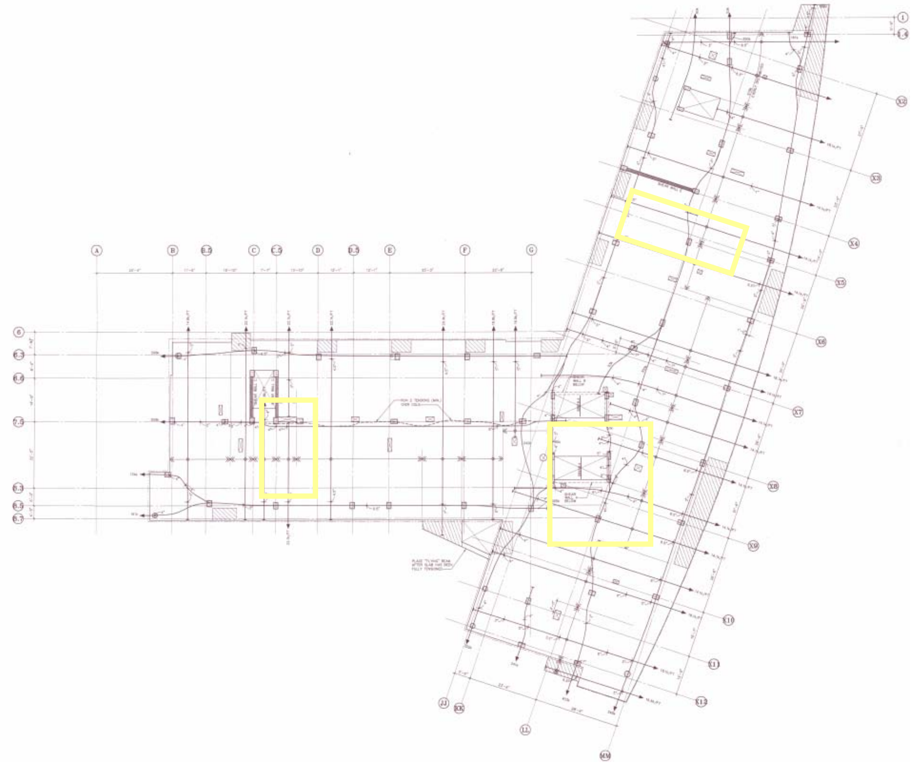
Townhouses are built adjacent to the 3 sub-grade garage levels with a one-way flat slab concrete structural system. The lower garage level is is composed of 4" concrete slab (f'c=5ksi) on grade and reinforced with 6x6 – w1.4 x w1.4 wire mesh. Foundation structures include two 54" mat foundations; however the typical foundations are concrete footings of various rectangular sizes, depths, and reinforcement. The remaining lower garage levels through the first floor are primarily 8.5" conventionally reinforced 2-way concrete flat slabs with drop panels typically extending 4-1/2" below the floor slab. The tower structure of the Odyssey makes up the majority of the 1st-16th levels with custom residential units ranging from studios to luxury condominiums. The overall height of the towers from grade is 167' with a pool terrace on the 15th level extending over the roof of the east tower. The floor system of the towers is primarily an 8" 2-way post tensioned flat concrete slab (f'c=5ksi) with continuous bottom reinforcement of #4 bars @ 24" o.c in each direction.

The lateral systems of the Odyssey are concrete shear walls with groupings throughout the building and integrated concrete slab frames. A set of walls surround elevator shafts at the central core of the Odyssey with another set located a stair well in the west wing of the building. The third and final shear wall is located in the east wing oriented at the askew angle of the adjoined towers.

Lateral System:

The lateral system of the Odyssey is a dual system of concrete shear walls and slab frames. All of the wall ends are integrated with columns, typically 18”x26” and 14”x28” with varying strengths of 8000psi on lower levels and 5000psi throughout the remaining residential levels. A set of C- channel walls each surround 2 elevator shafts at the core of the adjoining towers. These shear walls extend from the foundation 3 levels below grade to the 4th level of the Odyssey and have thicknesses of 10” and 14”. Labeled shear walls A & B, the distribution of shear to these walls is minimal with approximately half of their gross height below grade. With the central shear walls dropping off at the 4th level, the interaction of the slab frame will begin to contribute more lateral resistance in combination with the remaining shear walls. Slab frames are composed of columns and the column strip slab between adjacent columns. The relative joint stiffness resists lateral loading to the frame and is achieved by added reinforcement. The Odyssey has 8” slabs with added #4 bar reinforcement.

Shear walls C & C1, are located at the extent of the west tower wing. They rise on adjacent sides of a stair-well with wall C extending from the 1st level to the roof, while wall C1 terminates on the 10th level. These walls receive a larger distribution of lateral and torsional shear than the core walls on account of there eccentric orientation to the concentration of lateral story load at the center of mass. On the opposite extent of the Odyssey in the north wing of the east tower is shear wall E with a 10” thickness and overall length of 30’ rising from the 1st to 14th levels. The wall is oriented with the shorter dimension of the east tower and as a result is askew to primary lateral loading directions. On the 15th level is the roof top pool terrace with wall E located directly under the pool acting in both gravity and lateral capacities. An intricate distribution is associated to shear wall E considering the configuration to resisting both lateral load directions. A plan summary of individual shear walls is located in for further reference and their distribution throughout the building plan is depicted below.



Gravity loads:

The gravity loads for the lateral analysis were determined in accordance with ASCE7-02. General assumptions for several dead loads were made with interpretation of details and structural component averages. A list of relevant gravity loads follow:

Gravity: (psf)

Floor Live:	
Residential Units & Corridors	40
Public Areas	100
Mech. Room	150
Pool Terrace	100
Parking Garage	50
Stairs and Exits	100
Roof Live:	
Min. Roof Live Load	30
Roof Snow:	
Roof Snow Load	21
Floor Dead:	
Concrete Slab	100 –150 (varied thickness 8"-12")
Partitions	8
Flooring	4
Ceiling	5
Mechanical	10
Beams/Columns	(* varies)

Load Combinations:

Seismic loading was found to control the lateral design of the Odyssey and is further detailed in the following section. The strength design of the building components, structures, and foundations is determined from load combinations specified in accordance with ASCE7-02 section 2.3. A list of the combinations found in accordance with section 2.3 is listed below. A simplified check of each case is summarized in Appendix C with load combination II controlling. This takes into account of gravity loading design, however relevant seismic contributions are relevant in lateral design.

I. 1.4D

II. 1.2D + 1.6L + 0.5(Lr or S)

III. 1.2D + 1.6L + (Lr or 0.8W)

IV. 1.2D + 1.6L + L + .5(Lr or S)

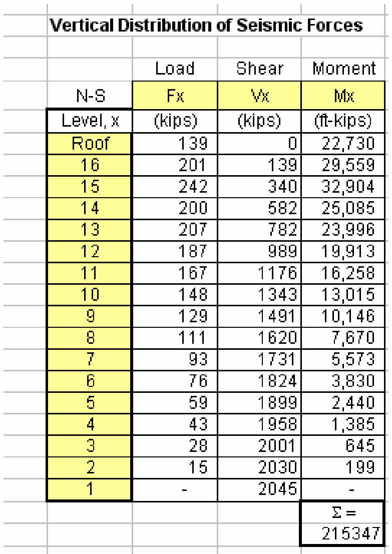
V. 1.2D + 1.0E + L + 0.2S

VI. 0.9D + 1.6W

VII. 0.9D + 1.0E

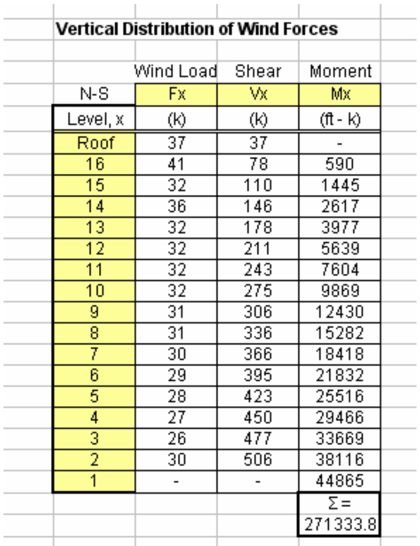
Lateral Design

The lateral loads on the Odyssey were determined in accordance with design procedures specified in ASCE7-02. Detailed analyses are found in the Structural Concepts and Existing Structural Conditions report. The lateral load analyses only considered the exposed levels above grade which receive loading upon the building diaphragm. Wind loads were calculated by the analytical procedure with loading summaries located in the Appendix D sections. Seismic loads were determined through the equivalent lateral force procedure outlined in Section 9 of ASCE7-02. A summary of resolved seismic and wind loads are listed below. The seismic loads were found to control the majority of loading in both primary lateral directions. Wind was found to control on the lower levels but was overtaken by seismic for the remaining levels. An ETABS model of the shear wall system was constructed for an analysis and comparison of alternative loading combinations which ultimately did not control. Wind loading at 45° to the primary lateral directions was considered based on possible implications of the irregular building shape. Design wind load case III specified in section 6 of ASCE7-02 as 75% of both primary lateral directions was also considered. The distributions of seismic story forces throughout the building are shown in subsequent diagrams on the next page. These forces cumulate into shear story forces that will be distributed throughout the various shear walls within the structure for the lateral analysis.



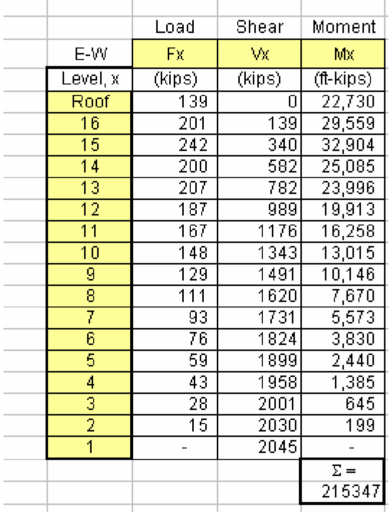
Vertical Distribution of Seismic Forces

	Load	Shear	Moment
N-S	Fx	Vx	Mx
Level, x	(kips)	(kips)	(ft-kips)
Roof	139	0	22,730
16	201	139	29,559
15	242	340	32,904
14	200	582	25,085
13	207	782	23,996
12	187	989	19,913
11	167	1176	16,258
10	148	1343	13,015
9	129	1491	10,146
8	111	1620	7,670
7	93	1731	5,573
6	76	1824	3,830
5	59	1899	2,440
4	43	1958	1,385
3	28	2001	645
2	15	2030	199
1	-	2045	-
			Σ = 215347



Vertical Distribution of Wind Forces

	Wind Load	Shear	Moment
N-S	Fx	Vx	Mx
Level, x	(k)	(k)	(ft - k)
Roof	37	37	-
16	41	78	590
15	32	110	1445
14	36	146	2617
13	32	178	3977
12	32	211	5639
11	32	243	7604
10	32	275	9869
9	31	306	12430
8	31	336	15282
7	30	366	18418
6	29	395	21832
5	28	423	25516
4	27	450	29466
3	26	477	33669
2	30	506	38116
1	-	-	44865
			Σ = 271333.8



