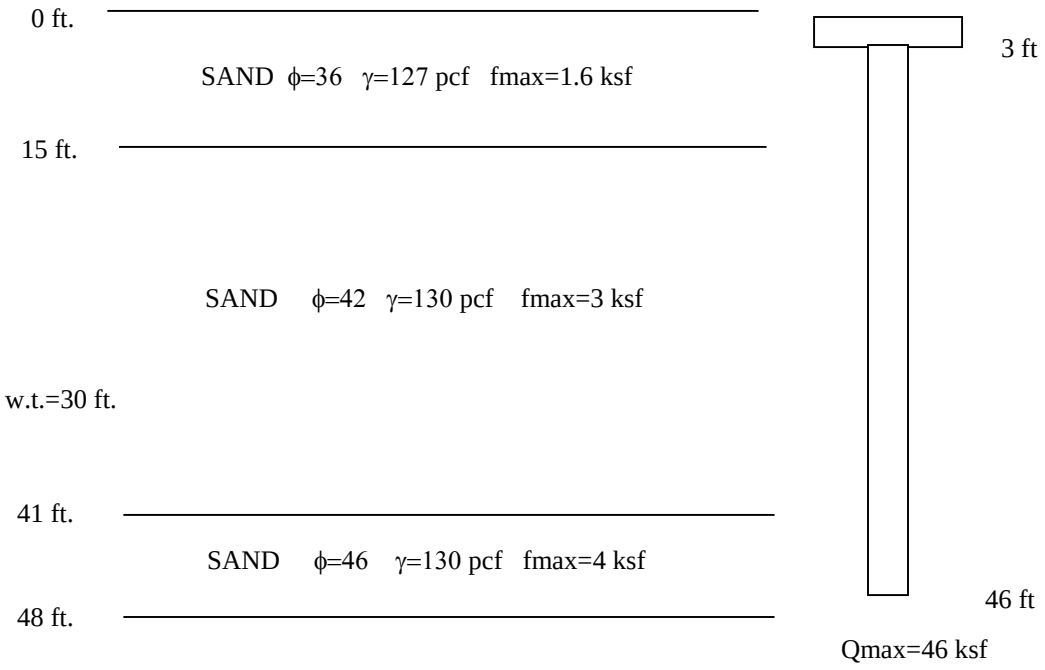
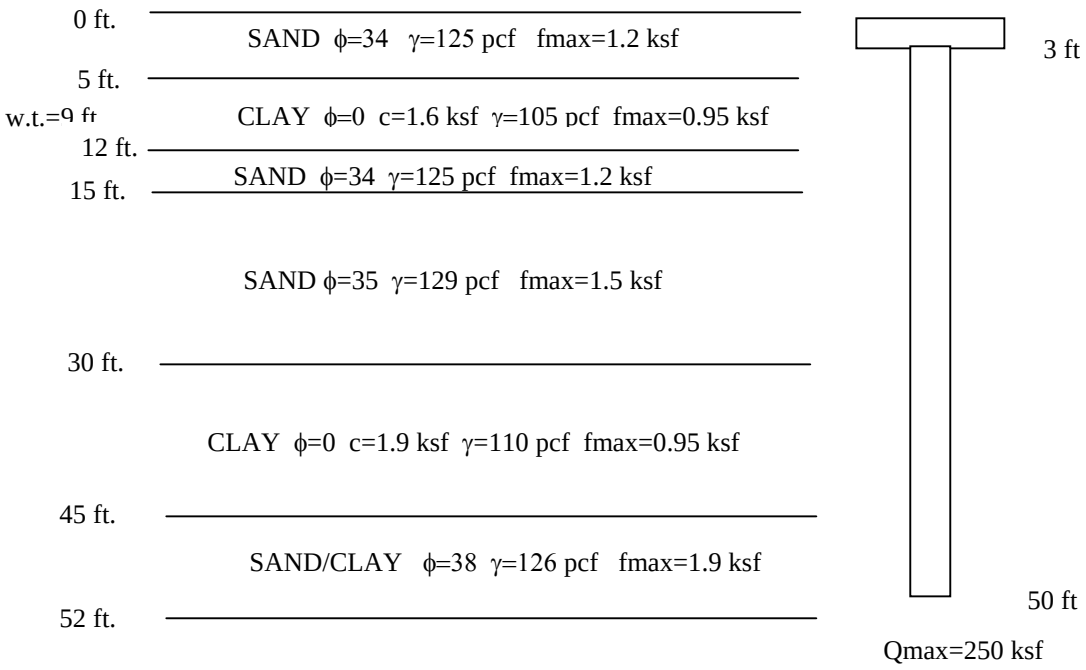
APPENDIX B: FOUNDATION ASSESSMENT CHARTS & TABLES

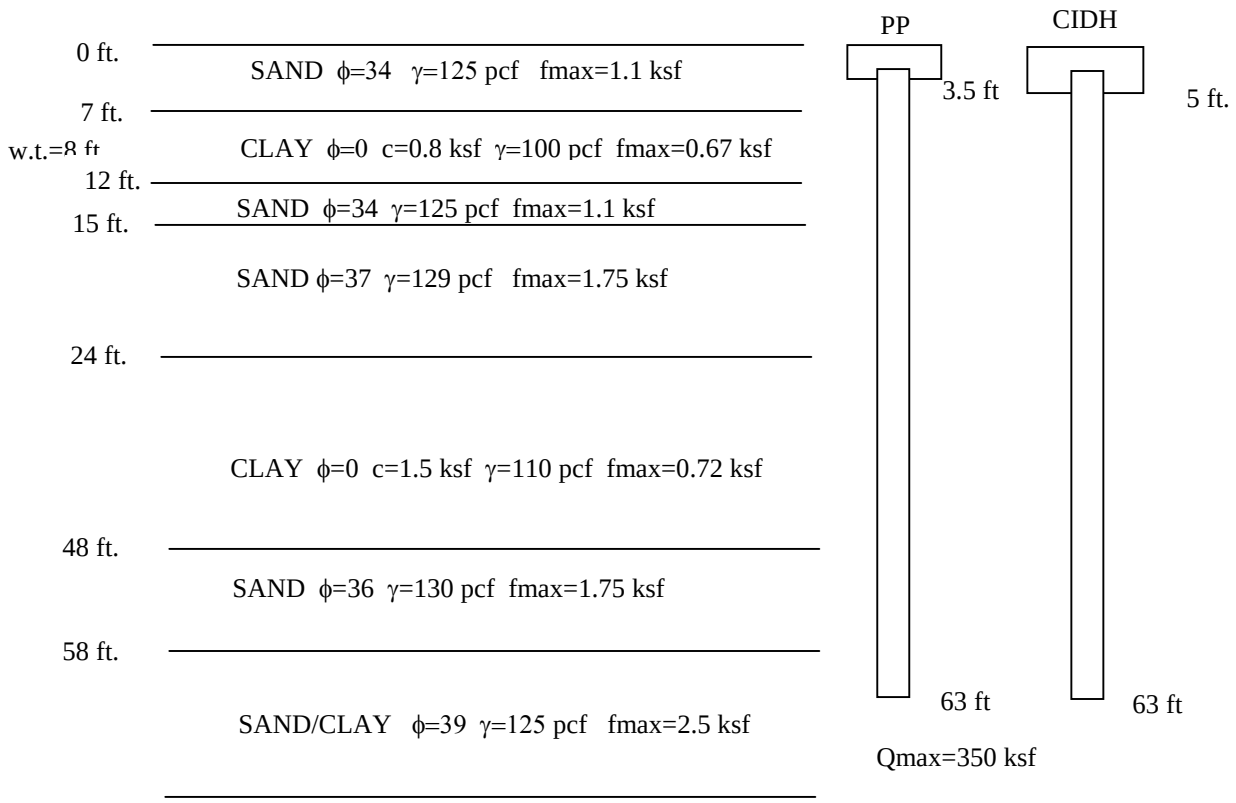
Typical H-Pile Profile



Typical Class 100 Precast Concrete Profile



Typical Pipe Pile and CIDH Profile



14 x 89 HP Single Column Footings

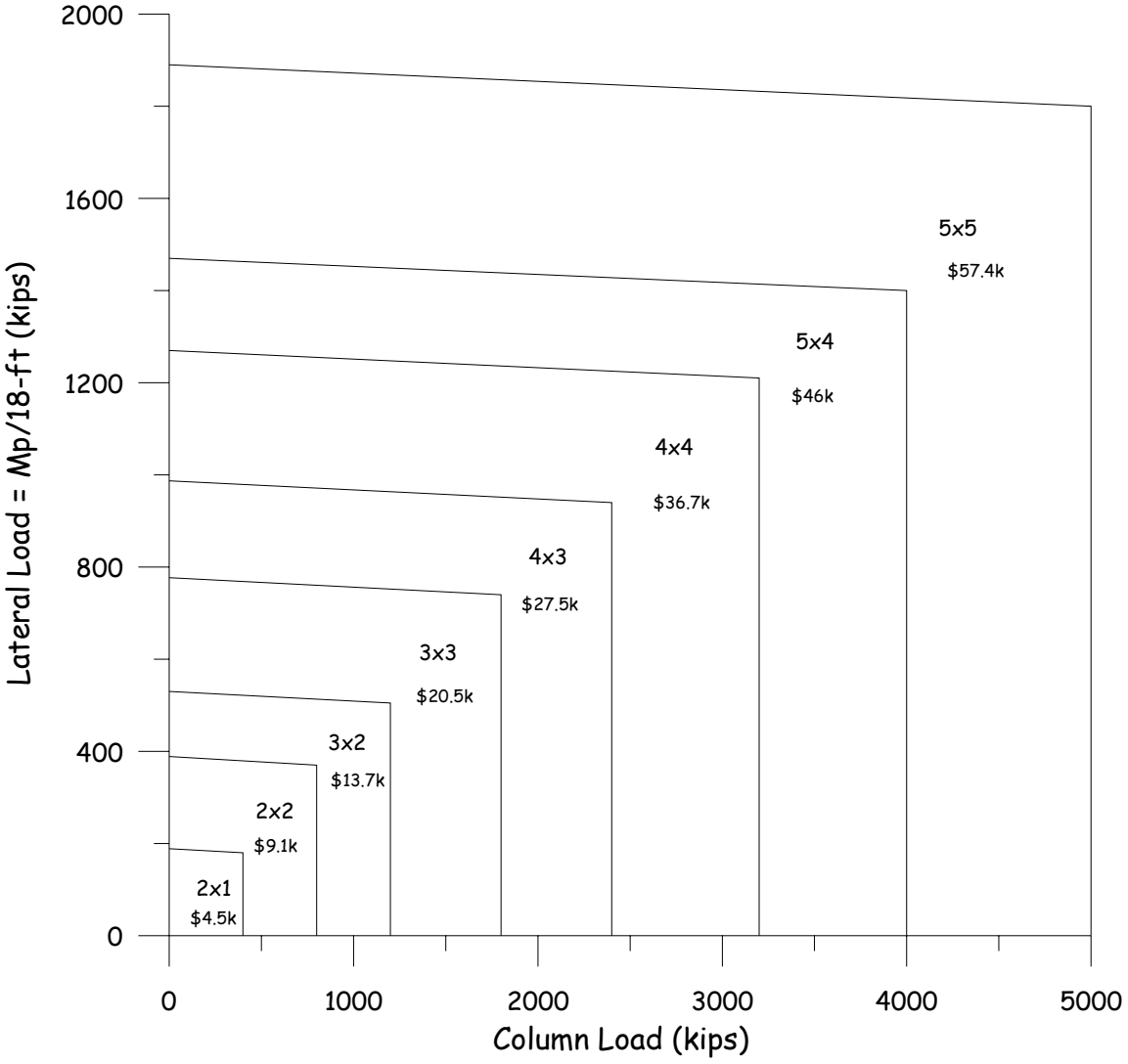
COSTS

Col. (ft)	ρ (%)	P (k)	M_p (k-ft)	M_o (k-ft)	Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish Piles	Drive Piles	Excav.	Backfill	Conc.	Steel	Total
3.0	1.00	900	1520	1820	3x2	6	38.5	10	6.5	3	2.8	4851	6000	944	758	2239	532	15325
3.0	1.00	1200	1670	2000	3x2	6	38.5	10	10	3	2.8	4851	6000	1333	1011	3444	819	17459
3.0	1.00	1600	1810	2170	3x3	9	38.5	10	10	3	2.8	7277	9000	1333	1011	3444	819	22884
3.0	2.00	900	2100	2520	3x2	6	38.5	10	6.5	3	2.8	4851	6000	944	758	2239	532	15325
3.0	2.00	1200	2230	2680	3x2	6	38.5	10	10	3	2.8	4851	6000	1333	1011	3444	819	17459
3.0	2.00	1600	2349	2820	3x3	9	38.5	10	10	3	2.8	7277	9000	1333	1011	3444	819	22884
3.0	3.00	900	2680	3220	3x2	6	38.5	10	6.5	3	2.8	4851	6000	944	758	2239	532	15325
3.0	3.00	1200	2790	3350	3x2	6	38.5	10	10	3	2.8	4851	6000	1333	1011	3444	819	17459
3.0	3.00	1600	2890	3470	3x3	9	38.5	10	10	3	2.8	7277	9000	1333	1011	3444	819	22884
4.0	1.00	900	3090	3710	3x3	9	43.5	10	6.5	3	2.8	8222	9000	944	758	2239	532	21696
4.0	1.00	1200	3350	4020	3x3	9	38.5	10	10	3	2.8	7277	9000	1333	1011	3444	819	22884
4.0	1.00	1600	3670	4400	3x3	9	38.5	10	10	3	2.8	7277	9000	1333	1011	3444	819	22884
4.0	2.00	900	4650	5580	3x3	9	40.5	10	10	3	2.8	7655	9000	1333	1011	3444	819	23262
4.0	2.00	1200	4860	5830	3x3	9	43.5	10	10	3	2.8	8222	9000	1333	1011	3444	819	23829
4.0	2.00	1600	5130	6160	3x3	9	38	13.5	10	3.5	3.6	7182	9000	1894	1325	5425	1658	26485
4.0	3.00	900	6110	7330	4x3	12	38	13.5	10	3.5	3.6	9576	12000	1894	1325	5425	1658	31879
4.0	3.00	1200	6310	7570	4x3	12	38	13.5	10	3.5	3.6	9576	12000	1894	1325	5425	1658	31879
4.0	3.00	1600	6540	7850	4x3	12	38	13.5	10	3.5	3.6	9576	12000	1894	1325	5425	1658	31879
5.0	1.00	900	5730	6880	4x3	12	38	13.5	10	3.5	3.6	9576	12000	1894	1325	5425	1658	31879
5.0	1.00	1200	6110	7330	4x3	12	38	13.5	10	3.5	3.6	9576	12000	1894	1325	5425	1658	31879
5.0	1.00	1600	6580	7900	4x3	12	38	13.5	10	3.5	3.6	9576	12000	1894	1325	5425	1658	31879
5.0	2.00	900	9080	10900	4x4	16	33	13.5	13.5	3.5	4.3	11088	16000	2447	1645	7324	2674	41178
5.0	2.00	1200	9370	11240	4x4	16	33	13.5	13.5	3.5	4.3	11088	16000	2447	1645	7324	2674	41178
5.0	2.00	1600	9750	11700	4x4	16	38	13.5	13.5	3.5	4.3	12768	16000	2447	1645	7324	2674	42858
5.0	3.00	900	12150	14580	5x4	20	32.75	17	13.5	3.75	5.2	13755	20000	3136	2005	9881	4363	53140
5.0	3.00	1200	12420	14900	5x4	20	32.75	17	13.5	3.75	5.2	13755	20000	3136	2005	9881	4363	53140
5.0	3.00	1600	12750	15300	5x4	20	32.5	20.5	13.5	4	5.8	13650	20000	3875	2373	12710	6260	58868
6.0	1.00	900	9540	11450	4x4	16	33	13.5	13.5	3.5	4.3	11088	16000	2447	1645	7324	2674	41178
6.0	1.00	1200	10020	12020	5x4	20	38	13.5	13.5	3.5	4.3	15960	20000	2447	1645	7324	2674	50050
6.0	1.00	1600	10760	12910	5x4	20	32.75	16.3	13.5	3.75	5.2	13755	20000	3020	1940	9474	4184	52373
6.0	2.00	900	15970	19160	6x4	24	32.5	20.5	17	4	6.7	16380	24000	4750	2819	16005	9106	73061
6.0	2.00	1200	16370	19640	6x4	24	32.5	20.5	17	4	6.7	16380	24000	4750	2819	16005	9106	73061
6.0	2.00	1600	16880	20260	6x4	24	32.5	20.5	17	4	6.7	16380	24000	4750	2819	16005	9106	73061
6.0	3.00	900	21770	26120	6x5	30	32.5	20.5	20.5	4	7.3	20475	30000	5625	3266	19300	11965	90631
6.0	3.00	1200	22100	26520	6x5	30	32.5	20.5	20.5	4	7.3	20475	30000	5625	3266	19300	11965	90631
6.0	3.00	1600	22510	27010	6x5	30	32.5	20.5	20.5	4	7.3	20475	30000	5625	3266	19300	11965	90631
7.0	1.00	900	14810	17770	6x4	24	32.5	20.5	13.5	4	5.8	16380	24000	3875	2373	12710	6260	65598
7.0	1.00	1200	15390	18470	6x4	24	32.5	20.5	13.5	4	5.8	16380	24000	3875	2373	12710	6260	65598
7.0	1.00	1600	16140	19370	6x4	24	32.5	20.5	17	4	6.7	16380	24000	4750	2819	16005	9106	73061
7.0	2.00	900	25150	30180	6x6	36	32	24	20.5	4.5	7.6	24192	36000	7042	3824	25420	16406	112884
7.0	2.00	1200	25630	30760	6x6	36	32	24	20.5	4.5	7.6	24192	36000	7042	3824	25420	16406	112884
7.0	2.00	1600	26250	31500	6x6	36	32	24	20.5	4.5	7.6	24192	36000	7042	3824	25420	16406	112884
7.0	3.00	900	34580	41500	7x6	42	31.75	27.5	24	4.75	8	28004	42000	9588	4917	35994	24453	144955
7.0	3.00	1200	34970	41960	7x6	42	31.75	27.5	24	4.75	8	28004	42000	9588	4917	35994	24453	144955
7.0	3.00	1600	35480	42580	7x6	42	31.75	27.5	24	4.75	8	28004	42000	9588	4917	35994	24453	144955
8.0	1.00	900	21320	25580	6x5	30	32.5	20.5	20.5	4	7.3	20475	30000	5625	3266	19300	11965	90631
8.0	1.00	1200	22280	26740	6x5	30	32.5	20.5	20.5	4	7.3	20475	30000	5625	3266	19300	11965	90631
8.0	1.00	1600	23190	27830	6x5	30	32.5	20.5	20.5	4	7.3	20475	30000	5625	3266	19300	11965	90631
8.0	2.00	900	37830	45400	7x6	42	31.75	27.5	27.5	4.75	8.2	28004	42000	10878	5494	41244	28720	156339
8.0	2.00	1200	38360	46030	7x6	42	31.75	27.5	27.5	4.75	8.2	28004	42000	10878	5494	41244	28720	156339
8.0	2.00	1600	39120	46940	7x6	42	31.75	27.5	27.5	4.75	8.2	28004	42000	10878	5494	41244	28720	156339
8.0	3.00	900	53050	63660	8x7	56	31.5	31	31	5	8.5	37044	56000	14117	6784	55169	39821	208935
8.0	3.00	1200	53530	64240	8x7	56	31.5	34.5	31	5	8.5	37044	56000	15614	7424	61397	44317	221797
8.0	3.00	1600	54080	64900	8x7	56	31.5	34.5	31	5	8.5	37044	56000	15614	7424	61397	44317	221797
		50' col	5.5' x 8.25' oblong		8x6	48	41.75	27.5	20.5	4.75	7.8	42084	48000	8297	4339	30745	20365	153830
		50' col	7' x 10.5' oblong		9x6	54	41.5	31	20.5	5	7.9	47061	54000	9625	4863	36482	24475	176506

Multicolumn Footings

Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish Piles	Drive Piles	Excav.	Backfill	Conc.	Steel	Total
2x2	4	43.5	6.5	6.5	3	2	3654	4000	669	565	1455	247	10590
3x2	6	43.5	10	6.5	3	2	5481	6000	944	758	2239	380	15803
3x3	9	43.5	10	10	3	2	8222	9000	1333	1011	3444	585	23595
4x3	12	43.5	13.5	10	3	2	10962	12000	1722	1264	4650	790	31388
4x4	16	43.5	13.5	13.5	3	2	14616	16000	2225	1576	6278	1066	41760
5x4	20	43.5	17	13.5	3	2	18270	20000	2727	1887	7905	1343	52132
5x5	25	43.5	17	17	3	2	22838	25000	3343	2258	9954	1691	65083

14x89 H Piles
Multicolumn Bents



14x14 (Class 100) Precast Concrete Pile Single Column Footings

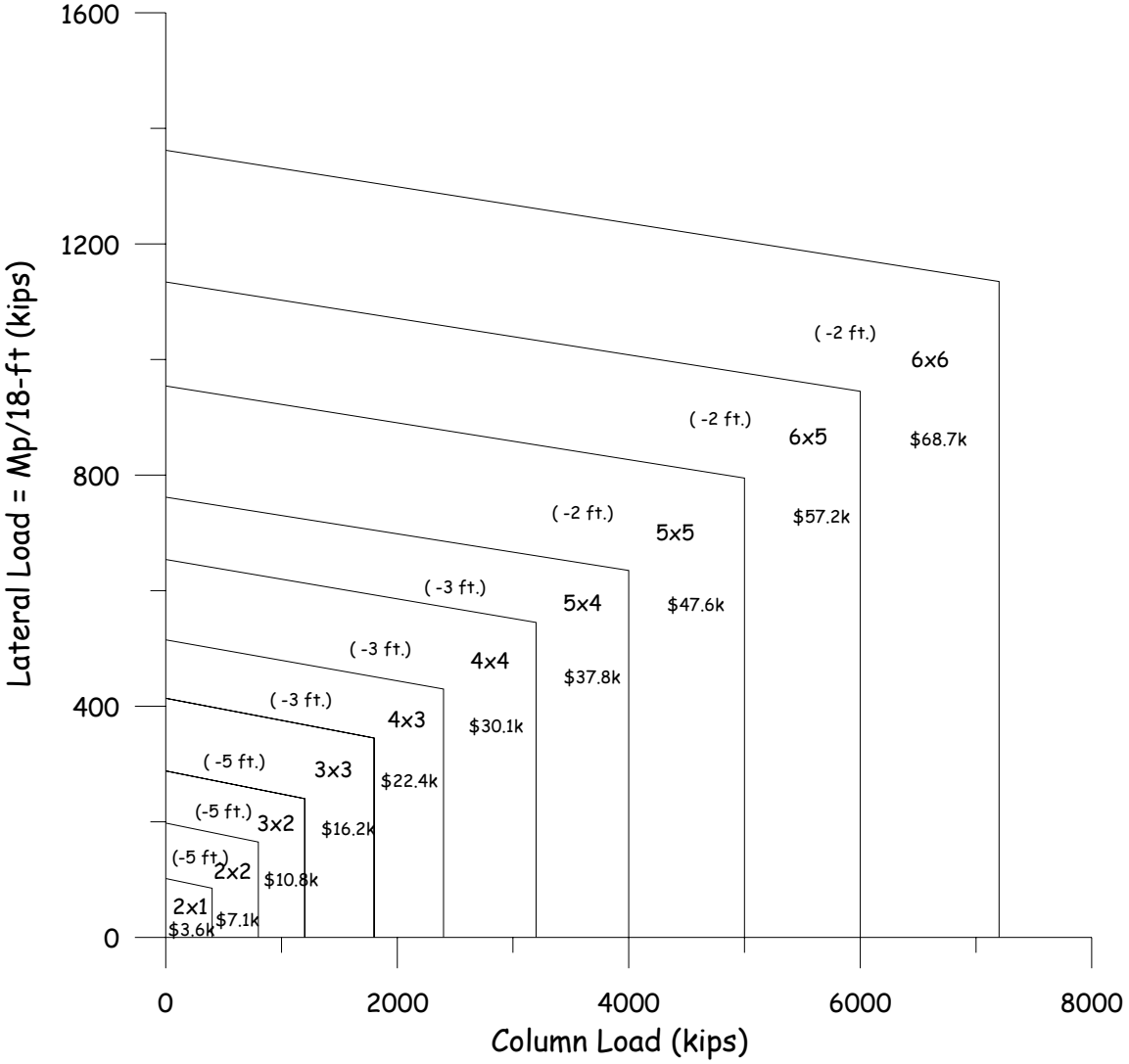
COSTS

Col. (ft)	ρ (%)	P (k)	M_p (k-ft)	M_o (k-ft)	Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish Piles	Drive Piles	Excav.	Backfill	Conc.	Steel	Total
3.0	1.00	900	1520	1820	3x2-5ft	6	42.5	10	6.5	3	2.8	3188	5700	944	758	2239	532	13362
3.0	1.00	1200	1670	2000	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
3.0	1.00	1600	1810	2170	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
3.0	2.00	900	2100	2520	3x2-5ft	6	42.5	10	6.5	3	2.8	3188	5700	944	758	2239	532	13362
3.0	2.00	1200	2230	2680	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
3.0	2.00	1600	2349	2820	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
3.0	3.00	900	2680	3220	3x2-5ft	6	42.5	10	6.5	3	2.8	3188	5700	944	758	2239	532	13362
3.0	3.00	1200	2790	3350	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
3.0	3.00	1600	2890	3470	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
4.0	1.00	900	3090	3710	3x2	6	47.5	10	6.5	3	2.8	3563	5700	944	758	2239	532	13737
4.0	1.00	1200	3350	4020	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
4.0	1.00	1600	3670	4400	3x3-5ft	9	42.5	10	10	3	2.8	4781	8550	1333	1011	3444	819	19939
4.0	2.00	900	4650	5580	3x3-3ft	9	44.5	10	10	3	2.8	5006	8550	1333	1011	3444	819	20164
4.0	2.00	1200	4860	5830	3x3	9	47.5	10	10	3	2.8	5344	8550	1333	1011	3444	819	20502
4.0	2.00	1600	5130	6160	4x3-5ft	12	42	13.5	10	3.5	3.6	6300	11400	1894	1325	5425	1658	28003
4.0	3.00	900	6110	7330	4x3-5ft	12	42	13.5	10	3.5	3.6	6300	11400	1894	1325	5425	1658	28003
4.0	3.00	1200	6310	7570	4x3-5ft	12	42	13.5	10	3.5	3.6	6300	11400	1894	1325	5425	1658	28003
4.0	3.00	1600	6540	7850	4x3-5ft	12	42	13.5	10	3.5	3.6	6300	11400	1894	1325	5425	1658	28003
5.0	1.00	900	5730	6880	4x3-5ft	12	42	13.5	10	3.5	3.6	6300	11400	1894	1325	5425	1658	28003
5.0	1.00	1200	6110	7330	4x3-5ft	12	42	13.5	10	3.5	3.6	6300	11400	1894	1325	5425	1658	28003
5.0	1.00	1600	6580	7900	4x3-5ft	12	42	13.5	10	3.5	3.6	6300	11400	1894	1325	5425	1658	28003
5.0	2.00	900	9080	10900	4x4-10ft	16	37	13.5	13.5	3.5	4.3	7400	15200	2447	1645	7324	2674	36690
5.0	2.00	1200	9370	11240	4x4-10ft	16	37	13.5	13.5	3.5	4.3	7400	15200	2447	1645	7324	2674	36690
5.0	2.00	1600	9750	11700	4x4-5ft	16	42	13.5	13.5	3.5	4.3	8400	15200	2447	1645	7324	2674	37690
5.0	3.00	900	12150	14580	5x4-10ft	20	36.75	17	13.5	3.75	5.2	9188	19000	3136	2005	9881	4363	47573
5.0	3.00	1200	12420	14900	5x4-10ft	20	36.75	17	13.5	3.75	5.2	9188	19000	3136	2005	9881	4363	47573
5.0	3.00	1600	12750	15300	6x4-10ft	24	36.5	20.5	13.5	4	5.8	10950	22800	3875	2373	12710	6260	58968
6.0	1.00	900	9540	11450	4x4-10ft	16	37	13.5	13.5	3.5	4.3	7400	15200	2447	1645	7324	2674	36690
6.0	1.00	1200	10020	12020	4x4-5ft	16	42	13.5	13.5	3.5	4.3	8400	15200	2447	1645	7324	2674	37690
6.0	1.00	1600	10760	12910	5x4-10ft	20	36.75	16.3	13.5	3.75	5.2	9188	19000	3020	1940	9474	4184	46806
6.0	2.00	900	15970	19160	6x5-10ft	30	36.5	20.5	17	4	6.7	13688	28500	4750	2819	16005	9106	74868
6.0	2.00	1200	16370	19640	6x5-10ft	30	36.5	20.5	17	4	6.7	13688	28500	4750	2819	16005	9106	74868
6.0	2.00	1600	16880	20260	6x5-10ft	30	36.5	20.5	17	4	6.7	13688	28500	4750	2819	16005	9106	74868
6.0	3.00	900	21770	26120	6x6-10ft	36	36.5	20.5	20.5	4	7.3	16425	34200	5625	3266	19300	11965	90781
6.0	3.00	1200	22100	26520	6x6-10ft	36	36.5	20.5	20.5	4	7.3	16425	34200	5625	3266	19300	11965	90781
6.0	3.00	1600	22510	27010	6x6-10ft	36	36.5	20.5	20.5	4	7.3	16425	34200	5625	3266	19300	11965	90781
7.0	1.00	900	14810	17770	6x4-10ft	24	36.5	20.5	13.5	4	5.8	10950	22800	3875	2373	12710	6260	58968
7.0	1.00	1200	15390	18470	6x4-10ft	24	36.5	20.5	13.5	4	5.8	10950	22800	3875	2373	12710	6260	58968
7.0	1.00	1600	16140	19370	6x5-10ft	30	36.5	20.5	17	4	6.7	13688	28500	4750	2819	16005	9106	74868
7.0	2.00	900	25150	30180	7x6-10ft	42	36	24	20.5	4.5	7.6	18900	39900	7042	3824	25420	16406	111492
7.0	2.00	1200	25630	30760	7x6-10ft	42	36	24	20.5	4.5	7.6	18900	39900	7042	3824	25420	16406	111492
7.0	2.00	1600	26250	31500	7x6-10ft	42	36	24	20.5	4.5	7.6	18900	39900	7042	3824	25420	16406	111492
7.0	3.00	900	34580	41500	8x7-10ft	56	35.75	27.5	24	4.75	8	25025	53200	9588	4917	35994	24453	153176
7.0	3.00	1200	34970	41960	8x7-10ft	56	35.75	27.5	24	4.75	8	25025	53200	9588	4917	35994	24453	153176
7.0	3.00	1600	35480	42580	8x7-10ft	56	35.75	27.5	24	4.75	8	25025	53200	9588	4917	35994	24453	153176
8.0	1.00	900	21320	25580	6x6-10ft	36	36.5	20.5	20.5	4	7.3	16425	34200	5625	3266	19300	11965	90781
8.0	1.00	1200	22280	26740	6x6-10ft	36	36.5	20.5	20.5	4	7.3	16425	34200	5625	3266	19300	11965	90781
8.0	1.00	1600	23190	27830	6x6-10ft	36	36.5	20.5	20.5	4	7.3	16425	34200	5625	3266	19300	11965	90781
8.0	2.00	900	37830	45400	8x8-10ft	64	35.75	27.5	27.5	4.75	8.2	28600	60800	10878	5494	41244	28720	175735
8.0	2.00	1200	38360	46030	8x8-10ft	64	35.75	27.5	27.5	4.75	8.2	28600	60800	10878	5494	41244	28720	175735
8.0	2.00	1600	39120	46940	8x8-10ft	64	35.75	27.5	27.5	4.75	8.2	28600	60800	10878	5494	41244	28720	175735
8.0	3.00	900	53050	63660	9x9-10ft	81	35.5	31	31	5	8.5	35944	76950	14117	6784	55169	39821	228784
8.0	3.00	1200	53530	64240	10x9-10ft	90	35.5	34.5	31	5	8.5	39938	85500	15614	7424	61397	44317	254190
8.0	3.00	1600	54080	64900	10x9-10ft	90	35.5	34.5	31	5	8.5	39938	85500	15614	7424	61397	44317	254190
		50' col	5.5' x 8.25' oblong		8x6	48	45.75	27.5	20.5	4.75	7.8	27450	45600	8297	4339	30745	20365	136796
		50' col	7' x 10.5' oblong		9x6	54	45.5	31	20.5	5	7.9	30713	51300	9625	4863	36482	24475	157458

Multicolumn Footings

Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish Piles	Drive Piles	Excav.	Backfill	Conc.	Steel	Total
2x2 -5ft	4	42.5	6.5	6.5	3	2	2125	3800	669	565	1455	247	8861
3x2-5ft	6	42.5	10	6.5	3	2	3188	5700	944	758	2239	380	13209
3x3 -5ft	9	42.5	10	10	3	2	4781	8550	1333	1011	3444	585	19705
4x3 -3ft	12	44.5	13.5	10	3	2	6675	11400	1722	1264	4650	790	26501
4x4 -3ft	16	44.5	13.5	13.5	3	2	8900	15200	2225	1576	6278	1066	35244
5x4 -3ft	20	44.5	17	13.5	3	2	11125	19000	2727	1887	7905	1343	43987
5x5 -2ft	25	45.5	17	17	3	2	14219	23750	3343	2258	9954	1691	55215
6x5 -2ft	30	45.5	20.5	17	3	2	17063	28500	3958	2629	12004	2039	66192
6x6 -2ft	36	45.5	20.5	20.5	3	2	20475	34200	4688	3059	14475	2458	79355

14-inch Square Precast Concrete Piles
Multicolumn Bents



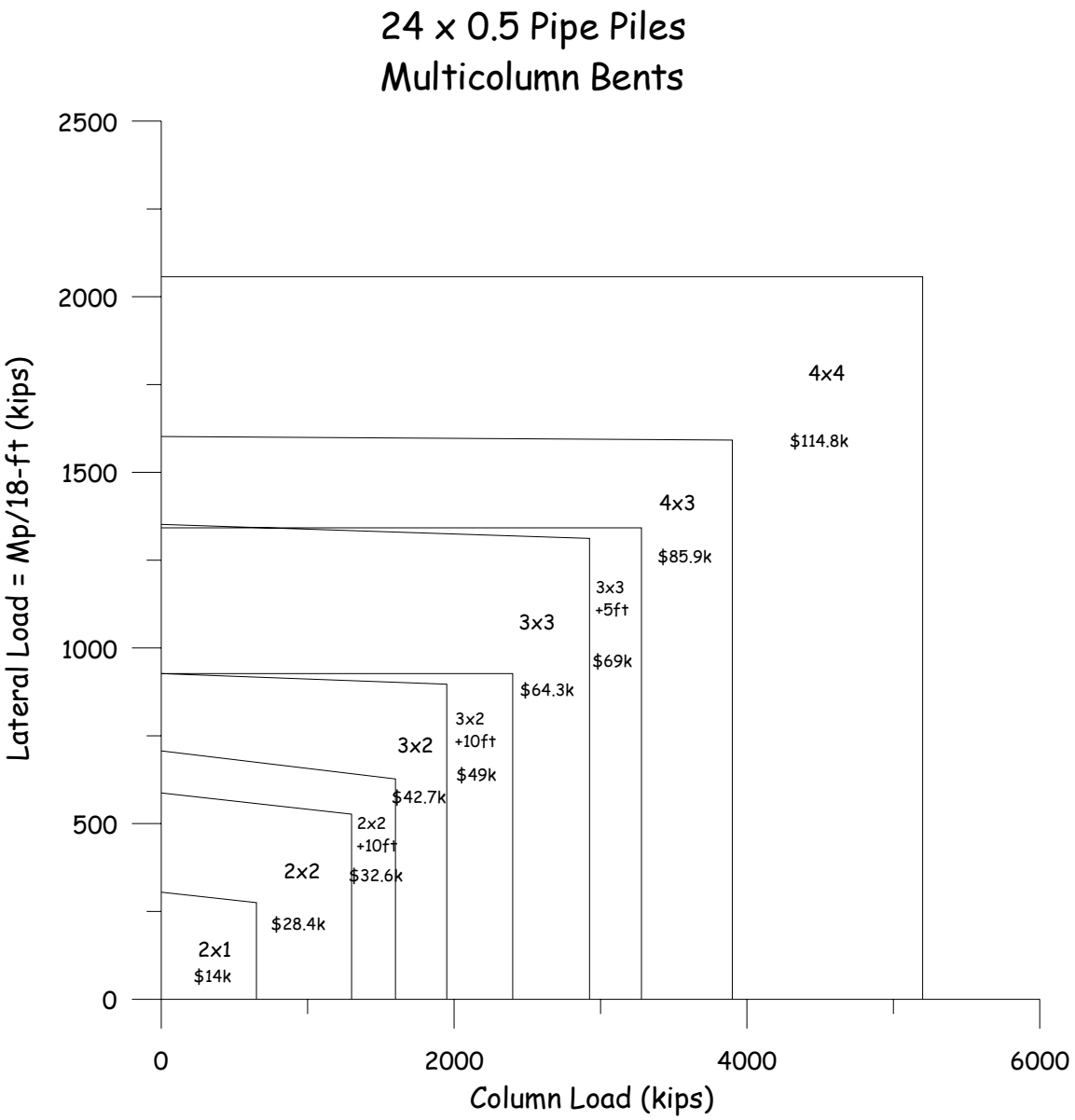
24 x 0.5 PP Single Column Footings

COSTS

Col. (ft)	ρ (%)	P (k)	M_p (k-ft)	M_o (k-ft)	Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish Piles	Drive Piles	Excav.	Backfill	Conc.	Steel	Total
3.0	1.00	900	1520	1820	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
3.0	1.00	1200	1670	2000	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
3.0	1.00	1600	1810	2170	2x2+10ft	4	70.5	10	10	3	2.3	15510	12000	1333	1011	3444	673	33972
3.0	2.00	900	2100	2520	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
3.0	2.00	1200	2230	2680	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
3.0	2.00	1600	2349	2820	2x2+10ft	4	70.5	10	10	3	2.3	15510	12000	1333	1011	3444	673	33972
3.0	3.00	900	2680	3220	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
3.0	3.00	1200	2790	3350	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
3.0	3.00	1600	2890	3470	2x2+10ft	4	70.5	10	10	3	2.3	15510	12000	1333	1011	3444	673	33972
4.0	1.00	900	3090	3710	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
4.0	1.00	1200	3350	4020	2x2	4	60.5	10	10	3	2.3	13310	12000	1333	1011	3444	673	31772
4.0	1.00	1600	3670	4400	2x2+10ft	4	70.5	10	10	3	2.3	15510	12000	1333	1011	3444	673	33972
4.0	2.00	900	4650	5580	2x2+10ft	4	70.5	10	10	3	2.3	15510	12000	1333	1011	3444	673	33972
4.0	2.00	1200	4860	5830	2x2+10ft	4	70.5	10	10	3	2.3	15510	12000	1333	1011	3444	673	33972
4.0	2.00	1600	5130	6160	3x2	6	60.25	15	10	3.25	3.65	19883	18000	1983	1405	5597	1735	48603
4.0	3.00	900	6110	7330	3x2	6	60.25	15	10	3.25	3.65	19883	18000	1983	1405	5597	1735	48603
4.0	3.00	1200	6310	7570	3x2	6	60.25	15	10	3.25	3.65	19883	18000	1983	1405	5597	1735	48603
4.0	3.00	1600	6540	7850	3x2	6	60.25	15	10	3.25	3.65	19883	18000	1983	1405	5597	1735	48603
5.0	1.00	900	5730	6880	3x2	6	60.25	15	10	3.25	3.65	19883	18000	1983	1405	5597	1735	48603
5.0	1.00	1200	6110	7330	3x2	6	60.25	15	10	3.25	3.65	19883	18000	1983	1405	5597	1735	48603
5.0	1.00	1600	6580	7900	3x2	6	60.25	15	10	3.25	3.65	19883	18000	1983	1405	5597	1735	48603
5.0	2.00	900	9080	10900	3x3	9	60.25	15	15	3.25	5	29824	27000	2810	1892	8396	3565	73486
5.0	2.00	1200	9370	11240	3x3	9	60.25	15	15	3.25	5	29824	27000	2810	1892	8396	3565	73486
5.0	2.00	1600	9750	11700	3x3	9	60.25	15	15	3.25	5	29824	27000	2810	1892	8396	3565	73486
5.0	3.00	900	12150	14580	3x3 + 10ft	9	70.25	15	15	3.25	5	34774	27000	2810	1892	8396	3565	78436
5.0	3.00	1200	12420	14900	3x3 + 10ft	9	70.25	15	15	3.25	5	34774	27000	2810	1892	8396	3565	78436
5.0	3.00	1600	12750	15300	3x3 + 10ft	9	70.25	15	15	3.25	5	34774	27000	2810	1892	8396	3565	78436
6.0	1.00	900	9540	11450	3x3	9	60.25	15	15	3.25	5	29824	27000	2810	1892	8396	3565	73486
6.0	1.00	1200	10020	12020	3x3	9	60.25	15	15	3.25	5	29824	27000	2810	1892	8396	3565	73486
6.0	1.00	1600	10760	12910	3x3	9	60.25	15	15	3.25	5	29824	27000	2810	1892	8396	3565	73486
6.0	2.00	900	15970	19160	4x3	12	59.25	20	15	4.25	5	39105	36000	4329	2558	14639	6216	102846
6.0	2.00	1200	16370	19640	4x3	12	59.25	20	15	4.25	5	39105	36000	4329	2558	14639	6216	102846
6.0	2.00	1600	16880	20260	4x3	12	59.25	20	15	4.25	5	39105	36000	4329	2558	14639	6216	102846
6.0	3.00	900	21770	26120	4x4	16	59.25	20	20	4.25	5	52140	48000	5602	3190	19519	8288	136738
6.0	3.00	1200	22100	26520	4x4	16	59.25	20	20	4.25	5	52140	48000	5602	3190	19519	8288	136738
6.0	3.00	1600	22510	27010	4x4	16	59.25	20	20	4.25	5	52140	48000	5602	3190	19519	8288	136738
7.0	1.00	900	14810	17770	4x3	12	59.25	20	15	4.25	5	39105	36000	4329	2558	14639	6216	102846
7.0	1.00	1200	15390	18470	4x3	12	59.25	20	15	4.25	5	39105	36000	4329	2558	14639	6216	102846
7.0	1.00	1600	16140	19370	4x3	12	59.25	20	15	4.25	5	39105	36000	4329	2558	14639	6216	102846
7.0	2.00	900	25150	30180	4x4 + 5ft	16	64.25	20	20	4.25	5	56540	48000	5602	3190	19519	8288	141138
7.0	2.00	1200	25630	30760	4x4 + 5ft	16	64.25	20	20	4.25	5	56540	48000	5602	3190	19519	8288	141138
7.0	2.00	1600	26250	31500	4x4 + 5ft	16	64.25	20	20	4.25	5	56540	48000	5602	3190	19519	8288	141138
7.0	3.00	900	34580	41500	5x4	20	59	25	20	4.5	5.9	64900	60000	7150	3878	25833	12943	174705
7.0	3.00	1200	34970	41960	5x4	20	59	25	20	4.5	5.9	64900	60000	7150	3878	25833	12943	174705
7.0	3.00	1600	35480	42580	5x4	20	59	25	20	4.5	5.9	64900	60000	7150	3878	25833	12943	174705
8.0	1.00	900	21320	25580	4x4	16	59.25	20	20	4.25	5	52140	48000	5602	3190	19519	8288	136738
8.0	1.00	1200	22280	26740	4x4	16	59.25	20	20	4.25	5	52140	48000	5602	3190	19519	8288	136738
8.0	1.00	1600	23190	27830	4x4	16	59.25	20	20	4.25	5	52140	48000	5602	3190	19519	8288	136738
8.0	2.00	900	37830	45400	6x4	24	58.75	30	20	4.75	6.35	77550	72000	8800	4579	32722	17645	213296
8.0	2.00	1200	38360	46030	6x4	24	58.75	30	20	4.75	6.35	77550	72000	8800	4579	32722	17645	213296
8.0	2.00	1600	39120	46940	6x4	24	58.75	30	20	4.75	6.35	77550	72000	8800	4579	32722	17645	213296
8.0	3.00	900	53050	63660	6x5	30	58.75	30	25	4.75	7.1	96938	90000	10800	5464	40903	24661	268765
8.0	3.00	1200	53530	64240	6x5	30	58.75	30	25	4.75	7.1	96938	90000	10800	5464	40903	24661	268765
8.0	3.00	1600	54080	64900	6x5	30	58.75	30	25	4.75	7.1	96938	90000	10800	5464	40903	24661	268765
		50' col	5.5' x 8.25' oblong		6x4	24	58.75	30	20	4.75	6.35	77550	72000	8800	4579	32722	17645	213296
		50' col	7' x 10.5' oblong		6x5 + 5ft	30	58.75	30	25	4.75	7.1	96938	90000	10800	5464	40903	24661	268765