	Load	Shear	Moment
E-W	Fx	Vx	Mx
Level, x	(kips)	(kips)	(ft-kips)
Roof	139	0	22,730
16	201	139	29,559
15	242	340	32,904
14	200	582	25,085
13	207	782	23,996
12	187	989	19,913
11	167	1176	16,258
10	148	1343	13,015
9	129	1491	10,146
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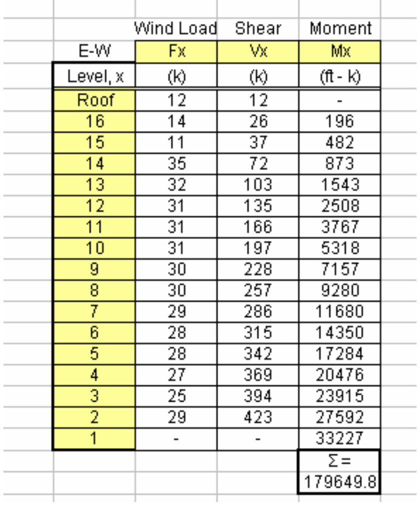
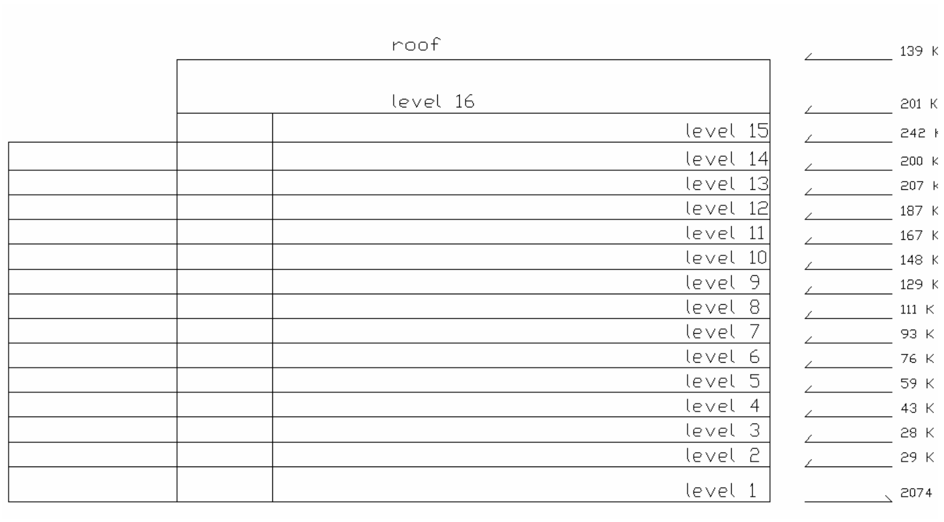
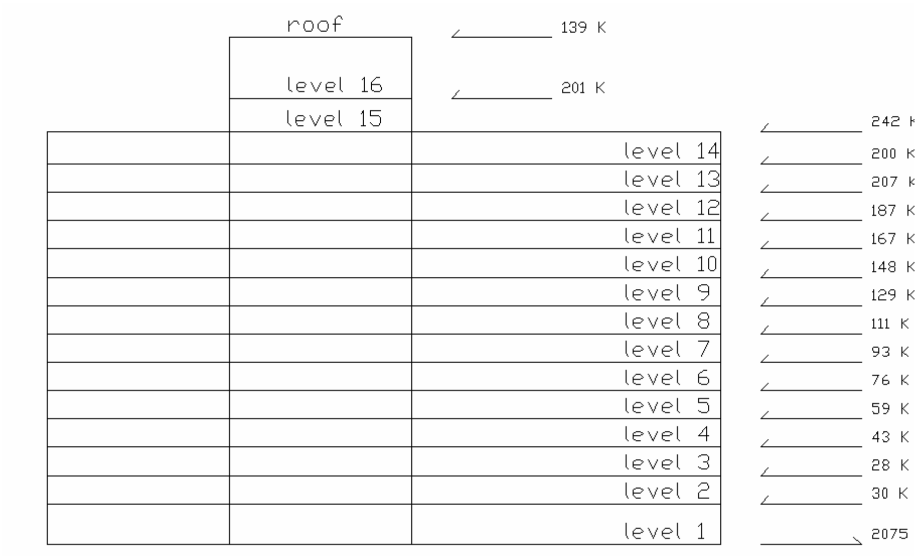
7	93	1731	5,573
6	76	1824	3,830
5	59	1899	2,440
4	43	1958	1,385
3	28	2001	645
2	15	2030	199
1	-	2045	-
			Σ = 215347



	Wind Load	Shear	Moment
E-W	Fx	Vx	Mx
Level, x	(k)	(k)	(ft - k)
Roof	12	12	-
16	14	26	196
15	11	37	482
14	35	72	873
13	32	103	1543
12	31	135	2508
11	31	166	3767
10	31	197	5318
9	30	228	7157
8	30	257	9280
7	29	286	11680
6	28	315	14350
5	28	342	17284
4	27	369	20476
3	25	394	23915
2	29	423	27592
1	-	-	33227
			Σ = 179649.8



E-W Distribution
(North Elevation)



N-S Distribution
(East Elevation)

The distribution of seismic shear forces to the shear walls was carried out by a simplified analysis by proportion of individual wall rigidities on each floor. This distribution assumes a design scenario in which the shear walls will control the lateral system and receive full lateral and torsional shears. The intent of this analysis is to determine the degree to which the slab frame contributes to the lateral system and weather the shear walls control the design. Rigidity of each wall accounts for thickness, modulus of elasticity, and the individual wall height to length ratio. The modulus of each wall is constant with concrete strengths of each wall identical throughout the height of the building.

$$Ec = 57000(f'c)^{.5} \qquad f'c = 4000psi$$

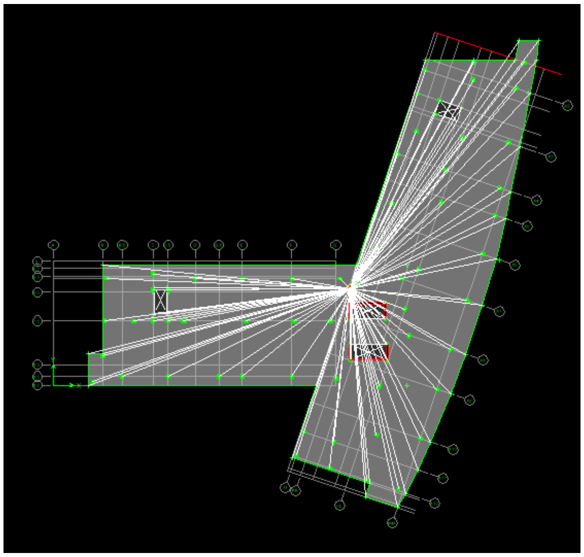
Rigidity: $R = Et(4(h/L)^3+3(h/L))^{-1}$

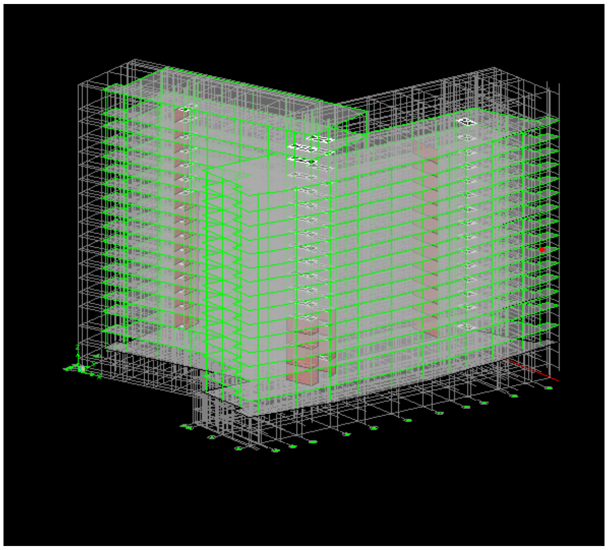
Distribution of shear to wall E, the skewed wall in the North wing of the East tower, will be proportionate to the rotation from the primary loading direction.

Shear wall E: $R_{E\text{-}W}=R\cos(\theta)$ $R_{N\text{-}S}=R\sin(\theta)$

The direct lateral load distribution developed reasonable story loads upon each shear wall proportionate to the overall wall lengths. The walls located on the wings of the building experienced a shear increase on the 4th level resulting from a redistribution of force from the loss of core walls. This shear redistribution would only reason to increase the reinforcement at this level where the design remains constant then decreases from #6 to #5 bars. This suggests that shear might be redistributed to an alternative system, thereby justifying this design of the shear reinforcement. This design limit of reinforcement is further addressed in the design check section of the report

The eccentric placement of the shear walls throughout the building suggests a large contribution of shear as a result of torsional effects. The distribution of torsional shear in the N-S shear walls was determined from the effects of loading and rotation from the center of rigidity to an eccentric shear wall. The concentration of lateral load was assumed at the center of mass determined by the ETABS model shown below. The distribution of torsional was approximated by a typical percentage of the shears distributed on floors with similar centers of rigidity. Torsional shear distributions upon the eccentric walls ranged from 40% to >100% of the direct shear. The distribution and calculations of story shears are located in Appendix E.





Design Spot Checks

Strength Check:

The shear wall reinforcement was checked for wall C.1 which is located in the wing of the east tower set at an eccentric location to the concentrated lateral shear. The intent of checking this particular wall is to determine weather the reinforcement of the wall will have the strength to resist the combination of direct and torsional shear without additional resistance from the slab frame.

The reinforcement design was checked in accordance with shear strength calculations specified in ACI318 section 11.10, special provisions for walls. The design limitation is based on the factored shear load such that:

$$Vu \leq \Phi\ Vn \qquad \text{where,} \qquad Vn = Vc + Vs.$$

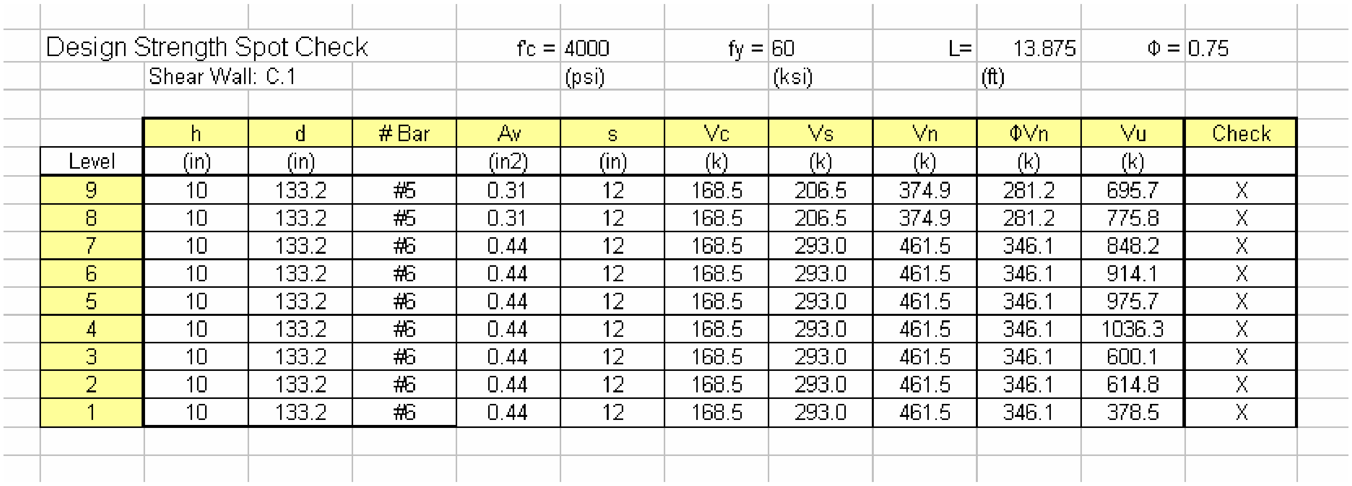
The nominal shear strength provided by concrete walls which are subjected to vertical compression is taken as:

$$Vc = 2(f'c)^{.5}\ hd \qquad \text{where,} \qquad d = .8l_w$$

The nominal shear strength provided by the horizontal reinforcement within the wall is determined by:

$$Vs = A_v\ f_y\ d/s$$

The design check reveals that the walls are under reinforced for the direct and torsional shear distribution. Speculations earlier of interaction between the dual systems at critical levels are apparent when comparing the design strength to the distributed lateral shear. More than 2/3 of the story shear would need to be redistributed into the slab frame for the present reinforcement design of the shear walls. The design check shows that shear walls do not control the lateral system of the Odyssey and it is likely that the slab frame contributes in the distribution of lateral forces.



Design Strength Spot Check — f'c = 4000 (psi) — fy = 60 (ksi) — L= 13.875 (ft) — Φ = 0.75

Shear Wall: C.1

	h	d	# Bar	Av	s	Vc	Vs	Vn	ΦVn	Vu	Check
Level	(in)	(in)		(in2)	(in)	(k)	(k)	(k)	(k)	(k)	
9	10	133.2	#5	0.31	12	168.5	206.5	374.9	281.2	695.7	X
8	10	133.2	#5	0.31	12	168.5	206.5	374.9	281.2	775.8	X
7	10	133.2	#6	0.44	12	168.5	293.0	461.5	346.1	848.2	X
6	10	133.2	#6	0.44	12	168.5	293.0	461.5	346.1	914.1	X
5	10	133.2	#6	0.44	12	168.5	293.0	461.5	346.1	975.7	X
4	10	133.2	#6	0.44	12	168.5	293.0	461.5	346.1	1036.3	X
3	10	133.2	#6	0.44	12	168.5	293.0	461.5	346.1	600.1	X
2	10	133.2	#6	0.44	12	168.5	293.0	461.5	346.1	614.8	X
1	10	133.2	#6	0.44	12	168.5	293.0	461.5	346.1	378.5	X

The overturning moment by the lateral effects upon eccentric shear walls was considered for this analysis. The shear walls will contribute a greater overturning moment to the structure by combined direct and torsional shears. These walls only extend from the 1st level and will distribute the overturning loads into the subsequent concrete floor system below grade. Overturning forces through a combined effect of both the shear walls and the slab frame will need to be considered to analyze full overturning effects on the mat foundation in the lower garage level. This analysis will consider the shear wall effects alone to determine the requirement, if any, of a contributing slab frame integrated with the shear walls. The dead load on account of both the shear wall itself and of accumulated tributary area floor loads was calculated as P = 3675k. The overturning moment was calculated from the resulting shear distribution to wall C.1, with M = 243980 ft –k.

$P_{res} = M/L_w - P = 13909$ k

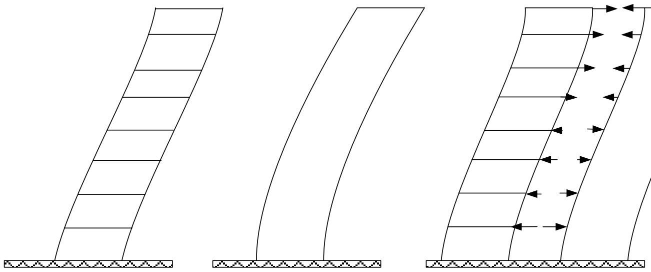
The result of this analysis does not take into account of added structural weight below grade. This includes the 54" mat slab which ties into the frame columns which are integrated into the shear above walls. The magnitude of the uplift force suggests that a significant contribution of the slab frame is required in resisting the lateral loading. A combined lateral system will distribute the overturning moment over a larger area than the shear wall alone.

Drift:

A drift analysis was calculated for an eccentric shear wall. Shear wall C.1 will experience deflection due to both flexure and shear cause by the distributed lateral loads acting at each level. The story drifts were calculated in Appendix E by the following deflection equations:

$\Delta\text{Flexure} = Ph^3/3EI$ $\Delta\text{Shear} = 2.78Ph/A_wE$

The maximum story drift for the shear wall was found to be $\Delta =$ 0.10" which more than satisfies the BOCA 96 drift limitation of H/240. These results are counterintuitive to the before mentioned theory in which the slab frame and shear walls act as an integral lateral system. Based on the minimal deflections, the shear walls appear to act alone in resisting the lateral deflections. A further drift analysis of a combined system may provide a better understanding of these results. An analysis of combined deflected behaviors producing interaction forces between the lateral systems may show decreases in overall drift of a dual system apposed to individual systems A schematic of the interactions is show below.



Summary/Conclusions

The Odyssey consists of two lateral resisting systems integrated into the building design. An assumption that shear walls controlled the lateral design was made to check if in fact the two systems worked as dual system or were redundant. The analyses and checks provided a better understanding of individual contributions of each system. The design shear reinforcement for shear walls was inadequate to resist the full distribution of the direct and eccentric loading. The nominal strength of the shear wall would only contribute to a third of the distributed load. An overturning check revealed the requirement of the slab frame contribution to distribute moment throughout the foundation with a resulting uplift by the shear wall lateral reaction. A further analysis into the combined deflections of the dual system must be addressed to determine the interaction of each system upon one another, thereby reducing overall drift.

A general conclusion can be made that the lateral system design of the Odyssey is two systems working together to distribute lateral loading. The interaction and economical implications of a dual system may be the basis of a proposal to study and redesign the system.

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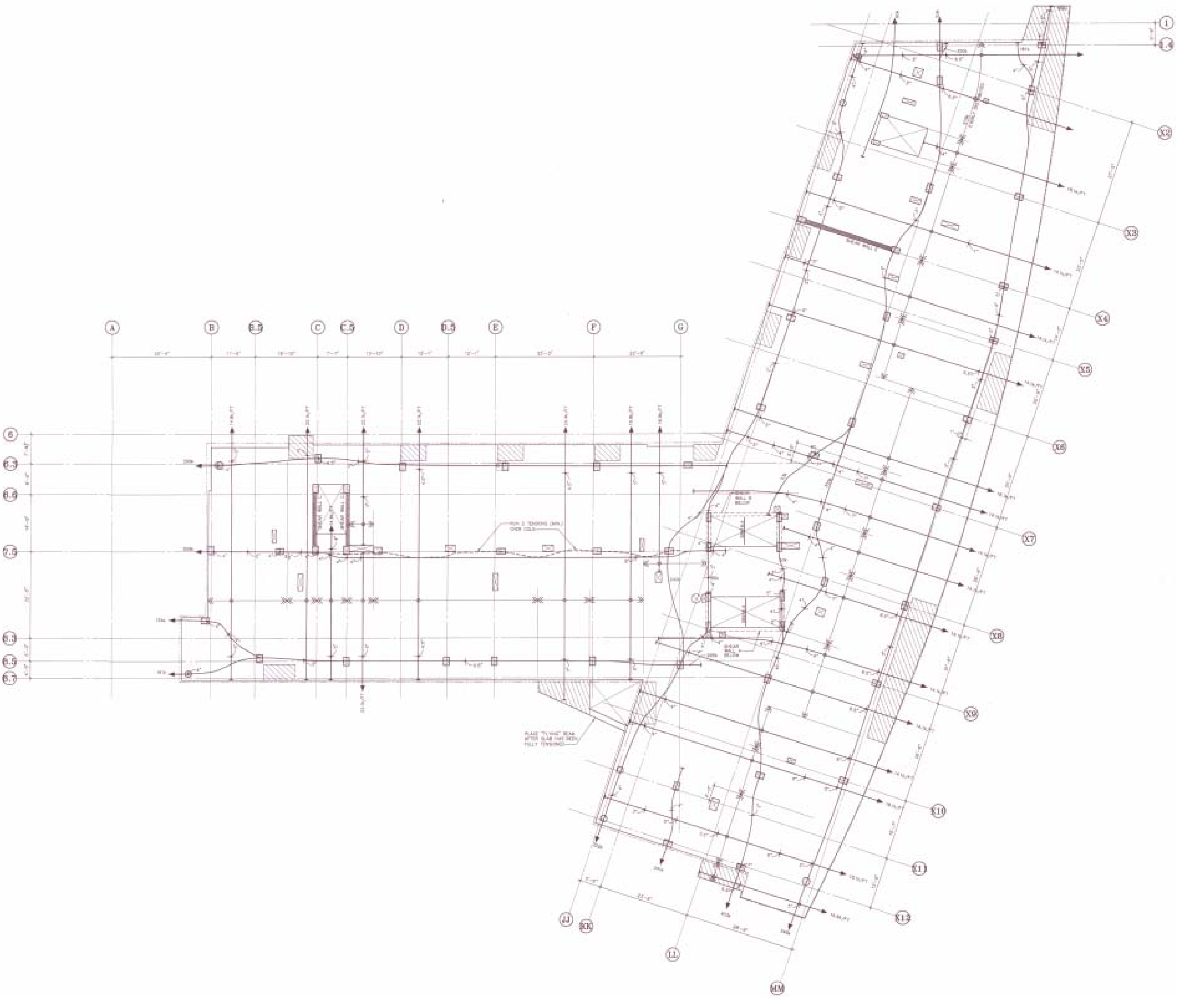
Appendix

Appendix – A ------------ Floor Plan
Appendix – B ------------ Shear Wall Plan Summary
Appendix – C ------------ Load Case Summary
Appendix – D ------------ Lateral Load Summary
Appendix – E ------------ Lateral Distribution
Appendix – F ------------ Drift Check

References:

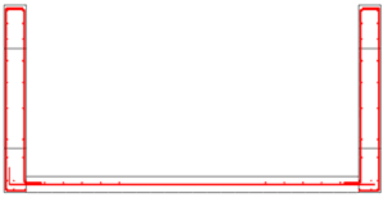
Appendix – A FLOOR PLAN



Appendix B – Shear Wall Plan Summary

Shear wall A:

Resists both lateral load directions: North-South & East-West.
Location: Surrounds north-core elevator shafts
Range: B3 - 4th level
Size: North-South walls - 1’-2” x 10’
Integrated columns - 14”x 28”
Column Reinforcement – 6 #9 bars
East-West wall – 10”x17’-10”
Wall Reinforcement: #5 & #6 bars @ 12”

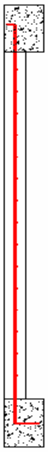


Shear wall B:

Resists both lateral load directions: North-South & East-West.
Location: Surrounding south-core elevator shafts
Range: B3 - 4th level
Size: North-South walls - 1’-2” x 10’-0”
Integrated into columns - 14”x 28”
Column Reinforcement – 6 #9 bars
East-West wall – 10”x17’-0”
Wall Reinforcement: #5 & #6 bars @ 12”

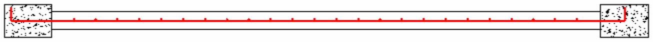
Shear wall C , C1:

Resists lateral load directions: North-South
Location: Surrounding West stair tower.
Range: 1st - 16th level
C1 terminates at 10th level
Size: North-South walls - 10”x 13’-10.5”
Ends attached to columns – 18”x 26” and 24”x 24”
Column Reinforcement – (varies) #11 bars
Wall Reinforcement: #5 & #6 bars @ 12”

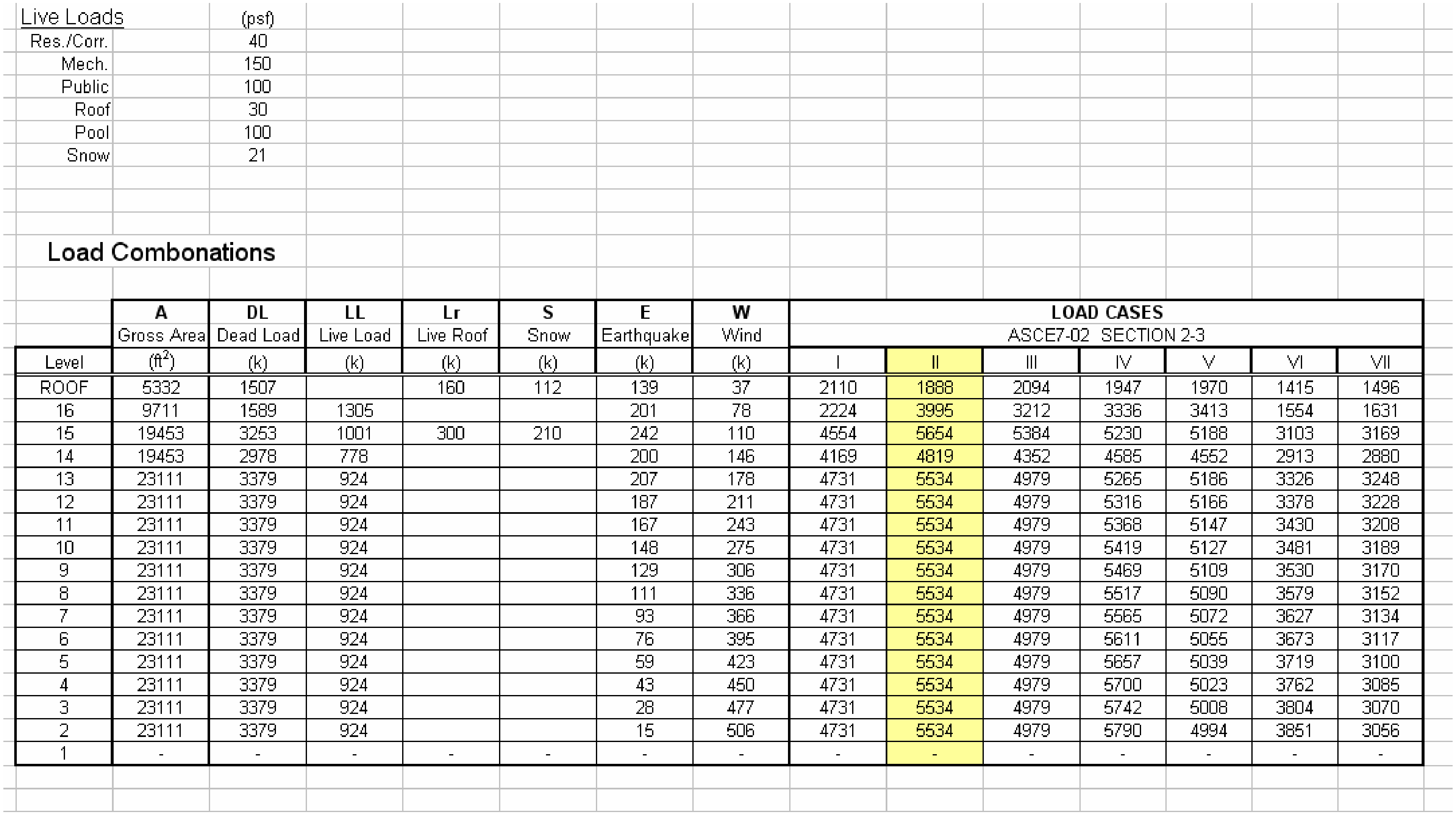


Shear wall E:

Resists lateral load directions: North West-South East
Location: Column line X4 - North side of East tower
Range: 1st - 14th level
Size: North-South walls - 10”x 29’-5”
Ends attached to columns – 18”x 26”
Column Reinforcement – (varies) #11 bars
Wall Reinforcement: #5 & #6 bars @ 12”



Appendix C – Load Case Summary

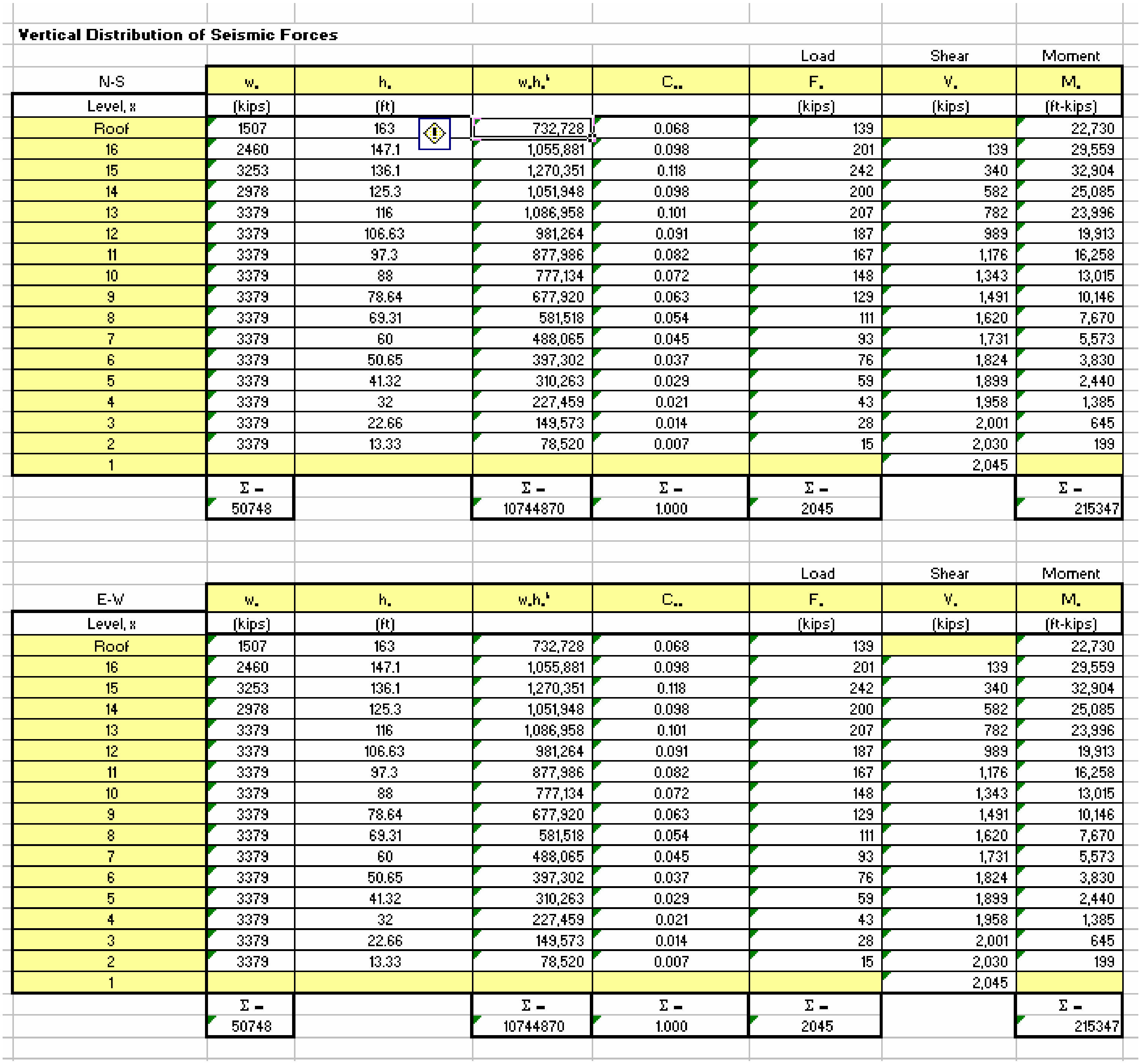


Live Loads	(psf)
Res./Corr.	40
Mech.	150
Public	100
Roof	30
Pool	100
Snow	21

Load Combonations

	A	DL	LL	Lr	S	E	W	LOAD CASES						
	Gross Area	Dead Load	Live Load	Live Roof	Snow	Earthquake	Wind	ASCE7-02 SECTION 2-3						
Level	(ft²)	(k)	(k)	(k)	(k)	(k)	(k)	I	II	III	IV	V	VI	VII
ROOF	5332	1507		160	112	139	37	2110	1888	2094	1947	1970	1415	1496
16	9711	1589	1305			201	78	2224	3995	3212	3336	3413	1554	1631
15	19453	3253	1001	300	210	242	110	4554	5654	5384	5230	5188	3103	3169
14	19453	2978	778			200	146	4169	4819	4352	4585	4552	2913	2880
13	23111	3379	924			207	178	4731	5534	4979	5265	5186	3326	3248
12	23111	3379	924			187	211	4731	5534	4979	5316	5166	3378	3228
11	23111	3379	924			167	243	4731	5534	4979	5368	5147	3430	3208
10	23111	3379	924			148	275	4731	5534	4979	5419	5127	3481	3189
9	23111	3379	924			129	306	4731	5534	4979	5469	5109	3530	3170
8	23111	3379	924			111	336	4731	5534	4979	5517	5090	3579	3152
7	23111	3379	924			93	366	4731	5534	4979	5565	5072	3627	3134
6	23111	3379	924			76	395	4731	5534	4979	5611	5055	3673	3117
5	23111	3379	924			59	423	4731	5534	4979	5657	5039	3719	3100
4	23111	3379	924			43	450	4731	5534	4979	5700	5023	3762	3085
3	23111	3379	924			28	477	4731	5534	4979	5742	5008	3804	3070
2	23111	3379	924			15	506	4731	5534	4979	5790	4994	3851	3056
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