Multicolumn Footings

Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish Piles	Drive Piles	Excav.	Backfill	Conc.	Steel	Total
2x2	4	60.5	10	10	3	2	13310	12000	1333	1011	3444	585	31684
2x2 + 10ft	4	70.5	10	10	3	2	15510	12000	1333	1011	3444	585	33884
3x2	6	60.5	15	10	3	2	19965	18000	1889	1372	5167	878	47270
3x2 +10ft	6	70.5	15	10	3	2	23265	18000	1889	1372	5167	878	50570
3x3	9	60.5	15	15	3	2	29948	27000	2676	1854	7750	1316	70543
3x3 + 5ft	9	65.5	15	15	3	2	32423	27000	2676	1854	7750	1316	73018
4x3	12	60.5	20	15	3	2	39930	36000	3463	2335	10333	1755	93816
4x4	16	60.5	20	20	3	2	53240	48000	4481	2937	13778	2340	124776


24 x 0.5 Pipe Piles
Multicolumn Bents
Lateral Load = Mp/18-ft (kips)
Column Load (kips)
0
500
1000
1500
2000
2500
0
2000
4000
6000
4x4
$114.8k
4x3
$85.9k
3x3
+5ft
$69k
3x3
$64.3k
3x2
+10ft
$49k
3x2
$42.7k
2x2
+10ft
$32.6k
2x2
$28.4k
2x1
$14k

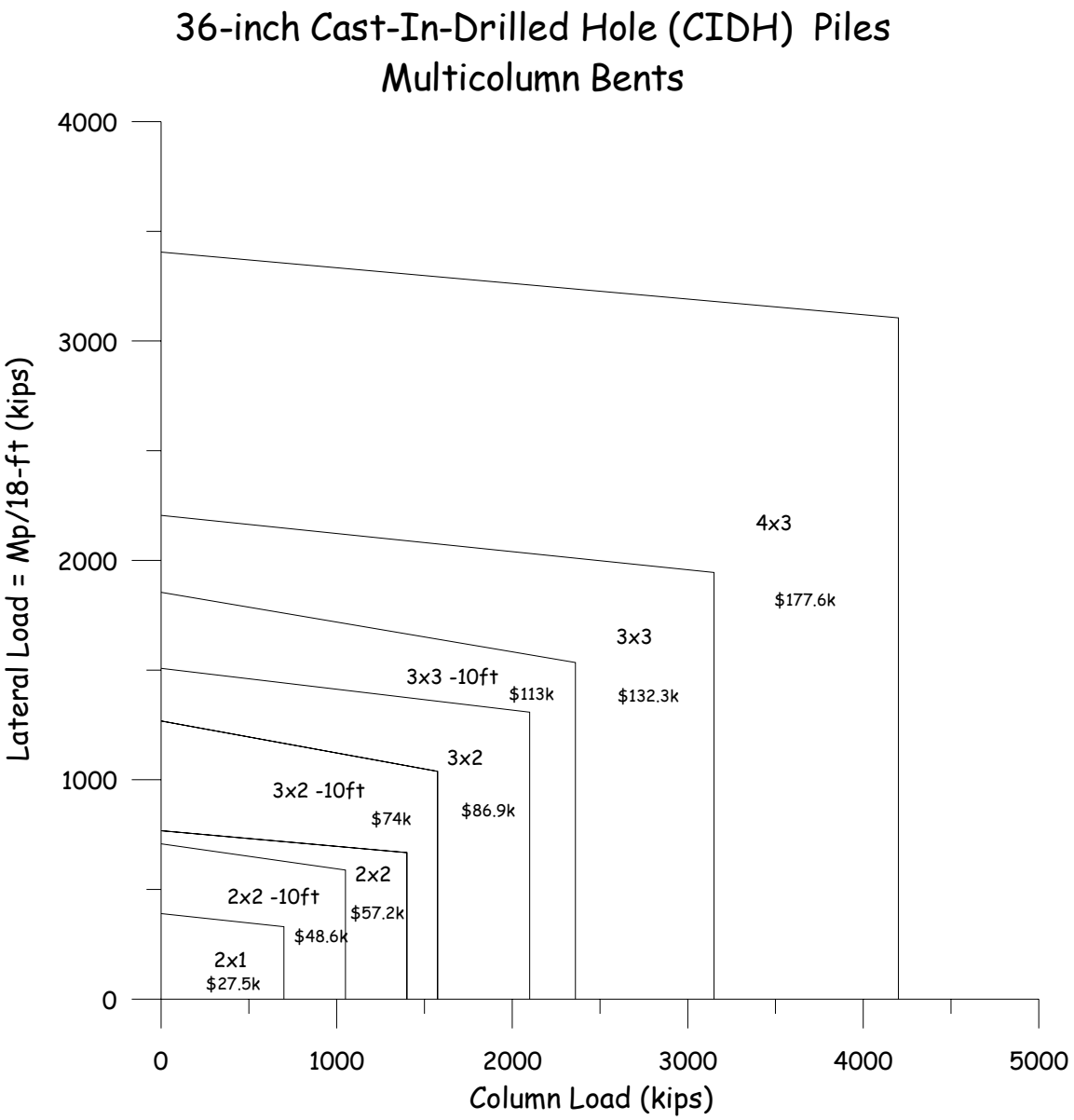
36-inch CIDH Single Column Footings

COSTS

Col. (ft)	ρ (%)	P (k)	M_p (k-ft)	M_o (k-ft)	Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish & Install Piles	Excav.	Backfill	Conc.	Steel	Total
3.0	1.00	900	1520	1820	2x2-14ft	4	46	15	15	3	2.5	39560	2676	1158	7750	1645	52789
3.0	1.00	1200	1670	2000	2x2-14ft	4	46	15	15	3	2.5	39560	2676	1158	7750	1645	52789
3.0	1.00	1600	1810	2170	2x2+5ft	4	65	15	15	3	2.5	55900	2676	1158	7750	1645	69129
3.0	2.00	900	2100	2520	2x2-14ft	4	46	15	15	3	2.5	39560	2676	1158	7750	1645	52789
3.0	2.00	1200	2230	2680	2x2-14ft	4	46	15	15	3	2.5	39560	2676	1158	7750	1645	52789
3.0	2.00	1600	2349	2820	2x2+5ft	4	65	15	15	3	2.5	55900	2676	1158	7750	1645	69129
3.0	3.00	900	2680	3220	2x2-14ft	4	46	15	15	3	2.5	39560	2676	1158	7750	1645	52789
3.0	3.00	1200	2790	3350	2x2-14ft	4	46	15	15	3	2.5	39560	2676	1158	7750	1645	52789
3.0	3.00	1600	2890	3470	2x2+5ft	4	65	15	15	3	2.5	55900	2676	1158	7750	1645	69129
4.0	1.00	900	3090	3710	2x2-10ft	4	50	15	15	3	2.5	43000	2676	1158	7750	1645	56229
4.0	1.00	1200	3350	4020	2x2-5ft	4	55	15	15	3	2.5	47300	2676	1158	7750	1645	60529
4.0	1.00	1600	3670	4400	2x2+5ft	4	65	15	15	3	2.5	55900	2676	1158	7750	1645	69129
4.0	2.00	900	4650	5580	2x2-5ft	4	55	15	15	3	2.5	47300	2676	1158	7750	1645	60529
4.0	2.00	1200	4860	5830	2x2	4	60	15	15	3	2.5	51600	2676	1158	7750	1645	64829
4.0	2.00	1600	5130	6160	2x2+10ft	4	70	15	15	3	2.5	60200	2676	1158	7750	1645	73429
4.0	3.00	900	6110	7330	2x2+5ft	4	65	15	15	3	2.5	55900	2676	1158	7750	1645	69129
4.0	3.00	1200	6310	7570	2x2+10ft	4	70	15	15	3	2.5	60200	2676	1158	7750	1645	73429
4.0	3.00	1600	6540	7850	3x2-10ft	6	49.3	22.5	15	3.7	3.6	63597	4396	1706	14338	4383	88420
5.0	1.00	900	5730	6880	2x2	4	60	15	15	3	2.5	51600	2676	1158	7750	1645	64829
5.0	1.00	1200	6110	7330	2x2+5ft	4	65	15	15	3	2.5	55900	2676	1158	7750	1645	69129
5.0	1.00	1600	6580	7900	3x2-10ft	6	49.3	22.5	15	3.7	3.6	63597	4396	1706	14338	4383	88420
5.0	2.00	900	9080	10900	3x2-5ft	6	54.3	22.5	15	3.7	3.6	70047	4396	1706	14338	4383	94870
5.0	2.00	1200	9370	11240	3x2-5ft	6	54.3	22.5	15	3.7	3.6	70047	4396	1706	14338	4383	94870
5.0	2.00	1600	9750	11700	3x2	6	59.3	22.5	15	3.7	3.6	76497	4396	1706	14338	4383	101320
5.0	3.00	900	12150	14580	3x3-10ft	9	49.3	22.5	22.5	3.7	4.7	95396	6336	2282	21506	8584	134104
5.0	3.00	1200	12420	14900	3x3-10ft	9	49.3	22.5	22.5	3.7	4.7	95396	6336	2282	21506	8584	134104
5.0	3.00	1600	12750	15300	3x3-10ft	9	49.3	22.5	22.5	3.7	4.7	95396	6336	2282	21506	8584	134104
6.0	1.00	900	9540	11450	3x2-5ft	6	54.3	22.5	15	3.7	3.6	70047	4396	1706	14338	4383	94870
6.0	1.00	1200	10020	12020	3x2-5ft	6	54.3	22.5	15	3.7	3.6	70047	4396	1706	14338	4383	94870
6.0	1.00	1600	10760	12910	3x2	6	59.3	22.5	15	3.7	3.6	76497	4396	1706	14338	4383	101320
6.0	2.00	900	15970	19160	3x3	9	59.3	22.5	22.5	3.7	4.7	114746	6336	2282	21506	8584	153454
6.0	2.00	1200	16370	19640	3x3	9	59.3	22.5	22.5	3.7	4.7	114746	6336	2282	21506	8584	153454
6.0	2.00	1600	16880	20260	3x3	9	59.3	22.5	22.5	3.7	4.7	114746	6336	2282	21506	8584	153454
6.0	3.00	900	21770	26120	4x3-10ft	12	48.5	30	22.5	4.5	5	125130	9437	3068	34875	14808	187318
6.0	3.00	1200	22100	26520	4x3-10ft	12	48.5	30	22.5	4.5	5	125130	9437	3068	34875	14808	187318
6.0	3.00	1600	22510	27010	4x3-5ft	12	53.5	30	22.5	4.5	5	138030	9437	3068	34875	14808	200218
7.0	1.00	900	14810	17770	3x3-5ft	9	54.3	22.5	22.5	3.7	4.7	105071	6336	2282	21506	8584	143779
7.0	1.00	1200	15390	18470	3x3-3ft	9	56.3	22.5	22.5	3.7	4.7	108941	6336	2282	21506	8584	147649
7.0	1.00	1600	16140	19370	3x3-3ft	9	56.3	22.5	22.5	3.7	4.7	108941	6336	2282	21506	8584	147649
7.0	2.00	900	25150	30180	4x3	12	58.5	30	22.5	4.5	5	150930	9437	3068	34875	14808	213118
7.0	2.00	1200	25630	30760	4x3	12	58.5	30	22.5	4.5	5	150930	9437	3068	34875	14808	213118
7.0	2.00	1600	26250	31500	4x3	12	58.5	30	22.5	4.5	5	150930	9437	3068	34875	14808	213118
7.0	3.00	900	34580	41500	4x4-5ft	16	53.5	30	30	4.5	5.2	184040	12326	3809	46500	20534	267208
7.0	3.00	1200	34970	41960	4x4-5ft	16	53.5	30	30	4.5	5.2	184040	12326	3809	46500	20534	267208
7.0	3.00	1600	35480	42580	4x4-5ft	16	53.5	30	30	4.5	5.2	184040	12326	3809	46500	20534	267208
8.0	1.00	900	21320	25580	4x3-10ft	12	48.5	30	22.5	4.5	5	125130	9437	3068	34875	14808	187318
8.0	1.00	1200	22280	26740	4x3-10ft	12	48.5	30	22.5	4.5	5	125130	9437	3068	34875	14808	187318
8.0	1.00	1600	23190	27830	4x3-5ft	12	53.5	30	22.5	4.5	5	138030	9437	3068	34875	14808	200218
8.0	2.00	900	37830	45400	4x4	16	58.5	30	30	4.5	5.2	201240	12326	3809	46500	20534	284408
8.0	2.00	1200	38360	46030	4x4	16	58.5	30	30	4.5	5.2	201240	12326	3809	46500	20534	284408
8.0	2.00	1600	39120	46940	4x4	16	58.5	30	30	4.5	5.2	201240	12326	3809	46500	20534	284408
8.0	3.00	900	53050	63660	5x4	20	57.5	37.5	30	5.5	5.2	247250	17556	4883	71042	31371	372101
8.0	3.00	1200	53530	64240	5x4	20	57.5	37.5	30	5.5	5.2	247250	17556	4883	71042	31371	372101
8.0	3.00	1600	54080	64900	5x4	20	57.5	37.5	30	5.5	5.2	247250	17556	4883	71042	31371	372101
		50' col	5.5' x 8.25' oblong		5x4-5ft.	20	52.5	37.5	30	5.5	5.2	225750	17556	4883	71042	31371	350601
		50' col	7' x 10.5' oblong		5x4+5ft	20	62.5	37.5	30	5.5	5.2	268750	17556	4883	71042	31371	393601

Multicolumn Footings

Req'd Group	No. Piles	Pile Length (ft)	Cap Dim 1	Cap Dim 2	Cap Depth	% Steel	Furnish & Install Piles	Excav.	Backfill	Conc.	Steel	Total
2x2 -10ft	4	50	15	15	3	2	43000	2676	1158	7750	1316	55900
2x2	4	60	15	15	3	2	51600	2676	1158	7750	1316	64500
3x2 - 10ft	6	50	22.5	15	3	2	64500	3856	1573	11625	1974	83529
3x2	6	60	22.5	15	3	2	77400	3856	1573	11625	1974	96429
3x3 -10ft	9	50	22.5	22.5	3	2	96750	5558	2124	17438	2962	124831
3x3	9	60	22.5	22.5	3	2	116100	5558	2124	17438	2962	144181
4x3	12	60	30	22.5	3	2	154800	7259	2675	23250	3949	191933


36-inch Cast-In-Drilled Hole (CIDH) Piles
Multicolumn Bents
Lateral Load = Mp/18-ft (kips)
Column Load (kips)
0
1000
2000
3000
4000
5000
4x3
$177.6k
3x3
$132.3k
3x3 -10ft
$113k
3x2
$86.9k
3x2 -10ft
$74k
2x2
$57.2k
2x2 -10ft
$48.6k
2x1
$27.5k

APPENDIX C: DESIGN SPREADSHEETS

Column Design, Displacement Capacity, and Displacement Demand for Model No. 1, M6.50 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
1 A	1837	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1837	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1877	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1864	6948	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1864	10723	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1864	14328	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1877	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1921	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1971	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1948	16254	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1948	27194	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	2052	31306	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	516	619	1796	1837	418	0	2255	1837	1837
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	673	808	1796	1837	418	0	2255	1837	1837
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	650	780	1796	1877	418	0	2295	1877	1877
Oblong	4.00	6.00	0.01	24	10	30	8.53	23.23	0.37	5790	6948	526	632	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.02	48	10	61	11.79	23.23	0.51	8936	10723	812	975	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.03	72	10	91	14.42	23.23	0.62	11940	14328	1085	1303	1796	1864	418	0	2282	1864	1864
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	983	1180	1796	1877	418	0	2295	1877	1877
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	1014	1217	1796	1921	418	0	2339	1921	1921
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	1531	1837	1796	1971	418	0	2389	1971	1971
Oblong	5.50	8.25	0.01	36	11	56	27.21	83.05	0.33	13545	16254	1231	1478	1796	1948	418	0	2366	1948	1948
Oblong	5.50	8.25	0.02	72	11	112	40.80	83.05	0.49	22662	27194	2060	2472	1796	1948	418	0	2366	1948	1948
Oblong	7.00	10.50	0.01	58	11	90	67.21	217.9	0.31	26088	31306	2372	2846	1796	2052	418	0	2470	2052	2052

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0065	0.0104	0.0056	0.0104	0.0159	5.3	43.563	0.74	1.5	954	350	1.1	0.070	102	1	704	685	619	0.90
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0065	0.0117	0.0084	0.0117	0.0210	5.4	43.500	0.64	1.5	1260	350	1.0	0.061	88	1	925	861	808	0.94
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0057	0.0081	0.0036	0.0081	0.0124	5.9	55.563	0.30	1.4	746	350	0.4	0.027	61	1	898	815	780	0.96
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0056	0.0080	0.0048	0.0080	0.0081	5.4	43.625	0.56	1.4	488	350	0.8	0.050	118	2	724	715	632	0.88
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0056	0.0093	0.0096	0.0096	0.0124	5.3	43.563	0.66	1.4	742	350	0.9	0.058	138	2	1095	1048	975	0.93
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0056	0.0106	0.0144	0.0144	0.0171	5.3	43.563	0.74	1.4	1027	350	1.0	0.065	155	2	1516	1420	1303	0.92
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0057	0.0094	0.0072	0.0094	0.0192	6.4	55.500	0.30	1.4	1149	350	0.4	0.027	61	1	1377	1222	1180	0.97
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0052	0.0075	0.0052	0.0075	0.0135	6.5	67.500	0.30	1.3	809	350	0.4	0.025	80	1	1436	1289	1217	0.94
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0049	0.0072	0.0072	0.0072	0.0133	8.1	79.500	0.30	1.2	800	350	0.4	0.023	103	1	1973	1765	1837	1.04
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0049	0.0071	0.0072	0.0072	0.0098	6.4	61.563	0.30	1.2	589	350	0.4	0.023	103	2	1741	1567	1478	0.94
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0049	0.0084	0.0144	0.0144	0.0159	6.9	61.500	0.30	1.2	956	350	0.4	0.023	103	2	2818	2483	2472	1.00
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0068	0.0116	0.0116	0.0123	8.3	79.500	0.30	1.1	738	350	0.3	0.022	157	2	3643	3230	2846	0.88

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
1 A	22.00	0.000130	0.001362	0.001232	1.27	68	25.9	0.032	1.51	7.6	9.11	0.63	2.14	9.74	6.0	4.5	7.94	4.0
1 B	22.00	0.000138	0.001538	0.001400	1.27	68	25.9	0.036	1.60	8.6	10.24	0.73	2.33	10.96	6.4	4.7	8.57	4.0
1 C	22.00	0.000094	0.001208	0.001114	1.41	68	28.8	0.032	1.09	7.5	8.63	0.70	1.79	9.33	7.9	5.2	6.45	4.0
1 D	22.00	0.000102	0.001157	0.001055	1.27	68	25.9	0.027	1.18	6.5	7.69	0.57	1.75	8.26	6.5	4.7	6.44	4.0
1 E	22.00	0.000115	0.001334	0.001219	1.27	68	25.9	0.032	1.33	7.5	8.85	0.59	1.93	9.45	6.6	4.9	7.11	4.0
1 F	22.00	0.000125	0.001488	0.001363	1.27	68	25.9	0.035	1.45	8.4	9.86	0.61	2.06	10.47	6.8	5.1	7.62	4.0
1 G	22.00	0.000103	0.001224	0.001121	1.41	68	28.8	0.032	1.20	7.6	8.78	0.95	2.15	9.74	7.3	4.5	7.66	4.0
1 H	22.00	0.000077	0.001040	0.000963	1.41	68	28.8	0.028	0.89	6.5	7.41	0.74	1.63	8.15	8.3	5.0	5.78	4.0
1 I	22.00	0.000065	0.000863	0.000798	1.41	68	28.8	0.023	0.76	5.4	6.16	1.12	1.88	7.28	8.1	3.9	6.16	3.9
1 J	22.00	0.000075	0.001124	0.001049	1.41	68	28.8	0.030	0.88	7.1	7.97	0.69	1.57	8.66	9.1	5.5	5.58	4.0
1 K	22.00	0.000084	0.001180	0.001096	1.41	68	28.8	0.032	0.98	7.4	8.39	0.93	1.91	9.32	8.6	4.9	6.71	4.0
1 L	22.00	0.000059	0.000869	0.000810	1.41	68	28.8	0.023	0.69	5.5	6.17	0.99	1.67	7.16	9.0	4.3	5.71	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	2.59	7.94
1 B	>2.44	8.57
1 C	>2.63	6.45
1 D	2.23	6.44
1 E	>1.88	7.11
1 F	>1.52	7.62
1 G	>2.49	7.66
1 H	>2.28	5.78
1 I	>1.73	6.16
1 J	>1.73	5.58
1 K	>1.73	6.71
1 L	>1.73	5.71

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
1 A	183.7	2021	5674	OK
1 B	183.7	2021	7406	OK
1 C	187.7	2065	7150	OK
1 D	186.4	2050	5790	OK
1 E	186.4	2050	8936	OK
1 F	186.4	2050	11940	OK
1 G	187.7	2065	10816	OK
1 H	192.1	2113	11152	OK
1 I	197.1	2168	16843	OK
1 J	194.8	2143	13545	OK
1 K	194.8	2143	22662	OK
1 L	205.2	2257	26088	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	697	No
1 B	1481	784	No
1 C	1430	675	No
1 D	1158	597	No
1 E	1787	688	No
1 F	2388	766	No
1 G	2163	687	No
1 H	2230	593	No
1 I	3369	506	No
1 J	2709	647	No
1 K	4532	681	No
1 L	5218	527	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.04	0.93	0.99	1.04	0.93	L	1.04	0.99	L
0.97	>1.0g	>1.09	0.97	> 1.0g	L	0.97	>1.09	L
0.89	>1.0g	>1.15	1.15	0.98	T	1.15	0.95	T
0.95	0.84	0.97	0.95	0.84	L	1.06	0.90	T
0.79	>1.0g	>1.21	0.79	> 1.0g	L	0.79	>1.21	L
0.71	>1.0g	>1.27	0.71	> 1.0g	L	0.71	>1.27	L
0.80	>1.0g	>1.21	0.80	> 1.0g	L	0.80	>1.21	L
0.68	>1.0g	>1.31	0.68	> 1.0g	L	0.68	>1.31	L
0.61	>1.0g	>1.38	0.61	> 1.0g	L	0.61	>1.38	L
0.61	>1.0g	>1.38	0.61	> 1.0g	L	0.61	>1.38	L
0.53	>1.0g	>1.43	0.53	> 1.0g	L	0.53	>1.43	L
0.49	>1.0g	>1.48	0.49	> 1.0g	L	0.49	>1.48	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 1, M6.50 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
1 A	1837	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1837	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1877	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1864	10345	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1864	15888	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1864	21069	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1877	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1921	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1971	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1948	24122	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1948	39816	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	2052	45778	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	221	266	1796	1837	418	0	2255	1837	1837
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	289	347	1796	1837	418	0	2255	1837	1837
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	279	335	1796	1877	418	0	2295	1877	1877
Oblong	4.00	6.00	0.01	24	10	30	17.64	49.13	0.36	8621	10345	336	404	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.02	48	10	61	24.62	49.13	0.50	13240	15888	517	620	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.03	72	10	91	30.02	49.13	0.61	17557	21069	685	822	1796	1864	418	0	2282	1864	1864
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	422	506	1796	1877	418	0	2295	1877	1877
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	435	522	1796	1921	418	0	2339	1921	1921
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	657	789	1796	1971	418	0	2389	1971	1971
Oblong	5.50	8.25	0.01	36	11	56	56.67	175.62	0.32	20101	24122	784	941	1796	1948	418	0	2366	1948	1948
Oblong	5.50	8.25	0.02	72	11	112	83.16	175.62	0.47	33180	39816	1295	1554	1796	1948	418	0	2366	1948	1948
Oblong	7.00	10.50	0.01	58	11	90	133.62	460.8	0.29	38148	45778	1488	1786	1796	2052	418	0	2470	2052	2052

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0065	0.0104	0.0056	0.0104	0.0159	4.2	43.56	1.82	1.5	954	350	2.7	0.173	250	1	704	811	266	0.33
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0065	0.0117	0.0084	0.0117	0.0210	4.2	43.50	1.81	1.5	1260	350	2.7	0.171	248	1	925	997	347	0.35
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0057	0.0081	0.0036	0.0081	0.0124	4.3	55.56	1.72	1.4	746	350	2.4	0.154	349	1	898	1060	335	0.32
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0056	0.0080	0.0048	0.0080	0.0081	4.3	67.63	1.67	1.4	488	350	2.3	0.147	348	2	1122	1249	404	0.32
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0056	0.0093	0.0096	0.0096	0.0124	4.4	67.56	1.58	1.4	742	350	2.2	0.139	330	2	1698	1724	620	0.36
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0056	0.0106	0.0144	0.0144	0.0171	4.4	67.56	1.60	1.4	1027	350	2.2	0.141	335	2	2351	2283	822	0.36
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0057	0.0094	0.0072	0.0094	0.0192	4.3	55.50	1.66	1.4	1149	350	2.3	0.148	335	1	1377	1456	506	0.35
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0052	0.0075	0.0052	0.0075	0.0135	4.4	67.50	1.62	1.3	809	350	2.1	0.133	433	1	1436	1589	522	0.33
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0049	0.0072	0.0072	0.0072	0.0133	4.7	79.50	1.33	1.2	800	350	1.6	0.103	457	1	1973	2065	789	0.38
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0049	0.0071	0.0072	0.0072	0.0098	4.7	94.56	1.26	1.2	589	350	1.5	0.097	435	2	2674	2642	941	0.36
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0049	0.0084	0.0144	0.0144	0.0159	4.9	94.50	1.10	1.2	956	350	1.3	0.084	378	2	4330	4002	1554	0.39
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0068	0.0116	0.0116	0.0123	5.3	121.50	0.70	1.1	738	350	0.8	0.050	366	2	5567	5043	1786	0.35

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
1 A	25.63	0.000130	0.001362	0.001232	1.27	68	37.6	0.046	4.10	13.36	17.46	0.25	4.35	17.71	4.3	4.1	17.15	4.0
1 B	25.63	0.000138	0.001538	0.001400	1.27	68	37.6	0.053	4.34	15.19	19.53	0.28	4.62	19.81	4.5	4.3	18.21	4.0
1 C	25.63	0.000094	0.001208	0.001114	1.41	68	39.0	0.043	2.95	12.52	15.47	0.27	3.22	15.74	5.2	4.9	12.62	4.0
1 D	25.63	0.00007	0.00080	0.000722	1.27	68	37.6	0.027	2.34	7.83	10.17	0.33	2.68	10.50	4.3	3.9	10.17	3.9
1 E	25.63	0.00008	0.00090	0.000817	1.27	68	37.6	0.031	2.56	8.86	11.42	0.36	2.92	11.78	4.5	4.0	11.31	4.0
1 F	25.63	0.00009	0.00100	0.000916	1.27	68	37.6	0.034	2.76	9.94	12.70	0.37	3.13	13.07	4.6	4.2	12.16	4.0
1 G	25.63	0.000103	0.001224	0.001121	1.41	68	39.0	0.044	3.26	12.58	15.85	0.38	3.64	16.22	4.9	4.5	14.18	4.0
1 H	25.63	0.000077	0.001040	0.000963	1.41	68	39.0	0.038	2.41	10.82	13.23	0.30	2.72	13.54	5.5	5.0	10.56	4.0
1 I	25.63	0.000065	0.000863	0.000798	1.41	68	39.0	0.031	2.06	8.96	11.02	0.46	2.52	11.48	5.4	4.6	9.60	4.0
1 J	25.63	0.00005	0.00070	0.000645	1.41	68	39.0	0.025	1.70	7.24	8.94	0.42	2.12	9.37	5.3	4.4	8.06	4.0
1 K	25.63	0.00006	0.000791	0.000732	1.41	68	39.0	0.029	1.87	8.22	10.09	0.57	2.44	10.66	5.4	4.4	9.20	4.0
1 L	25.63	0.00004	0.000581	0.000537	1.41	68	39.0	0.021	1.38	6.03	7.41	0.60	1.98	8.01	5.4	4.1	7.31	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	>2.65	17.15
1 B	>2.44	18.21
1 C	2.01	12.62
1 D	2.00	10.17
1 E	>1.88	11.31
1 F	>1.52	12.16
1 G	>2.49	14.18
1 H	>2.11	10.56
1 I	>2.28	9.60
1 J	>1.73	8.06

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
1 A	183.7	4708	5674	OK
1 B	183.7	4708	7406	OK
1 C	187.7	4811	7150	OK
1 D	186.4	4777	8621	OK
1 E	186.4	4777	13240	OK
1 F	186.4	4777	17557	OK
1 G	187.7	4811	10816	OK
1 H	192.1	4924	11152	OK
1 I	197.1	5052	16843	OK
1 J	194.8	4993	20101	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	2625	Yes
1 B	1481	2788	Yes
1 C	1430	1974	Yes
1 D	1724	1580	No
1 E	2648	1757	No
1 F	3511	1889	No
1 G	2163	2217	Yes
1 H	2230	1691	No
1 I	3369	1577	No
1 J	4020	1309	No
1 K	6636	1493	No
1 L	7630	1249	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{trans} (s)	PGA_{trans} (g)	$S_{A,trans}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.30	>1.0g	>0.91	1.04	0.93	L	1.04	0.99	L
1.27	>1.0g	>0.94	0.97	> 1.0g	L	0.97	>1.09	L
1.15	0.98	0.95	1.15	0.98	T	1.15	0.95	T
1.06	0.87	0.90	0.95	0.84	L	1.06	0.90	T
0.90	>1.0g	>1.11	0.79	> 1.0g	L	0.79	>1.21	L
0.83	>1.0g	>1.15	0.71	> 1.0g	L	0.71	>1.27	L
1.06	>1.0g	>1.01	0.80	> 1.0g	L	0.80	>1.21	L
0.93	>1.0g	>1.09	0.68	> 1.0g	L	0.68	>1.31	L
0.83	>1.0g	>1.16	0.61	> 1.0g	L	0.61	>1.38	L
0.73	>1.0g	>1.24	0.61	> 1.0g	L	0.61	>1.38	L
0.63	>1.0g	>1.35	0.53	> 1.0g	L	0.53	>1.43	L
0.57	>1.0g	>1.41	0.49	> 1.0g	L	0.49	>1.48	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 1, M7.25 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
1 A	1837	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1837	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1877	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1864	6948	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1864	10723	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1864	14328	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1877	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1921	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1971	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1948	16254	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1948	27194	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	2052	31306	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	516	619	1796	1837	418	0	2255	1837	1837
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	673	808	1796	1837	418	0	2255	1837	1837
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	650	780	1796	1877	418	0	2295	1877	1877
Oblong	4.00	6.00	0.01	24	10	30	8.53	23.23	0.37	5790	6948	526	632	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.02	48	10	61	11.79	23.23	0.51	8936	10723	812	975	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.03	72	10	91	14.42	23.23	0.62	11940	14328	1085	1303	1796	1864	418	0	2282	1864	1864
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	983	1180	1796	1877	418	0	2295	1877	1877
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	1014	1217	1796	1921	418	0	2339	1921	1921
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	1531	1837	1796	1971	418	0	2389	1971	1971
Oblong	5.50	8.25	0.01	36	11	56	27.21	83.05	0.33	13545	16254	1231	1478	1796	1948	418	0	2366	1948	1948
Oblong	5.50	8.25	0.02	72	11	112	40.80	83.05	0.49	22662	27194	2060	2472	1796	1948	418	0	2366	1948	1948
Oblong	7.00	10.50	0.01	58	11	90	67.21	217.9	0.31	26088	31306	2372	2846	1796	2052	418	0	2470	2052	2052

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0065	0.0104	0.0056	0.0104	0.0159	5.3	43.563	0.74	1.5	954	350	1.1	0.070	102	1	704	685	619	0.90
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0065	0.0117	0.0084	0.0117	0.0210	5.4	43.500	0.64	1.5	1260	350	1.0	0.061	88	1	925	861	808	0.94
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0057	0.0081	0.0036	0.0081	0.0124	5.9	55.563	0.30	1.4	746	350	0.4	0.027	61	1	898	815	780	0.96
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0056	0.0080	0.0048	0.0080	0.0081	5.4	43.625	0.56	1.4	488	350	0.8	0.050	118	2	724	715	632	0.88
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0056	0.0093	0.0096	0.0096	0.0124	5.3	43.563	0.66	1.4	742	350	0.9	0.058	138	2	1095	1048	975	0.93
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0056	0.0106	0.0144	0.0144	0.0171	5.3	43.563	0.74	1.4	1027	350	1.0	0.065	155	2	1516	1420	1303	0.92
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0057	0.0094	0.0072	0.0094	0.0192	6.4	55.500	0.30	1.4	1149	350	0.4	0.027	61	1	1377	1222	1180	0.97
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0052	0.0075	0.0052	0.0075	0.0135	6.5	67.500	0.30	1.3	809	350	0.4	0.025	80	1	1436	1289	1217	0.94
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0049	0.0072	0.0072	0.0072	0.0133	8.1	79.500	0.30	1.2	800	350	0.4	0.023	103	1	1973	1765	1837	1.04
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0049	0.0071	0.0072	0.0072	0.0098	6.4	61.563	0.30	1.2	589	350	0.4	0.023	103	2	1741	1567	1478	0.94
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0049	0.0084	0.0144	0.0144	0.0159	6.9	61.500	0.30	1.2	956	350	0.4	0.023	103	2	2818	2483	2472	1.00
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0068	0.0116	0.0116	0.0123	8.3	79.500	0.30	1.1	738	350	0.3	0.022	157	2	3643	3230	2846	0.88

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
1 A	22.00	0.000130	0.001362	0.001232	1.27	68	25.9	0.032	1.51	7.6	9.11	0.63	2.14	9.74	6.0	4.5	7.94	4.0
1 B	22.00	0.000138	0.001538	0.001400	1.27	68	25.9	0.036	1.60	8.6	10.24	0.73	2.33	10.96	6.4	4.7	8.57	4.0
1 C	22.00	0.000094	0.001208	0.001114	1.41	68	28.8	0.032	1.09	7.5	8.63	0.70	1.79	9.33	7.9	5.2	6.45	4.0
1 D	22.00	0.000102	0.001157	0.001055	1.27	68	25.9	0.027	1.18	6.5	7.69	0.57	1.75	8.26	6.5	4.7	6.44	4.0
1 E	22.00	0.000115	0.001334	0.001219	1.27	68	25.9	0.032	1.33	7.5	8.85	0.59	1.93	9.45	6.6	4.9	7.11	4.0
1 F	22.00	0.000125	0.001488	0.001363	1.27	68	25.9	0.035	1.45	8.4	9.86	0.61	2.06	10.47	6.8	5.1	7.62	4.0
1 G	22.00	0.000103	0.001224	0.001121	1.41	68	28.8	0.032	1.20	7.6	8.78	0.95	2.15	9.74	7.3	4.5	7.66	4.0
1 H	22.00	0.000077	0.001040	0.000963	1.41	68	28.8	0.028	0.89	6.5	7.41	0.74	1.63	8.15	8.3	5.0	5.78	4.0
1 I	22.00	0.000065	0.000863	0.000798	1.41	68	28.8	0.023	0.76	5.4	6.16	1.12	1.88	7.28	8.1	3.9	6.16	3.9
1 J	22.00	0.000075	0.001124	0.001049	1.41	68	28.8	0.030	0.88	7.1	7.97	0.69	1.57	8.66	9.1	5.5	5.58	4.0
1 K	22.00	0.000084	0.001180	0.001096	1.41	68	28.8	0.032	0.98	7.4	8.39	0.93	1.91	9.32	8.6	4.9	6.71	4.0
1 L	22.00	0.000059	0.000869	0.000810	1.41	68	28.8	0.023	0.69	5.5	6.17	0.99	1.67	7.16	9.0	4.3	5.71	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	3.33	7.94
1 B	2.69	8.57
1 C	3.22	6.45
1 D	2.01	6.44
1 E	1.88	7.11
1 F	2.04	7.62
1 G	3.58	7.66
1 H	>5.03	5.78
1 I	2.94	6.16
1 J	2.94	5.58
1 K	2.94	6.71
1 L	2.94	5.71

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
1 A	183.7	2021	5674	OK
1 B	183.7	2021	7406	OK
1 C	187.7	2065	7150	OK
1 D	186.4	2050	5790	OK
1 E	186.4	2050	8936	OK
1 F	186.4	2050	11940	OK
1 G	187.7	2065	10816	OK
1 H	192.1	2113	11152	OK
1 I	197.1	2168	16843	OK
1 J	194.8	2143	13545	OK
1 K	194.8	2143	22662	OK
1 L	205.2	2257	26088	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	697	No
1 B	1481	784	No
1 C	1430	675	No
1 D	1158	597	No
1 E	1787	688	No
1 F	2388	766	No
1 G	2163	687	No
1 H	2230	593	No
1 I	3369	506	No
1 J	2709	647	No
1 K	4532	681	No
1 L	5218	527	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.04	0.60	0.99	1.04	0.60	L	1.04	0.99	L
0.97	0.66	1.25	0.97	0.66	L	1.27	1.23	T
0.89	0.62	1.21	0.89	0.62	L	1.15	0.96	T
0.95	0.57	0.97	0.95	0.57	L	1.06	0.91	T
0.79	0.70	1.59	0.90	0.69	T	0.90	1.39	T
0.71	0.79	2.04	0.83	0.75	T	0.83	1.69	T
0.80	0.77	1.86	1.06	0.69	T	1.06	1.25	T
0.68	0.78	2.04	0.93	0.64	T	0.93	1.21	T
0.61	>1.0g	>3.05	0.83	0.68	T	0.83	1.43	T
0.61	0.85	2.36	0.73	0.69	T	0.73	1.53	T
0.53	>1.0g	>2.89	0.63	0.89	T	0.63	2.36	T
0.49	>1.0g	>2.79	0.57	0.90	T	0.57	2.38	T

Column Design, Displacement Capacity, and Displacement Demand for Model No. 1, M7.25 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
1 A	1837	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1837	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1877	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1864	10345	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1864	15888	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1864	21069	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1877	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1921	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1971	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1948	24122	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1948	39816	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	2052	45778	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	221	266	1796	1837	418	0	2255	1837	1837
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	289	347	1796	1837	418	0	2255	1837	1837
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	279	335	1796	1877	418	0	2295	1877	1877
Oblong	4.00	6.00	0.01	24	10	30	17.64	49.13	0.36	8621	10345	336	404	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.02	48	10	61	24.62	49.13	0.50	13240	15888	517	620	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.03	72	10	91	30.02	49.13	0.61	17557	21069	685	822	1796	1864	418	0	2282	1864	1864
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	422	506	1796	1877	418	0	2295	1877	1877
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	435	522	1796	1921	418	0	2339	1921	1921
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	657	789	1796	1971	418	0	2389	1971	1971
Oblong	5.50	8.25	0.01	36	11	56	56.67	175.62	0.32	20101	24122	784	941	1796	1948	418	0	2366	1948	1948
Oblong	5.50	8.25	0.02	72	11	112	83.16	175.62	0.47	33180	39816	1295	1554	1796	1948	418	0	2366	1948	1948
Oblong	7.00	10.50	0.01	58	11	90	133.62	460.8	0.29	38148	45778	1488	1786	1796	2052	418	0	2470	2052	2052

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0065	0.0104	0.0056	0.0104	0.0159	4.2	43.56	1.82	1.5	954	350	2.7	0.173	250	1	704	811	266	0.33
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0065	0.0117	0.0084	0.0117	0.0210	4.2	43.50	1.81	1.5	1260	350	2.7	0.171	248	1	925	997	347	0.35
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0057	0.0081	0.0036	0.0081	0.0124	4.3	55.56	1.72	1.4	746	350	2.4	0.154	349	1	898	1060	335	0.32
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0056	0.0080	0.0048	0.0080	0.0081	4.3	67.63	1.67	1.4	488	350	2.3	0.147	348	2	1122	1249	404	0.32
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0056	0.0093	0.0096	0.0096	0.0124	4.4	67.56	1.58	1.4	742	350	2.2	0.139	330	2	1698	1724	620	0.36
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0056	0.0106	0.0144	0.0144	0.0171	4.4	67.56	1.60	1.4	1027	350	2.2	0.141	335	2	2351	2283	822	0.36
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0057	0.0094	0.0072	0.0094	0.0192	4.3	55.50	1.66	1.4	1149	350	2.3	0.148	335	1	1377	1456	506	0.35
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0052	0.0075	0.0052	0.0075	0.0135	4.4	67.50	1.62	1.3	809	350	2.1	0.133	433	1	1436	1589	522	0.33
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0049	0.0072	0.0072	0.0072	0.0133	4.7	79.50	1.33	1.2	800	350	1.6	0.103	457	1	1973	2065	789	0.38
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0049	0.0071	0.0072	0.0072	0.0098	4.7	94.56	1.26	1.2	589	350	1.5	0.097	435	2	2674	2642	941	0.36
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0049	0.0084	0.0144	0.0144	0.0159	4.9	94.50	1.10	1.2	956	350	1.3	0.084	378	2	4330	4002	1554	0.39
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0068	0.0116	0.0116	0.0123	5.3	121.50	0.70	1.1	738	350	0.8	0.050	366	2	5567	5043	1786	0.35

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
1 A	25.63	0.000130	0.001362	0.001232	1.27	68	37.6	0.046	4.10	13.36	17.46	0.25	4.35	17.71	4.3	4.1	17.15	4.0
1 B	25.63	0.000138	0.001538	0.001400	1.27	68	37.6	0.053	4.34	15.19	19.53	0.28	4.62	19.81	4.5	4.3	18.21	4.0
1 C	25.63	0.000094	0.001208	0.001114	1.41	68	39.0	0.043	2.95	12.52	15.47	0.27	3.22	15.74	5.2	4.9	12.62	4.0
1 D	25.63	0.00007	0.00080	0.000722	1.27	68	37.6	0.027	2.34	7.83	10.17	0.33	2.68	10.50	4.3	3.9	10.17	3.9
1 E	25.63	0.00008	0.00090	0.000817	1.27	68	37.6	0.031	2.56	8.86	11.42	0.36	2.92	11.78	4.5	4.0	11.31	4.0
1 F	25.63	0.00009	0.00100	0.000916	1.27	68	37.6	0.034	2.76	9.94	12.70	0.37	3.13	13.07	4.6	4.2	12.16	4.0
1 G	25.63	0.000103	0.001224	0.001121	1.41	68	39.0	0.044	3.26	12.58	15.85	0.38	3.64	16.22	4.9	4.5	14.18	4.0
1 H	25.63	0.000077	0.001040	0.000963	1.41	68	39.0	0.038	2.41	10.82	13.23	0.30	2.72	13.54	5.5	5.0	10.56	4.0
1 I	25.63	0.000065	0.000863	0.000798	1.41	68	39.0	0.031	2.06	8.96	11.02	0.46	2.52	11.48	5.4	4.6	9.60	4.0
1 J	25.63	0.00005	0.00070	0.000645	1.41	68	39.0	0.025	1.70	7.24	8.94	0.42	2.12	9.37	5.3	4.4	8.06	4.0
1 K	25.63	0.00006	0.000791	0.000732	1.41	68	39.0	0.029	1.87	8.22	10.09	0.57	2.44	10.66	5.4	4.4	9.20	4.0
1 L	25.63	0.00004	0.000581	0.000537	1.41	68	39.0	0.021	1.38	6.03	7.41	0.60	1.98	8.01	5.4	4.1	7.31	4.0

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	3.20	17.15
1 B	2.81	18.21
1 C	2.40	12.62
1 D	1.71	10.17
1 E	1.78	11.31
1 F	2.12	12.16
1 G	1.96	14.18
1 H	2.02	10.56
1 I	2.05	9.60
1 J	1.69	8.06

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
1 A	183.7	4708	5674	OK
1 B	183.7	4708	7406	OK
1 C	187.7	4811	7150	OK
1 D	186.4	4777	8621	OK
1 E	186.4	4777	13240	OK
1 F	186.4	4777	17557	OK
1 G	187.7	4811	10816	OK
1 H	192.1	4924	11152	OK
1 I	197.1	5052	16843	OK
1 J	194.8	4993	20101	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	2625	Yes
1 B	1481	2788	Yes
1 C	1430	1974	Yes
1 D	1724	1580	No
1 E	2648	1757	No
1 F	3511	1889	No
1 G	2163	2217	Yes
1 H	2230	1691	No
1 I	3369	1577	No
1 J	4020	1309	No
1 K	6636	1493	No
1 L	7630	1249	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{trans} (s)	PGA_{trans} (g)	$S_{A,trans}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.30	0.70	1.07	1.04	0.60	L	1.04	0.99	L
1.27	0.73	1.23	0.97	0.66	L	1.27	1.23	T
1.15	0.63	0.96	0.89	0.62	L	1.15	0.96	T
1.06	0.59	0.91	0.95	0.57	L	1.06	0.91	T
0.90	0.69	1.39	0.90	0.69	T	0.90	1.39	T
0.83	0.75	1.69	0.83	0.75	T	0.83	1.69	T
1.06	0.69	1.25	1.06	0.69	T	1.06	1.25	T
0.93	0.64	1.21	0.93	0.64	T	0.93	1.21	T
0.83	0.68	1.43	0.83	0.68	T	0.83	1.43	T
0.73	0.69	1.53	0.73	0.69	T	0.73	1.53	T
0.63	0.89	2.36	0.63	0.89	T	0.63	2.36	T
0.57	0.90	2.38	0.57	0.90	T	0.57	2.38	T

Column Design, Displacement Capacity, and Displacement Demand for Model No. 1, M8.00 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
1 A	1837	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1837	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1877	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1864	6948	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1864	10723	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1864	14328	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1877	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1921	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1971	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1948	16254	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1948	27194	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	2052	31306	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	516	619	1796	1837	418	0	2255	1837	1837
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	673	808	1796	1837	418	0	2255	1837	1837
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	650	780	1796	1877	418	0	2295	1877	1877
Oblong	4.00	6.00	0.01	24	10	30	8.53	23.23	0.37	5790	6948	526	632	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.02	48	10	61	11.79	23.23	0.51	8936	10723	812	975	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.03	72	10	91	14.42	23.23	0.62	11940	14328	1085	1303	1796	1864	418	0	2282	1864	1864
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	983	1180	1796	1877	418	0	2295	1877	1877
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	1014	1217	1796	1921	418	0	2339	1921	1921
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	1531	1837	1796	1971	418	0	2389	1971	1971
Oblong	5.50	8.25	0.01	36	11	56	27.21	83.05	0.33	13545	16254	1231	1478	1796	1948	418	0	2366	1948	1948
Oblong	5.50	8.25	0.02	72	11	112	40.80	83.05	0.49	22662	27194	2060	2472	1796	1948	418	0	2366	1948	1948
Oblong	7.00	10.50	0.01	58	11	90	67.21	217.9	0.31	26088	31306	2372	2846	1796	2052	418	0	2470	2052	2052

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0065	0.0104	0.0056	0.0104	0.0159	5.3	43.563	0.74	1.5	954	350	1.1	0.070	102	1	704	685	619	0.90
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0065	0.0117	0.0084	0.0117	0.0210	5.4	43.500	0.64	1.5	1260	350	1.0	0.061	88	1	925	861	808	0.94
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0057	0.0081	0.0036	0.0081	0.0124	5.9	55.563	0.30	1.4	746	350	0.4	0.027	61	1	898	815	780	0.96
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0056	0.0080	0.0048	0.0080	0.0081	5.4	43.625	0.56	1.4	488	350	0.8	0.050	118	2	724	715	632	0.88
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0056	0.0093	0.0096	0.0096	0.0124	5.3	43.563	0.66	1.4	742	350	0.9	0.058	138	2	1095	1048	975	0.93
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0056	0.0106	0.0144	0.0144	0.0171	5.3	43.563	0.74	1.4	1027	350	1.0	0.065	155	2	1516	1420	1303	0.92
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0057	0.0094	0.0072	0.0094	0.0192	6.4	55.500	0.30	1.4	1149	350	0.4	0.027	61	1	1377	1222	1180	0.97
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0052	0.0075	0.0052	0.0075	0.0135	6.5	67.500	0.30	1.3	809	350	0.4	0.025	80	1	1436	1289	1217	0.94
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0049	0.0072	0.0072	0.0072	0.0133	8.1	79.500	0.30	1.2	800	350	0.4	0.023	103	1	1973	1765	1837	1.04
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0049	0.0071	0.0072	0.0072	0.0098	6.4	61.563	0.30	1.2	589	350	0.4	0.023	103	2	1741	1567	1478	0.94
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0049	0.0084	0.0144	0.0144	0.0159	6.9	61.500	0.30	1.2	956	350	0.4	0.023	103	2	2818	2483	2472	1.00
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0068	0.0116	0.0116	0.0123	8.3	79.500	0.30	1.1	738	350	0.3	0.022	157	2	3643	3230	2846	0.88

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
1 A	22.00	0.000130	0.001362	0.001232	1.27	68	25.9	0.032	1.51	7.6	9.11	0.63	2.14	9.74	6.0	4.5	7.94	4.0
1 B	22.00	0.000138	0.001538	0.001400	1.27	68	25.9	0.036	1.60	8.6	10.24	0.73	2.33	10.96	6.4	4.7	8.57	4.0
1 C	22.00	0.000094	0.001208	0.001114	1.41	68	28.8	0.032	1.09	7.5	8.63	0.70	1.79	9.33	7.9	5.2	6.45	4.0
1 D	22.00	0.000102	0.001157	0.001055	1.27	68	25.9	0.027	1.18	6.5	7.69	0.57	1.75	8.26	6.5	4.7	6.44	4.0
1 E	22.00	0.000115	0.001334	0.001219	1.27	68	25.9	0.032	1.33	7.5	8.85	0.59	1.93	9.45	6.6	4.9	7.11	4.0
1 F	22.00	0.000125	0.001488	0.001363	1.27	68	25.9	0.035	1.45	8.4	9.86	0.61	2.06	10.47	6.8	5.1	7.62	4.0
1 G	22.00	0.000103	0.001224	0.001121	1.41	68	28.8	0.032	1.20	7.6	8.78	0.95	2.15	9.74	7.3	4.5	7.66	4.0
1 H	22.00	0.000077	0.001040	0.000963	1.41	68	28.8	0.028	0.89	6.5	7.41	0.74	1.63	8.15	8.3	5.0	5.78	4.0
1 I	22.00	0.000065	0.000863	0.000798	1.41	68	28.8	0.023	0.76	5.4	6.16	1.12	1.88	7.28	8.1	3.9	6.16	3.9
1 J	22.00	0.000075	0.001124	0.001049	1.41	68	28.8	0.030	0.88	7.1	7.97	0.69	1.57	8.66	9.1	5.5	5.58	4.0
1 K	22.00	0.000084	0.001180	0.001096	1.41	68	28.8	0.032	0.98	7.4	8.39	0.93	1.91	9.32	8.6	4.9	6.71	4.0
1 L	22.00	0.000059	0.000869	0.000810	1.41	68	28.8	0.023	0.69	5.5	6.17	0.99	1.67	7.16	9.0	4.3	5.71	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	2.43	7.94
1 B	3.08	8.57
1 C	3.56	6.45
1 D	2.48	6.44
1 E	2.07	7.11
1 F	2.16	7.62
1 G	3.79	7.66
1 H	4.43	5.78
1 I	3.09	6.16
1 J	3.09	5.58
1 K	3.09	6.71
1 L	3.09	5.71

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
1 A	183.7	2021	5674	OK
1 B	183.7	2021	7406	OK
1 C	187.7	2065	7150	OK
1 D	186.4	2050	5790	OK
1 E	186.4	2050	8936	OK
1 F	186.4	2050	11940	OK
1 G	187.7	2065	10816	OK
1 H	192.1	2113	11152	OK
1 I	197.1	2168	16843	OK
1 J	194.8	2143	13545	OK
1 K	194.8	2143	22662	OK
1 L	205.2	2257	26088	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	697	No
1 B	1481	784	No
1 C	1430	675	No
1 D	1158	597	No
1 E	1787	688	No
1 F	2388	766	No
1 G	2163	687	No
1 H	2230	593	No
1 I	3369	506	No
1 J	2709	647	No
1 K	4532	681	No
1 L	5218	527	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.04	0.56	0.99	1.04	0.56	L	1.04	0.99	L
0.97	0.63	1.25	0.97	0.63	L	1.27	1.23	T
0.89	0.60	1.21	1.15	0.58	T	1.15	0.96	T
0.95	0.52	0.97	0.95	0.52	L	1.06	0.90	T
0.79	0.68	1.59	0.90	0.67	T	0.90	1.38	T
0.71	0.78	2.04	0.83	0.74	T	0.83	1.69	T
0.80	0.75	1.86	1.06	0.67	T	1.06	1.25	T
0.68	0.77	2.04	0.93	0.62	T	0.93	1.20	T
0.61	0.99	3.10	0.83	0.66	T	0.83	1.42	T
0.61	0.84	2.36	0.73	0.67	T	0.73	1.53	T
0.53	>1.0g	>3.01	0.63	0.87	T	0.63	2.38	T
0.49	>1.0g	>2.93	0.57	0.88	T	0.57	2.40	T

Column Design, Displacement Capacity, and Displacement Demand for Model No. 1, M8.00 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
1 A	1837	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1837	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1877	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1864	10345	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1864	15888	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1864	21069	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1877	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1921	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1971	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1948	24122	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1948	39816	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	2052	45778	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	221	266	1796	1837	418	0	2255	1837	1837
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	289	347	1796	1837	418	0	2255	1837	1837
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	279	335	1796	1877	418	0	2295	1877	1877
Oblong	4.00	6.00	0.01	24	10	30	17.64	49.13	0.36	8621	10345	336	404	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.02	48	10	61	24.62	49.13	0.50	13240	15888	517	620	1796	1864	418	0	2282	1864	1864
Oblong	4.00	6.00	0.03	72	10	91	30.02	49.13	0.61	17557	21069	685	822	1796	1864	418	0	2282	1864	1864
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	422	506	1796	1877	418	0	2295	1877	1877
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	435	522	1796	1921	418	0	2339	1921	1921
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	657	789	1796	1971	418	0	2389	1971	1971
Oblong	5.50	8.25	0.01	36	11	56	56.67	175.62	0.32	20101	24122	784	941	1796	1948	418	0	2366	1948	1948
Oblong	5.50	8.25	0.02	72	11	112	83.16	175.62	0.47	33180	39816	1295	1554	1796	1948	418	0	2366	1948	1948
Oblong	7.00	10.50	0.01	58	11	90	133.62	460.8	0.29	38148	45778	1488	1786	1796	2052	418	0	2470	2052	2052

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0065	0.0104	0.0056	0.0104	0.0159	4.2	43.56	1.82	1.5	954	350	2.7	0.173	250	1	704	811	266	0.33
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0065	0.0117	0.0084	0.0117	0.0210	4.2	43.50	1.81	1.5	1260	350	2.7	0.171	248	1	925	997	347	0.35
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0057	0.0081	0.0036	0.0081	0.0124	4.3	55.56	1.72	1.4	746	350	2.4	0.154	349	1	898	1060	335	0.32
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0056	0.0080	0.0048	0.0080	0.0081	4.3	67.63	1.67	1.4	488	350	2.3	0.147	348	2	1122	1249	404	0.32
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0056	0.0093	0.0096	0.0096	0.0124	4.4	67.56	1.58	1.4	742	350	2.2	0.139	330	2	1698	1724	620	0.36
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0056	0.0106	0.0144	0.0144	0.0171	4.4	67.56	1.60	1.4	1027	350	2.2	0.141	335	2	2351	2283	822	0.36
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0057	0.0094	0.0072	0.0094	0.0192	4.3	55.50	1.66	1.4	1149	350	2.3	0.148	335	1	1377	1456	506	0.35
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0052	0.0075	0.0052	0.0075	0.0135	4.4	67.50	1.62	1.3	809	350	2.1	0.133	433	1	1436	1589	522	0.33
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0049	0.0072	0.0072	0.0072	0.0133	4.7	79.50	1.33	1.2	800	350	1.6	0.103	457	1	1973	2065	789	0.38
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0049	0.0071	0.0072	0.0072	0.0098	4.7	94.56	1.26	1.2	589	350	1.5	0.097	435	2	2674	2642	941	0.36
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0049	0.0084	0.0144	0.0144	0.0159	4.9	94.50	1.10	1.2	956	350	1.3	0.084	378	2	4330	4002	1554	0.39
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0068	0.0116	0.0116	0.0123	5.3	121.50	0.70	1.1	738	350	0.8	0.050	366	2	5567	5043	1786	0.35

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
1 A	25.63	0.000130	0.001362	0.001232	1.27	68	37.6	0.046	4.10	13.36	17.46	0.25	4.35	17.71	4.3	4.1	17.15	4.0
1 B	25.63	0.000138	0.001538	0.001400	1.27	68	37.6	0.053	4.34	15.19	19.53	0.28	4.62	19.81	4.5	4.3	18.21	4.0
1 C	25.63	0.000094	0.001208	0.001114	1.41	68	39.0	0.043	2.95	12.52	15.47	0.27	3.22	15.74	5.2	4.9	12.62	4.0
1 D	25.63	0.00007	0.00080	0.000722	1.27	68	37.6	0.027	2.34	7.83	10.17	0.33	2.68	10.50	4.3	3.9	10.17	3.9
1 E	25.63	0.00008	0.00090	0.000817	1.27	68	37.6	0.031	2.56	8.86	11.42	0.36	2.92	11.78	4.5	4.0	11.31	4.0
1 F	25.63	0.00009	0.00100	0.000916	1.27	68	37.6	0.034	2.76	9.94	12.70	0.37	3.13	13.07	4.6	4.2	12.16	4.0
1 G	25.63	0.000103	0.001224	0.001121	1.41	68	39.0	0.044	3.26	12.58	15.85	0.38	3.64	16.22	4.9	4.5	14.18	4.0
1 H	25.63	0.000077	0.001040	0.000963	1.41	68	39.0	0.038	2.41	10.82	13.23	0.30	2.72	13.54	5.5	5.0	10.56	4.0
1 I	25.63	0.000065	0.000863	0.000798	1.41	68	39.0	0.031	2.06	8.96	11.02	0.46	2.52	11.48	5.4	4.6	9.60	4.0
1 J	25.63	0.00005	0.00070	0.000645	1.41	68	39.0	0.025	1.70	7.24	8.94	0.42	2.12	9.37	5.3	4.4	8.06	4.0
1 K	25.63	0.00006	0.000791	0.000732	1.41	68	39.0	0.029	1.87	8.22	10.09	0.57	2.44	10.66	5.4	4.4	9.20	4.0
1 L	25.63	0.00004	0.000581	0.000537	1.41	68	39.0	0.021	1.38	6.03	7.41	0.60	1.98	8.01	5.4	4.1	7.31	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	2.23	17.15
1 B	3.05	18.21
1 C	1.81	12.62
1 D	2.22	10.17
1 E	2.01	11.31
1 F	2.24	12.16
1 G	2.36	14.18
1 H	2.28	10.56
1 I	2.28	9.60
1 J	1.81	8.06

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
1 A	183.7	4708	5674	OK
1 B	183.7	4708	7406	OK
1 C	187.7	4811	7150	OK
1 D	186.4	4777	8621	OK
1 E	186.4	4777	13240	OK
1 F	186.4	4777	17557	OK
1 G	187.7	4811	10816	OK
1 H	192.1	4924	11152	OK
1 I	197.1	5052	16843	OK
1 J	194.8	4993	20101	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ	θ
1 A	1135	2625	Yes	#DIV/0!
1 B	1481	2788	Yes	#DIV/0!
1 C	1430	1974	Yes	#DIV/0!
1 D	1724	1580	No	
1 E	2648	1757	No	
1 F	3511	1889	No	
1 G	2163	2217	Yes	#DIV/0!
1 H	2230	1691	No	
1 I	3369	1577	No	
1 J	4020	1309	No	
1 K	6636	1493	No	
1 L	7630	1249	No	

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{trans} (s)	PGA_{trans} (g)	$S_{A,trans}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.30	0.67	1.07	1.04	0.56	L	1.04	0.99	L
1.27	0.71	1.23	0.97	0.63	L	1.27	1.23	T
1.15	0.58	0.96	1.15	0.58	T	1.15	0.96	T
1.06	0.54	0.90	0.95	0.52	L	1.06	0.90	T
0.90	0.67	1.38	0.90	0.67	T	0.90	1.38	T
0.83	0.74	1.69	0.83	0.74	T	0.83	1.69	T
1.06	0.67	1.25	1.06	0.67	T	1.06	1.25	T
0.93	0.62	1.20	0.93	0.62	T	0.93	1.20	T
0.83	0.66	1.42	0.83	0.66	T	0.83	1.42	T
0.73	0.67	1.53	0.73	0.67	T	0.73	1.53	T
0.63	0.87	2.38	0.63	0.87	T	0.63	2.38	T
0.57	0.88	2.40	0.57	0.88	T	0.57	2.40	T

Column Design, Displacement Capacity, and Displacement Demand for Model No. 3, M6.50 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.29 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
3 A	1171	4034	3 x 3	2 x 2	2 x 2 -5ft	725	8700	1,700,000
3 B	1171	6124	3 x 3	3 x 2	2 x 2 +10ft	725	8700	1,700,000
3 C	1171	8311	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
3 D	1198	6175	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
3 E	1198	10041	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 F	1198	13704	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
3 G	1215	7534	4 x 3	3 x 2	3 x 2 -10ft	880	10560	2,800,000
3 H	1215	12092	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 I	1288	14919	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
3 J	1288	25296	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.01	14	10	18	4.53	12.57	0.36	3362	4034	306	367	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.02	28	10	36	6.20	12.57	0.49	5103	6124	464	557	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.03	42	10	53	7.79	12.57	0.62	6926	8311	630	756	1130	1171	345	0	1516	1171	1171
Oblong	4.00	6.00	0.01	24	10	30	7.78	23.23	0.33	5146	6175	468	561	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.02	48	10	61	11.25	23.23	0.48	8368	10041	761	913	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.03	72	10	91	14.03	23.23	0.60	11420	13704	1038	1246	1130	1198	345	0	1543	1198	1198
Circular	5.00	5.00	0.01	18	11	28	10.38	30.68	0.34	6278	7534	571	685	1150	1215	345	0	1560	1215	1215
Circular	5.00	5.00	0.02	36	11	56	14.88	30.68	0.49	10077	12092	916	1099	1150	1215	345	0	1560	1215	1215
Oblong	5.50	8.25	0.01	36	11	56	25.53	83.05	0.31	12432	14919	1130	1356	1160	1288	345	0	1633	1288	1288
Oblong	5.50	8.25	0.02	72	11	112	39.38	83.05	0.47	21080	25296	1916	2300	1160	1288	345	0	1633	1288	1288

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
3 A	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0056	0.0080	0.0028	0.0080	0.0081	5.1	43.625	0.93	1.4	488	350	1.3	0.082	119	1	362	409	367	0.90
3 B	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0056	0.0093	0.0056	0.0093	0.0131	5.5	43.563	0.53	1.4	786	350	0.7	0.047	68	1	580	550	557	1.01
3 C	1810	1521	1448	8	0.79	1.24	3.75	43.00	0.0057	0.0056	0.0106	0.0084	0.0106	0.0196	5.9	43.500	0.30	1.4	1176	350	0.4	0.027	39	1	864	767	756	0.99
3 D	2962	2522	2369	6	0.44	0.69	5.50	43.25	0.0052	0.0050	0.0073	0.0048	0.0073	0.0074	5.3	43.625	0.69	1.3	444	350	0.9	0.055	130	2	658	670	561	0.84
3 E	2962	2522	2369	7	0.60	0.94	4.75	43.13	0.0052	0.0050	0.0086	0.0096	0.0096	0.0117	5.5	43.563	0.53	1.3	703	350	0.7	0.042	99	2	1037	966	913	0.95
3 F	2962	2522	2369	7	0.60	0.94	3.50	43.13	0.0052	0.0050	0.0099	0.0144	0.0144	0.0159	5.6	43.563	0.41	1.3	954	350	0.5	0.033	77	2	1408	1262	1246	0.99
3 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0109	6.0	55.563	0.30	1.3	653	350	0.4	0.024	54	1	785	714	685	0.96
3 H	2827	2463	2262	8	0.79	1.24	3.25	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0177	6.0	55.500	0.30	1.3	1061	350	0.4	0.024	54	1	1271	1127	1099	0.98
3 I	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0087	6.2	61.563	0.30	1.1	524	350	0.3	0.022	97	2	1547	1398	1356	0.97
3 J	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	6.8	61.500	0.30	1.1	956	350	0.3	0.022	97	2	2818	2478	2300	0.93

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
3 A	22.00	0.000113	0.001105	0.000992	1.27	68	25.9	0.026	1.31	6.1	7.43	0.47	1.78	7.90	5.7	4.4	6.64	4.0
3 B	22.00	0.000125	0.001345	0.001220	1.27	68	25.9	0.032	1.45	7.5	8.98	0.71	2.16	9.69	6.2	4.5	7.93	4.0
3 C	22.00	0.000134	0.001603	0.001469	1.27	68	25.9	0.038	1.56	9.1	10.62	0.97	2.53	11.59	6.8	4.6	9.14	4.0
3 D	22.00	0.000099	0.001230	0.001131	1.27	68	25.9	0.029	1.16	7.0	8.13	0.50	1.66	8.63	7.0	5.2	6.14	4.0
3 E	22.00	0.000113	0.001396	0.001283	1.27	68	25.9	0.033	1.31	7.9	9.22	0.64	1.95	9.87	7.0	5.1	7.17	4.0
3 F	22.00	0.000123	0.001552	0.001429	1.27	68	25.9	0.037	1.43	8.8	10.25	0.76	2.19	11.01	7.2	5.0	8.01	4.0
3 G	22.00	0.000091	0.001245	0.001154	1.41	68	28.8	0.033	1.06	7.8	8.86	0.70	1.76	9.57	8.4	5.4	6.33	4.0
3 H	22.00	0.000102	0.001295	0.001193	1.41	68	28.8	0.034	1.18	8.1	9.26	0.78	1.96	10.03	7.8	5.1	7.07	4.0
3 I	22.00	0.000073	0.001018	0.000945	1.41	68	28.8	0.027	0.85	6.4	7.24	0.63	1.48	7.88	8.6	5.3	5.29	4.0
3 J	22.00	0.000081	0.000921	0.000840	1.41	68	28.8	0.024	0.94	5.7	6.63	0.87	1.81	7.49	7.0	4.1	6.37	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
3 A	1.74	6.64
3 B	>2.33	7.93
3 C	>2.40	9.14
3 D	>1.78	6.14
3 E	>1.54	7.17
3 F	>1.40	8.01
3 G	>2.11	6.33
3 H	>1.61	7.07
3 I	>1.23	5.29
3 J	>1.08	6.37

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
3 A	117.1	1289	3362	OK
3 B	117.1	1289	5103	OK
3 C	117.1	1289	6926	OK
3 D	119.8	1318	5146	OK
3 E	119.8	1318	8368	OK
3 F	119.8	1318	11420	OK
3 G	121.5	1336	6278	OK
3 H	121.5	1336	10077	OK
3 I	128.8	1417	12432	OK
3 J	128.8	1417	21080	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
3 A	672	363	No
3 B	1021	438	No
3 C	1385	518	No
3 D	1029	406	No
3 E	1674	460	No
3 F	2284	511	No
3 G	1256	449	No
3 H	2015	469	No
3 I	2486	389	No
3 J	4216	356	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.99	0.76	0.87	0.99	0.76	L	0.99	0.87	L
0.91	>1.0g	>1.14	0.91	> 1.0g	L	0.91	>1.14	L
0.85	>1.0g	>1.18	0.85	> 1.0g	L	0.85	>1.18	L
0.79	>1.0g	>1.22	0.79	> 1.0g	L	0.79	>1.22	L
0.67	>1.0g	>1.33	0.67	> 1.0g	L	0.67	>1.33	L
0.61	>1.0g	>1.40	0.61	> 1.0g	L	0.61	>1.40	L
0.75	>1.0g	>1.26	0.75	> 1.0g	L	0.75	>1.26	L
0.62	>1.0g	>1.38	0.62	> 1.0g	L	0.62	>1.38	L
0.51	>1.0g	>1.51	0.51	> 1.0g	L	0.51	>1.51	L
0.43	>1.0g	>1.62	0.43	> 1.0g	L	0.43	>1.62	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 3, M6.50 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.29 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
3 A	1171	4034	3 x 3	2 x 2	2 x 2 -5ft	725	8700	1,700,000
3 B	1171	6124	3 x 3	3 x 2	2 x 2 +10ft	725	8700	1,700,000
3 C	1171	8311	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
3 D	1198	9131	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
3 E	1198	14856	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 F	1198	20060	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
3 G	1215	7534	4 x 3	3 x 2	3 x 2 -10ft	880	10560	2,800,000
3 H	1215	12092	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 I	1288	22151	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
3 J	1288	37871	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.01	14	10	18	4.53	12.57	0.36	3362	4034	138	166	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.02	28	10	36	6.20	12.57	0.49	5103	6124	210	252	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.03	42	10	53	7.79	12.57	0.62	6926	8311	285	342	1130	1171	345	0	1516	1171	1171
Oblong	4.00	6.00	0.01	24	10	30	15.89	49.13	0.32	7610	9131	313	376	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.02	48	10	61	23.30	49.13	0.47	12380	14856	510	612	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.03	72	10	91	28.99	49.13	0.59	16717	20060	688	826	1130	1198	345	0	1543	1198	1198
Circular	5.00	5.00	0.01	18	11	28	10.38	30.68	0.34	6278	7534	258	310	1150	1215	345	0	1560	1215	1215
Circular	5.00	5.00	0.02	36	11	56	14.88	30.68	0.49	10077	12092	415	498	1150	1215	345	0	1560	1215	1215
Oblong	5.50	8.25	0.01	36	11	56	51.43	175.62	0.29	18459	22151	760	912	1160	1288	345	0	1633	1288	1288
Oblong	5.50	8.25	0.02	72	11	112	79.88	175.62	0.45	31559	37871	1299	1559	1160	1288	345	0	1633	1288	1288

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
3 A	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0056	0.0080	0.0028	0.0080	0.0081	4.1	43.625	1.92	1.4	488	350	2.7	0.170	246	1	362	517	166	0.32
3 B	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0056	0.0093	0.0056	0.0093	0.0131	4.2	43.563	1.76	1.4	786	350	2.5	0.156	226	1	580	685	252	0.37
3 C	1810	1521	1448	8	0.79	1.24	3.75	43.00	0.0057	0.0056	0.0106	0.0084	0.0106	0.0196	4.3	43.500	1.69	1.4	1176	350	2.4	0.150	218	1	864	919	342	0.37
3 D	2962	2522	2369	6	0.44	0.69	5.50	43.25	0.0052	0.0050	0.0073	0.0048	0.0073	0.0074	4.5	67.625	1.55	1.3	444	350	1.9	0.123	292	2	1020	1115	376	0.34
3 E	2962	2522	2369	7	0.60	0.94	4.75	43.13	0.0052	0.0050	0.0086	0.0096	0.0096	0.0117	4.5	67.563	1.47	1.3	703	350	1.8	0.116	275	2	1609	1601	612	0.38
3 F	2962	2522	2369	7	0.60	0.94	3.50	43.13	0.0052	0.0050	0.0099	0.0144	0.0144	0.0159	4.6	67.563	1.42	1.3	954	350	1.8	0.113	267	2	2183	2083	826	0.40
3 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0109	4.3	55.563	1.66	1.3	653	350	2.1	0.133	301	1	785	924	310	0.34
3 H	2827	2463	2262	8	0.79	1.24	3.25	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0177	4.3	55.500	1.66	1.3	1061	350	2.1	0.133	301	1	1271	1337	498	0.37
3 I	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0087	4.8	94.563	1.20	1.1	524	350	1.4	0.087	388	2	2377	2350	912	0.39
3 J	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	5.0	94.500	0.99	1.1	956	350	1.1	0.071	319	2	4330	3952	1559	0.39

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
3 A	24.29	0.000113	0.001105	0.000992	1.27	68	36.3	0.036	3.19	9.84	13.03	0.19	3.38	13.22	4.1	3.9	13.03	3.9
3 B	24.29	0.000125	0.001345	0.001220	1.27	68	36.3	0.044	3.53	12.10	15.63	0.29	3.82	15.92	4.4	4.2	15.00	4.0
3 C	24.29	0.000134	0.001603	0.001469	1.27	68	36.3	0.053	3.81	14.56	18.37	0.39	4.20	18.76	4.8	4.5	16.40	4.0
3 D	24.29	0.00007	0.00083	0.000760	1.27	68	36.3	0.028	2.06	7.54	9.60	0.31	2.37	9.90	4.7	4.2	9.16	4.0
3 E	24.29	0.00008	0.00095	0.000868	1.27	68	36.3	0.031	2.28	8.60	10.88	0.41	2.68	11.29	4.8	4.2	10.33	4.0
3 F	24.29	0.00009	0.00101	0.000921	1.27	68	36.3	0.033	2.48	9.14	11.62	0.48	2.96	12.10	4.7	4.1	11.37	4.0
3 G	24.29	0.000091	0.001245	0.001154	1.41	68	37.7	0.044	2.57	11.86	14.44	0.29	2.87	14.73	5.6	5.1	11.18	4.0
3 H	24.29	0.000102	0.001295	0.001193	1.41	69	37.9	0.045	2.89	12.33	15.21	0.33	3.22	15.55	5.3	4.8	12.55	4.0
3 I	24.29	0.00005	0.00077	0.000717	1.41	68	37.7	0.027	1.52	7.37	8.89	0.41	1.92	9.30	5.9	4.8	7.29	4.0
3 J	24.29	0.00006	0.00075	0.000690	1.41	69	37.9	0.026	1.68	7.13	8.80	0.57	2.24	9.37	5.3	4.2	8.41	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
3 A	>2.18	13.03
3 B	>2.33	15.00
3 C	>2.40	16.40
3 D	>1.78	9.16
3 E	>1.54	10.33
3 F	>1.40	11.37
3 G	>2.11	11.18
3 H	>1.61	12.55
3 I	>1.23	7.29
3 J	>1.08	8.41