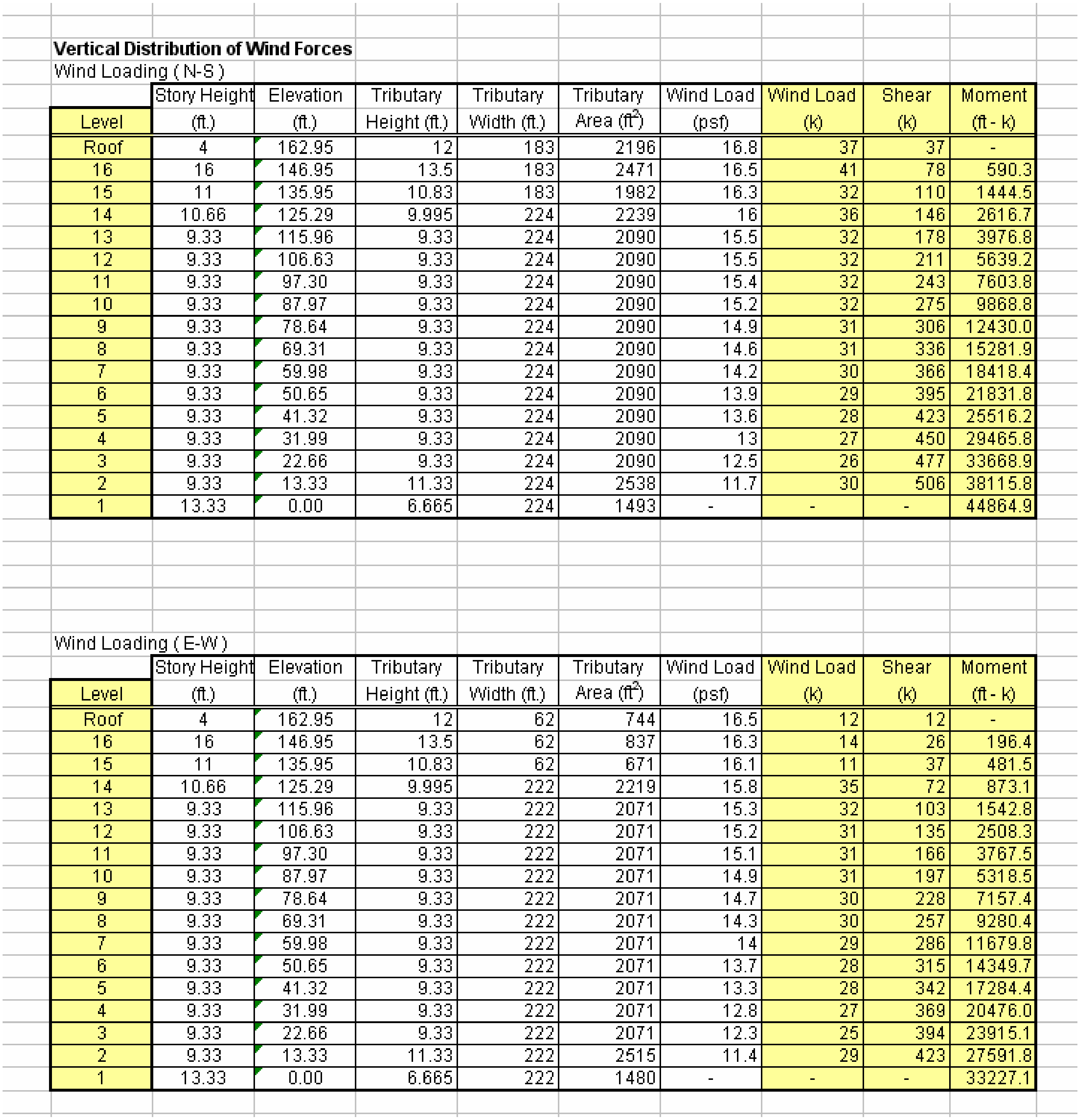
Appendix D – Lateral Load Summary



Vertical Distribution of Seismic Forces

					Load	Shear	Moment
N-S	w_x	h_x	$w_x h_x^k$	C_{vx}	F_x	V_x	M_x
Level, x	(kips)	(ft)			(kips)	(kips)	(ft-kips)
Roof	1507	163	732,728	0.068	139		22,730
16	2460	147.1	1,055,881	0.098	201	139	29,559
15	3253	136.1	1,270,351	0.118	242	340	32,904
14	2978	125.3	1,051,948	0.098	200	582	25,085
13	3379	116	1,086,958	0.101	207	782	23,996
12	3379	106.63	981,264	0.091	187	989	19,913
11	3379	97.3	877,986	0.082	167	1,176	16,258
10	3379	88	777,134	0.072	148	1,343	13,015
9	3379	78.64	677,920	0.063	129	1,491	10,146
8	3379	69.31	581,518	0.054	111	1,620	7,670
7	3379	60	488,065	0.045	93	1,731	5,573
6	3379	50.65	397,302	0.037	76	1,824	3,830
5	3379	41.32	310,263	0.029	59	1,899	2,440
4	3379	32	227,459	0.021	43	1,958	1,385
3	3379	22.66	149,573	0.014	28	2,001	645
2	3379	13.33	78,520	0.007	15	2,030	199
1						2,045	
	Σ =		Σ =	Σ =	Σ =		Σ =
	50748		10744870	1.000	2045		215347

					Load	Shear	Moment
E-W	w_x	h_x	$w_x h_x^k$	C_{vx}	F_x	V_x	M_x
Level, x	(kips)	(ft)			(kips)	(kips)	(ft-kips)
Roof	1507	163	732,728	0.068	139		22,730
16	2460	147.1	1,055,881	0.098	201	139	29,559
15	3253	136.1	1,270,351	0.118	242	340	32,904
14	2978	125.3	1,051,948	0.098	200	582	25,085
13	3379	116	1,086,958	0.101	207	782	23,996
12	3379	106.63	981,264	0.091	187	989	19,913
11	3379	97.3	877,986	0.082	167	1,176	16,258
10	3379	88	777,134	0.072	148	1,343	13,015
9	3379	78.64	677,920	0.063	129	1,491	10,146
8	3379	69.31	581,518	0.054	111	1,620	7,670
7	3379	60	488,065	0.045	93	1,731	5,573
6	3379	50.65	397,302	0.037	76	1,824	3,830
5	3379	41.32	310,263	0.029	59	1,899	2,440
4	3379	32	227,459	0.021	43	1,958	1,385
3	3379	22.66	149,573	0.014	28	2,001	645
2	3379	13.33	78,520	0.007	15	2,030	199
1						2,045	
	Σ =		Σ =	Σ =	Σ =		Σ =
	50748		10744870	1.000	2045		215347



Vertical Distribution of Wind Forces

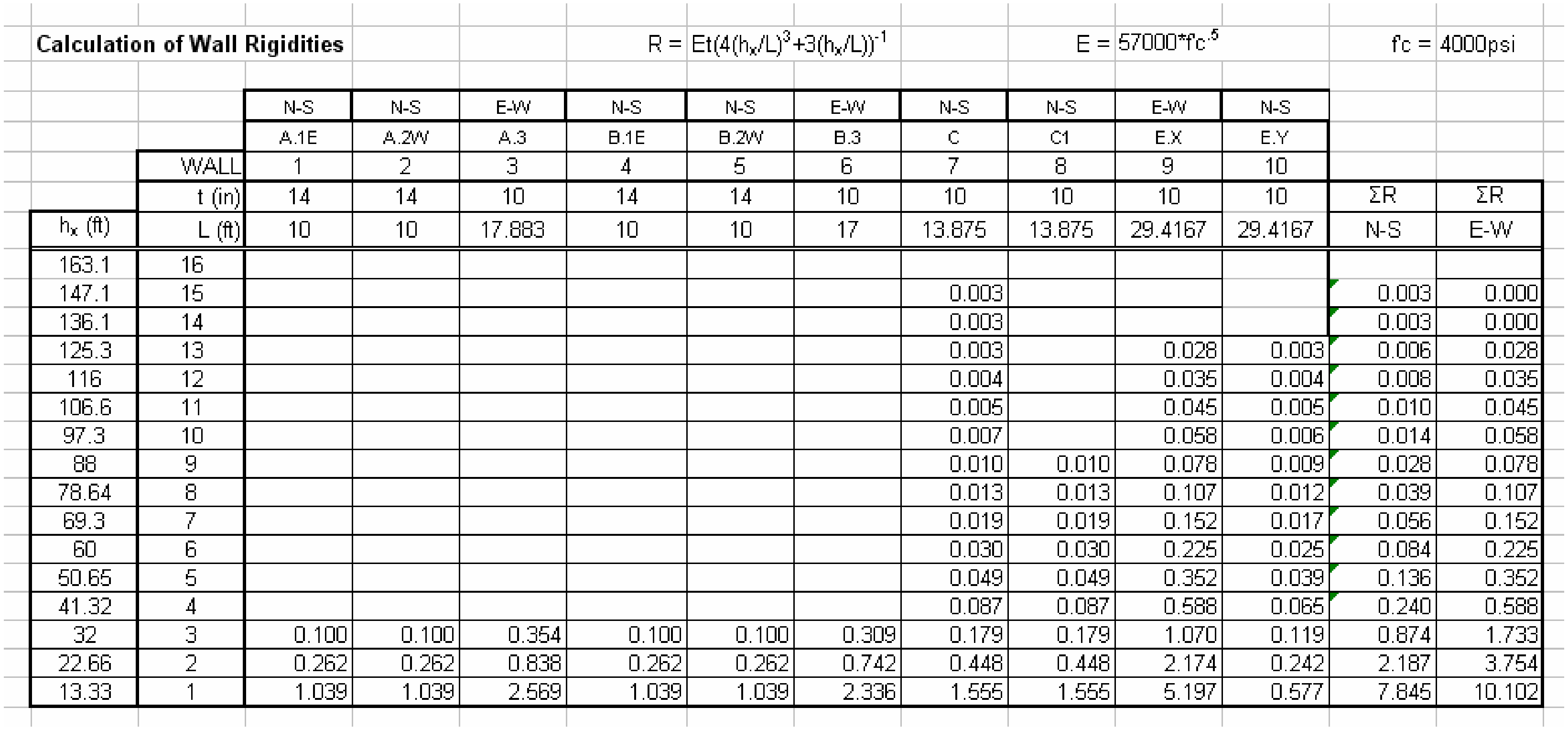
Wind Loading (N-S)