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
3 A	117.1	2845	3362	OK
3 B	117.1	2845	5103	OK
3 C	117.1	2845	6926	OK
3 D	119.8	2910	7610	OK
3 E	119.8	2910	12380	OK
3 F	119.8	2910	16717	OK
3 G	121.5	2951	6278	OK
3 H	121.5	2951	10077	OK
3 I	128.8	3129	18459	OK
3 J	128.8	3129	31559	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
3 A	672	1272	Yes
3 B	1021	1464	Yes
3 C	1385	1601	Yes
3 D	1522	914	No
3 E	2476	1031	No
3 F	3343	1135	No
3 G	1256	1131	No
3 H	2015	1271	No
3 I	3692	783	No
3 J	6312	903	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.16	>1.0g	>0.99	0.99	0.76	L	0.99	0.87	L
1.07	>1.0g	>1.03	0.91	> 1.0g	L	0.91	>1.14	L
1.02	>1.0g	>1.06	0.85	> 1.0g	L	0.85	>1.18	L
0.82	>1.0g	>1.18	0.79	> 1.0g	L	0.79	>1.22	L
0.71	>1.0g	>1.26	0.67	> 1.0g	L	0.67	>1.33	L
0.65	>1.0g	>1.32	0.61	> 1.0g	L	0.61	>1.40	L
0.92	>1.0g	>1.13	0.75	> 1.0g	L	0.75	>1.26	L
0.79	>1.0g	>1.21	0.62	> 1.0g	L	0.62	>1.38	L
0.56	>1.0g	>1.41	0.51	> 1.0g	L	0.51	>1.51	L
0.47	>1.0g	>1.51	0.43	> 1.0g	L	0.43	>1.62	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 3, M7.25 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.29 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
3 A	1171	4034	3 x 3	2 x 2	2 x 2 -5ft	725	8700	1,700,000
3 B	1171	6124	3 x 3	3 x 2	2 x 2 +10ft	725	8700	1,700,000
3 C	1171	8311	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
3 D	1198	6175	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
3 E	1198	10041	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 F	1198	13704	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
3 G	1215	7534	4 x 3	3 x 2	3 x 2 -10ft	880	10560	2,800,000
3 H	1215	12092	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 I	1288	14919	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
3 J	1288	25296	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.01	14	10	18	4.53	12.57	0.36	3362	4034	306	367	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.02	28	10	36	6.20	12.57	0.49	5103	6124	464	557	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.03	42	10	53	7.79	12.57	0.62	6926	8311	630	756	1130	1171	345	0	1516	1171	1171
Oblong	4.00	6.00	0.01	24	10	30	7.78	23.23	0.33	5146	6175	468	561	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.02	48	10	61	11.25	23.23	0.48	8368	10041	761	913	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.03	72	10	91	14.03	23.23	0.60	11420	13704	1038	1246	1130	1198	345	0	1543	1198	1198
Circular	5.00	5.00	0.01	18	11	28	10.38	30.68	0.34	6278	7534	571	685	1150	1215	345	0	1560	1215	1215
Circular	5.00	5.00	0.02	36	11	56	14.88	30.68	0.49	10077	12092	916	1099	1150	1215	345	0	1560	1215	1215
Oblong	5.50	8.25	0.01	36	11	56	25.53	83.05	0.31	12432	14919	1130	1356	1160	1288	345	0	1633	1288	1288
Oblong	5.50	8.25	0.02	72	11	112	39.38	83.05	0.47	21080	25296	1916	2300	1160	1288	345	0	1633	1288	1288

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
3 A	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0056	0.0080	0.0028	0.0080	0.0081	5.1	43.625	0.93	1.4	488	350	1.3	0.082	119	1	362	409	367	0.90
3 B	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0056	0.0093	0.0056	0.0093	0.0131	5.5	43.563	0.53	1.4	786	350	0.7	0.047	68	1	580	550	557	1.01
3 C	1810	1521	1448	8	0.79	1.24	3.75	43.00	0.0057	0.0056	0.0106	0.0084	0.0106	0.0196	5.9	43.500	0.30	1.4	1176	350	0.4	0.027	39	1	864	767	756	0.99
3 D	2962	2522	2369	6	0.44	0.69	5.50	43.25	0.0052	0.0050	0.0073	0.0048	0.0073	0.0074	5.3	43.625	0.69	1.3	444	350	0.9	0.055	130	2	658	670	561	0.84
3 E	2962	2522	2369	7	0.60	0.94	4.75	43.13	0.0052	0.0050	0.0086	0.0096	0.0096	0.0117	5.5	43.563	0.53	1.3	703	350	0.7	0.042	99	2	1037	966	913	0.95
3 F	2962	2522	2369	7	0.60	0.94	3.50	43.13	0.0052	0.0050	0.0099	0.0144	0.0144	0.0159	5.6	43.563	0.41	1.3	954	350	0.5	0.033	77	2	1408	1262	1246	0.99
3 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0109	6.0	55.563	0.30	1.3	653	350	0.4	0.024	54	1	785	714	685	0.96
3 H	2827	2463	2262	8	0.79	1.24	3.25	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0177	6.0	55.500	0.30	1.3	1061	350	0.4	0.024	54	1	1271	1127	1099	0.98
3 I	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0087	6.2	61.563	0.30	1.1	524	350	0.3	0.022	97	2	1547	1398	1356	0.97
3 J	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	6.8	61.500	0.30	1.1	956	350	0.3	0.022	97	2	2818	2478	2300	0.93

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
3 A	22.00	0.000113	0.001105	0.000992	1.27	68	25.9	0.026	1.31	6.1	7.43	0.47	1.78	7.90	5.7	4.4	6.64	4.0
3 B	22.00	0.000125	0.001345	0.001220	1.27	68	25.9	0.032	1.45	7.5	8.98	0.71	2.16	9.69	6.2	4.5	7.93	4.0
3 C	22.00	0.000134	0.001603	0.001469	1.27	68	25.9	0.038	1.56	9.1	10.62	0.97	2.53	11.59	6.8	4.6	9.14	4.0
3 D	22.00	0.000099	0.001230	0.001131	1.27	68	25.9	0.029	1.16	7.0	8.13	0.50	1.66	8.63	7.0	5.2	6.14	4.0
3 E	22.00	0.000113	0.001396	0.001283	1.27	68	25.9	0.033	1.31	7.9	9.22	0.64	1.95	9.87	7.0	5.1	7.17	4.0
3 F	22.00	0.000123	0.001552	0.001429	1.27	68	25.9	0.037	1.43	8.8	10.25	0.76	2.19	11.01	7.2	5.0	8.01	4.0
3 G	22.00	0.000091	0.001245	0.001154	1.41	68	28.8	0.033	1.06	7.8	8.86	0.70	1.76	9.57	8.4	5.4	6.33	4.0
3 H	22.00	0.000102	0.001295	0.001193	1.41	68	28.8	0.034	1.18	8.1	9.26	0.78	1.96	10.03	7.8	5.1	7.07	4.0
3 I	22.00	0.000073	0.001018	0.000945	1.41	68	28.8	0.027	0.85	6.4	7.24	0.63	1.48	7.88	8.6	5.3	5.29	4.0
3 J	22.00	0.000081	0.000921	0.000840	1.41	68	28.8	0.024	0.94	5.7	6.63	0.87	1.81	7.49	7.0	4.1	6.37	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
3 A	1.89	6.64
3 B	2.55	7.93
3 C	3.45	9.14
3 D	2.17	6.14
3 E	2.83	7.17
3 F	>3.07	8.01
3 G	3.43	6.33
3 H	3.42	7.07
3 I	>2.40	5.29
3 J	>1.83	6.37

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
3 A	117.1	1289	3362	OK
3 B	117.1	1289	5103	OK
3 C	117.1	1289	6926	OK
3 D	119.8	1318	5146	OK
3 E	119.8	1318	8368	OK
3 F	119.8	1318	11420	OK
3 G	121.5	1336	6278	OK
3 H	121.5	1336	10077	OK
3 I	128.8	1417	12432	OK
3 J	128.8	1417	21080	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
3 A	672	363	No
3 B	1021	438	No
3 C	1385	518	No
3 D	1029	406	No
3 E	1674	460	No
3 F	2284	511	No
3 G	1256	449	No
3 H	2015	469	No
3 I	2486	389	No
3 J	4216	356	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.99	0.54	0.87	0.99	0.54	L	0.99	0.87	L
0.91	0.66	1.33	0.91	0.66	L	0.91	1.33	L
0.85	0.76	1.81	0.85	0.76	L	1.02	1.81	T
0.79	0.63	1.32	0.79	0.63	L	0.79	1.32	L
0.67	0.83	2.27	0.67	0.83	L	0.71	2.21	T
0.61	>1.0g	>3.06	0.65	0.97	T	0.65	2.83	T
0.75	0.71	1.68	0.92	0.71	T	0.92	1.49	T
0.62	0.93	2.73	0.79	0.83	T	0.79	2.17	T
0.51	>1.0g	>2.96	0.56	0.90	T	0.56	2.44	T
0.43	>1.0g	>2.76	0.43	> 1.0g	L	0.43	>2.76	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 3, M7.25 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.29 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
3 A	1171	4034	3 x 3	2 x 2	2 x 2 -5ft	725	8700	1,700,000
3 B	1171	6124	3 x 3	3 x 2	2 x 2 +10ft	725	8700	1,700,000
3 C	1171	8311	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
3 D	1198	9131	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
3 E	1198	14856	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 F	1198	20060	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
3 G	1215	7534	4 x 3	3 x 2	3 x 2 -10ft	880	10560	2,800,000
3 H	1215	12092	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 I	1288	22151	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
3 J	1288	37871	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.01	14	10	18	4.53	12.57	0.36	3362	4034	138	166	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.02	28	10	36	6.20	12.57	0.49	5103	6124	210	252	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.03	42	10	53	7.79	12.57	0.62	6926	8311	285	342	1130	1171	345	0	1516	1171	1171
Oblong	4.00	6.00	0.01	24	10	30	15.89	49.13	0.32	7610	9131	313	376	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.02	48	10	61	23.30	49.13	0.47	12380	14856	510	612	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.03	72	10	91	28.99	49.13	0.59	16717	20060	688	826	1130	1198	345	0	1543	1198	1198
Circular	5.00	5.00	0.01	18	11	28	10.38	30.68	0.34	6278	7534	258	310	1150	1215	345	0	1560	1215	1215
Circular	5.00	5.00	0.02	36	11	56	14.88	30.68	0.49	10077	12092	415	498	1150	1215	345	0	1560	1215	1215
Oblong	5.50	8.25	0.01	36	11	56	51.43	175.62	0.29	18459	22151	760	912	1160	1288	345	0	1633	1288	1288
Oblong	5.50	8.25	0.02	72	11	112	79.88	175.62	0.45	31559	37871	1299	1559	1160	1288	345	0	1633	1288	1288

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,reqt}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
3 A	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0056	0.0080	0.0028	0.0080	0.0081	4.1	43.625	1.92	1.4	488	350	2.7	0.170	246	1	362	517	166	0.32
3 B	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0056	0.0093	0.0056	0.0093	0.0131	4.2	43.563	1.76	1.4	786	350	2.5	0.156	226	1	580	685	252	0.37
3 C	1810	1521	1448	8	0.79	1.24	3.75	43.00	0.0057	0.0056	0.0106	0.0084	0.0106	0.0196	4.3	43.500	1.69	1.4	1176	350	2.4	0.150	218	1	864	919	342	0.37
3 D	2962	2522	2369	6	0.44	0.69	5.50	43.25	0.0052	0.0050	0.0073	0.0048	0.0073	0.0074	4.5	67.625	1.55	1.3	444	350	1.9	0.123	292	2	1020	1115	376	0.34
3 E	2962	2522	2369	7	0.60	0.94	4.75	43.13	0.0052	0.0050	0.0086	0.0096	0.0096	0.0117	4.5	67.563	1.47	1.3	703	350	1.8	0.116	275	2	1609	1601	612	0.38
3 F	2962	2522	2369	7	0.60	0.94	3.50	43.13	0.0052	0.0050	0.0099	0.0144	0.0144	0.0159	4.6	67.563	1.42	1.3	954	350	1.8	0.113	267	2	2183	2083	826	0.40
3 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0109	4.3	55.563	1.66	1.3	653	350	2.1	0.133	301	1	785	924	310	0.34
3 H	2827	2463	2262	8	0.79	1.24	3.25	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0177	4.3	55.500	1.66	1.3	1061	350	2.1	0.133	301	1	1271	1337	498	0.37
3 I	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0087	4.8	94.563	1.20	1.1	524	350	1.4	0.087	388	2	2377	2350	912	0.39
3 J	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	5.0	94.500	0.99	1.1	956	350	1.1	0.071	319	2	4330	3952	1559	0.39

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
3 A	24.29	0.000113	0.001105	0.000992	1.27	68	36.3	0.036	3.19	9.84	13.03	0.19	3.38	13.22	4.1	3.9	13.03	3.9
3 B	24.29	0.000125	0.001345	0.001220	1.27	68	36.3	0.044	3.53	12.10	15.63	0.29	3.82	15.92	4.4	4.2	15.00	4.0
3 C	24.29	0.000134	0.001603	0.001469	1.27	68	36.3	0.053	3.81	14.56	18.37	0.39	4.20	18.76	4.8	4.5	16.40	4.0
3 D	24.29	0.00007	0.00083	0.000760	1.27	68	36.3	0.028	2.06	7.54	9.60	0.31	2.37	9.90	4.7	4.2	9.16	4.0
3 E	24.29	0.00008	0.00095	0.000868	1.27	68	36.3	0.031	2.28	8.60	10.88	0.41	2.68	11.29	4.8	4.2	10.33	4.0
3 F	24.29	0.00009	0.00101	0.000921	1.27	68	36.3	0.033	2.48	9.14	11.62	0.48	2.96	12.10	4.7	4.1	11.37	4.0
3 G	24.29	0.000091	0.001245	0.001154	1.41	68	37.7	0.044	2.57	11.86	14.44	0.29	2.87	14.73	5.6	5.1	11.18	4.0
3 H	24.29	0.000102	0.001295	0.001193	1.41	69	37.9	0.045	2.89	12.33	15.21	0.33	3.22	15.55	5.3	4.8	12.55	4.0
3 I	24.29	0.00005	0.00077	0.000717	1.41	68	37.7	0.027	1.52	7.37	8.89	0.41	1.92	9.30	5.9	4.8	7.29	4.0
3 J	24.29	0.00006	0.00075	0.000690	1.41	69	37.9	0.026	1.68	7.13	8.80	0.57	2.24	9.37	5.3	4.2	8.41	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
3 A	1.60	13.03
3 B	2.50	15.00
3 C	3.70	16.40
3 D	1.51	9.16
3 E	2.36	10.33
3 F	2.35	11.37
3 G	2.54	11.18
3 H	2.22	12.55
3 I	1.61	7.29
3 J	>1.83	8.41

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
3 A	117.1	2845	3362	OK
3 B	117.1	2845	5103	OK
3 C	117.1	2845	6926	OK
3 D	119.8	2910	7610	OK
3 E	119.8	2910	12380	OK
3 F	119.8	2910	16717	OK
3 G	121.5	2951	6278	OK
3 H	121.5	2951	10077	OK
3 I	128.8	3129	18459	OK
3 J	128.8	3129	31559	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
3 A	672	1272	Yes
3 B	1021	1464	Yes
3 C	1385	1601	Yes
3 D	1522	914	No
3 E	2476	1031	No
3 F	3343	1135	No
3 G	1256	1131	No
3 H	2015	1271	No
3 I	3692	783	No
3 J	6312	903	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.16	0.67	1.10	0.99	0.54	L	0.99	0.87	L
1.07	0.75	1.49	0.91	0.66	L	0.91	1.33	L
1.02	0.81	1.81	0.85	0.76	L	1.02	1.81	T
0.82	0.68	1.47	0.79	0.63	L	0.79	1.32	L
0.71	0.83	2.21	0.67	0.83	L	0.71	2.21	T
0.65	0.97	2.83	0.65	0.97	T	0.65	2.83	T
0.92	0.71	1.49	0.92	0.71	T	0.92	1.49	T
0.79	0.83	2.17	0.79	0.83	T	0.79	2.17	T
0.56	0.90	2.44	0.56	0.90	T	0.56	2.44	T
0.47	>1.0g	>2.69	0.43	> 1.0g	L	0.43	>2.76	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 3, M8.00 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.29 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
3 A	1171	4034	3 x 3	2 x 2	2 x 2 -5ft	725	8700	1,700,000
3 B	1171	6124	3 x 3	3 x 2	2 x 2 +10ft	725	8700	1,700,000
3 C	1171	8311	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
3 D	1198	6175	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
3 E	1198	10041	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 F	1198	13704	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
3 G	1215	7534	4 x 3	3 x 2	3 x 2 -10ft	880	10560	2,800,000
3 H	1215	12092	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 I	1288	14919	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
3 J	1288	25296	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.01	14	10	18	4.53	12.57	0.36	3362	4034	306	367	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.02	28	10	36	6.20	12.57	0.49	5103	6124	464	557	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.03	42	10	53	7.79	12.57	0.62	6926	8311	630	756	1130	1171	345	0	1516	1171	1171
Oblong	4.00	6.00	0.01	24	10	30	7.78	23.23	0.33	5146	6175	468	561	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.02	48	10	61	11.25	23.23	0.48	8368	10041	761	913	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.03	72	10	91	14.03	23.23	0.60	11420	13704	1038	1246	1130	1198	345	0	1543	1198	1198
Circular	5.00	5.00	0.01	18	11	28	10.38	30.68	0.34	6278	7534	571	685	1150	1215	345	0	1560	1215	1215
Circular	5.00	5.00	0.02	36	11	56	14.88	30.68	0.49	10077	12092	916	1099	1150	1215	345	0	1560	1215	1215
Oblong	5.50	8.25	0.01	36	11	56	25.53	83.05	0.31	12432	14919	1130	1356	1160	1288	345	0	1633	1288	1288
Oblong	5.50	8.25	0.02	72	11	112	39.38	83.05	0.47	21080	25296	1916	2300	1160	1288	345	0	1633	1288	1288

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
3 A	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0056	0.0080	0.0028	0.0080	0.0081	5.1	43.625	0.93	1.4	488	350	1.3	0.082	119	1	362	409	367	0.90
3 B	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0056	0.0093	0.0056	0.0093	0.0131	5.5	43.563	0.53	1.4	786	350	0.7	0.047	68	1	580	550	557	1.01
3 C	1810	1521	1448	8	0.79	1.24	3.75	43.00	0.0057	0.0056	0.0106	0.0084	0.0106	0.0196	5.9	43.500	0.30	1.4	1176	350	0.4	0.027	39	1	864	767	756	0.99
3 D	2962	2522	2369	6	0.44	0.69	5.50	43.25	0.0052	0.0050	0.0073	0.0048	0.0073	0.0074	5.3	43.625	0.69	1.3	444	350	0.9	0.055	130	2	658	670	561	0.84
3 E	2962	2522	2369	7	0.60	0.94	4.75	43.13	0.0052	0.0050	0.0086	0.0096	0.0096	0.0117	5.5	43.563	0.53	1.3	703	350	0.7	0.042	99	2	1037	966	913	0.95
3 F	2962	2522	2369	7	0.60	0.94	3.50	43.13	0.0052	0.0050	0.0099	0.0144	0.0144	0.0159	5.6	43.563	0.41	1.3	954	350	0.5	0.033	77	2	1408	1262	1246	0.99
3 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0109	6.0	55.563	0.30	1.3	653	350	0.4	0.024	54	1	785	714	685	0.96
3 H	2827	2463	2262	8	0.79	1.24	3.25	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0177	6.0	55.500	0.30	1.3	1061	350	0.4	0.024	54	1	1271	1127	1099	0.98
3 I	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0087	6.2	61.563	0.30	1.1	524	350	0.3	0.022	97	2	1547	1398	1356	0.97
3 J	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	6.8	61.500	0.30	1.1	956	350	0.3	0.022	97	2	2818	2478	2300	0.93

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
3 A	22.00	0.000113	0.001105	0.000992	1.27	68	25.9	0.026	1.31	6.1	7.43	0.47	1.78	7.90	5.7	4.4	6.64	4.0
3 B	22.00	0.000125	0.001345	0.001220	1.27	68	25.9	0.032	1.45	7.5	8.98	0.71	2.16	9.69	6.2	4.5	7.93	4.0
3 C	22.00	0.000134	0.001603	0.001469	1.27	68	25.9	0.038	1.56	9.1	10.62	0.97	2.53	11.59	6.8	4.6	9.14	4.0
3 D	22.00	0.000099	0.001230	0.001131	1.27	68	25.9	0.029	1.16	7.0	8.13	0.50	1.66	8.63	7.0	5.2	6.14	4.0
3 E	22.00	0.000113	0.001396	0.001283	1.27	68	25.9	0.033	1.31	7.9	9.22	0.64	1.95	9.87	7.0	5.1	7.17	4.0
3 F	22.00	0.000123	0.001552	0.001429	1.27	68	25.9	0.037	1.43	8.8	10.25	0.76	2.19	11.01	7.2	5.0	8.01	4.0
3 G	22.00	0.000091	0.001245	0.001154	1.41	68	28.8	0.033	1.06	7.8	8.86	0.70	1.76	9.57	8.4	5.4	6.33	4.0
3 H	22.00	0.000102	0.001295	0.001193	1.41	68	28.8	0.034	1.18	8.1	9.26	0.78	1.96	10.03	7.8	5.1	7.07	4.0
3 I	22.00	0.000073	0.001018	0.000945	1.41	68	28.8	0.027	0.85	6.4	7.24	0.63	1.48	7.88	8.6	5.3	5.29	4.0
3 J	22.00	0.000081	0.000921	0.000840	1.41	68	28.8	0.024	0.94	5.7	6.63	0.87	1.81	7.49	7.0	4.1	6.37	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
3 A	1.51	6.64
3 B	2.87	7.93
3 C	3.66	9.14
3 D	2.36	6.14
3 E	2.96	7.17
3 F	2.71	8.01
3 G	2.24	6.33
3 H	3.61	7.07
3 I	>2.51	5.29
3 J	>1.95	6.37

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
3 A	117.1	1289	3362	OK
3 B	117.1	1289	5103	OK
3 C	117.1	1289	6926	OK
3 D	119.8	1318	5146	OK
3 E	119.8	1318	8368	OK
3 F	119.8	1318	11420	OK
3 G	121.5	1336	6278	OK
3 H	121.5	1336	10077	OK
3 I	128.8	1417	12432	OK
3 J	128.8	1417	21080	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
3 A	672	363	No
3 B	1021	438	No
3 C	1385	518	No
3 D	1029	406	No
3 E	1674	460	No
3 F	2284	511	No
3 G	1256	449	No
3 H	2015	469	No
3 I	2486	389	No
3 J	4216	356	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.99	0.49	0.87	0.99	0.49	L	0.99	0.87	L
0.91	0.64	1.33	0.91	0.64	L	0.91	1.33	L
0.85	0.75	1.81	0.85	0.75	L	1.02	1.81	T
0.79	0.61	1.32	0.79	0.61	L	0.79	1.32	L
0.67	0.82	2.27	0.67	0.82	L	0.71	2.21	T
0.61	0.99	3.12	0.65	0.95	T	0.65	2.84	T
0.75	0.70	1.68	0.92	0.69	T	0.92	1.49	T
0.62	0.91	2.73	0.79	0.83	T	0.79	2.17	T
0.51	>1.0g	>3.10	0.56	0.88	T	0.56	2.44	T
0.43	>1.0g	>2.95	0.43	> 1.0g	L	0.43	>2.95	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 3, M8.00 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.29 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
3 A	1171	4034	3 x 3	2 x 2	2 x 2 -5ft	725	8700	1,700,000
3 B	1171	6124	3 x 3	3 x 2	2 x 2 +10ft	725	8700	1,700,000
3 C	1171	8311	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
3 D	1198	9131	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
3 E	1198	14856	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 F	1198	20060	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
3 G	1215	7534	4 x 3	3 x 2	3 x 2 -10ft	880	10560	2,800,000
3 H	1215	12092	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
3 I	1288	22151	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
3 J	1288	37871	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.01	14	10	18	4.53	12.57	0.36	3362	4034	138	166	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.02	28	10	36	6.20	12.57	0.49	5103	6124	210	252	1130	1171	345	0	1516	1171	1171
Circular	4.00	4.00	0.03	42	10	53	7.79	12.57	0.62	6926	8311	285	342	1130	1171	345	0	1516	1171	1171
Oblong	4.00	6.00	0.01	24	10	30	15.89	49.13	0.32	7610	9131	313	376	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.02	48	10	61	23.30	49.13	0.47	12380	14856	510	612	1130	1198	345	0	1543	1198	1198
Oblong	4.00	6.00	0.03	72	10	91	28.99	49.13	0.59	16717	20060	688	826	1130	1198	345	0	1543	1198	1198
Circular	5.00	5.00	0.01	18	11	28	10.38	30.68	0.34	6278	7534	258	310	1150	1215	345	0	1560	1215	1215
Circular	5.00	5.00	0.02	36	11	56	14.88	30.68	0.49	10077	12092	415	498	1150	1215	345	0	1560	1215	1215
Oblong	5.50	8.25	0.01	36	11	56	51.43	175.62	0.29	18459	22151	760	912	1160	1288	345	0	1633	1288	1288
Oblong	5.50	8.25	0.02	72	11	112	79.88	175.62	0.45	31559	37871	1299	1559	1160	1288	345	0	1633	1288	1288

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in) used for confinement calculation	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,reqt}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in) used for shear calculation	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	$\rho_s F_y$ For shear calculation	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
3 A	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0056	0.0080	0.0028	0.0080	0.0081	4.1	43.625	1.92	1.4	488	350	2.7	0.170	246	1	362	517	166	0.32
3 B	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0056	0.0093	0.0056	0.0093	0.0131	4.2	43.563	1.76	1.4	786	350	2.5	0.156	226	1	580	685	252	0.37
3 C	1810	1521	1448	8	0.79	1.24	3.75	43.00	0.0057	0.0056	0.0106	0.0084	0.0106	0.0196	4.3	43.500	1.69	1.4	1176	350	2.4	0.150	218	1	864	919	342	0.37
3 D	2962	2522	2369	6	0.44	0.69	5.50	43.25	0.0052	0.0050	0.0073	0.0048	0.0073	0.0074	4.5	67.625	1.55	1.3	444	350	1.9	0.123	292	2	1020	1115	376	0.34
3 E	2962	2522	2369	7	0.60	0.94	4.75	43.13	0.0052	0.0050	0.0086	0.0096	0.0096	0.0117	4.5	67.563	1.47	1.3	703	350	1.8	0.116	275	2	1609	1601	612	0.38
3 F	2962	2522	2369	7	0.60	0.94	3.50	43.13	0.0052	0.0050	0.0099	0.0144	0.0144	0.0159	4.6	67.563	1.42	1.3	954	350	1.8	0.113	267	2	2183	2083	826	0.40
3 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0109	4.3	55.563	1.66	1.3	653	350	2.1	0.133	301	1	785	924	310	0.34
3 H	2827	2463	2262	8	0.79	1.24	3.25	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0177	4.3	55.500	1.66	1.3	1061	350	2.1	0.133	301	1	1271	1337	498	0.37
3 I	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0087	4.8	94.563	1.20	1.1	524	350	1.4	0.087	388	2	2377	2350	912	0.39
3 J	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	5.0	94.500	0.99	1.1	956	350	1.1	0.071	319	2	4330	3952	1559	0.39

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
3 A	24.29	0.000113	0.001105	0.000992	1.27	68	36.3	0.036	3.19	9.84	13.03	0.19	3.38	13.22	4.1	3.9	13.03	3.9
3 B	24.29	0.000125	0.001345	0.001220	1.27	68	36.3	0.044	3.53	12.10	15.63	0.29	3.82	15.92	4.4	4.2	15.00	4.0
3 C	24.29	0.000134	0.001603	0.001469	1.27	68	36.3	0.053	3.81	14.56	18.37	0.39	4.20	18.76	4.8	4.5	16.40	4.0
3 D	24.29	0.00007	0.00083	0.000760	1.27	68	36.3	0.028	2.06	7.54	9.60	0.31	2.37	9.90	4.7	4.2	9.16	4.0
3 E	24.29	0.00008	0.00095	0.000868	1.27	68	36.3	0.031	2.28	8.60	10.88	0.41	2.68	11.29	4.8	4.2	10.33	4.0
3 F	24.29	0.00009	0.00101	0.000921	1.27	68	36.3	0.033	2.48	9.14	11.62	0.48	2.96	12.10	4.7	4.1	11.37	4.0
3 G	24.29	0.000091	0.001245	0.001154	1.41	68	37.7	0.044	2.57	11.86	14.44	0.29	2.87	14.73	5.6	5.1	11.18	4.0
3 H	24.29	0.000102	0.001295	0.001193	1.41	69	37.9	0.045	2.89	12.33	15.21	0.33	3.22	15.55	5.3	4.8	12.55	4.0
3 I	24.29	0.00005	0.00077	0.000717	1.41	68	37.7	0.027	1.52	7.37	8.89	0.41	1.92	9.30	5.9	4.8	7.29	4.0
3 J	24.29	0.00006	0.00075	0.000690	1.41	69	37.9	0.026	1.68	7.13	8.80	0.57	2.24	9.37	5.3	4.2	8.41	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
3 A	1.99	13.03
3 B	2.67	15.00
3 C	3.65	16.40
3 D	1.67	9.16
3 E	2.47	10.33
3 F	2.48	11.37
3 G	1.66	11.18
3 H	2.28	12.55
3 I	1.70	7.29
3 J	>1.95	8.41

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
3 A	117.1	2845	3362	OK
3 B	117.1	2845	5103	OK
3 C	117.1	2845	6926	OK
3 D	119.8	2910	7610	OK
3 E	119.8	2910	12380	OK
3 F	119.8	2910	16717	OK
3 G	121.5	2951	6278	OK
3 H	121.5	2951	10077	OK
3 I	128.8	3129	18459	OK
3 J	128.8	3129	31559	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
3 A	672	1272	Yes
3 B	1021	1464	Yes
3 C	1385	1601	Yes
3 D	1522	914	No
3 E	2476	1031	No
3 F	3343	1135	No
3 G	1256	1131	No
3 H	2015	1271	No
3 I	3692	783	No
3 J	6312	903	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.16	0.63	1.10	0.99	0.49	L	0.99	0.87	L
1.07	0.73	1.49	0.91	0.64	L	0.91	1.33	L
1.02	0.80	1.81	0.85	0.75	L	1.02	1.81	T
0.82	0.66	1.47	0.79	0.61	L	0.79	1.32	L
0.71	0.82	2.21	0.67	0.82	L	0.71	2.21	T
0.65	0.95	2.84	0.65	0.95	T	0.65	2.84	T
0.92	0.69	1.49	0.92	0.69	T	0.92	1.49	T
0.79	0.83	2.17	0.79	0.83	T	0.79	2.17	T
0.56	0.88	2.44	0.56	0.88	T	0.56	2.44	T
0.47	>1.0g	>2.85	0.43	> 1.0g	L	0.43	>2.95	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 4, M6.50 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.24 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	Lateral Load (k)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)
4 A	919	73	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 B	919	107	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 C	919	139	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 D	952	157	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 E	952	244	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 F	952	332	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 G	990	295	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 H	990	482	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 I	990	659	3 x 3	2 x 2 +10ft	2 x 2	344	4132

3. Column Main Bar Design and Design Forces

Column Diam.(ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL} (k)	P_{LL} (k)	P_{EQ} (k)	P_{DL+LL} (k)	P_{DL+EQ} (k)	P_{DL-EQ} (k)
3.0	0.01	10	9	10.00	1.34	0.34	1343	1612	61	73	694	225	121	919	815	573
3.0	0.02	20	9	20.00	1.773	0.45	1964	2357	89	107	694	225	177	919	871	517
3.0	0.03	30	9	30.00	2.23	0.56	2544	3052	116	139	694	225	229	919	923	465
4.0	0.01	14	10	17.78	3.98	0.32	2870	3445	130	157	727	225	259	952	986	468
4.0	0.02	28	10	35.56	5.65	0.45	4477	5373	204	244	727	225	404	952	1131	323
4.0	0.03	42	10	53.34	7.25	0.58	6080	7296	276	332	727	225	548	952	1275	179
5.0	0.01	18	11	28.08	9.261	0.30	5416	6499	246	295	765	225	488	990	1253	277
5.0	0.02	36	11	56.16	13.861	0.45	8833	10599	401	482	765	225	796	990	1561	-31
5.0	0.03	54	11	84.24	18.097	0.59	12082	14499	549	659	765	225	1089	990	1854	-324

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
4 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	4.1	1.87	1.4	520	350	2.5	0.160	130	199	280	73	0.26
4 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.8	2.21	1.3	614	350	2.9	0.184	150	236	327	107	0.33
4 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.6	2.37	1.3	711	350	3.0	0.193	157	273	365	139	0.38
4 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.5	1.50	1.2	465	350	1.7	0.110	159	342	426	157	0.37
4 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0093	0.0056	0.0093	0.0096	4.2	1.78	1.1	574	350	2.0	0.125	181	422	513	244	0.48
4 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	4.1	1.93	1.1	698	350	2.0	0.130	188	512	595	332	0.56
4 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	5.2	0.83	1.1	450	350	0.9	0.056	126	539	566	295	0.52
4 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.5	1.46	0.0	546	350	0.0	0.000	0	655	556	482	0.87
4 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	4.2	1.81	0.0	637	350	0.0	0.000	0	764	649	659	1.02

5. Column Displacement Capacity

Model	L (ft)	Based on compression column ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D
4 A	22.00	0.00015	0.00151	0.001355	1.128	68	32.6	0.044	3.50	11.0	14.45	0.19	3.68	14.64	4.1	4.0
4 B	22.00	0.00017	0.00151	0.001345	1.128	68	32.6	0.044	3.88	10.9	14.75	0.27	4.16	15.03	3.8	3.6
4 C	22.00	0.00017	0.00147	0.001301	1.128	68	32.6	0.042	4.00	10.5	14.51	0.36	4.35	14.86	3.6	3.4
4 D	22.00	0.00011	0.00116	0.001054	1.270	68	34.1	0.036	2.53	8.9	11.40	0.39	2.92	11.79	4.5	4.0
4 E	22.00	0.00012	0.00118	0.001060	1.270	68	34.1	0.036	2.77	8.9	11.69	0.61	3.38	12.30	4.2	3.6
4 F	22.00	0.00013	0.00120	0.001075	1.270	68	34.1	0.037	2.94	9.0	11.99	0.83	3.77	12.82	4.1	3.4
4 G	22.00	0.00009	0.00107	0.000984	1.410	68	35.5	0.035	2.06	8.6	10.67	0.71	2.78	11.38	5.2	4.1
4 H	22.00	0.00010	0.00100	0.000900	1.410	68	35.5	0.032	2.22	7.9	10.08	1.17	3.38	11.25	4.5	3.3
4 I	22.00	0.00010	0.00095	0.000852	1.410	68	35.5	0.030	2.33	7.4	9.78	1.60	3.93	11.37	4.2	2.9

6. Displacement Demand

Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
0.57	14.45
0.92	14.75
1.04	14.51
1.54	11.40
2.01	11.69
>2.75	11.99
>2.94	10.67
>3.29	10.08
>3.52	9.78

7. Minimum Lateral Strength Check

$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
69.4	1527	1389	NG
69.4	1527	1978	OK
69.4	1527	2544	OK
72.7	1599	2870	OK
72.7	1599	4477	OK
72.7	1599	6080	OK
76.5	1683	5416	OK
76.5	1683	8833	OK
76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
4 A	269	836	Yes
4 B	393	853	Yes
4 C	509	839	Yes
4 D	574	691	Yes
4 E	895	708	No
4 F	1216	727	No
4 G	1083	680	No
4 H	1767	643	No
4 I	2416	623	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.40	0.65	0.26	2.19	0.65	T	2.40	0.26	L
2.12	0.71	0.35	2.12	0.71	L	2.12	0.35	L
1.93	0.75	0.42	1.93	0.75	L	1.93	0.42	L
1.55	0.73	0.54	1.55	0.73	L	1.55	0.54	L
1.34	0.89	0.78	1.34	0.89	L	1.34	0.78	L
1.25	>1.0g	>0.93	1.25	> 1.0g	L	1.25	>0.93	L
1.17	>1.0g	>0.97	1.17	> 1.0g	L	1.17	>0.97	L
1.06	>1.0g	>1.02	1.06	> 1.0g	L	1.06	>1.02	L
1.00	>1.0g	>1.04	1.00	> 1.0g	L	1.00	>1.04	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 4, M6.50 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000	psi
f'_{ce} =	5200	psi
f_y =	60	ksi
f_{ye} =	68	ksi
h_{bent} =	24.24	ft
h_{col} =	22.00	ft
b_{bent} =	44.00	ft

2. Footing Design

Model	Column Load (k)	Lateral Load (k)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)
4 A	919	73	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 B	919	107	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 C	919	139	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 D	952	157	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 E	952	244	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 F	952	332	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 G	990	295	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 H	990	482	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 I	990	659	3 x 3	2 x 2 +10ft	2 x 2	344	4132

3. Column Main Bar Design and Design Forces

Column Diam.(ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL} (k)	P_{LL} (k)	P_{EQ} (k)	P_{DL+LL} (k)	P_{DL+EQ} (k)	P_{DL-EQ} (k)
3.0	0.01	10	9	10.00	1.34	0.34	1343	1612	61	73	694	225	121	919	815	573
3.0	0.02	20	9	20.00	1.77	0.45	1964	2357	89	107	694	225	177	919	871	517
3.0	0.03	30	9	30.00	2.23	0.56	2544	3052	116	139	694	225	229	919	923	465
4.0	0.01	14	10	17.78	3.98	0.32	2870	3445	130	157	727	225	259	952	986	468
4.0	0.02	28	10	35.56	5.65	0.45	4477	5373	204	244	727	225	404	952	1131	323
4.0	0.03	42	10	53.34	7.25	0.58	6080	7296	276	332	727	225	548	952	1275	179
5.0	0.01	18	11	28.08	9.26	0.30	5416	6499	246	295	765	225	488	990	1253	277
5.0	0.02	36	11	56.16	13.86	0.45	8833	10599	401	482	765	225	796	990	1561	-31
5.0	0.03	54	11	84.24	18.10	0.59	12082	14499	549	659	765	225	1089	990	1854	-324

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_k (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
4 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	2.17	1.4	520	350	2.9	0.186	151	199	298	73	0.25
4 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	2.47	1.3	614	350	3.3	0.206	168	236	343	107	0.31
4 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	2.58	1.3	711	350	3.3	0.209	170	273	377	139	0.37
4 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	1.77	1.2	465	350	2.1	0.130	188	342	450	157	0.35
4 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0093	0.0056	0.0093	0.0096	3.9	2.09	1.1	574	350	2.3	0.147	212	422	539	244	0.45
4 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	2.23	1.1	698	350	2.4	0.150	217	512	620	332	0.53
4 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	1.25	1.1	450	350	1.3	0.084	190	539	620	295	0.48
4 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	1.96	0.0	546	350	0.0	0.000	0	655	556	482	0.87
4 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	2.22	0.0	637	350	0.0	0.000	0	764	649	659	1.02

5. Column Displacement Capacity

Model	L (ft)	Based on compression column ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D
4 A	22.00	0.00015	0.00140	0.001250	1.128	68	32.6	0.041	3.57	10.1	13.67	0.19	3.76	13.86	3.8	3.7
4 B	22.00	0.00017	0.00140	0.001230	1.128	68	32.6	0.040	3.93	9.9	13.87	0.27	4.20	14.14	3.5	3.4
4 C	22.00	0.00018	0.00140	0.001222	1.128	68	32.6	0.040	4.07	9.9	13.94	0.36	4.42	14.30	3.4	3.2
4 D	22.00	0.00011	0.00109	0.000983	1.270	68	34.1	0.033	2.56	8.3	10.83	0.39	2.95	11.22	4.2	3.8
4 E	22.00	0.00012	0.00110	0.000981	1.270	68	34.1	0.033	2.83	8.3	11.09	0.61	3.44	11.70	3.9	3.4
4 F	22.00	0.00013	0.00111	0.000982	1.270	68	34.1	0.033	2.98	8.3	11.24	0.83	3.81	12.07	3.8	3.2
4 G	22.00	0.00009	0.00096	0.000876	1.410	68	35.5	0.031	2.04	7.7	9.70	0.71	2.76	10.42	4.8	3.8
4 H	22.00	0.00010	0.00088	0.000787	1.410	68	35.5	0.028	2.26	6.9	9.14	1.17	3.43	10.30	4.0	3.0
4 I	22.00	0.00010	0.00085	0.000752	1.410	68	35.5	0.027	2.36	6.6	8.94	1.60	3.96	10.53	3.8	2.7

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
4 A	0.55	13.67
4 B	0.88	13.87
4 C	0.93	13.94
4 D	1.58	10.83
4 E	>2.01	11.09
4 F	>2.12	11.24
4 G	>2.25	9.70
4 H	>2.41	9.14
4 I	>2.52	8.94

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
4 A	69.4	1527	1389	NG
4 B	69.4	1527	1978	OK
4 C	69.4	1527	2544	OK
4 D	72.7	1599	2870	OK
4 E	72.7	1599	4477	OK
4 F	72.7	1599	6080	OK
4 G	76.5	1683	5416	OK
4 H	76.5	1683	8833	OK
4 I	76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
4 A	269	791	Yes
4 B	393	802	Yes
4 C	509	806	Yes
4 D	574	656	Yes
4 E	895	672	No
4 F	1216	681	No
4 G	1083	618	No
4 H	1767	583	No
4 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.19	0.65	0.30	2.19	0.65	T	2.40	0.26	L
1.88	0.72	0.41	2.12	0.71	L	2.12	0.35	L
1.68	0.78	0.54	1.93	0.75	L	1.93	0.42	L
1.28	0.81	0.74	1.55	0.73	L	1.55	0.54	L
1.08	>1.0g	>1.02	1.34	0.89	L	1.34	0.78	L
0.98	>1.0g	>1.07	1.25	> 1.0g	L	1.25	>0.93	L
0.90	>1.0g	>1.12	1.17	> 1.0g	L	1.17	>0.97	L
0.78	>1.0g	>1.20	1.06	> 1.0g	L	1.06	>1.02	L
0.71	>1.0g	>1.25	1.00	> 1.0g	L	1.00	>1.04	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 4, M7.25 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.24 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	Lateral Load (k)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)
4 A	919	73	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 B	919	107	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 C	919	139	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 D	952	157	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 E	952	244	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 F	952	332	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 G	990	295	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 H	990	482	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 I	990	659	3 x 3	2 x 2 +10ft	2 x 2	344	4132

3. Column Main Bar Design and Design Forces

Column Diam.(ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL} (k)	P_{LL} (k)	P_{EQ} (k)	P_{DL+LL} (k)	P_{DL+EQ} (k)	P_{DL-EQ} (k)
3.0	0.01	10	9	10.00	1.34	0.34	1343	1612	61	73	694	225	121	919	815	573
3.0	0.02	20	9	20.00	1.773	0.45	1964	2357	89	107	694	225	177	919	871	517
3.0	0.03	30	9	30.00	2.23	0.56	2544	3052	116	139	694	225	229	919	923	465
4.0	0.01	14	10	17.78	3.98	0.32	2870	3445	130	157	727	225	259	952	986	468
4.0	0.02	28	10	35.56	5.65	0.45	4477	5373	204	244	727	225	404	952	1131	323
4.0	0.03	42	10	53.34	7.25	0.58	6080	7296	276	332	727	225	548	952	1275	179
5.0	0.01	18	11	28.08	9.261	0.30	5416	6499	246	295	765	225	488	990	1253	277
5.0	0.02	36	11	56.16	13.861	0.45	8833	10599	401	482	765	225	796	990	1561	-31
5.0	0.03	54	11	84.24	18.097	0.59	12082	14499	549	659	765	225	1089	990	1854	-324

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
4 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	4.1	1.87	1.4	520	350	2.5	0.160	130	199	280	73	0.26
4 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.8	2.21	1.3	614	350	2.9	0.184	150	236	327	107	0.33
4 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.6	2.37	1.3	711	350	3.0	0.193	157	273	365	139	0.38
4 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.5	1.50	1.2	465	350	1.7	0.110	159	342	426	157	0.37
4 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0093	0.0056	0.0093	0.0096	4.2	1.78	1.1	574	350	2.0	0.125	181	422	513	244	0.48
4 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	4.1	1.93	1.1	698	350	2.0	0.130	188	512	595	332	0.56
4 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	5.2	0.83	1.1	450	350	0.9	0.056	126	539	566	295	0.52
4 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.5	1.46	0.0	546	350	0.0	0.000	0	655	556	482	0.87
4 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	4.2	1.81	0.0	637	350	0.0	0.000	0	764	649	659	1.02

5. Column Displacement Capacity

Model	L (ft)	Based on compression column ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D
4 A	22.00	0.00015	0.00151	0.001355	1.128	68	32.6	0.044	3.50	11.0	14.45	0.19	3.68	14.64	4.1	4.0
4 B	22.00	0.00017	0.00151	0.001345	1.128	68	32.6	0.044	3.88	10.9	14.75	0.27	4.16	15.03	3.8	3.6
4 C	22.00	0.00017	0.00147	0.001301	1.128	68	32.6	0.042	4.00	10.5	14.51	0.36	4.35	14.86	3.6	3.4
4 D	22.00	0.00011	0.00116	0.001054	1.270	68	34.1	0.036	2.53	8.9	11.40	0.39	2.92	11.79	4.5	4.0
4 E	22.00	0.00012	0.00118	0.001060	1.270	68	34.1	0.036	2.77	8.9	11.69	0.61	3.38	12.30	4.2	3.6
4 F	22.00	0.00013	0.00120	0.001075	1.270	68	34.1	0.037	2.94	9.0	11.99	0.83	3.77	12.82	4.1	3.4
4 G	22.00	0.00009	0.00107	0.000984	1.410	68	35.5	0.035	2.06	8.6	10.67	0.71	2.78	11.38	5.2	4.1
4 H	22.00	0.00010	0.00100	0.000900	1.410	68	35.5	0.032	2.22	7.9	10.08	1.17	3.38	11.25	4.5	3.3
4 I	22.00	0.00010	0.00095	0.000852	1.410	68	35.5	0.030	2.33	7.4	9.78	1.60	3.93	11.37	4.2	2.9

6. Displacement Demand

Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
0.72	14.45
0.82	14.75
0.93	14.51
1.43	11.40
2.71	11.69
2.73	11.99
3.06	10.67
3.16	10.08
5.66	9.78

7. Minimum Lateral Strength Check

$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
69.4	1527	1389	NG
69.4	1527	1978	OK
69.4	1527	2544	OK
72.7	1599	2870	OK
72.7	1599	4477	OK
72.7	1599	6080	OK
76.5	1683	5416	OK
76.5	1683	8833	OK
76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
4 A	269	836	Yes
4 B	393	853	Yes
4 C	509	839	Yes
4 D	574	691	Yes
4 E	895	708	No
4 F	1216	727	No
4 G	1083	680	No
4 H	1767	643	No
4 I	2416	623	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.40	0.52	0.26	2.19	0.51	T	2.40	0.26	L
2.12	0.55	0.35	2.12	0.55	L	2.12	0.35	L
1.93	0.56	0.42	1.93	0.56	L	1.93	0.42	L
1.55	0.55	0.54	1.55	0.55	L	1.55	0.54	L
1.34	0.62	0.78	1.34	0.62	L	1.34	0.78	L
1.25	0.66	0.95	1.25	0.66	L	1.25	0.95	L
1.17	0.65	1.00	1.17	0.65	L	1.17	1.00	L
1.06	0.69	1.24	1.06	0.69	L	1.06	1.24	L
1.00	0.72	1.44	1.00	0.72	L	1.00	1.44	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 4, M7.25 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.24 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	Lateral Load (k)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)
4 A	919	73	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 B	919	107	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 C	919	139	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 D	952	157	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 E	952	244	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 F	952	332	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 G	990	295	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 H	990	482	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 I	990	659	3 x 3	2 x 2 +10ft	2 x 2	344	4132

3. Column Main Bar Design and Design Forces

Column Diam.(ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL} (k)	P_{LL} (k)	P_{EQ} (k)	P_{DL+LL} (k)	P_{DL+EQ} (k)	P_{DL-EQ} (k)
3.0	0.01	10	9	10.00	1.34	0.34	1343	1612	61	73	694	225	121	919	815	573
3.0	0.02	20	9	20.00	1.77	0.45	1964	2357	89	107	694	225	177	919	871	517
3.0	0.03	30	9	30.00	2.23	0.56	2544	3052	116	139	694	225	229	919	923	465
4.0	0.01	14	10	17.78	3.98	0.32	2870	3445	130	157	727	225	259	952	986	468
4.0	0.02	28	10	35.56	5.65	0.45	4477	5373	204	244	727	225	404	952	1131	323
4.0	0.03	42	10	53.34	7.25	0.58	6080	7296	276	332	727	225	548	952	1275	179
5.0	0.01	18	11	28.08	9.26	0.30	5416	6499	246	295	765	225	488	990	1253	277
5.0	0.02	36	11	56.16	13.86	0.45	8833	10599	401	482	765	225	796	990	1561	-31
5.0	0.03	54	11	84.24	18.10	0.59	12082	14499	549	659	765	225	1089	990	1854	-324

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_k (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
4 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	2.17	1.4	520	350	2.9	0.186	151	199	298	73	0.25
4 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	2.47	1.3	614	350	3.3	0.206	168	236	343	107	0.31
4 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	2.58	1.3	711	350	3.3	0.209	170	273	377	139	0.37
4 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	1.77	1.2	465	350	2.1	0.130	188	342	450	157	0.35
4 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0093	0.0056	0.0093	0.0096	3.9	2.09	1.1	574	350	2.3	0.147	212	422	539	244	0.45
4 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	2.23	1.1	698	350	2.4	0.150	217	512	620	332	0.53
4 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	1.25	1.1	450	350	1.3	0.084	190	539	620	295	0.48
4 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	1.96	0.0	546	350	0.0	0.000	0	655	556	482	0.87
4 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	2.22	0.0	637	350	0.0	0.000	0	764	649	659	1.02

5. Column Displacement Capacity

Model	L (ft)	Based on compression column ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D
4 A	22.00	0.00015	0.00140	0.001250	1.128	68	32.6	0.041	3.57	10.1	13.67	0.19	3.76	13.86	3.8	3.7
4 B	22.00	0.00017	0.00140	0.001230	1.128	68	32.6	0.040	3.93	9.9	13.87	0.27	4.20	14.14	3.5	3.4
4 C	22.00	0.00018	0.00140	0.001222	1.128	68	32.6	0.040	4.07	9.9	13.94	0.36	4.42	14.30	3.4	3.2
4 D	22.00	0.00011	0.00109	0.000983	1.270	68	34.1	0.033	2.56	8.3	10.83	0.39	2.95	11.22	4.2	3.8
4 E	22.00	0.00012	0.00110	0.000981	1.270	68	34.1	0.033	2.83	8.3	11.09	0.61	3.44	11.70	3.9	3.4
4 F	22.00	0.00013	0.00111	0.000982	1.270	68	34.1	0.033	2.98	8.3	11.24	0.83	3.81	12.07	3.8	3.2
4 G	22.00	0.00009	0.00096	0.000876	1.410	68	35.5	0.031	2.04	7.7	9.70	0.71	2.76	10.42	4.8	3.8
4 H	22.00	0.00010	0.00088	0.000787	1.410	68	35.5	0.028	2.26	6.9	9.14	1.17	3.43	10.30	4.0	3.0
4 I	22.00	0.00010	0.00085	0.000752	1.410	68	35.5	0.027	2.36	6.6	8.94	1.60	3.96	10.53	3.8	2.7

6. Displacement Demand

Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
0.71	13.67
0.78	13.87
0.84	13.94
1.20	10.83
2.12	11.09
3.48	11.24
3.65	9.70
4.83	9.14
6.03	8.94

7. Minimum Lateral Strength Check

$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
69.4	1527	1389	NG
69.4	1527	1978	OK
69.4	1527	2544	OK
72.7	1599	2870	OK
72.7	1599	4477	OK
72.7	1599	6080	OK
76.5	1683	5416	OK
76.5	1683	8833	OK
76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
4 A	269	791	Yes
4 B	393	802	Yes
4 C	509	806	Yes
4 D	574	656	Yes
4 E	895	672	No
4 F	1216	681	No
4 G	1083	618	No
4 H	1767	583	No
4 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.19	0.51	0.30	2.19	0.51	T	2.40	0.26	L
1.88	0.55	0.42	2.12	0.55	L	2.12	0.35	L
1.68	0.58	0.53	1.93	0.56	L	1.93	0.42	L
1.28	0.58	0.74	1.55	0.55	L	1.55	0.54	L
1.08	0.66	1.12	1.34	0.62	L	1.34	0.78	L
0.98	0.71	1.44	1.25	0.66	L	1.25	0.95	L
0.90	0.71	1.52	1.17	0.65	L	1.17	1.00	L
0.78	0.81	2.06	1.06	0.69	L	1.06	1.24	L
0.71	0.91	2.55	1.00	0.72	L	1.00	1.44	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 4, M8.00 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.24 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	Lateral Load (k)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)
4 A	919	73	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 B	919	107	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 C	919	139	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 D	952	157	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 E	952	244	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 F	952	332	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 G	990	295	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 H	990	482	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 I	990	659	3 x 3	2 x 2 +10ft	2 x 2	344	4132
4 J	1028	498	3 x 3	2 x 2	2 x 2 -10ft	355	4255
4 K	1028	852	4 x 3	3 x 2	3 x 2 -10ft	355	4255
4 L	1028	1176	4 x 4	3 x 3	3 x 2 -10ft	355	4255
4 M	1066	803	4 x 3	3 x 2	3 x 2 -10ft	365	4378
4 N	1066	1402	5 x 4	4 x 3	3 x 3 -10ft	365	4378

3. Column Main Bar Design and Design Forces

Model	Column Diam.(ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL} (k)	P_{LL} (k)	P_{EQ} (k)	P_{DL+LL} (k)	P_{DL+EQ} (k)	P_{DL-EQ} (k)
4 A	3.0	0.01	10	9	10.00	1.34	0.34	1343	1612	61	73	694	225	0	919	694	694
4 B	3.0	0.02	20	9	20.00	1.773	0.45	1964	2357	89	107	694	225	0	919	694	694
4 C	3.0	0.03	30	9	30.00	2.23	0.56	2544	3052	116	139	694	225	0	919	694	694
4 D	4.0	0.01	14	10	17.78	3.98	0.32	2870	3445	130	157	727	225	0	952	727	727
4 E	4.0	0.02	28	10	35.56	5.65	0.45	4477	5373	204	244	727	225	0	952	727	727
4 F	4.0	0.03	42	10	53.34	7.25	0.58	6080	7296	276	332	727	225	0	952	727	727
4 G	5.0	0.01	18	11	28.08	9.26	0.30	5416	6499	246	295	765	225	0	990	765	765
4 H	5.0	0.02	36	11	56.16	13.86	0.45	8833	10599	401	482	765	225	0	990	765	765
4 I	5.0	0.03	54	11	84.24	18.10	0.59	12082	14499	549	659	765	225	0	990	765	765
4 J	6.0	0.01	26	11	40.56	18.53	0.29	9121	10945	415	498	803	225	0	1028	803	803
4 K	6.0	0.02	52	11	81.12	28.64	0.45	15625	18750	710	852	803	225	0	1028	803	803
4 L	6.0	0.03	54	14	121.50	36.20	0.57	21558	25870	980	1176	803	225	0	1028	803	803
4 M	7.0	0.01	36	11	56.16	34.99	0.30	14725	17670	669	803	841	225	0	1066	841	841
4 N	7.0	0.02	72	11	112.32	54.47	0.46	25705	30846	1168	1402	841	225	0	1066	841	841

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
4 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0057	0.0081	0.0020	0.0081	0.0087	4.1	1.87	1.4	520	350	2.7	0.169	137	199	286	73	0.26
4 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0057	0.0094	0.0040	0.0094	0.0102	3.8	2.21	1.4	614	350	3.1	0.199	162	236	338	107	0.32
4 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0057	0.0107	0.0060	0.0107	0.0119	3.6	2.37	1.4	711	350	3.4	0.214	174	273	380	139	0.37
4 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0050	0.0073	0.0028	0.0073	0.0078	4.5	1.50	1.3	465	350	1.9	0.118	172	342	436	157	0.36
4 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0050	0.0086	0.0056	0.0086	0.0096	4.2	1.78	1.3	574	350	2.2	0.141	204	422	532	244	0.46
4 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0050	0.0099	0.0084	0.0099	0.0116	4.1	1.93	1.3	698	350	2.4	0.153	221	512	624	332	0.53
4 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0047	0.0069	0.0036	0.0069	0.0075	5.2	0.83	1.2	450	350	1.0	0.062	139	539	577	295	0.51
4 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0047	0.0082	0.0072	0.0082	0.0091	4.5	1.46	1.2	546	350	1.7	0.108	244	655	764	482	0.63
4 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0047	0.0095	0.0108	0.0108	0.0106	4.2	1.81	1.2	637	350	2.1	0.134	303	764	907	659	0.73
4 J	4072	3632	3257	7	0.60	0.94	4.50	67.13	0.0036	0.0045	0.0067	0.0052	0.0067	0.0079	5.6	0.37	1.1	477	350	0.4	0.026	85	844	789	498	0.63
4 K	4072	3632	3257	7	0.60	0.94	3.00	67.13	0.0036	0.0045	0.0080	0.0104	0.0104	0.0119	5.2	0.76	1.1	715	350	0.9	0.054	177	1265	1226	852	0.70
4 L	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0045	0.0093	0.0108	0.0108	0.0135	4.9	1.13	1.1	809	350	1.3	0.080	261	1425	1433	1176	0.82
4 M	5542	5027	4433	7	0.60	0.94	4.00	79.13	0.0031	0.0044	0.0066	0.0072	0.0072	0.0076	4.4	1.64	1.1	455	350	1.8	0.113	502	1119	1378	803	0.58
4 N	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0044	0.0079	0.0144	0.0144	0.0145	5.4	0.64	1.1	873	350	0.7	0.044	196	2139	1985	1402	0.71

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D
		Based on compression column														
4 A	22.00	0.00015	0.00151	0.001355	1.128	68	32.6	0.044	3.50	11.0	14.45	0.19	3.68	14.64	4.1	4.0
4 B	22.00	0.00017	0.00151	0.001345	1.128	68	32.6	0.044	3.88	10.9	14.75	0.27	4.16	15.03	3.8	3.6
4 C	22.00	0.00017	0.00147	0.001301	1.128	68	32.6	0.042	4.00	10.5	14.51	0.36	4.35	14.86	3.6	3.4
4 D	22.00	0.00011	0.00116	0.001054	1.27	68	34.1	0.036	2.53	8.9	11.40	0.39	2.92	11.79	4.5	4.0
4 E	22.00	0.00012	0.00118	0.001060	1.27	68	34.1	0.036	2.77	8.9	11.69	0.61	3.38	12.30	4.2	3.6
4 F	22.00	0.00013	0.00120	0.001075	1.27	68	34.1	0.037	2.94	9.0	11.99	0.83	3.77	12.82	4.1	3.4
4 G	22.00	0.00009	0.00107	0.000984	1.41	68	35.5	0.035	2.06	8.6	10.67	0.71	2.78	11.38	5.2	4.1
4 H	22.00	0.00010	0.00100	0.000900	1.41	68	35.5	0.032	2.22	7.9	10.08	1.17	3.38	11.25	4.5	3.3
4 I	22.00	0.00010	0.00095	0.000852	1.41	68	35.5	0.030	2.33	7.4	9.78	1.60	3.93	11.37	4.2	2.9
4 J	22.00	0.00007	0.00099	0.000917	1.41	68	35.5	0.033	1.73	8.0	9.74	1.17	2.90	10.91	5.6	3.8
4 K	22.00	0.00008	0.00101	0.000927	1.41	68	35.5	0.033	1.91	8.1	10.01	2.00	3.91	12.02	5.2	3.1
4 L	22.00	0.00009	0.00096	0.000868	1.69	68	38.4	0.033	2.10	8.2	10.27	2.76	4.87	13.03	4.9	2.7
4 M	22.00	0.00008	0.00078	0.000703	1.41	68	35.5	0.025	1.83	6.15	7.98	1.83	3.66	9.81	4.4	2.7
4 N	22.00	0.00007	0.00090	0.000829	1.41	68	35.5	0.029	1.66	7.3	8.91	3.20	4.86	12.12	5.4	2.5

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
4 A	0.52	14.45
4 B	0.85	14.75
4 C	0.94	14.51
4 D	1.33	11.40
4 E	2.17	11.69
4 F	3.40	11.99
4 G	3.75	10.67
4 H	3.79	10.08
4 I	5.96	9.78
4 J	3.79	9.74
4 K	5.96	10.01
4 L	3.79	10.27
4 M	3.79	7.98
4 N	3.79	8.91

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
4 A	69.4	1527	1389	NG
4 B	69.4	1527	1978	OK
4 C	69.4	1527	2544	OK
4 D	72.7	1599	2870	OK
4 E	72.7	1599	4477	OK
4 F	72.7	1599	6080	OK
4 G	76.5	1683	5416	OK
4 H	76.5	1683	8833	OK
4 I	76.5	1683	12082	OK
4 J	80.3	1767	9121	OK
4 K	80.3	1767	15625	OK
4 L	80.3	1767	21558	OK
4 M	84.1	1850	14725	OK
4 N	84.1	1850	25705	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
4 A	269	836	Yes
4 B	393	853	Yes
4 C	509	839	Yes
4 D	574	691	Yes
4 E	895	708	No
4 F	1216	727	No
4 G	1083	680	No
4 H	1767	643	No
4 I	2416	623	No
4 J	1824	652	No
4 K	3125	670	No
4 L	4312	687	No
4 M	2945	559	No
4 N	5141	625	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.40	0.38	0.26	2.40	0.38	L	2.40	0.26	L
2.12	0.44	0.35	2.12	0.44	L	2.12	0.35	L
1.93	0.47	0.42	1.93	0.47	L	1.93	0.42	L
1.55	0.46	0.54	1.55	0.46	L	1.55	0.54	L
1.34	0.55	0.78	1.34	0.55	L	1.34	0.78	L
1.25	0.61	0.95	1.25	0.61	L	1.25	0.95	L
1.17	0.61	1.00	1.17	0.61	L	1.17	1.00	L
1.06	0.66	1.24	1.06	0.66	L	1.06	1.24	L
1.00	0.70	1.44	1.00	0.70	L	1.00	1.44	L
1.01	0.70	1.48	1.01	0.70	L	1.01	1.48	L
0.93	0.80	1.96	0.93	0.80	L	0.93	1.96	L
0.88	0.85	2.25	0.88	0.85	L	0.88	2.25	L
0.93	0.68	1.58	0.93	0.68	L	0.93	1.58	L
0.76	0.80	2.12	0.76	0.80	L	0.76	2.12	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 4, M8.00 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.24 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	Lateral Load (k)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)
4 A	919	73	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 B	919	107	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 C	919	139	3 x 2	2 x 2	2 x 2 -10ft	325	3902
4 D	952	157	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 E	952	244	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 F	952	332	3 x 2	2 x 2	2 x 2 -10ft	334	4008
4 G	990	295	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 H	990	482	3 x 2	2 x 2	2 x 2 -10ft	344	4132
4 I	990	659	3 x 3	2 x 2 +10ft	2 x 2	344	4132
4 J	1028	501	3 x 3	2 x 2	2 x 2 -10ft	355	4255
4 K	1106	852	4 x 3	3 x 2	3 x 2 -10ft	376	4507
4 L	1373	1176	4 x 4	3 x 3	3 x 2 -10ft	448	5373
4 M	1084	803	4 x 3	3 x 2	3 x 2 -10ft	370	4437
4 N	1579	1402	5 x 4	4 x 3	3 x 3 -10ft	503	6040

3. Column Main Bar Design and Design Forces

Column Diam.(ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL} (k)	P_{LL} (k)	P_{EQ} (k)	P_{DL+LL} (k)	P_{DL+EQ} (k)	P_{DL-EQ} (k)
3.0	0.01	10	9	10.00	1.34	0.34	1343	1612	61	73	694	225	121	919	815	573
3.0	0.02	20	9	20.00	1.77	0.45	1964	2357	89	107	694	225	177	919	871	517
3.0	0.03	30	9	30.00	2.23	0.56	2544	3052	116	139	694	225	229	919	923	465
4.0	0.01	14	10	17.78	3.98	0.32	2870	3445	130	157	727	225	259	952	986	468
4.0	0.02	28	10	35.56	5.65	0.45	4477	5373	204	244	727	225	404	952	1131	323
4.0	0.03	42	10	53.34	7.25	0.58	6080	7296	276	332	727	225	548	952	1275	179
5.0	0.01	18	11	28.08	9.26	0.30	5416	6499	246	295	765	225	488	990	1253	277
5.0	0.02	36	11	56.16	13.86	0.45	8833	10599	401	482	765	225	796	990	1561	-31
5.0	0.03	54	11	84.24	18.10	0.59	12082	14499	549	659	765	225	1089	990	1854	-324
6.0	0.01	26	11	40.56	18.54	0.29	9185	11021	417	501	803	225	828	1028	1631	-25
6.0	0.02	52	11	81.12	28.64	0.45	15625	18750	710	852	803	225	1409	1028	2212	-606
6.0	0.03	54	14	121.50	36.20	0.57	21558	25870	980	1176	803	225	1943	1028	2746	-1140
7.0	0.01	36	11	56.16	34.99	0.30	14725	17670	669	803	841	225	1327	1066	2168	-486
7.0	0.02	72	11	112.32	54.47	0.46	25705	30846	1168	1402	841	225	2317	1066	3158	-1476

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_s (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
4 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	2.17	1.4	520	350	2.9	0.186	151	199	298	73	0.25
4 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	2.47	1.3	614	350	3.3	0.206	168	236	343	107	0.31
4 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	2.58	1.3	711	350	3.3	0.209	170	273	377	139	0.37
4 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	1.77	1.2	465	350	2.1	0.130	188	342	450	157	0.35
4 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0093	0.0056	0.0093	0.0096	3.9	2.09	1.1	574	350	2.3	0.147	212	422	539	244	0.45
4 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	2.23	1.1	698	350	2.4	0.150	217	512	620	332	0.53
4 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	1.25	1.1	450	350	1.3	0.084	190	539	620	295	0.48
4 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	1.96	0.0	546	350	0.0	0.000	0	655	556	482	0.87
4 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	2.22	0.0	637	350	0.0	0.000	0	764	649	659	1.02
4 J	4072	3632	3257	7	0.60	0.94	4.00	67.13	0.0036	0.0050	0.0073	0.0052	0.0073	0.0089	5.1	0.88	0.0	536	350	0.0	0.000	0	949	807	501	0.62
4 K	4072	3632	3257	7	0.60	0.94	3.00	67.13	0.0036	0.0054	0.0090	0.0104	0.0104	0.0119	4.7	1.31	0.0	715	350	0.0	0.000	0	1265	1075	852	0.79
4 L	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0057	0.0107	0.0108	0.0108	0.0135	4.3	1.69	0.0	809	350	0.0	0.000	0	1425	1212	1176	0.97
4 M	5542	5027	4433	7	0.60	0.94	4.00	79.13	0.0031	0.0050	0.0073	0.0072	0.0073	0.0076	5.0	1.03	0.0	455	350	0.0	0.000	0	1119	951	803	0.84
4 N	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0054	0.0091	0.0144	0.0144	0.0145	5.1	0.92	0.0	873	350	0.0	0.000	0	2139	1818	1402	0.77

5. Column Displacement Capacity

Model	L (ft)	Based on compression column ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D
4 A	22.00	0.00015	0.00140	0.001250	1.128	68	32.6	0.041	3.57	10.1	13.67	0.19	3.76	13.86	3.8	3.7
4 B	22.00	0.00017	0.00140	0.001230	1.128	68	32.6	0.040	3.93	9.9	13.87	0.27	4.20	14.14	3.5	3.4
4 C	22.00	0.00018	0.00140	0.001222	1.128	68	32.6	0.040	4.07	9.9	13.94	0.36	4.42	14.30	3.4	3.2
4 D	22.00	0.00011	0.00109	0.000983	1.27	68	34.1	0.033	2.56	8.3	10.83	0.39	2.95	11.22	4.2	3.8
4 E	22.00	0.00012	0.00110	0.000981	1.27	68	34.1	0.033	2.83	8.3	11.09	0.61	3.44	11.70	3.9	3.4
4 F	22.00	0.00013	0.00111	0.000982	1.27	68	34.1	0.033	2.98	8.3	11.24	0.83	3.81	12.07	3.8	3.2
4 G	22.00	0.00009	0.00096	0.000876	1.41	68	35.5	0.031	2.04	7.7	9.70	0.71	2.76	10.42	4.8	3.8
4 H	22.00	0.00010	0.00088	0.000787	1.41	68	35.5	0.028	2.26	6.9	9.14	1.17	3.43	10.30	4.0	3.0
4 I	22.00	0.00010	0.00085	0.000752	1.41	68	35.5	0.027	2.36	6.6	8.94	1.60	3.96	10.53	3.8	2.7
4 J	22.00	0.00007	0.00090	0.000820	1.41	68	35.5	0.029	1.74	7.2	8.91	1.18	2.91	10.09	5.1	3.5
4 K	22.00	0.00008	0.00089	0.000809	1.41	68	35.5	0.029	1.91	7.1	8.98	1.89	3.80	10.87	4.7	2.9
4 L	22.00	0.00009	0.00084	0.000746	1.693	68	38.4	0.029	2.11	7.0	9.12	2.19	4.30	11.31	4.3	2.6
4 M	22.00	0.00006	0.00073	0.000662	1.41	68	35.5	0.024	1.46	5.8	7.25	1.81	3.27	9.06	5.0	2.8
4 N	22.00	0.00007	0.00087	0.000793	1.41	68	35.5	0.028	1.70	6.9	8.63	2.32	4.02	10.95	5.1	2.7

6. Displacement Demand

Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
0.50	13.67
0.78	13.87
0.79	13.94
1.70	10.83
2.52	11.09
2.25	11.24
2.35	9.70
4.98	9.14
4.28	8.94
4.28	8.91
4.28	8.98
4.28	9.12
3.79	7.25
3.79	8.63

7. Minimum Lateral Strength Check

$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
69.4	1527	1389	NG
69.4	1527	1978	OK
69.4	1527	2544	OK
72.7	1599	2870	OK
72.7	1599	4477	OK
72.7	1599	6080	OK
76.5	1683	5416	OK
76.5	1683	8833	OK
76.5	1683	12082	OK
80.3	1767	9185	OK
80.3	1767	15625	OK
80.3	1767	21558	OK
84.1	1850	14725	OK
84.1	1850	25705	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
4 A	269	791	Yes
4 B	393	802	Yes
4 C	509	806	Yes
4 D	574	656	Yes
4 E	895	672	No
4 F	1216	681	No
4 G	1083	618	No
4 H	1767	583	No
4 I	2416	570	No
4 J	1837	596	No
4 K	3125	601	No
4 L	4312	611	No
4 M	2945	508	No
4 N	5141	605	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.19	0.39	0.30	2.40	0.38	L	2.40	0.26	L
1.88	0.45	0.42	2.12	0.44	L	2.12	0.35	L
1.68	0.49	0.53	1.93	0.47	L	1.93	0.42	L
1.28	0.51	0.74	1.55	0.46	L	1.55	0.54	L
1.08	0.62	1.12	1.34	0.55	L	1.34	0.78	L
0.98	0.69	1.44	1.25	0.61	L	1.25	0.95	L
0.90	0.70	1.52	1.17	0.61	L	1.17	1.00	L
0.78	0.80	2.06	1.06	0.66	L	1.06	1.24	L
0.71	0.90	2.55	1.00	0.70	L	1.00	1.44	L
0.72	0.89	2.64	1.01	0.70	L	1.01	1.48	L
0.63	>1.0g	>3.22	0.93	0.80	L	0.93	1.96	L
0.58	>1.0g	>3.18	0.88	0.85	L	0.88	2.25	L
0.62	0.98	3.14	0.93	0.68	L	0.93	1.58	L
0.48	>1.0g	>3.01	0.76	0.80	L	0.76	2.12	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 6, M6.50 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
h_{girder} =	29.66 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
6 A	1015	2418	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 B	1015	3100	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 C	1033	3546	3 x 3	2 x 2	2 x 2 -10ft	725	8700	1,700,000
6 D	1033	5581	3 x 3	2 x 2 +10ft	2 x 2 -5ft	725	8700	1,700,000
6 E	1033	7704	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
6 F	1057	6718	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
6 G	1057	11204	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
6 H	1057	15539	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
6 I	1085	11171	4 x 4	3 x 3	3 x 2 -5ft	1120	13440	3,500,000
6 J	1085	19040	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.02	20	9	20	1.81	3.98	0.46	2015	2418	68	82	767	790	225	0	1015	790	790
Circular	3.00	3.00	0.03	30	9	30	2.25	3.98	0.57	2583	3100	87	105	767	790	225	0	1015	790	790
Circular	4.00	4.00	0.01	14	10	18	4.07	12.57	0.32	2955	3546	100	120	767	808	225	0	1033	808	808
Circular	4.00	4.00	0.02	28	10	36	5.73	12.57	0.46	4651	5581	157	188	767	808	225	0	1033	808	808
Circular	4.00	4.00	0.03	42	10	53	7.33	12.57	0.58	6420	7704	216	260	767	808	225	0	1033	808	808
Circular	5.00	5.00	0.01	18	11	28	9.41	30.68	0.31	5599	6718	189	226	767	832	225	0	1057	832	832
Circular	5.00	5.00	0.02	36	11	56	14.01	30.68	0.46	9336	11204	315	378	767	832	225	0	1057	832	832
Circular	5.00	5.00	0.03	54	11	84	18.27	30.68	0.60	12949	15539	437	524	767	832	225	0	1057	832	832
Circular	6.00	6.00	0.01	26	11	41	18.75	63.62	0.29	9309	11171	314	377	767	860	225	0	1085	860	860
Circular	6.00	6.00	0.02	52	11	81	28.87	63.62	0.45	15867	19040	535	642	767	860	225	0	1085	860	860

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{mis} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
6 A	1018	804	814	6	0.44	0.69	5.25	31.25	0.0080	0.0059	0.0097	0.0040	0.0097	0.0107	3.7	31.63	2.34	1.5	644	350	3.5	0.220	179	1	250	365	82	0.22
6 B	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0059	0.0110	0.0060	0.0110	0.0119	3.5	31.63	2.47	1.5	711	350	3.7	0.232	189	1	276	395	105	0.26
6 C	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0051	0.0074	0.0028	0.0074	0.0081	4.6	43.63	1.45	1.3	488	350	1.9	0.117	170	1	362	452	120	0.26
6 D	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0051	0.0087	0.0056	0.0087	0.0131	4.8	43.56	1.25	1.3	786	350	1.6	0.101	146	1	580	617	188	0.31
6 E	1810	1521	1448	8	0.79	1.24	4.00	43.00	0.0057	0.0051	0.0100	0.0084	0.0100	0.0184	5.0	43.50	1.00	1.3	1102	350	1.3	0.081	117	1	810	788	260	0.33
6 F	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0047	0.0070	0.0036	0.0070	0.0075	5.4	55.63	0.59	1.2	450	350	0.7	0.044	100	1	543	546	226	0.41
6 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0047	0.0083	0.0072	0.0083	0.0109	5.4	55.56	0.61	1.2	653	350	0.7	0.046	104	1	785	756	378	0.50
6 H	2827	2463	2262	8	0.60	0.94	3.50	55.00	0.0044	0.0047	0.0096	0.0108	0.0108	0.0125	5.2	55.50	0.79	1.2	748	350	0.9	0.060	135	1	897	877	524	0.60
6 I	4072	3632	3257	7	0.60	0.94	4.75	67.13	0.0036	0.0045	0.0067	0.0052	0.0067	0.0075	5.6	67.56	0.36	1.1	452	350	0.4	0.026	83	1	804	754	377	0.50
6 J	4072	3632	3257	8	0.79	1.24	3.25	67.00	0.0036	0.0045	0.0080	0.0104	0.0104	0.0145	5.1	67.50	0.89	1.1	871	350	1.0	0.064	208	1	1546	1491	642	0.43

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Usable System Ductility Demand μ_D
6 A	22.00	0.000169	0.001459	0.001290	1.128	68	32.6	0.042	3.92	10.4	14.34	0.11	4.03	14.46	3.7	3.6	14.34	3.6
6 B	22.00	0.000173	0.001437	0.001264	1.128	68	32.6	0.041	4.03	10.2	14.24	0.15	4.17	14.38	3.5	3.4	14.24	3.4
6 C	22.00	0.000109	0.00118	0.001070	1.27	68	34.1	0.036	2.53	9.0	11.54	0.14	2.67	11.68	4.6	4.4	11.54	4.4
6 D	22.00	0.00012	0.00139	0.001267	1.27	68	34.1	0.043	2.84	10.7	13.50	0.22	3.05	13.71	4.8	4.5	13.50	4.5
6 E	22.00	0.00013	0.00160	0.001468	1.27	68	34.1	0.050	3.08	12.4	15.44	0.30	3.38	15.74	5.0	4.7	15.44	4.7
6 F	22.00	0.00009	0.00122	0.001132	1.41	68	35.5	0.040	2.08	9.9	11.98	0.21	2.30	12.20	5.8	5.3	11.26	5.0
6 G	22.00	0.00010	0.00128	0.001177	1.41	68	35.5	0.042	2.34	10.3	12.63	0.31	2.65	12.94	5.4	4.9	12.63	4.9
6 H	22.00	0.00011	0.00130	0.001191	1.41	68	35.5	0.042	2.47	10.4	12.88	0.35	2.82	13.23	5.2	4.7	12.88	4.7
6 I	22.00	0.00007	0.00103	0.000956	1.41	68	35.5	0.034	1.73	8.4	10.09	0.28	2.01	10.37	5.8	5.2	9.79	5.0
6 J	22.00	0.00008	0.00099	0.000903	1.41	68	35.5	0.032	1.92	7.9	9.82	0.37	2.29	10.19	5.1	4.4	9.82	4.4

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
6 A	0.30	14.34
6 B	0.49	14.24
6 C	0.60	11.54
6 D	>0.93	13.50
6 E	>1.01	15.44
6 F	>0.91	11.26
6 G	>0.88	12.63
6 H	>0.76	12.88
6 I	>0.87	9.79
6 J	>0.77	9.82

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
6 A	79.0	1739	2015	OK
6 B	79.0	1739	2583	OK
6 C	80.8	1779	2955	OK
6 D	80.8	1779	4651	OK
6 E	80.8	1779	6420	OK
6 F	83.2	1830	5599	OK
6 G	83.2	1830	9336	OK
6 H	83.2	1830	12949	OK
6 I	86.0	1893	9309	OK
6 J	86.0	1893	15867	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
6 A	403	945	Yes
6 B	517	938	Yes
6 C	591	777	Yes
6 D	930	909	No
6 E	1284	1040	No
6 F	1120	830	No
6 G	1867	876	No
6 H	2590	893	No
6 I	1862	724	No
6 J	3173	704	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.16	0.67	0.32	2.16	0.67	L	2.16	0.32	L
1.93	0.71	0.39	1.93	0.71	L	1.93	0.39	L
1.44	0.73	0.59	1.44	0.73	L	1.44	0.59	L
1.23	>1.0g	>0.95	1.23	> 1.0g	L	1.23	>0.95	L
1.09	>1.0g	>1.02	1.09	> 1.0g	L	1.09	>1.02	L
0.97	>1.0g	>1.11	0.97	> 1.0g	L	0.97	>1.11	L
0.81	>1.0g	>1.22	0.81	> 1.0g	L	0.81	>1.22	L
0.71	>1.0g	>1.30	0.71	> 1.0g	L	0.71	>1.30	L
0.71	>1.0g	>1.33	0.71	> 1.0g	L	0.71	>1.33	L
0.58	>1.0g	>1.47	0.58	> 1.0g	L	0.58	>1.47	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 6, M6.50 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 ksi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
h_{girder} =	29.66 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	Fixed at footing K (k/in)	K (k/ft)	K_{ij} (k/rad)
6 A	1015	2418	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 B	1015	3100	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 C	1033	3546	3 x 3	2 x 2	2 x 2 -10ft	725	8700	1,700,000
6 D	1033	5581	3 x 3	2 x 2 +10ft	2 x 2 -5ft	725	8700	1,700,000
6 E	1033	7584	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
6 F	1057	6718	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
6 G	1057	11204	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
6 H	1057	15539	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
6 I	1085	11171	4 x 4	3 x 3	3 x 2 -5ft	1120	13440	3,500,000
6 J	1159	19040	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.02	20	9	20	1.81	3.98	0.46	2015	2418	183	220	767	790	225	185	1015	976	605
Circular	3.00	3.00	0.03	30	9	30	2.25	3.98	0.57	2583	3100	235	282	767	790	225	237	1015	1028	553
Circular	4.00	4.00	0.01	14	10	18	4.07	12.57	0.32	2955	3546	269	322	767	808	225	272	1033	1080	537
Circular	4.00	4.00	0.02	28	10	36	5.73	12.57	0.46	4651	5581	423	507	767	808	225	428	1033	1236	381
Circular	4.00	4.00	0.03	42	10	53	7.33	12.57	0.58	6320	7584	575	689	767	808	225	581	1033	1389	227
Circular	5.00	5.00	0.01	18	11	28	9.41	30.68	0.31	5599	6718	509	611	767	832	225	515	1057	1346	317
Circular	5.00	5.00	0.02	36	11	56	14.01	30.68	0.46	9336	11204	849	1019	767	832	225	858	1057	1690	-27
Circular	5.00	5.00	0.03	54	11	84	18.27	30.68	0.60	12949	15539	1177	1413	767	832	225	1190	1057	2022	-359
Circular	6.00	6.00	0.01	26	11	41	18.75	63.62	0.29	9309	11171	846	1016	767	860	225	856	1085	1716	4
Circular	6.00	6.00	0.02	52	11	81	28.865	63.62	0.45	15867	19040	1442	1731	767	860	225	1459	1085	2319	-598