Level	Story Height (ft.)	Elevation (ft.)	Tributary Height (ft.)	Tributary Width (ft.)	Tributary Area (ft^2)	Wind Load (psf)	Wind Load (k)	Shear (k)	Moment (ft - k)
Roof	4	162.95	12	183	2196	16.8	37	37	-
16	16	146.95	13.5	183	2471	16.5	41	78	590.3
15	11	135.95	10.83	183	1982	16.3	32	110	1444.5
14	10.66	125.29	9.995	224	2239	16	36	146	2616.7
13	9.33	115.96	9.33	224	2090	15.5	32	178	3976.8
12	9.33	106.63	9.33	224	2090	15.5	32	211	5639.2
11	9.33	97.30	9.33	224	2090	15.4	32	243	7603.8
10	9.33	87.97	9.33	224	2090	15.2	32	275	9868.8
9	9.33	78.64	9.33	224	2090	14.9	31	306	12430.0
8	9.33	69.31	9.33	224	2090	14.6	31	336	15281.9
7	9.33	59.98	9.33	224	2090	14.2	30	366	18418.4
6	9.33	50.65	9.33	224	2090	13.9	29	395	21831.8
5	9.33	41.32	9.33	224	2090	13.6	28	423	25516.2
4	9.33	31.99	9.33	224	2090	13	27	450	29465.8
3	9.33	22.66	9.33	224	2090	12.5	26	477	33668.9
2	9.33	13.33	11.33	224	2538	11.7	30	506	38115.8
1	13.33	0.00	6.665	224	1493	-	-	-	44864.9

Wind Loading (E-W)

Level	Story Height (ft.)	Elevation (ft.)	Tributary Height (ft.)	Tributary Width (ft.)	Tributary Area (ft^2)	Wind Load (psf)	Wind Load (k)	Shear (k)	Moment (ft - k)
Roof	4	162.95	12	62	744	16.5	12	12	-
16	16	146.95	13.5	62	837	16.3	14	26	196.4
15	11	135.95	10.83	62	671	16.1	11	37	481.5
14	10.66	125.29	9.995	222	2219	15.8	35	72	873.1
13	9.33	115.96	9.33	222	2071	15.3	32	103	1542.8
12	9.33	106.63	9.33	222	2071	15.2	31	135	2508.3
11	9.33	97.30	9.33	222	2071	15.1	31	166	3767.5
10	9.33	87.97	9.33	222	2071	14.9	31	197	5318.5
9	9.33	78.64	9.33	222	2071	14.7	30	228	7157.4
8	9.33	69.31	9.33	222	2071	14.3	30	257	9280.4
7	9.33	59.98	9.33	222	2071	14	29	286	11679.8
6	9.33	50.65	9.33	222	2071	13.7	28	315	14349.7
5	9.33	41.32	9.33	222	2071	13.3	28	342	17284.4
4	9.33	31.99	9.33	222	2071	12.8	27	369	20476.0
3	9.33	22.66	9.33	222	2071	12.3	25	394	23915.1
2	9.33	13.33	11.33	222	2515	11.4	29	423	27591.8
1	13.33	0.00	6.665	222	1480	-	-	-	33227.1

Appendix E – Shear Distribution



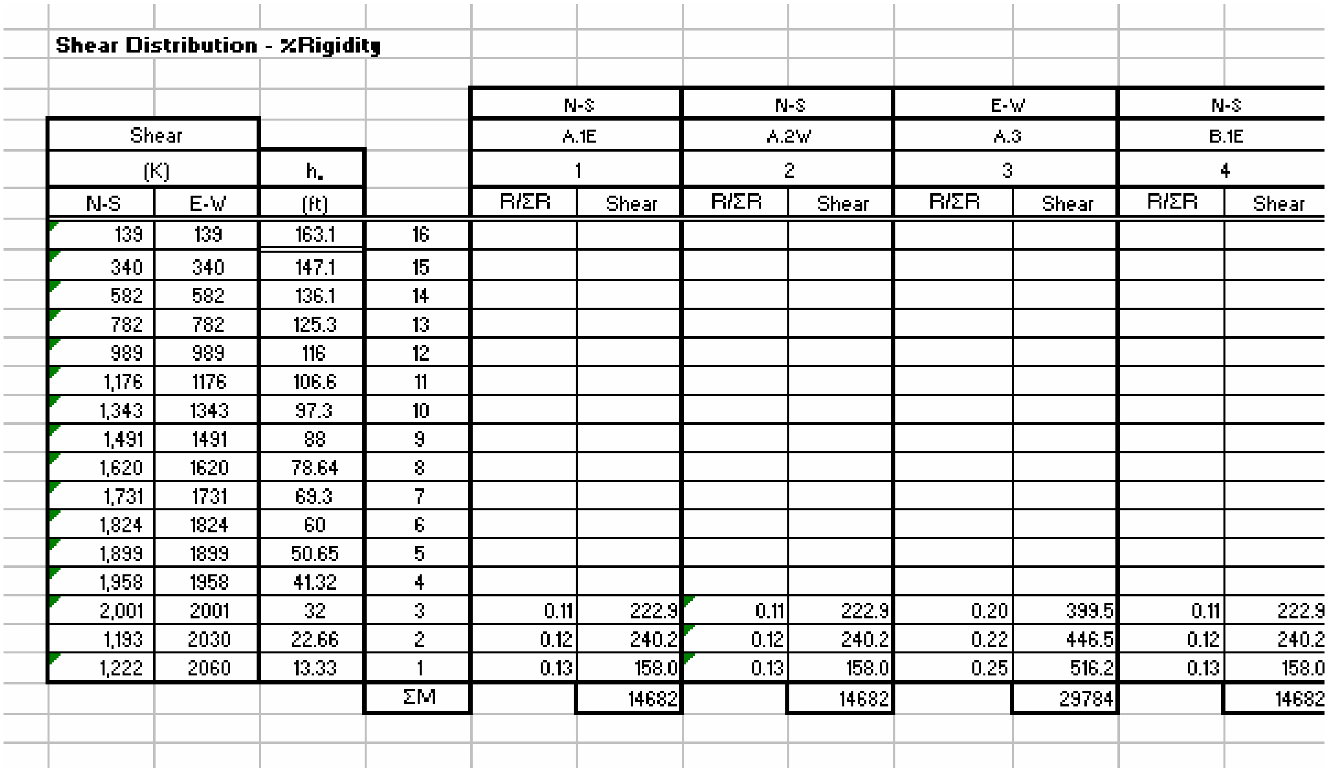
Calculation of Wall Rigidities

R = $Et(4(h_x/L)^3+3(h_x/L))^{-1}$

E = $57000*f'c^{.5}$

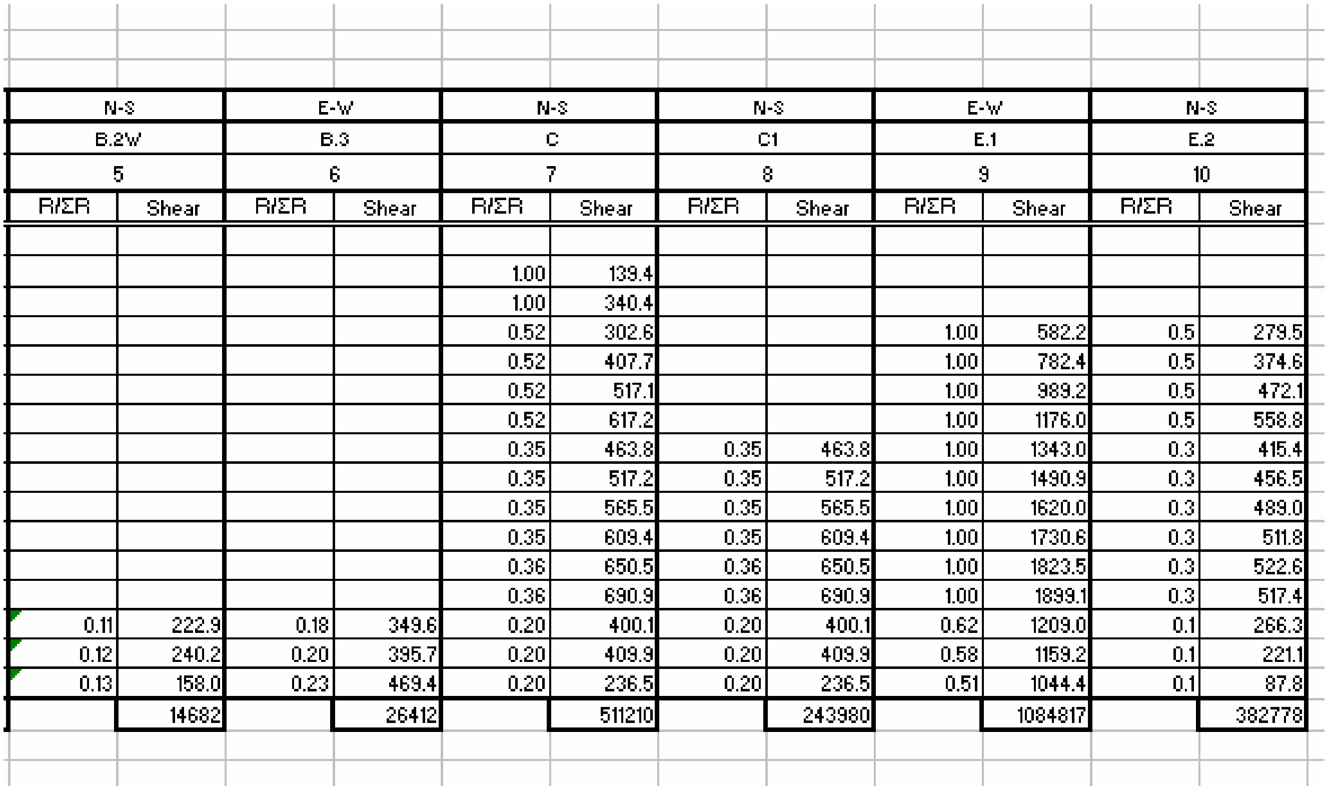
f'c = 4000psi

		N-S	N-S	E-W	N-S	N-S	E-W	N-S	N-S	E-W	N-S		
		A.1E	A.2W	A.3	B.1E	B.2W	B.3	C	C1	E.X	E.Y		
	WALL	1	2	3	4	5	6	7	8	9	10		
	t (in)	14	14	10	14	14	10	10	10	10	10	ΣR	ΣR
h_x (ft)	L (ft)	10	10	17.883	10	10	17	13.875	13.875	29.4167	29.4167	N-S	E-W
163.1	16												
147.1	15							0.003				0.003	0.000
136.1	14							0.003				0.003	0.000
125.3	13							0.003		0.028	0.003	0.006	0.028
116	12							0.004		0.035	0.004	0.008	0.035
106.6	11							0.005		0.045	0.005	0.010	0.045
97.3	10							0.007		0.058	0.006	0.014	0.058
88	9							0.010	0.010	0.078	0.009	0.028	0.078
78.64	8							0.013	0.013	0.107	0.012	0.039	0.107
69.3	7							0.019	0.019	0.152	0.017	0.056	0.152
60	6							0.030	0.030	0.225	0.025	0.084	0.225
50.65	5							0.049	0.049	0.352	0.039	0.136	0.352
41.32	4							0.087	0.087	0.588	0.065	0.240	0.588
32	3	0.100	0.100	0.354	0.100	0.100	0.309	0.179	0.179	1.070	0.119	0.874	1.733
22.66	2	0.262	0.262	0.838	0.262	0.262	0.742	0.448	0.448	2.174	0.242	2.187	3.754
13.33	1	1.039	1.039	2.569	1.039	1.039	2.336	1.555	1.555	5.197	0.577	7.845	10.102