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	For shear calculation $\rho_s F_y$	$\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
6 A	1018	804	814	6	0.44	0.69	5.25	31.25	0.0080	0.0064	0.0102	0.0040	0.0102	0.0107	4.3	31.63	1.71	1.6	644	350	2.7	0.173	141	1	250	332	220	0.66
6 B	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0065	0.0117	0.0060	0.0117	0.0119	4.2	31.63	1.79	1.6	711	350	2.9	0.185	150	1	276	362	282	0.78
6 C	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0055	0.0079	0.0028	0.0079	0.0081	5.8	43.63	0.30	1.4	488	350	0.4	0.026	38	1	362	340	322	0.95
6 D	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0131	6.0	43.56	0.30	1.4	786	350	0.4	0.027	39	1	580	526	507	0.96
6 E	1810	1521	1448	8	0.79	1.24	4.00	43.00	0.0057	0.0059	0.0110	0.0084	0.0110	0.0184	6.3	43.50	0.30	1.5	1102	350	0.4	0.028	41	1	810	723	689	0.95
6 F	2827	2463	2262	7	0.60	0.94	4.50	55.13	0.0044	0.0052	0.0075	0.0036	0.0075	0.0097	7.2	55.56	0.30	1.3	580	350	0.4	0.025	56	1	698	641	611	0.95
6 G	2827	2463	2262	8	0.79	1.24	3.50	55.00	0.0044	0.0055	0.0092	0.0072	0.0092	0.0164	7.7	55.50	0.30	0.0	985	350	0.0	0.000	0	1	1181	1004	1019	1.01
6 H	2827	2463	2262	8	0.79	1.24	2.50	55.00	0.0044	0.0058	0.0108	0.0108	0.0108	0.0230	7.8	55.50	0.30	0.0	1379	350	0.0	0.000	0	1	1653	1405	1413	1.01
6 I	4072	3632	3257	8	0.79	1.24	4.50	67.00	0.0036	0.0051	0.0074	0.0052	0.0074	0.0105	8.0	67.50	0.30	1.3	629	350	0.4	0.024	78	1	1117	1016	1016	1.00
6 J	4072	3632	3257	8	0.79	1.24	2.50	67.00	0.0036	0.0054	0.0091	0.0104	0.0104	0.0189	7.7	67.50	0.30	0.0	1132	350	0.0	0.000	0	1	2010	1709	1731	1.01

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Restricted System Ductility Demand μ_D
6 A	22.00	0.000171	0.001352	0.001181	1.13	68	23.0	0.027	1.99	6.55	8.54	0.31	2.29	8.84	4.3	3.9	8.54	3.9
6 B	22.00	0.000176	0.00136	0.001186	1.13	68	23.0	0.027	2.05	6.58	8.62	0.39	2.44	9.01	4.2	3.7	8.62	3.7
6 C	22.00	0.000110	0.00111	0.000997	1.27	68	25.9	0.026	1.28	6.15	7.43	0.37	1.65	7.80	5.8	4.7	7.43	4.7
6 D	22.00	0.00012	0.00131	0.001180	1.27	68	25.9	0.031	1.45	7.28	8.73	0.58	2.03	9.31	6.0	4.6	8.73	4.6
6 E	22.00	0.00013	0.00148	0.001348	1.27	68	25.9	0.035	1.56	8.31	9.87	0.79	2.35	10.67	6.3	4.5	9.87	4.5
6 F	22.00	0.00009	0.00110	0.001007	1.41	68	28.8	0.029	1.05	6.81	7.86	0.58	1.62	8.44	7.5	5.2	7.54	5.0
6 G	22.00	0.00010	0.00127	0.001171	1.41	68	28.8	0.034	1.19	7.92	9.11	0.84	2.03	9.95	7.7	4.9	9.11	4.9
6 H	22.00	0.00011	0.00141	0.001299	1.41	68	28.8	0.037	1.29	8.79	10.08	0.94	2.23	11.02	7.8	4.9	10.08	4.9
6 I	22.00	0.00008	0.00099	0.000910	1.41	68	28.8	0.026	0.88	6.15	7.03	0.76	1.63	7.79	8.0	4.8	7.03	4.8
6 J	22.00	0.00008	0.00107	0.000982	1.41	68	28.8	0.028	0.99	6.65	7.63	1.01	1.99	8.64	7.7	4.3	7.63	4.3

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
6 A	1.19	8.54
6 B	>0.66	8.62
6 C	>0.80	7.43
6 D	>0.93	8.73
6 E	>1.01	9.87
6 F	>0.91	7.54
6 G	>0.88	9.11
6 H	>0.76	10.08
6 I	>0.87	7.03
6 J	>0.77	7.63

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
6 A	76.7	844	2015	OK
6 B	76.7	844	2583	OK
6 C	76.7	844	2955	OK
6 D	76.7	844	4651	OK
6 E	76.7	844	6320	OK
6 F	76.7	844	5599	OK
6 G	76.7	844	9336	OK
6 H	76.7	844	12949	OK
6 I	76.7	844	9309	OK
6 J	76.7	844	15867	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
6 A	403	546	Yes
6 B	517	551	Yes
6 C	591	475	No
6 D	930	558	No
6 E	1264	631	No
6 F	1120	482	No
6 G	1867	582	No
6 H	2590	644	No
6 I	1862	449	No
6 J	3173	488	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.98	0.96	1.04	2.16	0.67	L	2.16	0.32	L
0.89	>1.0g	>1.13	1.93	0.71	L	1.93	0.39	L
0.69	>1.0g	>1.31	1.44	0.73	L	1.44	0.59	L
0.60	>1.0g	>1.41	1.23	> 1.0g	L	1.23	>0.95	L
0.55	>1.0g	>1.46	1.09	> 1.0g	L	1.09	>1.02	L
0.50	>1.0g	>1.56	0.97	> 1.0g	L	0.97	>1.11	L
0.43	>1.0g	>1.70	0.81	> 1.0g	L	0.81	>1.22	L
0.38	>1.0g	>1.79	0.71	> 1.0g	L	0.71	>1.30	L
0.39	>1.0g	>1.83	0.71	> 1.0g	L	0.71	>1.33	L
0.33	>1.0g	>1.96	0.58	> 1.0g	L	0.58	>1.47	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 6, M7.25 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
h_{girder} =	29.66 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
6 A	1015	2418	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 B	1015	3100	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 C	1033	3546	3 x 3	2 x 2	2 x 2 -10ft	725	8700	1,700,000
6 D	1033	5581	3 x 3	2 x 2 +10ft	2 x 2 -5ft	725	8700	1,700,000
6 E	1033	7704	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
6 F	1057	6718	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
6 G	1057	11204	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
6 H	1057	15539	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
6 I	1085	11171	4 x 4	3 x 3	3 x 2 -5ft	1120	13440	3,500,000
6 J	1085	19040	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.02	20	9	20	1.81	3.98	0.46	2015	2418	68	82	767	790	225	0	1015	790	790
Circular	3.00	3.00	0.03	30	9	30	2.25	3.98	0.57	2583	3100	87	105	767	790	225	0	1015	790	790
Circular	4.00	4.00	0.01	14	10	18	4.07	12.57	0.32	2955	3546	100	120	767	808	225	0	1033	808	808
Circular	4.00	4.00	0.02	28	10	36	5.73	12.57	0.46	4651	5581	157	188	767	808	225	0	1033	808	808
Circular	4.00	4.00	0.03	42	10	53	7.33	12.57	0.58	6420	7704	216	260	767	808	225	0	1033	808	808
Circular	5.00	5.00	0.01	18	11	28	9.41	30.68	0.31	5599	6718	189	226	767	832	225	0	1057	832	832
Circular	5.00	5.00	0.02	36	11	56	14.01	30.68	0.46	9336	11204	315	378	767	832	225	0	1057	832	832
Circular	5.00	5.00	0.03	54	11	84	18.27	30.68	0.60	12949	15539	437	524	767	832	225	0	1057	832	832
Circular	6.00	6.00	0.01	26	11	41	18.75	63.62	0.29	9309	11171	314	377	767	860	225	0	1085	860	860
Circular	6.00	6.00	0.02	52	11	81	28.87	63.62	0.45	15867	19040	535	642	767	860	225	0	1085	860	860

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{mis} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
6 A	1018	804	814	6	0.44	0.69	5.25	31.25	0.0080	0.0059	0.0097	0.0040	0.0097	0.0107	3.7	31.63	2.34	1.5	644	350	3.5	0.220	179	1	250	365	82	0.22
6 B	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0059	0.0110	0.0060	0.0110	0.0119	3.5	31.63	2.47	1.5	711	350	3.7	0.232	189	1	276	395	105	0.26
6 C	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0051	0.0074	0.0028	0.0074	0.0081	4.6	43.63	1.45	1.3	488	350	1.9	0.117	170	1	362	452	120	0.26
6 D	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0051	0.0087	0.0056	0.0087	0.0131	4.8	43.56	1.25	1.3	786	350	1.6	0.101	146	1	580	617	188	0.31
6 E	1810	1521	1448	8	0.79	1.24	4.00	43.00	0.0057	0.0051	0.0100	0.0084	0.0100	0.0184	5.0	43.50	1.00	1.3	1102	350	1.3	0.081	117	1	810	788	260	0.33
6 F	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0047	0.0070	0.0036	0.0070	0.0075	5.4	55.63	0.59	1.2	450	350	0.7	0.044	100	1	543	546	226	0.41
6 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0047	0.0083	0.0072	0.0083	0.0109	5.4	55.56	0.61	1.2	653	350	0.7	0.046	104	1	785	756	378	0.50
6 H	2827	2463	2262	8	0.60	0.94	3.50	55.00	0.0044	0.0047	0.0096	0.0108	0.0108	0.0125	5.2	55.50	0.79	1.2	748	350	0.9	0.060	135	1	897	877	524	0.60
6 I	4072	3632	3257	7	0.60	0.94	4.75	67.13	0.0036	0.0045	0.0067	0.0052	0.0067	0.0075	5.6	67.56	0.36	1.1	452	350	0.4	0.026	83	1	804	754	377	0.50
6 J	4072	3632	3257	8	0.79	1.24	3.25	67.00	0.0036	0.0045	0.0080	0.0104	0.0104	0.0145	5.1	67.50	0.89	1.1	871	350	1.0	0.064	208	1	1546	1491	642	0.43

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Usable System Ductility Demand μ_D
6 A	22.00	0.000169	0.001459	0.001290	1.128	68	32.6	0.042	3.92	10.4	14.34	0.11	4.03	14.46	3.7	3.6	14.34	3.6
6 B	22.00	0.000173	0.001437	0.001264	1.128	68	32.6	0.041	4.03	10.2	14.24	0.15	4.17	14.38	3.5	3.4	14.24	3.4
6 C	22.00	0.000109	0.00118	0.001070	1.27	68	34.1	0.036	2.53	9.0	11.54	0.14	2.67	11.68	4.6	4.4	11.54	4.4
6 D	22.00	0.00012	0.00139	0.001267	1.27	68	34.1	0.043	2.84	10.7	13.50	0.22	3.05	13.71	4.8	4.5	13.50	4.5
6 E	22.00	0.00013	0.00160	0.001468	1.27	68	34.1	0.050	3.08	12.4	15.44	0.30	3.38	15.74	5.0	4.7	15.44	4.7
6 F	22.00	0.00009	0.00122	0.001132	1.41	68	35.5	0.040	2.08	9.9	11.98	0.21	2.30	12.20	5.8	5.3	11.26	5.0
6 G	22.00	0.00010	0.00128	0.001177	1.41	68	35.5	0.042	2.34	10.3	12.63	0.31	2.65	12.94	5.4	4.9	12.63	4.9
6 H	22.00	0.00011	0.00130	0.001191	1.41	68	35.5	0.042	2.47	10.4	12.88	0.35	2.82	13.23	5.2	4.7	12.88	4.7
6 I	22.00	0.00007	0.00103	0.000956	1.41	68	35.5	0.034	1.73	8.4	10.09	0.28	2.01	10.37	5.8	5.2	9.79	5.0
6 J	22.00	0.00008	0.00099	0.000903	1.41	68	35.5	0.032	1.92	7.9	9.82	0.37	2.29	10.19	5.1	4.4	9.82	4.4

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
6 A	0.39	14.34
6 B	0.44	14.24
6 C	0.56	11.54
6 D	0.93	13.50
6 E	1.48	15.44
6 F	0.93	11.26
6 G	1.66	12.63
6 H	1.61	12.88
6 I	1.63	9.79
6 J	>1.63	9.82

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
6 A	79.0	1739	2015	OK
6 B	79.0	1739	2583	OK
6 C	80.8	1779	2955	OK
6 D	80.8	1779	4651	OK
6 E	80.8	1779	6420	OK
6 F	83.2	1830	5599	OK
6 G	83.2	1830	9336	OK
6 H	83.2	1830	12949	OK
6 I	86.0	1893	9309	OK
6 J	86.0	1893	15867	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
6 A	403	945	Yes
6 B	517	938	Yes
6 C	591	777	Yes
6 D	930	909	No
6 E	1284	1040	No
6 F	1120	830	No
6 G	1867	876	No
6 H	2590	893	No
6 I	1862	724	No
6 J	3173	704	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.16	0.53	0.32	2.16	0.53	L	2.16	0.32	L
1.93	0.55	0.39	1.93	0.55	L	1.93	0.39	L
1.44	0.55	0.59	1.44	0.55	L	1.44	0.59	L
1.23	0.65	0.98	1.23	0.65	L	1.23	0.98	L
1.09	0.74	1.43	1.09	0.74	L	1.09	1.43	L
0.97	0.68	1.35	0.97	0.68	L	0.97	1.35	L
0.81	0.85	2.26	0.81	0.85	L	0.81	2.26	L
0.71	0.98	3.01	0.71	0.98	L	0.71	3.01	L
0.71	0.84	2.37	0.71	0.84	L	0.71	2.37	L
0.58	>1.0g	>3.14	0.58	> 1.0g	L	0.58	>3.14	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 6, M7.25 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 ksi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
h_{girder} =	29.66 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	Fixed at footing K (k/in)	K (k/ft)	K_{ij} (k/rad)
6 A	1015	2418	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 B	1015	3100	3 x 2	2 x 2	2 x 2 -14ft	600	7200	1,700,000
6 C	1033	3546	3 x 3	2 x 2	2 x 2 -10ft	725	8700	1,700,000
6 D	1033	5581	3 x 3	2 x 2 +10ft	2 x 2 -5ft	725	8700	1,700,000
6 E	1033	7584	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
6 F	1057	6718	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
6 G	1057	11204	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
6 H	1057	15539	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
6 I	1085	11171	4 x 4	3 x 3	3 x 2 -5ft	1120	13440	3,500,000
6 J	1159	19040	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.02	20	9	20	1.81	3.98	0.46	2015	2418	183	220	767	790	225	185	1015	976	605
Circular	3.00	3.00	0.03	30	9	30	2.25	3.98	0.57	2583	3100	235	282	767	790	225	237	1015	1028	553
Circular	4.00	4.00	0.01	14	10	18	4.07	12.57	0.32	2955	3546	269	322	767	808	225	272	1033	1080	537
Circular	4.00	4.00	0.02	28	10	36	5.73	12.57	0.46	4651	5581	423	507	767	808	225	428	1033	1236	381
Circular	4.00	4.00	0.03	42	10	53	7.33	12.57	0.58	6320	7584	575	689	767	808	225	581	1033	1389	227
Circular	5.00	5.00	0.01	18	11	28	9.41	30.68	0.31	5599	6718	509	611	767	832	225	515	1057	1346	317
Circular	5.00	5.00	0.02	36	11	56	14.01	30.68	0.46	9336	11204	849	1019	767	832	225	858	1057	1690	-27
Circular	5.00	5.00	0.03	54	11	84	18.27	30.68	0.60	12949	15539	1177	1413	767	832	225	1190	1057	2022	-359
Circular	6.00	6.00	0.01	26	11	41	18.75	63.62	0.29	9309	11171	846	1016	767	860	225	856	1085	1716	4
Circular	6.00	6.00	0.02	52	11	81	28.865	63.62	0.45	15867	19040	1442	1731	767	860	225	1459	1085	2319	-598

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
6 A	1018	804	814	6	0.44	0.69	5.25	31.25	0.0080	0.0064	0.0102	0.0040	0.0102	0.0107	4.3	31.63	1.71	1.6	644	350	2.7	0.173	141	1	250	332	220	0.66
6 B	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0065	0.0117	0.0060	0.0117	0.0119	4.2	31.63	1.79	1.6	711	350	2.9	0.185	150	1	276	362	282	0.78
6 C	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0055	0.0079	0.0028	0.0079	0.0081	5.8	43.63	0.30	1.4	488	350	0.4	0.026	38	1	362	340	322	0.95
6 D	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0131	6.0	43.56	0.30	1.4	786	350	0.4	0.027	39	1	580	526	507	0.96
6 E	1810	1521	1448	8	0.79	1.24	4.00	43.00	0.0057	0.0059	0.0110	0.0084	0.0110	0.0184	6.3	43.50	0.30	1.5	1102	350	0.4	0.028	41	1	810	723	689	0.95
6 F	2827	2463	2262	7	0.60	0.94	4.50	55.13	0.0044	0.0052	0.0075	0.0036	0.0075	0.0097	7.2	55.56	0.30	1.3	580	350	0.4	0.025	56	1	698	641	611	0.95
6 G	2827	2463	2262	8	0.79	1.24	3.50	55.00	0.0044	0.0055	0.0092	0.0072	0.0092	0.0164	7.7	55.50	0.30	0.0	985	350	0.0	0.000	0	1	1181	1004	1019	1.01
6 H	2827	2463	2262	8	0.79	1.24	2.50	55.00	0.0044	0.0058	0.0108	0.0108	0.0108	0.0230	7.8	55.50	0.30	0.0	1379	350	0.0	0.000	0	1	1653	1405	1413	1.01
6 I	4072	3632	3257	8	0.79	1.24	4.50	67.00	0.0036	0.0051	0.0074	0.0052	0.0074	0.0105	8.0	67.50	0.30	1.3	629	350	0.4	0.024	78	1	1117	1016	1016	1.00
6 J	4072	3632	3257	8	0.79	1.24	2.50	67.00	0.0036	0.0054	0.0091	0.0104	0.0104	0.0189	7.7	67.50	0.30	0.0	1132	350	0.0	0.000	0	1	2010	1709	1731	1.01

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Restricted System Ductility Demand μ_D
6 A	22.00	0.000171	0.001352	0.001181	1.13	68	23.0	0.027	1.99	6.55	8.54	0.31	2.29	8.84	4.3	3.9	8.54	3.9
6 B	22.00	0.000176	0.00136	0.001186	1.13	68	23.0	0.027	2.05	6.58	8.62	0.39	2.44	9.01	4.2	3.7	8.62	3.7
6 C	22.00	0.000110	0.00111	0.000997	1.27	68	25.9	0.026	1.28	6.15	7.43	0.37	1.65	7.80	5.8	4.7	7.43	4.7
6 D	22.00	0.00012	0.00131	0.001180	1.27	68	25.9	0.031	1.45	7.28	8.73	0.58	2.03	9.31	6.0	4.6	8.73	4.6
6 E	22.00	0.00013	0.00148	0.001348	1.27	68	25.9	0.035	1.56	8.31	9.87	0.79	2.35	10.67	6.3	4.5	9.87	4.5
6 F	22.00	0.00009	0.00110	0.001007	1.41	68	28.8	0.029	1.05	6.81	7.86	0.58	1.62	8.44	7.5	5.2	7.54	5.0
6 G	22.00	0.00010	0.00127	0.001171	1.41	68	28.8	0.034	1.19	7.92	9.11	0.84	2.03	9.95	7.7	4.9	9.11	4.9
6 H	22.00	0.00011	0.00141	0.001299	1.41	68	28.8	0.037	1.29	8.79	10.08	0.94	2.23	11.02	7.8	4.9	10.08	4.9
6 I	22.00	0.00008	0.00099	0.000910	1.41	68	28.8	0.026	0.88	6.15	7.03	0.76	1.63	7.79	8.0	4.8	7.03	4.8
6 J	22.00	0.00008	0.00107	0.000982	1.41	68	28.8	0.028	0.99	6.65	7.63	1.01	1.99	8.64	7.7	4.3	7.63	4.3

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
6 A	1.58	8.54
6 B	1.46	8.62
6 C	1.67	7.43
6 D	>2.30	8.73
6 E	>2.60	9.87
6 F	>2.40	7.54
6 G	>2.22	9.11
6 H	>1.84	10.08
6 I	>2.11	7.03
6 J	>1.63	7.63

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{nx} (k-ft)	check
6 A	76.7	844	2015	OK
6 B	76.7	844	2583	OK
6 C	76.7	844	2955	OK
6 D	76.7	844	4651	OK
6 E	76.7	844	6320	OK
6 F	76.7	844	5599	OK
6 G	76.7	844	9336	OK
6 H	76.7	844	12949	OK
6 I	76.7	844	9309	OK
6 J	76.7	844	15867	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
6 A	403	546	Yes
6 B	517	551	Yes
6 C	591	475	No
6 D	930	558	No
6 E	1264	631	No
6 F	1120	482	No
6 G	1867	582	No
6 H	2590	644	No
6 I	1862	449	No
6 J	3173	488	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.98	0.61	1.04	2.16	0.53	L	2.16	0.32	L
0.89	0.66	1.32	1.93	0.55	L	1.93	0.39	L
0.69	0.79	2.09	1.44	0.55	L	1.44	0.59	L
0.60	>1.0g	>3.06	1.23	0.65	L	1.23	0.98	L
0.55	>1.0g	>3.01	1.09	0.74	L	1.09	1.43	L
0.50	>1.0g	>3.01	0.97	0.68	L	0.97	1.35	L
0.43	>1.0g	>2.83	0.81	0.85	L	0.81	2.26	L
0.38	>1.0g	>2.72	0.71	0.98	L	0.71	3.01	L
0.39	>1.0g	>2.83	0.71	0.84	L	0.71	2.37	L
0.33	>1.0g	>2.69	0.58	> 1.0g	L	0.58	>3.14	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 6, M8.00 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
h_{girder} =	29.66 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
6 A	1015	2418	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 B	1015	3100	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 C	1033	3546	3 x 3	2 x 2	2 x 2 -10ft	725	8700	1,700,000
6 D	1033	5581	3 x 3	2 x 2 +10ft	2 x 2 -5ft	725	8700	1,700,000
6 E	1033	7704	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
6 F	1057	6718	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
6 G	1057	11204	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
6 H	1057	15539	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
6 I	1085	11171	4 x 4	3 x 3	3 x 2 -5ft	1120	13440	3,500,000
6 J	1085	19040	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.02	20	9	20	1.81	3.98	0.46	2015	2418	68	82	767	790	225	0	1015	790	790
Circular	3.00	3.00	0.03	30	9	30	2.25	3.98	0.57	2583	3100	87	105	767	790	225	0	1015	790	790
Circular	4.00	4.00	0.01	14	10	18	4.07	12.57	0.32	2955	3546	100	120	767	808	225	0	1033	808	808
Circular	4.00	4.00	0.02	28	10	36	5.73	12.57	0.46	4651	5581	157	188	767	808	225	0	1033	808	808
Circular	4.00	4.00	0.03	42	10	53	7.33	12.57	0.58	6420	7704	216	260	767	808	225	0	1033	808	808
Circular	5.00	5.00	0.01	18	11	28	9.41	30.68	0.31	5599	6718	189	226	767	832	225	0	1057	832	832
Circular	5.00	5.00	0.02	36	11	56	14.01	30.68	0.46	9336	11204	315	378	767	832	225	0	1057	832	832
Circular	5.00	5.00	0.03	54	11	84	18.27	30.68	0.60	12949	15539	437	524	767	832	225	0	1057	832	832
Circular	6.00	6.00	0.01	26	11	41	18.75	63.62	0.29	9309	11171	314	377	767	860	225	0	1085	860	860
Circular	6.00	6.00	0.02	52	11	81	28.87	63.62	0.45	15867	19040	535	642	767	860	225	0	1085	860	860

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{mis} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
6 A	1018	804	814	6	0.44	0.69	5.25	31.25	0.0080	0.0059	0.0097	0.0040	0.0097	0.0107	3.7	31.63	2.34	1.5	644	350	3.5	0.220	179	1	250	365	82	0.22
6 B	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0059	0.0110	0.0060	0.0110	0.0119	3.5	31.63	2.47	1.5	711	350	3.7	0.232	189	1	276	395	105	0.26
6 C	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0051	0.0074	0.0028	0.0074	0.0081	4.6	43.63	1.45	1.3	488	350	1.9	0.117	170	1	362	452	120	0.26
6 D	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0051	0.0087	0.0056	0.0087	0.0131	4.8	43.56	1.25	1.3	786	350	1.6	0.101	146	1	580	617	188	0.31
6 E	1810	1521	1448	8	0.79	1.24	4.00	43.00	0.0057	0.0051	0.0100	0.0084	0.0100	0.0184	5.0	43.50	1.00	1.3	1102	350	1.3	0.081	117	1	810	788	260	0.33
6 F	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0047	0.0070	0.0036	0.0070	0.0075	5.4	55.63	0.59	1.2	450	350	0.7	0.044	100	1	543	546	226	0.41
6 G	2827	2463	2262	7	0.60	0.94	4.00	55.13	0.0044	0.0047	0.0083	0.0072	0.0083	0.0109	5.4	55.56	0.61	1.2	653	350	0.7	0.046	104	1	785	756	378	0.50
6 H	2827	2463	2262	8	0.60	0.94	3.50	55.00	0.0044	0.0047	0.0096	0.0108	0.0108	0.0125	5.2	55.50	0.79	1.2	748	350	0.9	0.060	135	1	897	877	524	0.60
6 I	4072	3632	3257	7	0.60	0.94	4.75	67.13	0.0036	0.0045	0.0067	0.0052	0.0067	0.0075	5.6	67.56	0.36	1.1	452	350	0.4	0.026	83	1	804	754	377	0.50
6 J	4072	3632	3257	8	0.79	1.24	3.25	67.00	0.0036	0.0045	0.0080	0.0104	0.0104	0.0145	5.1	67.50	0.89	1.1	871	350	1.0	0.064	208	1	1546	1491	642	0.43

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foos}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Usable System Ductility Demand μ_D
6 A	22.00	0.000169	0.001459	0.001290	1.128	68	32.6	0.042	3.92	10.4	14.34	0.11	4.03	14.46	3.7	3.6	14.34	3.6
6 B	22.00	0.000173	0.001437	0.001264	1.128	68	32.6	0.041	4.03	10.2	14.24	0.15	4.17	14.38	3.5	3.4	14.24	3.4
6 C	22.00	0.000109	0.00118	0.001070	1.27	68	34.1	0.036	2.53	9.0	11.54	0.14	2.67	11.68	4.6	4.4	11.54	4.4
6 D	22.00	0.00012	0.00139	0.001267	1.27	68	34.1	0.043	2.84	10.7	13.50	0.22	3.05	13.71	4.8	4.5	13.50	4.5
6 E	22.00	0.00013	0.00160	0.001468	1.27	68	34.1	0.050	3.08	12.4	15.44	0.30	3.38	15.74	5.0	4.7	15.44	4.7
6 F	22.00	0.00009	0.00122	0.001132	1.41	68	35.5	0.040	2.08	9.9	11.98	0.21	2.30	12.20	5.8	5.3	11.26	5.0
6 G	22.00	0.00010	0.00128	0.001177	1.41	68	35.5	0.042	2.34	10.3	12.63	0.31	2.65	12.94	5.4	4.9	12.63	4.9
6 H	22.00	0.00011	0.00130	0.001191	1.41	68	35.5	0.042	2.47	10.4	12.88	0.35	2.82	13.23	5.2	4.7	12.88	4.7
6 I	22.00	0.00007	0.00103	0.000956	1.41	68	35.5	0.034	1.73	8.4	10.09	0.28	2.01	10.37	5.8	5.2	9.79	5.0
6 J	22.00	0.00008	0.00099	0.000903	1.41	68	35.5	0.032	1.92	7.9	9.82	0.37	2.29	10.19	5.1	4.4	9.82	4.4

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
6 A	0.40	14.34
6 B	0.44	14.24
6 C	0.51	11.54
6 D	1.16	13.50
6 E	1.59	15.44
6 F	1.07	11.26
6 G	1.70	12.63
6 H	1.68	12.88
6 I	1.71	9.79
6 J	>1.69	9.82

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
6 A	79.0	1739	2015	OK
6 B	79.0	1739	2583	OK
6 C	80.8	1779	2955	OK
6 D	80.8	1779	4651	OK
6 E	80.8	1779	6420	OK
6 F	83.2	1830	5599	OK
6 G	83.2	1830	9336	OK
6 H	83.2	1830	12949	OK
6 I	86.0	1893	9309	OK
6 J	86.0	1893	15867	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
6 A	403	945	Yes
6 B	517	938	Yes
6 C	591	777	Yes
6 D	930	909	No
6 E	1284	1040	No
6 F	1120	830	No
6 G	1867	876	No
6 H	2590	893	No
6 I	1862	724	No
6 J	3173	704	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)
2.16	0.41	0.32
1.93	0.44	0.39
1.44	0.47	0.59
1.23	0.61	0.98
1.09	0.72	1.43
0.97	0.66	1.35
0.81	0.84	2.26
0.71	0.96	3.01
0.71	0.83	2.37
0.58	>1.0g	>3.25

Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.16	0.41	L	2.16	0.32	L
1.93	0.44	L	1.93	0.39	L
1.44	0.47	L	1.44	0.59	L
1.23	0.61	L	1.23	0.98	L
1.09	0.72	L	1.09	1.43	L
0.97	0.66	L	0.97	1.35	L
0.81	0.84	L	0.81	2.26	L
0.71	0.96	L	0.71	3.01	L
0.71	0.83	L	0.71	2.37	L
0.58	> 1.0g	L	0.58	>3.25	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 6, M8.00 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 ksi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
h_{girder} =	29.66 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	Fixed at footing K (k/in)	K (k/ft)	K_{ij} (k/rad)
6 A	1015	2418	3 x 2	2 x 2	2 x 2 -14ft	600	7200	700,000
6 B	1015	3100	3 x 2	2 x 2	2 x 2 -14ft	600	7200	1,700,000
6 C	1033	3546	3 x 3	2 x 2	2 x 2 -10ft	725	8700	1,700,000
6 D	1033	5581	3 x 3	2 x 2 +10ft	2 x 2 -5ft	725	8700	1,700,000
6 E	1033	7584	4 x 3	3 x 2	3 x 2 -10ft	725	8700	1,700,000
6 F	1057	6718	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
6 G	1057	11204	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
6 H	1057	15539	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
6 I	1085	11171	4 x 4	3 x 3	3 x 2 -5ft	1120	13440	3,500,000
6 J	1159	19040	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.02	20	9	20	1.81	3.98	0.46	2015	2418	183	220	767	790	225	185	1015	976	605
Circular	3.00	3.00	0.03	30	9	30	2.25	3.98	0.57	2583	3100	235	282	767	790	225	237	1015	1028	553
Circular	4.00	4.00	0.01	14	10	18	4.07	12.57	0.32	2955	3546	269	322	767	808	225	272	1033	1080	537
Circular	4.00	4.00	0.02	28	10	36	5.73	12.57	0.46	4651	5581	423	507	767	808	225	428	1033	1236	381
Circular	4.00	4.00	0.03	42	10	53	7.33	12.57	0.58	6320	7584	575	689	767	808	225	581	1033	1389	227
Circular	5.00	5.00	0.01	18	11	28	9.41	30.68	0.31	5599	6718	509	611	767	832	225	515	1057	1346	317
Circular	5.00	5.00	0.02	36	11	56	14.01	30.68	0.46	9336	11204	849	1019	767	832	225	858	1057	1690	-27
Circular	5.00	5.00	0.03	54	11	84	18.27	30.68	0.60	12949	15539	1177	1413	767	832	225	1190	1057	2022	-359
Circular	6.00	6.00	0.01	26	11	41	18.75	63.62	0.29	9309	11171	846	1016	767	860	225	856	1085	1716	4
Circular	6.00	6.00	0.02	52	11	81	28.865	63.62	0.45	15867	19040	1442	1731	767	860	225	1459	1085	2319	-598

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
6 A	1018	804	814	6	0.44	0.69	5.25	31.25	0.0080	0.0064	0.0102	0.0040	0.0102	0.0107	4.3	31.63	1.71	1.6	644	350	2.7	0.173	141	1	250	332	220	0.66
6 B	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0065	0.0117	0.0060	0.0117	0.0119	4.2	31.63	1.79	1.6	711	350	2.9	0.185	150	1	276	362	282	0.78
6 C	1810	1521	1448	6	0.44	0.69	5.00	43.25	0.0057	0.0055	0.0079	0.0028	0.0079	0.0081	5.8	43.63	0.30	1.4	488	350	0.4	0.026	38	1	362	340	322	0.95
6 D	1810	1521	1448	7	0.60	0.94	4.25	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0131	6.0	43.56	0.30	1.4	786	350	0.4	0.027	39	1	580	526	507	0.96
6 E	1810	1521	1448	8	0.79	1.24	4.00	43.00	0.0057	0.0059	0.0110	0.0084	0.0110	0.0184	6.3	43.50	0.30	1.5	1102	350	0.4	0.028	41	1	810	723	689	0.95
6 F	2827	2463	2262	7	0.60	0.94	4.50	55.13	0.0044	0.0052	0.0075	0.0036	0.0075	0.0097	7.2	55.56	0.30	1.3	580	350	0.4	0.025	56	1	698	641	611	0.95
6 G	2827	2463	2262	8	0.79	1.24	3.50	55.00	0.0044	0.0055	0.0092	0.0072	0.0092	0.0164	7.7	55.50	0.30	0.0	985	350	0.0	0.000	0	1	1181	1004	1019	1.01
6 H	2827	2463	2262	8	0.79	1.24	2.50	55.00	0.0044	0.0058	0.0108	0.0108	0.0108	0.0230	7.8	55.50	0.30	0.0	1379	350	0.0	0.000	0	1	1653	1405	1413	1.01
6 I	4072	3632	3257	8	0.79	1.24	4.50	67.00	0.0036	0.0051	0.0074	0.0052	0.0074	0.0105	8.0	67.50	0.30	1.3	629	350	0.4	0.024	78	1	1117	1016	1016	1.00
6 J	4072	3632	3257	8	0.79	1.24	2.50	67.00	0.0036	0.0054	0.0091	0.0104	0.0104	0.0189	7.7	67.50	0.30	0.0	1132	350	0.0	0.000	0	1	2010	1709	1731	1.01

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Restricted System Ductility Demand μ_D
6 A	22.00	0.000171	0.001352	0.001181	1.13	68	23.0	0.027	1.99	6.55	8.54	0.31	2.29	8.84	4.3	3.9	8.54	3.9
6 B	22.00	0.000176	0.00136	0.001186	1.13	68	23.0	0.027	2.05	6.58	8.62	0.39	2.44	9.01	4.2	3.7	8.62	3.7
6 C	22.00	0.000110	0.00111	0.000997	1.27	68	25.9	0.026	1.28	6.15	7.43	0.37	1.65	7.80	5.8	4.7	7.43	4.7
6 D	22.00	0.00012	0.00131	0.001180	1.27	68	25.9	0.031	1.45	7.28	8.73	0.58	2.03	9.31	6.0	4.6	8.73	4.6
6 E	22.00	0.00013	0.00148	0.001348	1.27	68	25.9	0.035	1.56	8.31	9.87	0.79	2.35	10.67	6.3	4.5	9.87	4.5
6 F	22.00	0.00009	0.00110	0.001007	1.41	68	28.8	0.029	1.05	6.81	7.86	0.58	1.62	8.44	7.5	5.2	7.54	5.0
6 G	22.00	0.00010	0.00127	0.001171	1.41	68	28.8	0.034	1.19	7.92	9.11	0.84	2.03	9.95	7.7	4.9	9.11	4.9
6 H	22.00	0.00011	0.00141	0.001299	1.41	68	28.8	0.037	1.29	8.79	10.08	0.94	2.23	11.02	7.8	4.9	10.08	4.9
6 I	22.00	0.00008	0.00099	0.000910	1.41	68	28.8	0.026	0.88	6.15	7.03	0.76	1.63	7.79	8.0	4.8	7.03	4.8
6 J	22.00	0.00008	0.00107	0.000982	1.41	68	28.8	0.028	0.99	6.65	7.63	1.01	1.99	8.64	7.7	4.3	7.63	4.3

6. Displacement Demand

Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1.12	8.54
1.63	8.62
1.76	7.43
>2.13	8.73
>2.45	9.87
>2.30	7.54
>2.21	9.11
>1.88	10.08
>2.15	7.03
>1.69	7.63

7. Minimum Lateral Strength Check

$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
76.7	844	2015	OK
76.7	844	2583	OK
76.7	844	2955	OK
76.7	844	4651	OK
76.7	844	6320	OK
76.7	844	5599	OK
76.7	844	9336	OK
76.7	844	12949	OK
76.7	844	9309	OK
76.7	844	15867	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
6 A	403	546	Yes
6 B	517	551	Yes
6 C	591	475	No
6 D	930	558	No
6 E	1264	631	No
6 F	1120	482	No
6 G	1867	582	No
6 H	2590	644	No
6 I	1862	449	No
6 J	3173	488	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.98	0.57	1.04	2.16	0.41	L	2.16	0.32	L
0.89	0.64	1.32	1.93	0.44	L	1.93	0.39	L
0.69	0.78	2.09	1.44	0.47	L	1.44	0.59	L
0.60	>1.0g	>3.17	1.23	0.61	L	1.23	0.98	L
0.55	>1.0g	>3.13	1.09	0.72	L	1.09	1.43	L
0.50	>1.0g	>3.16	0.97	0.66	L	0.97	1.35	L
0.43	>1.0g	>3.04	0.81	0.84	L	0.81	2.26	L
0.38	>1.0g	>2.97	0.71	0.96	L	0.71	3.01	L
0.39	>1.0g	>3.08	0.71	0.83	L	0.71	2.37	L
0.33	>1.0g	>3.00	0.58	> 1.0g	L	0.58	>3.25	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 9, M6.50 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
1 A	1247	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1247	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1279	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1274	6948	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1274	10723	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1274	14328	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1279	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1315	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1357	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1346	16254	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1346	27194	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	1438	31306	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	516	619	1206	1247	418	0	1665	1247	1247
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	673	808	1206	1247	418	0	1665	1247	1247
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	650	780	1214	1279	418	0	1697	1279	1279
Oblong	4.00	6.00	0.01	24	10	30	8.53	23.23	0.37	5790	6948	526	632	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.02	48	10	61	11.79	23.23	0.51	8936	10723	812	975	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.03	72	10	91	14.42	23.23	0.62	11940	14328	1085	1303	1206	1274	418	0	1692	1274	1274
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	983	1180	1214	1279	418	0	1697	1279	1279
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	1014	1217	1222	1315	418	0	1733	1315	1315
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	1531	1837	1230	1357	418	0	1775	1357	1357
Oblong	5.50	8.25	0.01	36	11	56	27.21	83.05	0.33	13545	16254	1231	1478	1218	1346	418	0	1764	1346	1346
Oblong	5.50	8.25	0.02	72	11	112	40.80	83.05	0.49	22662	27194	2060	2472	1218	1346	418	0	1764	1346	1346
Oblong	7.00	10.50	0.01	58	11	90	67.21	217.9	0.31	26088	31306	2372	2846	1230	1438	418	0	1856	1438	1438

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0159	5.3	43.563	0.74	1.4	954	350	1.1	0.067	97	1	704	681	619	0.91
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0057	0.0107	0.0084	0.0107	0.0210	5.4	43.500	0.64	1.4	1260	350	0.9	0.058	84	1	925	858	808	0.94
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0124	5.9	55.563	0.30	1.3	746	350	0.4	0.024	55	1	898	810	780	0.96
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0051	0.0074	0.0048	0.0074	0.0081	5.4	43.625	0.56	1.3	488	350	0.7	0.045	107	2	724	706	632	0.89
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0051	0.0087	0.0096	0.0096	0.0124	5.3	43.563	0.66	1.3	742	350	0.8	0.053	126	2	1095	1038	975	0.94
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0051	0.0100	0.0144	0.0144	0.0171	5.3	43.563	0.74	1.3	1027	350	0.9	0.059	141	2	1516	1408	1303	0.92
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0192	6.4	55.500	0.30	1.3	1149	350	0.4	0.024	55	1	1377	1218	1180	0.97
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0048	0.0071	0.0052	0.0071	0.0135	6.5	67.500	0.30	1.2	809	350	0.4	0.023	74	1	1436	1284	1217	0.95
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0046	0.0068	0.0072	0.0072	0.0133	8.1	79.500	0.30	1.2	800	350	0.3	0.022	97	1	1973	1760	1837	1.04
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0098	6.4	61.563	0.30	1.2	589	350	0.3	0.022	98	2	1741	1563	1478	0.95
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	6.9	61.500	0.30	1.2	956	350	0.3	0.022	98	2	2818	2478	2472	1.00
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0044	0.0066	0.0116	0.0116	0.0123	8.3	79.500	0.30	1.1	738	350	0.3	0.021	151	2	3643	3225	2846	0.88

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
1 A	22.00	0.000130	0.001362	0.001232	1.27	68	25.9	0.032	1.51	7.6	9.11	0.63	2.14	9.74	6.0	4.5	7.94	4.0
1 B	22.00	0.000138	0.001538	0.001400	1.27	68	25.9	0.036	1.60	8.6	10.24	0.73	2.33	10.96	6.4	4.7	8.57	4.0
1 C	22.00	0.000094	0.001208	0.001114	1.41	68	28.8	0.032	1.09	7.5	8.63	0.70	1.79	9.33	7.9	5.2	6.45	4.0
1 D	22.00	0.000102	0.001157	0.001055	1.27	68	25.9	0.027	1.18	6.5	7.69	0.57	1.75	8.26	6.5	4.7	6.44	4.0
1 E	22.00	0.000115	0.001334	0.001219	1.27	68	25.9	0.032	1.33	7.5	8.85	0.59	1.93	9.45	6.6	4.9	7.11	4.0
1 F	22.00	0.000125	0.001488	0.001363	1.27	68	25.9	0.035	1.45	8.4	9.86	0.61	2.06	10.47	6.8	5.1	7.62	4.0
1 G	22.00	0.000103	0.001224	0.001121	1.41	68	28.8	0.032	1.20	7.6	8.78	0.95	2.15	9.74	7.3	4.5	7.66	4.0
1 H	22.00	0.000077	0.001040	0.000963	1.41	68	28.8	0.028	0.89	6.5	7.41	0.74	1.63	8.15	8.3	5.0	5.78	4.0
1 I	22.00	0.000065	0.000863	0.000798	1.41	68	28.8	0.023	0.76	5.4	6.16	1.12	1.88	7.28	8.1	3.9	6.16	3.9
1 J	22.00	0.000075	0.001124	0.001049	1.41	68	28.8	0.030	0.88	7.1	7.97	0.69	1.57	8.66	9.1	5.5	5.58	4.0
1 K	22.00	0.000084	0.001180	0.001096	1.41	68	28.8	0.032	0.98	7.4	8.39	0.93	1.91	9.32	8.6	4.9	6.71	4.0
1 L	22.00	0.000059	0.000869	0.000810	1.41	68	28.8	0.023	0.69	5.5	6.17	0.99	1.67	7.16	9.0	4.3	5.71	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	>2.00	7.94
1 B	>1.82	8.57
1 C	>1.95	6.45
1 D	>1.81	6.44
1 E	>1.36	7.11
1 F	>1.10	7.62
1 G	>1.85	7.66
1 H	>1.62	5.78
1 I	>1.21	6.16
1 J	>1.21	5.58
1 K	>1.21	6.71
1 L	>1.21	5.71

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
1 A	124.7	1372	5674	OK
1 B	124.7	1372	7406	OK
1 C	127.9	1407	7150	OK
1 D	127.4	1401	5790	OK
1 E	127.4	1401	8936	OK
1 F	127.4	1401	11940	OK
1 G	127.9	1407	10816	OK
1 H	131.5	1447	11152	OK
1 I	135.7	1493	16843	OK
1 J	134.6	1481	13545	OK
1 K	134.6	1481	22662	OK
1 L	143.8	1582	26088	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	473	No
1 B	1481	532	No
1 C	1430	460	No
1 D	1158	408	No
1 E	1787	470	No
1 F	2388	523	No
1 G	2163	468	No
1 H	2230	406	No
1 I	3369	348	No
1 J	2709	447	No
1 K	4532	471	No
1 L	5218	369	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.87	>1.0g	>1.13	0.87	> 1.0g	L	0.87	>1.13	L
0.81	>1.0g	>1.17	0.81	> 1.0g	L	0.81	>1.17	L
0.74	>1.0g	>1.21	0.74	> 1.0g	L	0.74	>1.21	L
0.80	>1.0g	>1.21	0.97	0.99	T	0.97	1.02	T
0.67	>1.0g	>1.23	0.67	> 1.0g	L	0.67	>1.23	L
0.61	>1.0g	>1.28	0.61	> 1.0g	L	0.61	>1.28	L
0.67	>1.0g	>1.26	0.67	> 1.0g	L	0.67	>1.26	L
0.58	>1.0g	>1.33	0.58	> 1.0g	L	0.58	>1.33	L
0.53	>1.0g	>1.34	0.53	> 1.0g	L	0.53	>1.34	L
0.54	>1.0g	>1.30	0.54	> 1.0g	L	0.54	>1.30	L
0.48	>1.0g	>1.29	0.48	> 1.0g	L	0.48	>1.29	L
0.45	>1.0g	>1.28	0.45	> 1.0g	L	0.45	>1.28	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 9, M6.50 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
9 A	1247	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
9 B	1247	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 C	1279	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 D	1274	10345	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 E	1274	15888	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
9 F	1274	21069	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
9 G	1279	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
9 H	1315	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
9 I	1357	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
9 J	1346	24122	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
9 K	1346	39816	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
9 L	1438	45778	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	221	266	1206	1247	418	0	1665	1247	1247
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	289	347	1206	1247	418	0	1665	1247	1247
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	279	335	1214	1279	418	0	1697	1279	1279
Oblong	4.00	6.00	0.01	24	10	30	17.64	49.13	0.36	8621	10345	336	404	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.02	48	10	61	24.62	49.13	0.50	13240	15888	517	620	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.03	72	10	91	30.02	49.13	0.61	17557	21069	685	822	1206	1274	418	0	1692	1274	1274
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	422	506	1214	1279	418	0	1697	1279	1279
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	435	522	1222	1315	418	0	1733	1315	1315
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	657	789	1230	1357	418	0	1775	1357	1357
Oblong	5.50	8.25	0.01	36	11	56	56.67	175.62	0.32	20101	24122	784	941	1218	1346	418	0	1764	1346	1346
Oblong	5.50	8.25	0.02	72	11	112	83.16	175.62	0.47	33180	39816	1295	1554	1218	1346	418	0	1764	1346	1346
Oblong	7.00	10.50	0.01	58	11	90	133.62	460.8	0.29	38148	45778	1488	1786	1230	1438	418	0	1856	1438	1438

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0159	4.2	43.56	1.82	1.4	954	350	2.6	0.165	238	1	704	801	266	0.33
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0057	0.0107	0.0084	0.0107	0.0210	4.2	43.50	1.81	1.4	1260	350	2.6	0.163	237	1	925	988	347	0.35
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0124	4.3	55.56	1.72	1.3	746	350	2.2	0.140	316	1	898	1032	335	0.32
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0051	0.0074	0.0048	0.0074	0.0081	4.3	67.63	1.67	1.3	488	350	2.1	0.134	317	2	1122	1223	404	0.33
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0051	0.0087	0.0096	0.0096	0.0124	4.4	67.56	1.58	1.3	742	350	2.0	0.127	300	2	1698	1699	620	0.36
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0051	0.0100	0.0144	0.0144	0.0171	4.4	67.56	1.60	1.3	1027	350	2.0	0.129	305	2	2351	2258	822	0.36
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0192	4.3	55.50	1.66	1.3	1149	350	2.1	0.134	304	1	1377	1429	506	0.35
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0048	0.0071	0.0052	0.0071	0.0135	4.4	67.50	1.62	1.2	809	350	2.0	0.124	402	1	1436	1563	522	0.33
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0046	0.0068	0.0072	0.0072	0.0133	4.7	79.50	1.33	1.2	800	350	1.5	0.097	431	1	1973	2043	789	0.39
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0098	4.7	94.56	1.26	1.2	589	350	1.5	0.092	411	2	2674	2622	941	0.36
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	4.9	94.50	1.10	1.2	956	350	1.3	0.080	357	2	4330	3984	1554	0.39
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0044	0.0066	0.0116	0.0116	0.0123	5.3	121.50	0.70	1.1	738	350	0.8	0.049	352	2	5567	5031	1786	0.35

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
1 A	25.63	0.000130	0.001362	0.001232	1.27	68	37.6	0.046	4.10	13.36	17.46	0.25	4.35	17.71	4.3	4.1	17.15	4.0
1 B	25.63	0.000138	0.001538	0.001400	1.27	68	37.6	0.053	4.34	15.19	19.53	0.28	4.62	19.81	4.5	4.3	18.21	4.0
1 C	25.63	0.000094	0.001208	0.001114	1.41	68	39.0	0.043	2.95	12.52	15.47	0.27	3.22	15.74	5.2	4.9	12.62	4.0
1 D	25.63	0.00007	0.00080	0.000722	1.27	68	37.6	0.027	2.34	7.83	10.17	0.33	2.68	10.50	4.3	3.9	10.17	3.9
1 E	25.63	0.00008	0.00090	0.000817	1.27	68	37.6	0.031	2.56	8.86	11.42	0.36	2.92	11.78	4.5	4.0	11.31	4.0
1 F	25.63	0.00009	0.00100	0.000916	1.27	68	37.6	0.034	2.76	9.94	12.70	0.37	3.13	13.07	4.6	4.2	12.16	4.0
1 G	25.63	0.000103	0.001224	0.001121	1.41	68	39.0	0.044	3.26	12.58	15.85	0.38	3.64	16.22	4.9	4.5	14.18	4.0
1 H	25.63	0.000077	0.001040	0.000963	1.41	68	39.0	0.038	2.41	10.82	13.23	0.30	2.72	13.54	5.5	5.0	10.56	4.0
1 I	25.63	0.000065	0.000863	0.000798	1.41	68	39.0	0.031	2.06	8.96	11.02	0.46	2.52	11.48	5.4	4.6	9.60	4.0
1 J	25.63	0.00005	0.00070	0.000645	1.41	68	39.0	0.025	1.70	7.24	8.94	0.42	2.12	9.37	5.3	4.4	8.06	4.0
1 K	25.63	0.00006	0.000791	0.000732	1.41	68	39.0	0.029	1.87	8.22	10.09	0.57	2.44	10.66	5.4	4.4	9.20	4.0
1 L	25.63	0.00004	0.000581	0.000537	1.41	68	39.0	0.021	1.38	6.03	7.41	0.60	1.98	8.01	5.4	4.1	7.31	4.0

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	>2.00	17.15
1 B	>1.82	18.21
1 C	>1.95	12.62
1 D	1.65	10.17
1 E	>1.36	11.31
1 F	>1.10	12.16
1 G	>1.85	14.18
1 H	>1.54	10.56
1 I	>1.62	9.60
1 J	>1.21	8.06

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
1 A	124.7	3197	5674	OK
1 B	124.7	3197	7406	OK
1 C	127.9	3278	7150	OK
1 D	127.4	3265	8621	OK
1 E	127.4	3265	13240	OK
1 F	127.4	3265	17557	OK
1 G	127.9	3278	10816	OK
1 H	131.5	3371	11152	OK
1 I	135.7	3478	16843	OK
1 J	134.6	3451	20101	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	1783	Yes
1 B	1481	1893	Yes
1 C	1430	1345	No
1 D	1724	1080	No
1 E	2648	1201	No
1 F	3511	1291	No
1 G	2163	1511	No
1 H	2230	1158	No
1 I	3369	1086	No
1 J	4020	904	No
1 K	6636	1032	No
1 L	7630	875	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{trans} (s)	PGA_{trans} (g)	$S_{A,trans}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.17	>1.0g	>0.91	0.87	> 1.0g	L	0.87	>1.13	L
1.11	>1.0g	>0.93	0.81	> 1.0g	L	0.81	>1.17	L
1.04	>1.0g	>0.96	0.74	> 1.0g	L	0.74	>1.21	L
0.97	0.99	1.02	0.97	0.99	T	0.97	1.02	T
0.81	>1.0g	>1.02	0.67	> 1.0g	L	0.67	>1.23	L
0.74	>1.0g	>1.18	0.61	> 1.0g	L	0.61	>1.28	L
0.96	>1.0g	>1.01	0.67	> 1.0g	L	0.67	>1.26	L
0.83	>1.0g	>1.09	0.58	> 1.0g	L	0.58	>1.33	L
0.73	>1.0g	>1.16	0.53	> 1.0g	L	0.53	>1.34	L
0.64	>1.0g	>1.25	0.54	> 1.0g	L	0.54	>1.30	L
0.55	>1.0g	>1.33	0.48	> 1.0g	L	0.48	>1.29	L
0.49	>1.0g	>1.36	0.45	> 1.0g	L	0.45	>1.28	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 9, M7.25 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
1 A	1247	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1247	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1279	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1274	6948	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1274	10723	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1274	14328	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1279	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1315	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1357	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1346	16254	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1346	27194	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	1438	31306	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	516	619	1206	1247	418	0	1665	1247	1247
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	673	808	1206	1247	418	0	1665	1247	1247
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	650	780	1214	1279	418	0	1697	1279	1279
Oblong	4.00	6.00	0.01	24	10	30	8.53	23.23	0.37	5790	6948	526	632	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.02	48	10	61	11.79	23.23	0.51	8936	10723	812	975	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.03	72	10	91	14.42	23.23	0.62	11940	14328	1085	1303	1206	1274	418	0	1692	1274	1274
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	983	1180	1214	1279	418	0	1697	1279	1279
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	1014	1217	1222	1315	418	0	1733	1315	1315
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	1531	1837	1230	1357	418	0	1775	1357	1357
Oblong	5.50	8.25	0.01	36	11	56	27.21	83.05	0.33	13545	16254	1231	1478	1218	1346	418	0	1764	1346	1346
Oblong	5.50	8.25	0.02	72	11	112	40.80	83.05	0.49	22662	27194	2060	2472	1218	1346	418	0	1764	1346	1346
Oblong	7.00	10.50	0.01	58	11	90	67.21	217.9	0.31	26088	31306	2372	2846	1230	1438	418	0	1856	1438	1438

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0159	5.3	43.563	0.74	1.4	954	350	1.1	0.067	97	1	704	681	619	0.91
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0057	0.0107	0.0084	0.0107	0.0210	5.4	43.500	0.64	1.4	1260	350	0.9	0.058	84	1	925	858	808	0.94
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0124	5.9	55.563	0.30	1.3	746	350	0.4	0.024	55	1	898	810	780	0.96
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0051	0.0074	0.0048	0.0074	0.0081	5.4	43.625	0.56	1.3	488	350	0.7	0.045	107	2	724	706	632	0.89
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0051	0.0087	0.0096	0.0096	0.0124	5.3	43.563	0.66	1.3	742	350	0.8	0.053	126	2	1095	1038	975	0.94
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0051	0.0100	0.0144	0.0144	0.0171	5.3	43.563	0.74	1.3	1027	350	0.9	0.059	141	2	1516	1408	1303	0.92
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0192	6.4	55.500	0.30	1.3	1149	350	0.4	0.024	55	1	1377	1218	1180	0.97
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0048	0.0071	0.0052	0.0071	0.0135	6.5	67.500	0.30	1.2	809	350	0.4	0.023	74	1	1436	1284	1217	0.95
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0046	0.0068	0.0072	0.0072	0.0133	8.1	79.500	0.30	1.2	800	350	0.3	0.022	97	1	1973	1760	1837	1.04
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0098	6.4	61.563	0.30	1.2	589	350	0.3	0.022	98	2	1741	1563	1478	0.95
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	6.9	61.500	0.30	1.2	956	350	0.3	0.022	98	2	2818	2478	2472	1.00
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0044	0.0066	0.0116	0.0116	0.0123	8.3	79.500	0.30	1.1	738	350	0.3	0.021	151	2	3643	3225	2846	0.88

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
1 A	22.00	0.000130	0.001362	0.001232	1.27	68	25.9	0.032	1.51	7.6	9.11	0.63	2.14	9.74	6.0	4.5	7.94	4.0
1 B	22.00	0.000138	0.001538	0.001400	1.27	68	25.9	0.036	1.60	8.6	10.24	0.73	2.33	10.96	6.4	4.7	8.57	4.0
1 C	22.00	0.000094	0.001208	0.001114	1.41	68	28.8	0.032	1.09	7.5	8.63	0.70	1.79	9.33	7.9	5.2	6.45	4.0
1 D	22.00	0.000102	0.001157	0.001055	1.27	68	25.9	0.027	1.18	6.5	7.69	0.57	1.75	8.26	6.5	4.7	6.44	4.0
1 E	22.00	0.000115	0.001334	0.001219	1.27	68	25.9	0.032	1.33	7.5	8.85	0.59	1.93	9.45	6.6	4.9	7.11	4.0
1 F	22.00	0.000125	0.001488	0.001363	1.27	68	25.9	0.035	1.45	8.4	9.86	0.61	2.06	10.47	6.8	5.1	7.62	4.0
1 G	22.00	0.000103	0.001224	0.001121	1.41	68	28.8	0.032	1.20	7.6	8.78	0.95	2.15	9.74	7.3	4.5	7.66	4.0
1 H	22.00	0.000077	0.001040	0.000963	1.41	68	28.8	0.028	0.89	6.5	7.41	0.74	1.63	8.15	8.3	5.0	5.78	4.0
1 I	22.00	0.000065	0.000863	0.000798	1.41	68	28.8	0.023	0.76	5.4	6.16	1.12	1.88	7.28	8.1	3.9	6.16	3.9
1 J	22.00	0.000075	0.001124	0.001049	1.41	68	28.8	0.030	0.88	7.1	7.97	0.69	1.57	8.66	9.1	5.5	5.58	4.0
1 K	22.00	0.000084	0.001180	0.001096	1.41	68	28.8	0.032	0.98	7.4	8.39	0.93	1.91	9.32	8.6	4.9	6.71	4.0
1 L	22.00	0.000059	0.000869	0.000810	1.41	68	28.8	0.023	0.69	5.5	6.17	0.99	1.67	7.16	9.0	4.3	5.71	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	2.11	7.94
1 B	2.72	8.57
1 C	3.12	6.45
1 D	2.03	6.44
1 E	2.44	7.11
1 F	2.10	7.62
1 G	4.30	7.66
1 H	>3.26	5.78
1 I	>2.43	6.16
1 J	>2.43	5.58
1 K	>2.43	6.71
1 L	>2.43	5.71

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
1 A	124.7	1372	5674	OK
1 B	124.7	1372	7406	OK
1 C	127.9	1407	7150	OK
1 D	127.4	1401	5790	OK
1 E	127.4	1401	8936	OK
1 F	127.4	1401	11940	OK
1 G	127.9	1407	10816	OK
1 H	131.5	1447	11152	OK
1 I	135.7	1493	16843	OK
1 J	134.6	1481	13545	OK
1 K	134.6	1481	22662	OK
1 L	143.8	1582	26088	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	473	No
1 B	1481	532	No
1 C	1430	460	No
1 D	1158	408	No
1 E	1787	470	No
1 F	2388	523	No
1 G	2163	468	No
1 H	2230	406	No
1 I	3369	348	No
1 J	2709	447	No
1 K	4532	471	No
1 L	5218	369	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.87	0.68	1.38	0.87	0.68	L	1.17	1.14	T
0.81	0.75	1.74	1.11	0.74	T	1.11	1.32	T
0.74	0.71	1.63	1.04	0.65	T	1.04	1.05	T
0.80	0.66	1.34	0.97	0.61	T	0.97	1.03	T
0.67	0.84	2.14	0.81	0.74	T	0.81	1.61	T
0.61	0.98	2.71	0.74	0.83	T	0.74	1.99	T
0.67	0.90	2.48	0.96	0.73	T	0.96	1.40	T
0.58	0.95	2.62	0.83	0.70	T	0.83	1.39	T
0.53	>1.0g	>2.69	0.73	0.76	T	0.73	1.69	T
0.54	>1.0g	>2.60	0.64	0.78	T	0.64	1.83	T
0.48	>1.0g	>2.32	0.48	> 1.0g	L	0.48	>2.32	L
0.45	>1.0g	>2.14	0.45	> 1.0g	L	0.45	>2.14	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 9, M7.25 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
9 A	1247	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
9 B	1247	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 C	1279	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 D	1274	10345	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 E	1274	15888	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
9 F	1274	21069	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
9 G	1279	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
9 H	1315	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
9 I	1357	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
9 J	1346	24122	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
9 K	1346	39816	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
9 L	1438	45778	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	221	266	1206	1247	418	0	1665	1247	1247
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	289	347	1206	1247	418	0	1665	1247	1247
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	279	335	1214	1279	418	0	1697	1279	1279
Oblong	4.00	6.00	0.01	24	10	30	17.64	49.13	0.36	8621	10345	336	404	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.02	48	10	61	24.62	49.13	0.50	13240	15888	517	620	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.03	72	10	91	30.02	49.13	0.61	17557	21069	685	822	1206	1274	418	0	1692	1274	1274
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	422	506	1214	1279	418	0	1697	1279	1279
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	435	522	1222	1315	418	0	1733	1315	1315
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	657	789	1230	1357	418	0	1775	1357	1357
Oblong	5.50	8.25	0.01	36	11	56	56.67	175.62	0.32	20101	24122	784	941	1218	1346	418	0	1764	1346	1346
Oblong	5.50	8.25	0.02	72	11	112	83.16	175.62	0.47	33180	39816	1295	1554	1218	1346	418	0	1764	1346	1346
Oblong	7.00	10.50	0.01	58	11	90	133.62	460.8	0.29	38148	45778	1488	1786	1230	1438	418	0	1856	1438	1438

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0159	4.2	43.56	1.82	1.4	954	350	2.6	0.165	238	1	704	801	266	0.33
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0057	0.0107	0.0084	0.0107	0.0210	4.2	43.50	1.81	1.4	1260	350	2.6	0.163	237	1	925	988	347	0.35
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0124	4.3	55.56	1.72	1.3	746	350	2.2	0.140	316	1	898	1032	335	0.32
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0051	0.0074	0.0048	0.0074	0.0081	4.3	67.63	1.67	1.3	488	350	2.1	0.134	317	2	1122	1223	404	0.33
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0051	0.0087	0.0096	0.0096	0.0124	4.4	67.56	1.58	1.3	742	350	2.0	0.127	300	2	1698	1699	620	0.36
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0051	0.0100	0.0144	0.0144	0.0171	4.4	67.56	1.60	1.3	1027	350	2.0	0.129	305	2	2351	2258	822	0.36
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0192	4.3	55.50	1.66	1.3	1149	350	2.1	0.134	304	1	1377	1429	506	0.35
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0048	0.0071	0.0052	0.0071	0.0135	4.4	67.50	1.62	1.2	809	350	2.0	0.124	402	1	1436	1563	522	0.33
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0046	0.0068	0.0072	0.0072	0.0133	4.7	79.50	1.33	1.2	800	350	1.5	0.097	431	1	1973	2043	789	0.39
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0098	4.7	94.56	1.26	1.2	589	350	1.5	0.092	411	2	2674	2622	941	0.36
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	4.9	94.50	1.10	1.2	956	350	1.3	0.080	357	2	4330	3984	1554	0.39
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0044	0.0066	0.0116	0.0116	0.0123	5.3	121.50	0.70	1.1	738	350	0.8	0.049	352	2	5567	5031	1786	0.35

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
1 A	25.63	0.000130	0.001362	0.001232	1.27	68	37.6	0.046	4.10	13.36	17.46	0.25	4.35	17.71	4.3	4.1	17.15	4.0
1 B	25.63	0.000138	0.001538	0.001400	1.27	68	37.6	0.053	4.34	15.19	19.53	0.28	4.62	19.81	4.5	4.3	18.21	4.0
1 C	25.63	0.000094	0.001208	0.001114	1.41	68	39.0	0.043	2.95	12.52	15.47	0.27	3.22	15.74	5.2	4.9	12.62	4.0
1 D	25.63	0.00007	0.00080	0.000722	1.27	68	37.6	0.027	2.34	7.83	10.17	0.33	2.68	10.50	4.3	3.9	10.17	3.9
1 E	25.63	0.00008	0.00090	0.000817	1.27	68	37.6	0.031	2.56	8.86	11.42	0.36	2.92	11.78	4.5	4.0	11.31	4.0
1 F	25.63	0.00009	0.00100	0.000916	1.27	68	37.6	0.034	2.76	9.94	12.70	0.37	3.13	13.07	4.6	4.2	12.16	4.0
1 G	25.63	0.000103	0.001224	0.001121	1.41	68	39.0	0.044	3.26	12.58	15.85	0.38	3.64	16.22	4.9	4.5	14.18	4.0
1 H	25.63	0.000077	0.001040	0.000963	1.41	68	39.0	0.038	2.41	10.82	13.23	0.30	2.72	13.54	5.5	5.0	10.56	4.0
1 I	25.63	0.000065	0.000863	0.000798	1.41	68	39.0	0.031	2.06	8.96	11.02	0.46	2.52	11.48	5.4	4.6	9.60	4.0
1 J	25.63	0.00005	0.00070	0.000645	1.41	68	39.0	0.025	1.70	7.24	8.94	0.42	2.12	9.37	5.3	4.4	8.06	4.0
1 K	25.63	0.00006	0.000791	0.000732	1.41	68	39.0	0.029	1.87	8.22	10.09	0.57	2.44	10.66	5.4	4.4	9.20	4.0
1 L	25.63	0.00004	0.000581	0.000537	1.41	68	39.0	0.021	1.38	6.03	7.41	0.60	1.98	8.01	5.4	4.1	7.31	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	2.54	17.15
1 B	2.19	18.21
1 C	1.81	12.62
1 D	2.21	10.17
1 E	1.99	11.31
1 F	2.02	12.16
1 G	2.47	14.18
1 H	1.28	10.56
1 I	2.04	9.60
1 J	1.58	8.06

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
1 A	124.7	3197	5674	OK
1 B	124.7	3197	7406	OK
1 C	127.9	3278	7150	OK
1 D	127.4	3265	8621	OK
1 E	127.4	3265	13240	OK
1 F	127.4	3265	17557	OK
1 G	127.9	3278	10816	OK
1 H	131.5	3371	11152	OK
1 I	135.7	3478	16843	OK
1 J	134.6	3451	20101	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	1783	Yes
1 B	1481	1893	Yes
1 C	1430	1345	No
1 D	1724	1080	No
1 E	2648	1201	No
1 F	3511	1291	No
1 G	2163	1511	No
1 H	2230	1158	No
1 I	3369	1086	No
1 J	4020	904	No
1 K	6636	1032	No
1 L	7630	875	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{trans} (s)	PGA_{trans} (g)	$S_{A,trans}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.17	0.71	1.14	0.87	0.68	L	1.17	1.14	T
1.11	0.74	1.32	1.11	0.74	T	1.11	1.32	T
1.04	0.65	1.05	1.04	0.65	T	1.04	1.05	T
0.97	0.61	1.03	0.97	0.61	T	0.97	1.03	T
0.81	0.74	1.61	0.81	0.74	T	0.81	1.61	T
0.74	0.83	1.99	0.74	0.83	T	0.74	1.99	T
0.96	0.73	1.40	0.96	0.73	T	0.96	1.40	T
0.83	0.70	1.39	0.83	0.70	T	0.83	1.39	T
0.73	0.76	1.69	0.73	0.76	T	0.73	1.69	T
0.64	0.78	1.83	0.64	0.78	T	0.64	1.83	T
0.55	>1.0g	>2.57	0.48	> 1.0g	L	0.48	>2.32	L
0.49	>1.0g	>2.44	0.45	> 1.0g	L	0.45	>2.14	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 9, M8.00 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
1 A	1247	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
1 B	1247	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 C	1279	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 D	1274	6948	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
1 E	1274	10723	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
1 F	1274	14328	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
1 G	1279	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
1 H	1315	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
1 I	1357	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
1 J	1346	16254	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
1 K	1346	27194	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
1 L	1438	31306	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	516	619	1206	1247	418	0	1665	1247	1247
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	673	808	1206	1247	418	0	1665	1247	1247
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	650	780	1214	1279	418	0	1697	1279	1279
Oblong	4.00	6.00	0.01	24	10	30	8.53	23.23	0.37	5790	6948	526	632	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.02	48	10	61	11.79	23.23	0.51	8936	10723	812	975	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.03	72	10	91	14.42	23.23	0.62	11940	14328	1085	1303	1206	1274	418	0	1692	1274	1274
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	983	1180	1214	1279	418	0	1697	1279	1279
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	1014	1217	1222	1315	418	0	1733	1315	1315
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	1531	1837	1230	1357	418	0	1775	1357	1357
Oblong	5.50	8.25	0.01	36	11	56	27.21	83.05	0.33	13545	16254	1231	1478	1218	1346	418	0	1764	1346	1346
Oblong	5.50	8.25	0.02	72	11	112	40.80	83.05	0.49	22662	27194	2060	2472	1218	1346	418	0	1764	1346	1346
Oblong	7.00	10.50	0.01	58	11	90	67.21	217.9	0.31	26088	31306	2372	2846	1230	1438	418	0	1856	1438	1438

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0159	5.3	43.563	0.74	1.4	954	350	1.1	0.067	97	1	704	681	619	0.91
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0057	0.0107	0.0084	0.0107	0.0210	5.4	43.500	0.64	1.4	1260	350	0.9	0.058	84	1	925	858	808	0.94
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0124	5.9	55.563	0.30	1.3	746	350	0.4	0.024	55	1	898	810	780	0.96
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0051	0.0074	0.0048	0.0074	0.0081	5.4	43.625	0.56	1.3	488	350	0.7	0.045	107	2	724	706	632	0.89
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0051	0.0087	0.0096	0.0096	0.0124	5.3	43.563	0.66	1.3	742	350	0.8	0.053	126	2	1095	1038	975	0.94
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0051	0.0100	0.0144	0.0144	0.0171	5.3	43.563	0.74	1.3	1027	350	0.9	0.059	141	2	1516	1408	1303	0.92
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0192	6.4	55.500	0.30	1.3	1149	350	0.4	0.024	55	1	1377	1218	1180	0.97
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0048	0.0071	0.0052	0.0071	0.0135	6.5	67.500	0.30	1.2	809	350	0.4	0.023	74	1	1436	1284	1217	0.95
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0046	0.0068	0.0072	0.0072	0.0133	8.1	79.500	0.30	1.2	800	350	0.3	0.022	97	1	1973	1760	1837	1.04
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0098	6.4	61.563	0.30	1.2	589	350	0.3	0.022	98	2	1741	1563	1478	0.95
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	6.9	61.500	0.30	1.2	956	350	0.3	0.022	98	2	2818	2478	2472	1.00
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0044	0.0066	0.0116	0.0116	0.0123	8.3	79.500	0.30	1.1	738	350	0.3	0.021	151	2	3643	3225	2846	0.88

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
1 A	22.00	0.000130	0.001362	0.001232	1.27	68	25.9	0.032	1.51	7.6	9.11	0.63	2.14	9.74	6.0	4.5	7.94	4.0
1 B	22.00	0.000138	0.001538	0.001400	1.27	68	25.9	0.036	1.60	8.6	10.24	0.73	2.33	10.96	6.4	4.7	8.57	4.0
1 C	22.00	0.000094	0.001208	0.001114	1.41	68	28.8	0.032	1.09	7.5	8.63	0.70	1.79	9.33	7.9	5.2	6.45	4.0
1 D	22.00	0.000102	0.001157	0.001055	1.27	68	25.9	0.027	1.18	6.5	7.69	0.57	1.75	8.26	6.5	4.7	6.44	4.0
1 E	22.00	0.000115	0.001334	0.001219	1.27	68	25.9	0.032	1.33	7.5	8.85	0.59	1.93	9.45	6.6	4.9	7.11	4.0
1 F	22.00	0.000125	0.001488	0.001363	1.27	68	25.9	0.035	1.45	8.4	9.86	0.61	2.06	10.47	6.8	5.1	7.62	4.0
1 G	22.00	0.000103	0.001224	0.001121	1.41	68	28.8	0.032	1.20	7.6	8.78	0.95	2.15	9.74	7.3	4.5	7.66	4.0
1 H	22.00	0.000077	0.001040	0.000963	1.41	68	28.8	0.028	0.89	6.5	7.41	0.74	1.63	8.15	8.3	5.0	5.78	4.0
1 I	22.00	0.000065	0.000863	0.000798	1.41	68	28.8	0.023	0.76	5.4	6.16	1.12	1.88	7.28	8.1	3.9	6.16	3.9
1 J	22.00	0.000075	0.001124	0.001049	1.41	68	28.8	0.030	0.88	7.1	7.97	0.69	1.57	8.66	9.1	5.5	5.58	4.0
1 K	22.00	0.000084	0.001180	0.001096	1.41	68	28.8	0.032	0.98	7.4	8.39	0.93	1.91	9.32	8.6	4.9	6.71	4.0
1 L	22.00	0.000059	0.000869	0.000810	1.41	68	28.8	0.023	0.69	5.5	6.17	0.99	1.67	7.16	9.0	4.3	5.71	4.0

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	2.36	7.94
1 B	2.88	8.57
1 C	3.28	6.45
1 D	2.22	6.44
1 E	2.56	7.11
1 F	2.23	7.62
1 G	3.11	7.66
1 H	>3.40	5.78
1 I	>2.53	6.16
1 J	>2.53	5.58
1 K	>2.53	6.71
1 L	>2.53	5.71

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
1 A	124.7	1372	5674	OK
1 B	124.7	1372	7406	OK
1 C	127.9	1407	7150	OK
1 D	127.4	1401	5790	OK
1 E	127.4	1401	8936	OK
1 F	127.4	1401	11940	OK
1 G	127.9	1407	10816	OK
1 H	131.5	1447	11152	OK
1 I	135.7	1493	16843	OK
1 J	134.6	1481	13545	OK
1 K	134.6	1481	22662	OK
1 L	143.8	1582	26088	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	473	No
1 B	1481	532	No
1 C	1430	460	No
1 D	1158	408	No
1 E	1787	470	No
1 F	2388	523	No
1 G	2163	468	No
1 H	2230	406	No
1 I	3369	348	No
1 J	2709	447	No
1 K	4532	471	No
1 L	5218	369	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.87	0.66	1.38	0.87	0.66	L	1.17	1.14	T
0.81	0.74	1.74	1.11	0.73	T	1.11	1.32	T
0.74	0.70	1.63	1.04	0.62	T	1.04	1.05	T
0.80	0.64	1.34	0.97	0.58	T	0.97	1.02	T
0.67	0.83	2.14	0.81	0.73	T	0.81	1.61	T
0.61	0.96	2.70	0.74	0.82	T	0.74	2.00	T
0.67	0.89	2.48	0.96	0.71	T	0.96	1.40	T
0.58	0.93	2.62	0.83	0.68	T	0.83	1.39	T
0.53	>1.0g	>2.80	0.73	0.75	T	0.73	1.69	T
0.54	>1.0g	>2.72	0.64	0.77	T	0.64	1.84	T
0.48	>1.0g	>2.46	0.48	> 1.0g	L	0.48	>2.46	L
0.45	>1.0g	>2.29	0.45	> 1.0g	L	0.45	>2.29	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 9, M8.00 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	25.63 ft
h_{col} =	22.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
9 A	1247	6809	4 x 3	3 x 2	2 x 2	880	10560	2,800,000
9 B	1247	8887	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 C	1279	8580	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 D	1274	10345	4 x 4	3 x 3	3 x 2 -5ft	1015	12180	2,800,000
9 E	1274	15888	4 x 4	3 x 3	3 x 2 -5ft	1430	17160	8,000,000
9 F	1274	21069	6 x 4	4 x 3	3 x 3	1865	22380	10,500,000
9 G	1279	12980	6 x 5	4 x 4	4 x 3 -10ft	1120	13440	3,500,000
9 H	1315	13383	5 x 4	3 x 3	3 x 3	1430	17160	8,000,000
9 I	1357	20212	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
9 J	1346	24122	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
9 K	1346	39816	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
9 L	1438	45778	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	4.00	4.00	0.02	28	10	36	6.59	12.57	0.52	5674	6809	221	266	1206	1247	418	0	1665	1247	1247
Circular	4.00	4.00	0.03	42	10	53	8.11	12.57	0.65	7406	8887	289	347	1206	1247	418	0	1665	1247	1247
Circular	5.00	5.00	0.01	18	11	28	11.50	30.68	0.37	7150	8580	279	335	1214	1279	418	0	1697	1279	1279
Oblong	4.00	6.00	0.01	24	10	30	17.64	49.13	0.36	8621	10345	336	404	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.02	48	10	61	24.62	49.13	0.50	13240	15888	517	620	1206	1274	418	0	1692	1274	1274
Oblong	4.00	6.00	0.03	72	10	91	30.02	49.13	0.61	17557	21069	685	822	1206	1274	418	0	1692	1274	1274
Circular	5.00	5.00	0.02	36	11	56	15.74	30.68	0.51	10816	12980	422	506	1214	1279	418	0	1697	1279	1279
Circular	6.00	6.00	0.01	26	11	41	22.00	63.62	0.35	11152	13383	435	522	1222	1315	418	0	1733	1315	1315
Circular	7.00	7.00	0.01	36	11	56	39.23	117.86	0.33	16843	20212	657	789	1230	1357	418	0	1775	1357	1357
Oblong	5.50	8.25	0.01	36	11	56	56.67	175.62	0.32	20101	24122	784	941	1218	1346	418	0	1764	1346	1346
Oblong	5.50	8.25	0.02	72	11	112	83.16	175.62	0.47	33180	39816	1295	1554	1218	1346	418	0	1764	1346	1346
Oblong	7.00	10.50	0.01	58	11	90	133.62	460.8	0.29	38148	45778	1488	1786	1230	1438	418	0	1856	1438	1438

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,reqt}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
1 A	1810	1521	1448	7	0.60	0.94	3.50	43.13	0.0057	0.0057	0.0094	0.0056	0.0094	0.0159	4.2	43.56	1.82	1.4	954	350	2.6	0.165	238	1	704	801	266	0.33
1 B	1810	1521	1448	8	0.79	1.24	3.50	43.00	0.0057	0.0057	0.0107	0.0084	0.0107	0.0210	4.2	43.50	1.81	1.4	1260	350	2.6	0.163	237	1	925	988	347	0.35
1 C	2827	2463	2262	7	0.60	0.94	3.50	55.13	0.0044	0.0051	0.0074	0.0036	0.0074	0.0124	4.3	55.56	1.72	1.3	746	350	2.2	0.140	316	1	898	1032	335	0.32
1 D	2962	2522	2369	6	0.44	0.69	5.00	43.25	0.0052	0.0051	0.0074	0.0048	0.0074	0.0081	4.3	67.63	1.67	1.3	488	350	2.1	0.134	317	2	1122	1223	404	0.33
1 E	2962	2522	2369	7	0.60	0.94	4.50	43.13	0.0052	0.0051	0.0087	0.0096	0.0096	0.0124	4.4	67.56	1.58	1.3	742	350	2.0	0.127	300	2	1698	1699	620	0.36
1 F	2962	2522	2369	7	0.60	0.94	3.25	43.13	0.0052	0.0051	0.0100	0.0144	0.0144	0.0171	4.4	67.56	1.60	1.3	1027	350	2.0	0.129	305	2	2351	2258	822	0.36
1 G	2827	2463	2262	8	0.79	1.24	3.00	55.00	0.0044	0.0051	0.0087	0.0072	0.0087	0.0192	4.3	55.50	1.66	1.3	1149	350	2.1	0.134	304	1	1377	1429	506	0.35
1 H	4072	3632	3257	8	0.79	1.24	3.50	67.00	0.0036	0.0048	0.0071	0.0052	0.0071	0.0135	4.4	67.50	1.62	1.2	809	350	2.0	0.124	402	1	1436	1563	522	0.33
1 I	5542	5027	4433	8	0.79	1.24	3.00	79.00	0.0031	0.0046	0.0068	0.0072	0.0072	0.0133	4.7	79.50	1.33	1.2	800	350	1.5	0.097	431	1	1973	2043	789	0.39
1 J	5599	4964	4479	7	0.60	0.94	4.00	61.13	0.0038	0.0046	0.0068	0.0072	0.0072	0.0098	4.7	94.56	1.26	1.2	589	350	1.5	0.092	411	2	2674	2622	941	0.36
1 K	5599	4964	4479	8	0.79	1.24	3.25	61.00	0.0038	0.0046	0.0081	0.0144	0.0144	0.0159	4.9	94.50	1.10	1.2	956	350	1.3	0.080	357	2	4330	3984	1554	0.39
1 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0044	0.0066	0.0116	0.0116	0.0123	5.3	121.50	0.70	1.1	738	350	0.8	0.049	352	2	5567	5031	1786	0.35