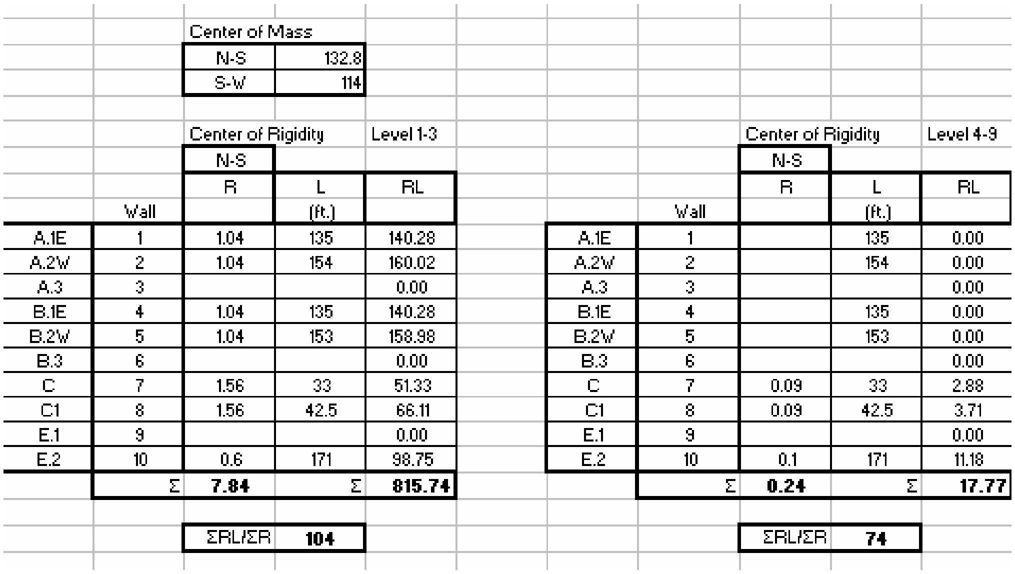


Shear Distribution - %Rigidity

				N-S		N-S		E-W		N-S	
Shear				A.1E		A.2W		A.3		B.1E	
(K)		h_x		1		2		3		4	
N-S	E-W	(ft)		R/ΣR	Shear	R/ΣR	Shear	R/ΣR	Shear	R/ΣR	Shear
139	139	163.1	16								
340	340	147.1	15								
582	582	136.1	14								
782	782	125.3	13								
989	989	116	12								
1,176	1176	106.6	11								
1,343	1343	97.3	10								
1,491	1491	88	9								
1,620	1620	78.64	8								
1,731	1731	69.3	7								
1,824	1824	60	6								
1,899	1899	50.65	5								
1,958	1958	41.32	4								
2,001	2001	32	3	0.11	222.9	0.11	222.9	0.20	399.5	0.11	222.9
1,193	2030	22.66	2	0.12	240.2	0.12	240.2	0.22	446.5	0.12	240.2
1,222	2060	13.33	1	0.13	158.0	0.13	158.0	0.25	516.2	0.13	158.0
			ΣM		14682		14682		29784		14682



N-S		E-W		N-S		N-S		E-W		N-S	
B.2W		B.3		C		C1		E.1		E.2	
5		6		7		8		9		10	
R/ΣR	Shear	R/ΣR	Shear	R/ΣR	Shear	R/ΣR	Shear	R/ΣR	Shear	R/ΣR	Shear
				1.00	139.4						
				1.00	340.4						
				0.52	302.6			1.00	582.2	0.5	279.5
				0.52	407.7			1.00	782.4	0.5	374.6
				0.52	517.1			1.00	989.2	0.5	472.1
				0.52	617.2			1.00	1176.0	0.5	558.8
				0.35	463.8	0.35	463.8	1.00	1343.0	0.3	415.4
				0.35	517.2	0.35	517.2	1.00	1490.9	0.3	456.5
				0.35	565.5	0.35	565.5	1.00	1620.0	0.3	489.0
				0.35	609.4	0.35	609.4	1.00	1730.6	0.3	511.8
				0.36	650.5	0.36	650.5	1.00	1823.5	0.3	522.6
				0.36	690.9	0.36	690.9	1.00	1899.1	0.3	517.4
0.11	222.9	0.18	349.6	0.20	400.1	0.20	400.1	0.62	1209.0	0.1	266.3
0.12	240.2	0.20	395.7	0.20	409.9	0.20	409.9	0.58	1159.2	0.1	221.1
0.13	158.0	0.23	469.4	0.20	236.5	0.20	236.5	0.51	1044.4	0.1	87.8
	14682		26412		511210		243980		1084817		382778



Center of Mass

N-S	132.8
S-W	114

Center of Rigidity Level 1-3

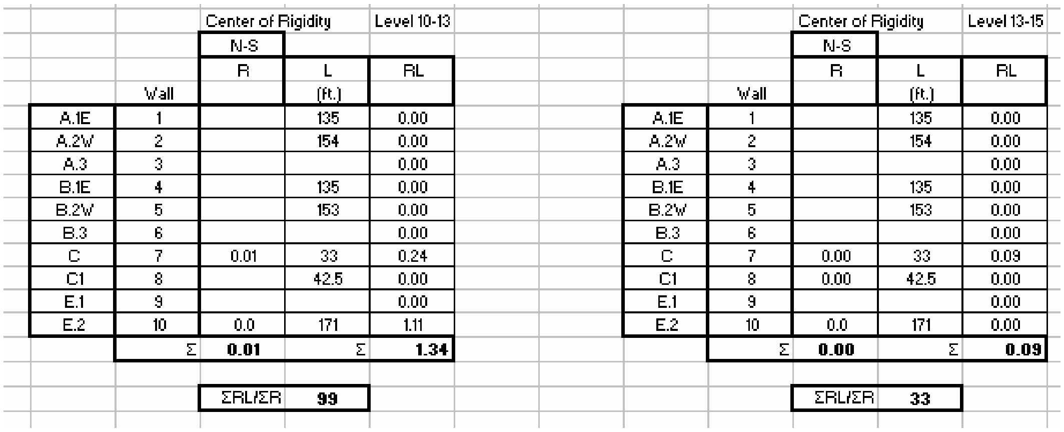
		N-S R	L (ft.)	RL
	Wall			
A.1E	1	1.04	135	140.28
A.2W	2	1.04	154	160.02
A.3	3			0.00
B.1E	4	1.04	135	140.28
B.2W	5	1.04	153	158.98
B.3	6			0.00
C	7	1.56	33	51.33
C1	8	1.56	42.5	66.11
E.1	9			0.00
E.2	10	0.6	171	98.75
	Σ	**7.84**	Σ	**815.74**

ΣRL/ΣR	**104**

Center of Rigidity Level 4-9

		N-S R	L (ft.)	RL
	Wall			
A.1E	1		135	0.00
A.2W	2		154	0.00
A.3	3			0.00
B.1E	4		135	0.00
B.2W	5		153	0.00
B.3	6			0.00
C	7	0.09	33	2.88
C1	8	0.09	42.5	3.71
E.1	9			0.00
E.2	10	0.1	171	11.18
	Σ	**0.24**	Σ	**17.77**

ΣRL/ΣR	**74**



Center of Rigidity Level 10-13

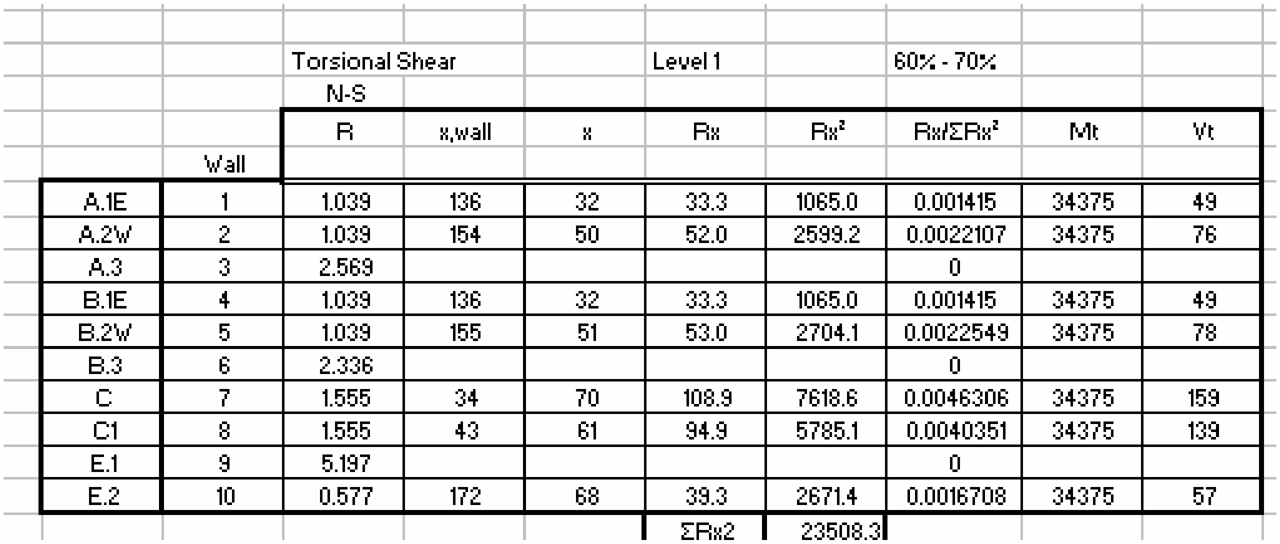
		N-S R	L (ft.)	RL
	Wall			
A.1E	1		135	0.00
A.2W	2		154	0.00
A.3	3			0.00
B.1E	4		135	0.00
B.2W	5		153	0.00
B.3	6			0.00
C	7	0.01	33	0.24
C1	8		42.5	0.00
E.1	9			0.00
E.2	10	0.0	171	1.11
	Σ	**0.01**	Σ	**1.34**

ΣRL/ΣR	**99**

Center of Rigidity Level 13-15

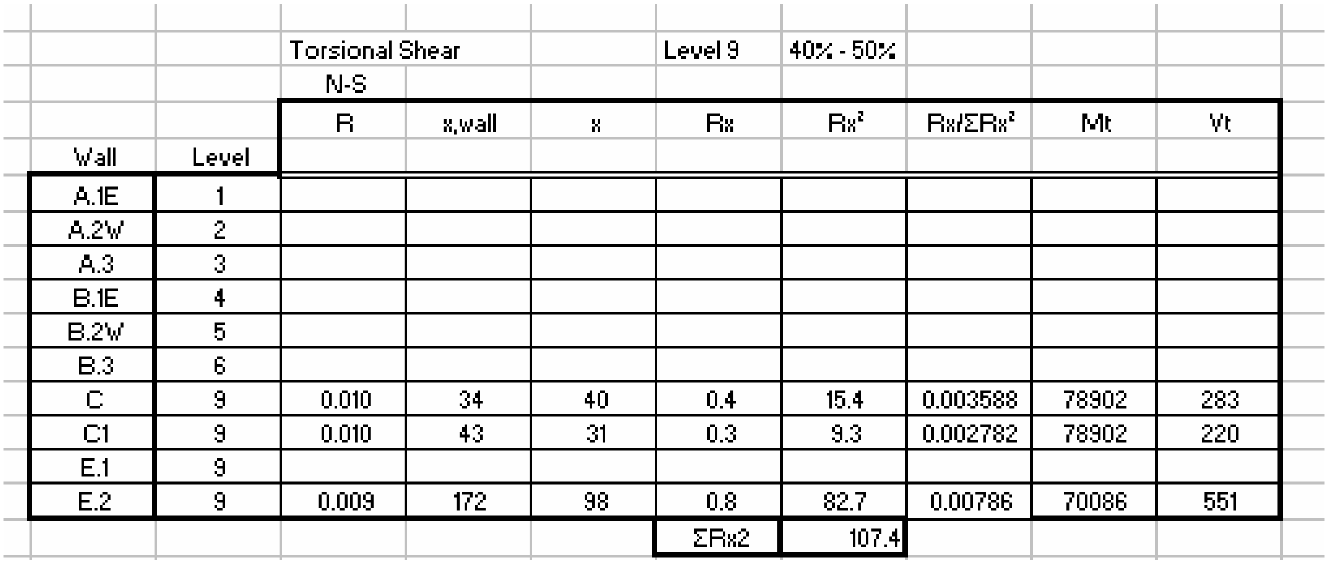
		N-S R	L (ft.)	RL
	Wall			
A.1E	1		135	0.00
A.2W	2		154	0.00
A.3	3			0.00
B.1E	4		135	0.00
B.2W	5		153	0.00
B.3	6			0.00
C	7	0.00	33	0.09
C1	8	0.00	42.5	0.00
E.1	9			0.00
E.2	10	0.0	171	0.00
	Σ	**0.00**	Σ	**0.09**

ΣRL/ΣR	**33**



Torsional Shear Level 1 60% - 70%

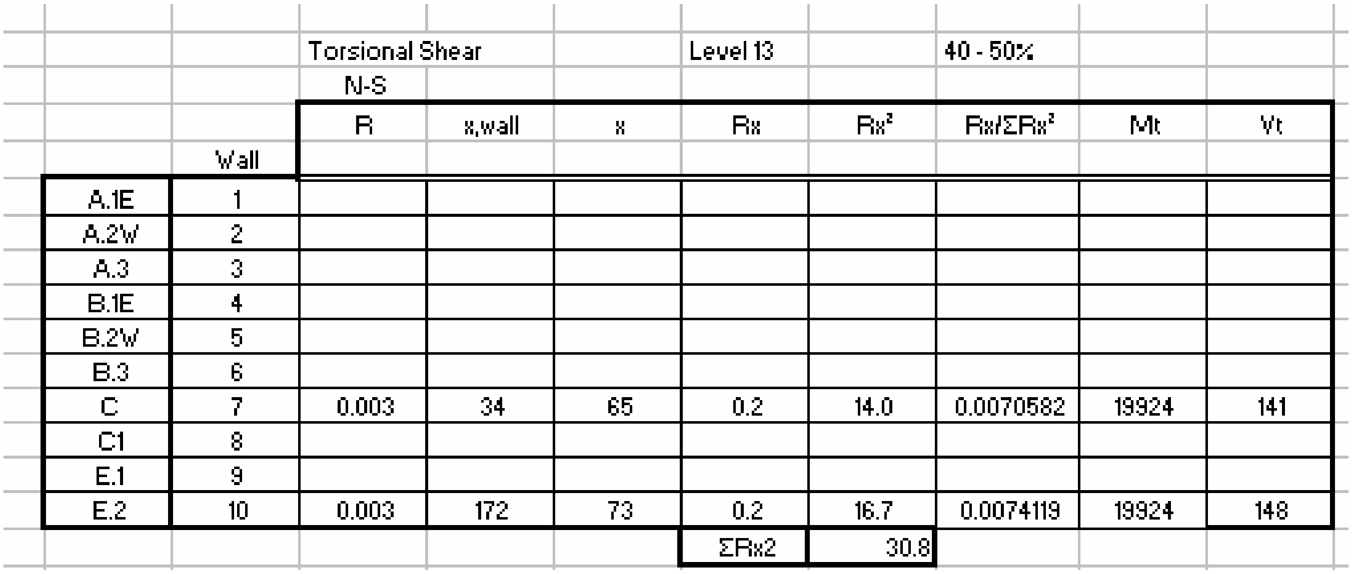
		N-S R	x,wall	x	Rx	Rx²	Rx/ΣRx²	Mt	Vt
	Wall								
A.1E	1	1.039	136	32	33.3	1065.0	0.001415	34375	49
A.2W	2	1.039	154	50	52.0	2599.2	0.0022107	34375	76
A.3	3	2.569					0		
B.1E	4	1.039	136	32	33.3	1065.0	0.001415	34375	49
B.2W	5	1.039	155	51	53.0	2704.1	0.0022549	34375	78
B.3	6	2.336					0		
C	7	1.555	34	70	108.9	7618.6	0.0046306	34375	159
C1	8	1.555	43	61	94.9	5785.1	0.0040351	34375	139
E.1	9	5.197					0		
E.2	10	0.577	172	68	39.3	2671.4	0.0016708	34375	57
					ΣRx2	23508.3			



Torsional Shear Level 9 40% - 50%

N-S

Wall	Level	R	x,wall	x	Rx	Rx^2	$Rx/\Sigma Rx^2$	Mt	Vt
A.1E	1								
A.2W	2								
A.3	3								
B.1E	4								
B.2W	5								
B.3	6								
C	9	0.010	34	40	0.4	15.4	0.003588	78902	283
C1	9	0.010	43	31	0.3	9.3	0.002782	78902	220
E.1	9								
E.2	9	0.009	172	98	0.8	82.7	0.00786	70086	551
					$\Sigma Rx2$	107.4			

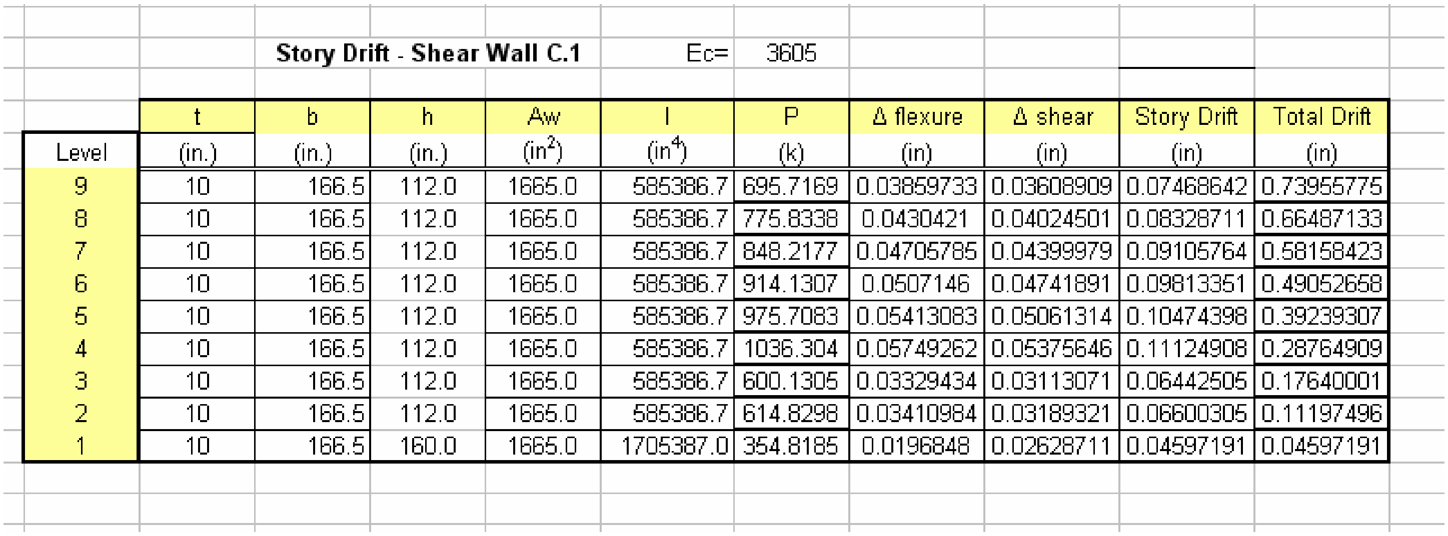


Torsional Shear Level 13 40 - 50%

N-S

	Wall	R	x,wall	x	Rx	Rx^2	$Rx/\Sigma Rx^2$	Mt	Vt
A.1E	1								
A.2W	2								
A.3	3								
B.1E	4								
B.2W	5								
B.3	6								
C	7	0.003	34	65	0.2	14.0	0.0070582	19924	141
C1	8								
E.1	9								
E.2	10	0.003	172	73	0.2	16.7	0.0074119	19924	148
					$\Sigma Rx2$	30.8			

Appendix E – Drift Check



Story Drift - Shear Wall C.1 Ec= 3605

	t	b	h	Aw	I	P	Δ flexure	Δ shear	Story Drift	Total Drift
Level	(in.)	(in.)	(in.)	(in^2)	(in^4)	(k)	(in)	(in)	(in)	(in)
9	10	166.5	112.0	1665.0	585386.7	695.7169	0.03859733	0.03608909	0.07468642	0.73955775
8	10	166.5	112.0	1665.0	585386.7	775.8338	0.0430421	0.04024501	0.08328711	0.66487133
7	10	166.5	112.0	1665.0	585386.7	848.2177	0.04705785	0.04399979	0.09105764	0.58158423
6	10	166.5	112.0	1665.0	585386.7	914.1307	0.0507146	0.04741891	0.09813351	0.49052658
5	10	166.5	112.0	1665.0	585386.7	975.7083	0.05413083	0.05061314	0.10474398	0.39239307
4	10	166.5	112.0	1665.0	585386.7	1036.304	0.05749262	0.05375646	0.11124908	0.28764909
3	10	166.5	112.0	1665.0	585386.7	600.1305	0.03329434	0.03113071	0.06442505	0.17640001
2	10	166.5	112.0	1665.0	585386.7	614.8298	0.03410984	0.03189321	0.06600305	0.11197496
1	10	166.5	160.0	1665.0	1705387.0	354.8185	0.0196848	0.02628711	0.04597191	0.04597191