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
1 A	25.63	0.000130	0.001362	0.001232	1.27	68	37.6	0.046	4.10	13.36	17.46	0.25	4.35	17.71	4.3	4.1	17.15	4.0
1 B	25.63	0.000138	0.001538	0.001400	1.27	68	37.6	0.053	4.34	15.19	19.53	0.28	4.62	19.81	4.5	4.3	18.21	4.0
1 C	25.63	0.000094	0.001208	0.001114	1.41	68	39.0	0.043	2.95	12.52	15.47	0.27	3.22	15.74	5.2	4.9	12.62	4.0
1 D	25.63	0.00007	0.00080	0.000722	1.27	68	37.6	0.027	2.34	7.83	10.17	0.33	2.68	10.50	4.3	3.9	10.17	3.9
1 E	25.63	0.00008	0.00090	0.000817	1.27	68	37.6	0.031	2.56	8.86	11.42	0.36	2.92	11.78	4.5	4.0	11.31	4.0
1 F	25.63	0.00009	0.00100	0.000916	1.27	68	37.6	0.034	2.76	9.94	12.70	0.37	3.13	13.07	4.6	4.2	12.16	4.0
1 G	25.63	0.000103	0.001224	0.001121	1.41	68	39.0	0.044	3.26	12.58	15.85	0.38	3.64	16.22	4.9	4.5	14.18	4.0
1 H	25.63	0.000077	0.001040	0.000963	1.41	68	39.0	0.038	2.41	10.82	13.23	0.30	2.72	13.54	5.5	5.0	10.56	4.0
1 I	25.63	0.000065	0.000863	0.000798	1.41	68	39.0	0.031	2.06	8.96	11.02	0.46	2.52	11.48	5.4	4.6	9.60	4.0
1 J	25.63	0.00005	0.00070	0.000645	1.41	68	39.0	0.025	1.70	7.24	8.94	0.42	2.12	9.37	5.3	4.4	8.06	4.0
1 K	25.63	0.00006	0.000791	0.000732	1.41	68	39.0	0.029	1.87	8.22	10.09	0.57	2.44	10.66	5.4	4.4	9.20	4.0
1 L	25.63	0.00004	0.000581	0.000537	1.41	68	39.0	0.021	1.38	6.03	7.41	0.60	1.98	8.01	5.4	4.1	7.31	4.0

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1 A	1.74	17.15
1 B	2.36	18.21
1 C	2.11	12.62
1 D	1.56	10.17
1 E	2.10	11.31
1 F	2.10	12.16
1 G	2.61	14.18
1 H	1.42	10.56
1 I	2.15	9.60
1 J	1.65	8.06

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
1 A	124.7	3197	5674	OK
1 B	124.7	3197	7406	OK
1 C	127.9	3278	7150	OK
1 D	127.4	3265	8621	OK
1 E	127.4	3265	13240	OK
1 F	127.4	3265	17557	OK
1 G	127.9	3278	10816	OK
1 H	131.5	3371	11152	OK
1 I	135.7	3478	16843	OK
1 J	134.6	3451	20101	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
1 A	1135	1783	Yes
1 B	1481	1893	Yes
1 C	1430	1345	No
1 D	1724	1080	No
1 E	2648	1201	No
1 F	3511	1291	No
1 G	2163	1511	No
1 H	2230	1158	No
1 I	3369	1086	No
1 J	4020	904	No
1 K	6636	1032	No
1 L	7630	875	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{trans} (s)	PGA_{trans} (g)	$S_{A,trans}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.17	0.68	1.14	0.87	0.66	L	1.17	1.14	T
1.11	0.73	1.32	1.11	0.73	T	1.11	1.32	T
1.04	0.62	1.05	1.04	0.62	T	1.04	1.05	T
0.97	0.58	1.02	0.97	0.58	T	0.97	1.02	T
0.81	0.73	1.61	0.81	0.73	T	0.81	1.61	T
0.74	0.82	2.00	0.74	0.82	T	0.74	2.00	T
0.96	0.71	1.40	0.96	0.71	T	0.96	1.40	T
0.83	0.68	1.39	0.83	0.68	T	0.83	1.39	T
0.73	0.75	1.69	0.73	0.75	T	0.73	1.69	T
0.64	0.77	1.84	0.64	0.77	T	0.64	1.84	T
0.55	>1.0g	>2.69	0.48	> 1.0g	L	0.48	>2.46	L
0.49	>1.0g	>2.59	0.45	> 1.0g	L	0.45	>2.29	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 10, M6.50 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
10 A	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 B	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 C	694	1	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 D	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 E	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 F	727	1	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 G	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 H	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 I	765	1	3 x 3	2 x 2 +10ft	2 x 2	284	3403	1,700,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.01	10	9	10	1.343	3.98	0.34	1343	1612	61	73	694	694	225	120	919	814	574
Circular	3.00	3.00	0.02	20	9	20	1.77	3.98	0.45	1964	2357	89	107	694	694	225	175	919	869	519
Circular	3.00	3.00	0.03	30	9	30	2.23	3.98	0.56	2544	3052	116	139	694	694	225	227	919	921	467
Circular	4.00	4.00	0.01	14	10	18	3.98	12.57	0.32	2870	3445	130	157	727	727	225	256	952	983	471
Circular	4.00	4.00	0.02	28	10	36	5.65	12.57	0.45	4477	5373	204	244	727	727	225	400	952	1127	327
Circular	4.00	4.00	0.03	42	10	53	7.25	12.57	0.58	6080	7296	276	332	727	727	225	543	952	1270	184
Circular	5.00	5.00	0.01	18	11	28	9.26	30.68	0.30	5416	6499	246	295	765	765	225	483	990	1248	282
Circular	5.00	5.00	0.02	36	11	56	13.86	30.68	0.45	8833	10599	401	482	765	765	225	788	990	1553	-23
Circular	5.00	5.00	0.03	54	11	84	18.10	30.68	0.59	12082	14499	549	659	765	765	225	1078	990	1843	-313

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	For shear calculation $\rho_s F_y$	$\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_d (k)	D/C Ratio
10 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	31.63	2.17	1.5	520	350	3.3	0.206	168	1	202	314	73	0.23
10 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	31.63	2.47	1.5	614	350	3.7	0.234	191	1	238	365	107	0.29
10 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	31.63	2.58	1.5	711	350	3.9	0.244	199	1	276	404	139	0.34
10 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	43.63	1.77	1.3	465	350	2.4	0.150	217	1	345	477	157	0.33
10 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0092	0.0056	0.0092	0.0096	3.9	43.63	2.09	1.4	574	350	2.9	0.183	265	1	426	587	244	0.42
10 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	43.63	2.23	1.4	698	350	3.2	0.203	294	1	517	689	332	0.48
10 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	55.63	1.25	1.3	450	350	1.6	0.101	228	1	543	655	295	0.45
10 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	55.63	1.96	1.3	546	350	2.6	0.166	377	1	659	880	482	0.55
10 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	55.63	2.22	1.4	637	350	3.1	0.197	446	1	769	1033	659	0.64

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Usable System Ductility Demand μ_D
10 A	22.00	0.000154	0.001404	0.001250	1.128	68	32.6	0.041	3.57	10.1	13.67	0.23	3.80	13.90	3.8	3.7	13.67	3.7
10 B	22.00	0.000169	0.001399	0.001230	1.128	68	32.6	0.040	3.93	9.9	13.87	0.34	4.26	14.20	3.5	3.3	13.87	3.3
10 C	22.00	0.000175	0.001397	0.001222	1.128	68	32.6	0.040	4.07	9.9	13.94	0.44	4.50	14.38	3.4	3.2	13.94	3.2
10 D	22.00	0.000110	0.001093	0.000983	1.27	68	34.1	0.033	2.56	8.3	10.83	0.48	3.03	11.31	4.2	3.7	10.83	3.7
10 E	22.00	0.000122	0.001103	0.000981	1.27	68	34.1	0.033	2.83	8.3	11.09	0.74	3.58	11.83	3.9	3.3	11.09	3.3
10 F	22.00	0.000128	0.001110	0.000982	1.27	68	34.1	0.033	2.98	8.3	11.24	1.01	3.99	12.25	3.8	3.1	11.24	3.1
10 G	22.00	0.000088	0.000964	0.000876	1.41	68	35.5	0.031	2.04	7.7	9.70	0.87	2.91	10.57	4.8	3.6	9.70	3.6
10 H	22.00	0.000097	0.000884	0.000787	1.41	68	35.5	0.028	2.26	6.9	9.14	1.42	3.68	10.55	4.0	2.9	9.14	2.9
10 I	22.00	0.000102	0.000854	0.000752	1.41	68	35.5	0.027	2.36	6.6	8.94	1.94	4.30	10.88	3.8	2.5	8.94	2.5

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
10 A	0.53	13.67
10 B	0.87	13.87
10 C	0.96	13.94
10 D	1.48	10.83
10 E	1.91	11.09
10 F	2.34	11.24
10 G	2.64	9.70
10 H	>3.12	9.14
10 I	>3.34	8.94

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
10 A	69.4	1527	1343	NG
10 B	69.4	1527	1964	OK
10 C	69.4	1527	2544	OK
10 D	72.7	1599	2870	OK
10 E	72.7	1599	4477	OK
10 F	72.7	1599	6080	OK
10 G	76.5	1683	5416	OK
10 H	76.5	1683	8833	OK
10 I	76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
10 A	269	791	Yes
10 B	393	802	Yes
10 C	509	806	Yes
10 D	574	656	Yes
10 E	895	672	No
10 F	1216	681	No
10 G	1083	618	No
10 H	1767	583	No
10 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.16	0.68	0.27	2.16	0.68	L	2.16	0.27	L
1.93	0.73	0.35	1.93	0.73	L	1.93	0.35	L
1.44	0.78	0.43	1.44	0.78	L	1.44	0.43	L
1.23	0.75	0.41	1.23	0.75	L	1.23	0.41	L
1.09	0.87	0.73	1.09	0.87	L	1.09	0.73	L
0.97	0.99	0.88	0.97	0.99	L	0.97	0.88	L
0.81	0.96	0.91	0.81	0.96	L	0.81	0.91	L
0.71	>1.0g	>0.99	0.71	> 1.0g	L	0.71	>0.99	L
0.71	>1.0g	>1.01	0.71	> 1.0g	L	0.71	>1.01	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 10, M6.50 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 ksi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	Fixed at footing K (k/in)	K (k/ft)	K_{ij} (k/rad)
10 A	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 B	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 C	694	1	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 D	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 E	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 F	727	1	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 G	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 H	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 I	765	1	3 x 3	2 x 2 +10ft	2 x 2	284	3403	1,700,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.0	3.0	0.01	10	9	10.00	1.34	3.98	0.34	1343	1612	61	73	694	694	225	120	919	814	574
Circular	3.0	3.0	0.02	20	9	20.00	1.77	3.98	0.45	1964	2357	89	107	694	694	225	175	919	869	519
Circular	3.0	3.0	0.03	30	9	30.00	2.23	3.98	0.56	2544	3052	116	139	694	694	225	227	919	921	467
Circular	4.0	4.0	0.01	14	10	17.78	3.98	12.57	0.32	2870	3445	130	157	727	727	225	256	952	983	471
Circular	4.0	4.0	0.02	28	10	35.56	5.65	12.57	0.45	4477	5373	204	244	727	727	225	400	952	1127	327
Circular	4.0	4.0	0.03	42	10	53.34	7.25	12.57	0.58	6080	7296	276	332	727	727	225	543	952	1270	184
Circular	5.0	5.0	0.01	18	11	28.08	9.26	30.68	0.30	5416	6499	246	295	765	765	225	483	990	1248	282
Circular	5.0	5.0	0.02	36	11	56.16	13.86	30.68	0.45	8833	10599	401	482	765	765	225	788	990	1553	-23
Circular	5.0	5.0	0.03	54	11	84.24	18.10	30.68	0.59	12082	14499	549	659	765	765	225	1078	990	1843	-313

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
10 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	31.63	2.17	1.5	520	350	3.3	0.206	168	1	202	314	73	0.23
10 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	31.63	2.47	1.5	614	350	3.8	0.240	195	1	238	369	107	0.29
10 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	31.63	2.58	1.6	711	350	4.0	0.253	206	1	276	410	139	0.34
10 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	43.63	1.77	1.3	465	350	2.4	0.150	217	1	345	477	157	0.33
10 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0092	0.0056	0.0092	0.0096	3.9	43.63	2.09	1.4	574	350	2.9	0.183	265	1	426	587	244	0.42
10 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	43.63	2.23	1.4	698	350	3.2	0.203	294	1	517	689	332	0.48
10 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	55.63	1.25	1.3	450	350	1.6	0.101	228	1	543	655	295	0.45
10 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	55.63	1.96	0.0	546	350	0.0	0.000	0	1	659	560	482	0.86
10 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	55.63	2.22	0.0	637	350	0.0	0.000	0	1	769	654	659	1.01

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Restricted System Ductility Demand μ_D
10 A	22.00	0.00015	0.00140	0.001250	1.13	68	32.6	0.041	3.57	10.10	13.67	0.23	3.80	13.90	3.8	3.7	13.67	3.7
10 B	22.00	0.00017	0.00140	0.001230	1.13	68	32.6	0.040	3.93	9.94	13.87	0.34	4.26	14.20	3.5	3.3	13.87	3.3
10 C	22.00	0.00018	0.00140	0.001222	1.13	68	32.6	0.040	4.07	9.87	13.94	0.44	4.50	14.38	3.4	3.2	13.94	3.2
10 D	22.00	0.00011	0.00109	0.000983	1.27	68	34.1	0.033	2.56	8.27	10.83	0.48	3.03	11.31	4.2	3.7	10.83	3.7
10 E	22.00	0.00012	0.00110	0.000981	1.27	68	34.1	0.033	2.83	8.26	11.09	0.74	3.58	11.83	3.9	3.3	11.09	3.3
10 F	22.00	0.00013	0.00111	0.000982	1.27	68	34.1	0.033	2.98	8.26	11.24	1.01	3.99	12.25	3.8	3.1	11.24	3.1
10 G	22.00	0.00009	0.00096	0.000876	1.41	68	35.5	0.031	2.04	7.66	9.70	0.87	2.91	10.57	4.8	3.6	9.70	3.6
10 H	22.00	0.00010	0.00088	0.000787	1.41	68	35.5	0.028	2.26	6.88	9.14	1.42	3.68	10.55	4.0	2.9	9.14	2.9
10 I	22.00	0.00010	0.00085	0.000752	1.41	68	35.5	0.027	2.36	6.58	8.94	1.94	4.30	10.88	3.8	2.5	8.94	2.5

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
10 A	0.69	13.67
10 B	0.78	13.87
10 C	1.12	13.94
10 D	1.43	10.83
10 E	>2.34	11.09
10 F	>2.58	11.24
10 G	>2.79	9.70
10 H	>3.12	9.14
10 I	>3.34	8.94

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
10 A	69.4	1527	1343	NG
10 B	69.4	1527	1964	OK
10 C	69.4	1527	2544	OK
10 D	72.7	1599	2870	OK
10 E	72.7	1599	4477	OK
10 F	72.7	1599	6080	OK
10 G	76.5	1683	5416	OK
10 H	76.5	1683	8833	OK
10 I	76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
10 A	269	791	Yes
10 B	393	802	Yes
10 C	509	806	Yes
10 D	574	656	Yes
10 E	895	672	No
10 F	1216	681	No
10 G	1083	618	No
10 H	1767	583	No
10 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.98	0.71	0.32	2.16	0.68	L	2.16	0.27	L
0.89	0.77	0.45	1.93	0.73	L	1.93	0.35	L
0.69	0.83	0.58	1.44	0.78	L	1.44	0.43	L
0.60	0.87	0.82	1.23	0.75	L	1.23	0.41	L
0.55	>1.0g	>0.95	1.09	0.87	L	1.09	0.73	L
0.50	>1.0g	>1.11	0.97	0.99	L	0.97	0.88	L
0.43	>1.0g	>1.21	0.81	0.96	L	0.81	0.91	L
0.38	>1.0g	>1.30	0.71	> 1.0g	L	0.71	>0.99	L
0.39	>1.0g	>1.35	0.71	> 1.0g	L	0.71	>1.01	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 10, M7.25 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
10 A	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 B	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 C	694	1	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 D	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 E	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 F	727	1	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 G	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 H	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 I	765	1	3 x 3	2 x 2 +10ft	2 x 2	284	3403	1,700,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.01	10	9	10	1.343	3.98	0.34	1343	1612	61	73	694	694	225	120	919	814	574
Circular	3.00	3.00	0.02	20	9	20	1.77	3.98	0.45	1964	2357	89	107	694	694	225	175	919	869	519
Circular	3.00	3.00	0.03	30	9	30	2.23	3.98	0.56	2544	3052	116	139	694	694	225	227	919	921	467
Circular	4.00	4.00	0.01	14	10	18	3.98	12.57	0.32	2870	3445	130	157	727	727	225	256	952	983	471
Circular	4.00	4.00	0.02	28	10	36	5.65	12.57	0.45	4477	5373	204	244	727	727	225	400	952	1127	327
Circular	4.00	4.00	0.03	42	10	53	7.25	12.57	0.58	6080	7296	276	332	727	727	225	543	952	1270	184
Circular	5.00	5.00	0.01	18	11	28	9.26	30.68	0.30	5416	6499	246	295	765	765	225	483	990	1248	282
Circular	5.00	5.00	0.02	36	11	56	13.86	30.68	0.45	8833	10599	401	482	765	765	225	788	990	1553	-23
Circular	5.00	5.00	0.03	54	11	84	18.10	30.68	0.59	12082	14499	549	659	765	765	225	1078	990	1843	-313

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_k (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	For shear calculation $\rho_s F_y$	$\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_d (k)	D/C Ratio
10 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	31.63	2.17	1.5	520	350	3.3	0.206	168	1	202	314	73	0.23
10 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	31.63	2.47	1.5	614	350	3.7	0.234	191	1	238	365	107	0.29
10 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	31.63	2.58	1.5	711	350	3.9	0.244	199	1	276	404	139	0.34
10 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	43.63	1.77	1.3	465	350	2.4	0.150	217	1	345	477	157	0.33
10 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0092	0.0056	0.0092	0.0096	3.9	43.63	2.09	1.4	574	350	2.9	0.183	265	1	426	587	244	0.42
10 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	43.63	2.23	1.4	698	350	3.2	0.203	294	1	517	689	332	0.48
10 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	55.63	1.25	1.3	450	350	1.6	0.101	228	1	543	655	295	0.45
10 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	55.63	1.96	1.3	546	350	2.6	0.166	377	1	659	880	482	0.55
10 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	55.63	2.22	1.4	637	350	3.1	0.197	446	1	769	1033	659	0.64

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Usable System Ductility Demand μ_D
10 A	22.00	0.000154	0.001404	0.001250	1.128	68	32.6	0.041	3.57	10.1	13.67	0.23	3.80	13.90	3.8	3.7	13.67	3.7
10 B	22.00	0.000169	0.001399	0.001230	1.128	68	32.6	0.040	3.93	9.9	13.87	0.34	4.26	14.20	3.5	3.3	13.87	3.3
10 C	22.00	0.000175	0.001397	0.001222	1.128	68	32.6	0.040	4.07	9.9	13.94	0.44	4.50	14.38	3.4	3.2	13.94	3.2
10 D	22.00	0.000110	0.001093	0.000983	1.27	68	34.1	0.033	2.56	8.3	10.83	0.48	3.03	11.31	4.2	3.7	10.83	3.7
10 E	22.00	0.000122	0.001103	0.000981	1.27	68	34.1	0.033	2.83	8.3	11.09	0.74	3.58	11.83	3.9	3.3	11.09	3.3
10 F	22.00	0.000128	0.001110	0.000982	1.27	68	34.1	0.033	2.98	8.3	11.24	1.01	3.99	12.25	3.8	3.1	11.24	3.1
10 G	22.00	0.000088	0.000964	0.000876	1.41	68	35.5	0.031	2.04	7.7	9.70	0.87	2.91	10.57	4.8	3.6	9.70	3.6
10 H	22.00	0.000097	0.000884	0.000787	1.41	68	35.5	0.028	2.26	6.9	9.14	1.42	3.68	10.55	4.0	2.9	9.14	2.9
10 I	22.00	0.000102	0.000854	0.000752	1.41	68	35.5	0.027	2.36	6.6	8.94	1.94	4.30	10.88	3.8	2.5	8.94	2.5

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
10 A	0.68	13.67
10 B	0.78	13.87
10 C	0.85	13.94
10 D	1.34	10.83
10 E	2.55	11.09
10 F	2.61	11.24
10 G	3.04	9.70
10 H	3.22	9.14
10 I	3.14	8.94

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
10 A	69.4	1527	1343	NG
10 B	69.4	1527	1964	OK
10 C	69.4	1527	2544	OK
10 D	72.7	1599	2870	OK
10 E	72.7	1599	4477	OK
10 F	72.7	1599	6080	OK
10 G	76.5	1683	5416	OK
10 H	76.5	1683	8833	OK
10 I	76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
10 A	269	791	Yes
10 B	393	802	Yes
10 C	509	806	Yes
10 D	574	656	Yes
10 E	895	672	No
10 F	1216	681	No
10 G	1083	618	No
10 H	1767	583	No
10 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.16	0.53	0.27	2.16	0.53	L	2.16	0.27	L
1.93	0.56	0.35	1.93	0.56	L	1.93	0.35	L
1.44	0.58	0.43	1.44	0.58	L	1.44	0.43	L
1.23	0.56	0.40	1.23	0.56	L	1.23	0.40	L
1.09	0.62	0.73	1.09	0.62	L	1.09	0.73	L
0.97	0.65	0.88	0.97	0.65	L	0.97	0.88	L
0.81	0.63	0.91	0.81	0.63	L	0.81	0.91	L
0.71	0.66	1.12	0.71	0.66	L	0.71	1.12	L
0.71	0.70	1.29	0.71	0.70	L	0.71	1.29	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 10, M7.25 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 ksi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	Fixed at footing K (k/in)	K (k/ft)	K_{ij} (k/rad)
10 A	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 B	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 C	694	1	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 D	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 E	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 F	727	1	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 G	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 H	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 I	765	1	3 x 3	2 x 2 +10ft	2 x 2	284	3403	1,700,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.0	3.0	0.01	10	9	10.00	1.34	3.98	0.34	1343	1612	61	73	694	694	225	120	919	814	574
Circular	3.0	3.0	0.02	20	9	20.00	1.77	3.98	0.45	1964	2357	89	107	694	694	225	175	919	869	519
Circular	3.0	3.0	0.03	30	9	30.00	2.23	3.98	0.56	2544	3052	116	139	694	694	225	227	919	921	467
Circular	4.0	4.0	0.01	14	10	17.78	3.98	12.57	0.32	2870	3445	130	157	727	727	225	256	952	983	471
Circular	4.0	4.0	0.02	28	10	35.56	5.65	12.57	0.45	4477	5373	204	244	727	727	225	400	952	1127	327
Circular	4.0	4.0	0.03	42	10	53.34	7.25	12.57	0.58	6080	7296	276	332	727	727	225	543	952	1270	184
Circular	5.0	5.0	0.01	18	11	28.08	9.26	30.68	0.30	5416	6499	246	295	765	765	225	483	990	1248	282
Circular	5.0	5.0	0.02	36	11	56.16	13.86	30.68	0.45	8833	10599	401	482	765	765	225	788	990	1553	-23
Circular	5.0	5.0	0.03	54	11	84.24	18.10	30.68	0.59	12082	14499	549	659	765	765	225	1078	990	1843	-313

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
10 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	31.63	2.17	1.5	520	350	3.3	0.206	168	1	202	314	73	0.23
10 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	31.63	2.47	1.5	614	350	3.8	0.240	195	1	238	369	107	0.29
10 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	31.63	2.58	1.6	711	350	4.0	0.253	206	1	276	410	139	0.34
10 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	43.63	1.77	1.3	465	350	2.4	0.150	217	1	345	477	157	0.33
10 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0092	0.0056	0.0092	0.0096	3.9	43.63	2.09	1.4	574	350	2.9	0.183	265	1	426	587	244	0.42
10 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	43.63	2.23	1.4	698	350	3.2	0.203	294	1	517	689	332	0.48
10 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	55.63	1.25	1.3	450	350	1.6	0.101	228	1	543	655	295	0.45
10 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	55.63	1.96	0.0	546	350	0.0	0.000	0	1	659	560	482	0.86
10 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	55.63	2.22	0.0	637	350	0.0	0.000	0	1	769	654	659	1.01

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Restricted System Ductility Demand μ_D
10 A	22.00	0.00015	0.00140	0.001250	1.13	68	32.6	0.041	3.57	10.10	13.67	0.23	3.80	13.90	3.8	3.7	13.67	3.7
10 B	22.00	0.00017	0.00140	0.001230	1.13	68	32.6	0.040	3.93	9.94	13.87	0.34	4.26	14.20	3.5	3.3	13.87	3.3
10 C	22.00	0.00018	0.00140	0.001222	1.13	68	32.6	0.040	4.07	9.87	13.94	0.44	4.50	14.38	3.4	3.2	13.94	3.2
10 D	22.00	0.00011	0.00109	0.000983	1.27	68	34.1	0.033	2.56	8.27	10.83	0.48	3.03	11.31	4.2	3.7	10.83	3.7
10 E	22.00	0.00012	0.00110	0.000981	1.27	68	34.1	0.033	2.83	8.26	11.09	0.74	3.58	11.83	3.9	3.3	11.09	3.3
10 F	22.00	0.00013	0.00111	0.000982	1.27	68	34.1	0.033	2.98	8.26	11.24	1.01	3.99	12.25	3.8	3.1	11.24	3.1
10 G	22.00	0.00009	0.00096	0.000876	1.41	68	35.5	0.031	2.04	7.66	9.70	0.87	2.91	10.57	4.8	3.6	9.70	3.6
10 H	22.00	0.00010	0.00088	0.000787	1.41	68	35.5	0.028	2.26	6.88	9.14	1.42	3.68	10.55	4.0	2.9	9.14	2.9
10 I	22.00	0.00010	0.00085	0.000752	1.41	68	35.5	0.027	2.36	6.58	8.94	1.94	4.30	10.88	3.8	2.5	8.94	2.5

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
10 A	0.63	13.67
10 B	0.69	13.87
10 C	1.40	13.94
10 D	1.90	10.83
10 E	1.86	11.09
10 F	3.14	11.24
10 G	3.30	9.70
10 H	4.42	9.14
10 I	5.59	8.94

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
10 A	69.4	1527	1343	NG
10 B	69.4	1527	1964	OK
10 C	69.4	1527	2544	OK
10 D	72.7	1599	2870	OK
10 E	72.7	1599	4477	OK
10 F	72.7	1599	6080	OK
10 G	76.5	1683	5416	OK
10 H	76.5	1683	8833	OK
10 I	76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
10 A	269	791	Yes
10 B	393	802	Yes
10 C	509	806	Yes
10 D	574	656	Yes
10 E	895	672	No
10 F	1216	681	No
10 G	1083	618	No
10 H	1767	583	No
10 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.98	0.54	0.32	2.16	0.53	L	2.16	0.27	L
0.89	0.58	0.45	1.93	0.56	L	1.93	0.35	L
0.69	0.61	0.58	1.44	0.58	L	1.44	0.43	L
0.60	0.61	0.82	1.23	0.56	L	1.23	0.40	L
0.55	0.67	1.00	1.09	0.62	L	1.09	0.73	L
0.50	0.72	1.53	0.97	0.65	L	0.97	0.88	L
0.43	0.72	1.67	0.81	0.63	L	0.81	0.91	L
0.38	0.82	2.27	0.71	0.66	L	0.71	1.12	L
0.39	0.91	2.80	0.71	0.70	L	0.71	1.29	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 10, M8.00 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
10 A	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 B	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 C	694	1	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 D	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 E	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 F	727	1	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 G	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 H	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 I	765	1	3 x 3	2 x 2 +10ft	2 x 2	284	3403	1,700,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.00	3.00	0.01	10	9	10	1.343	3.98	0.34	1343	1612	61	73	694	694	225	120	919	814	574
Circular	3.00	3.00	0.02	20	9	20	1.77	3.98	0.45	1964	2357	89	107	694	694	225	175	919	869	519
Circular	3.00	3.00	0.03	30	9	30	2.23	3.98	0.56	2544	3052	116	139	694	694	225	227	919	921	467
Circular	4.00	4.00	0.01	14	10	18	3.98	12.57	0.32	2870	3445	130	157	727	727	225	256	952	983	471
Circular	4.00	4.00	0.02	28	10	36	5.65	12.57	0.45	4477	5373	204	244	727	727	225	400	952	1127	327
Circular	4.00	4.00	0.03	42	10	53	7.25	12.57	0.58	6080	7296	276	332	727	727	225	543	952	1270	184
Circular	5.00	5.00	0.01	18	11	28	9.26	30.68	0.30	5416	6499	246	295	765	765	225	483	990	1248	282
Circular	5.00	5.00	0.02	36	11	56	13.86	30.68	0.45	8833	10599	401	482	765	765	225	788	990	1553	-23
Circular	5.00	5.00	0.03	54	11	84	18.10	30.68	0.59	12082	14499	549	659	765	765	225	1078	990	1843	-313

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_d (k)	D/C Ratio
10 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	31.63	2.17	1.5	520	350	3.3	0.206	168	1	202	314	73	0.23
10 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	31.63	2.47	1.5	614	350	3.7	0.234	191	1	238	365	107	0.29
10 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	31.63	2.58	1.5	711	350	3.9	0.244	199	1	276	404	139	0.34
10 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	43.63	1.77	1.3	465	350	2.4	0.150	217	1	345	477	157	0.33
10 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0092	0.0056	0.0092	0.0096	3.9	43.63	2.09	1.4	574	350	2.9	0.183	265	1	426	587	244	0.42
10 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	43.63	2.23	1.4	698	350	3.2	0.203	294	1	517	689	332	0.48
10 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	55.63	1.25	1.3	450	350	1.6	0.101	228	1	543	655	295	0.45
10 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	55.63	1.96	1.3	546	350	2.6	0.166	377	1	659	880	482	0.55
10 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	55.63	2.22	1.4	637	350	3.1	0.197	446	1	769	1033	659	0.64

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Usable System Ductility Demand μ_D
10 A	22.00	0.000154	0.001404	0.001250	1.128	68	32.6	0.041	3.57	10.1	13.67	0.23	3.80	13.90	3.8	3.7	13.67	3.7
10 B	22.00	0.000169	0.001399	0.001230	1.128	68	32.6	0.040	3.93	9.9	13.87	0.34	4.26	14.20	3.5	3.3	13.87	3.3
10 C	22.00	0.000175	0.001397	0.001222	1.128	68	32.6	0.040	4.07	9.9	13.94	0.44	4.50	14.38	3.4	3.2	13.94	3.2
10 D	22.00	0.000110	0.001093	0.000983	1.27	68	34.1	0.033	2.56	8.3	10.83	0.48	3.03	11.31	4.2	3.7	10.83	3.7
10 E	22.00	0.000122	0.001103	0.000981	1.27	68	34.1	0.033	2.83	8.3	11.09	0.74	3.58	11.83	3.9	3.3	11.09	3.3
10 F	22.00	0.000128	0.001110	0.000982	1.27	68	34.1	0.033	2.98	8.3	11.24	1.01	3.99	12.25	3.8	3.1	11.24	3.1
10 G	22.00	0.000088	0.000964	0.000876	1.41	68	35.5	0.031	2.04	7.7	9.70	0.87	2.91	10.57	4.8	3.6	9.70	3.6
10 H	22.00	0.000097	0.000884	0.000787	1.41	68	35.5	0.028	2.26	6.9	9.14	1.42	3.68	10.55	4.0	2.9	9.14	2.9
10 I	22.00	0.000102	0.000854	0.000752	1.41	68	35.5	0.027	2.36	6.6	8.94	1.94	4.30	10.88	3.8	2.5	8.94	2.5

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
10 A	0.73	13.67
10 B	0.81	13.87
10 C	0.86	13.94
10 D	1.24	10.83
10 E	2.05	11.09
10 F	3.24	11.24
10 G	2.33	9.70
10 H	3.85	9.14
10 I	3.73	8.94

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
10 A	69.4	1527	1343	NG
10 B	69.4	1527	1964	OK
10 C	69.4	1527	2544	OK
10 D	72.7	1599	2870	OK
10 E	72.7	1599	4477	OK
10 F	72.7	1599	6080	OK
10 G	76.5	1683	5416	OK
10 H	76.5	1683	8833	OK
10 I	76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
10 A	269	791	Yes
10 B	393	802	Yes
10 C	509	806	Yes
10 D	574	656	Yes
10 E	895	672	No
10 F	1216	681	No
10 G	1083	618	No
10 H	1767	583	No
10 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)
2.16	0.41	0.27
1.93	0.45	0.35
1.44	0.49	0.43
1.23	0.48	0.42
1.09	0.55	0.73
0.97	0.60	0.88
0.81	0.58	0.91
0.71	0.63	1.12
0.71	0.68	1.29

Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.16	0.41	L	2.16	0.27	L
1.93	0.45	L	1.93	0.35	L
1.44	0.49	L	1.44	0.43	L
1.23	0.48	L	1.23	0.42	L
1.09	0.55	L	1.09	0.73	L
0.97	0.60	L	0.97	0.88	L
0.81	0.58	L	0.81	0.91	L
0.71	0.63	L	0.71	1.12	L
0.71	0.68	L	0.71	1.29	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 10, M8.00 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 ksi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	24.00 ft
h_{col} =	22.00 ft
b_{bent} =	44.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	Fixed at footing K (k/in)	K (k/ft)	K_{ij} (k/rad)
10 A	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 B	694	0	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 C	694	1	3 x 2	2 x 2	2 x 2 -10ft	264	3173	700,000
10 D	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 E	727	0	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 F	727	1	3 x 2	2 x 2	2 x 2 -10ft	273	3279	700,000
10 G	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 H	765	0	3 x 2	2 x 2	2 x 2 -10ft	284	3403	700,000
10 I	765	1	3 x 3	2 x 2 +10ft	2 x 2	284	3403	1,700,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Circular	3.0	3.0	0.01	10	9	10.00	1.34	3.98	0.34	1343	1612	61	73	694	694	225	120	919	814	574
Circular	3.0	3.0	0.02	20	9	20.00	1.77	3.98	0.45	1964	2357	89	107	694	694	225	175	919	869	519
Circular	3.0	3.0	0.03	30	9	30.00	2.23	3.98	0.56	2544	3052	116	139	694	694	225	227	919	921	467
Circular	4.0	4.0	0.01	14	10	17.78	3.98	12.57	0.32	2870	3445	130	157	727	727	225	256	952	983	471
Circular	4.0	4.0	0.02	28	10	35.56	5.65	12.57	0.45	4477	5373	204	244	727	727	225	400	952	1127	327
Circular	4.0	4.0	0.03	42	10	53.34	7.25	12.57	0.58	6080	7296	276	332	727	727	225	543	952	1270	184
Circular	5.0	5.0	0.01	18	11	28.08	9.26	30.68	0.30	5416	6499	246	295	765	765	225	483	990	1248	282
Circular	5.0	5.0	0.02	36	11	56.16	13.86	30.68	0.45	8833	10599	401	482	765	765	225	788	990	1553	-23
Circular	5.0	5.0	0.03	54	11	84.24	18.10	30.68	0.59	12082	14499	549	659	765	765	225	1078	990	1843	-313

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
10 A	1018	804	814	6	0.44	0.69	6.50	31.25	0.0080	0.0060	0.0085	0.0020	0.0085	0.0087	3.8	31.63	2.17	1.5	520	350	3.3	0.206	168	1	202	314	73	0.23
10 B	1018	804	814	6	0.44	0.69	5.50	31.25	0.0080	0.0061	0.0099	0.0040	0.0099	0.0102	3.5	31.63	2.47	1.5	614	350	3.8	0.240	195	1	238	369	107	0.29
10 C	1018	804	814	6	0.44	0.69	4.75	31.25	0.0080	0.0063	0.0114	0.0060	0.0114	0.0119	3.4	31.63	2.58	1.6	711	350	4.0	0.253	206	1	276	410	139	0.34
10 D	1810	1521	1448	6	0.44	0.69	5.25	43.25	0.0057	0.0054	0.0077	0.0028	0.0077	0.0078	4.2	43.63	1.77	1.3	465	350	2.4	0.150	217	1	345	477	157	0.33
10 E	1810	1521	1448	6	0.44	0.69	4.25	43.25	0.0057	0.0056	0.0092	0.0056	0.0092	0.0096	3.9	43.63	2.09	1.4	574	350	2.9	0.183	265	1	426	587	244	0.42
10 F	1810	1521	1448	6	0.44	0.69	3.50	43.25	0.0057	0.0058	0.0108	0.0084	0.0108	0.0116	3.8	43.63	2.23	1.4	698	350	3.2	0.203	294	1	517	689	332	0.48
10 G	2827	2463	2262	6	0.44	0.69	4.25	55.25	0.0044	0.0051	0.0074	0.0036	0.0074	0.0075	4.8	55.63	1.25	1.3	450	350	1.6	0.101	228	1	543	655	295	0.45
10 H	2827	2463	2262	6	0.44	0.69	3.50	55.25	0.0044	0.0054	0.0090	0.0072	0.0090	0.0091	4.0	55.63	1.96	0.0	546	350	0.0	0.000	0	1	659	560	482	0.86
10 I	2827	2463	2262	6	0.44	0.69	3.00	55.25	0.0044	0.0056	0.0106	0.0108	0.0108	0.0106	3.8	55.63	2.22	0.0	637	350	0.0	0.000	0	1	769	654	659	1.01

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 5 Δ_c	Restricted System Ductility Demand μ_D
10 A	22.00	0.00015	0.00140	0.001250	1.13	68	32.6	0.041	3.57	10.10	13.67	0.23	3.80	13.90	3.8	3.7	13.67	3.7
10 B	22.00	0.00017	0.00140	0.001230	1.13	68	32.6	0.040	3.93	9.94	13.87	0.34	4.26	14.20	3.5	3.3	13.87	3.3
10 C	22.00	0.00018	0.00140	0.001222	1.13	68	32.6	0.040	4.07	9.87	13.94	0.44	4.50	14.38	3.4	3.2	13.94	3.2
10 D	22.00	0.00011	0.00109	0.000983	1.27	68	34.1	0.033	2.56	8.27	10.83	0.48	3.03	11.31	4.2	3.7	10.83	3.7
10 E	22.00	0.00012	0.00110	0.000981	1.27	68	34.1	0.033	2.83	8.26	11.09	0.74	3.58	11.83	3.9	3.3	11.09	3.3
10 F	22.00	0.00013	0.00111	0.000982	1.27	68	34.1	0.033	2.98	8.26	11.24	1.01	3.99	12.25	3.8	3.1	11.24	3.1
10 G	22.00	0.00009	0.00096	0.000876	1.41	68	35.5	0.031	2.04	7.66	9.70	0.87	2.91	10.57	4.8	3.6	9.70	3.6
10 H	22.00	0.00010	0.00088	0.000787	1.41	68	35.5	0.028	2.26	6.88	9.14	1.42	3.68	10.55	4.0	2.9	9.14	2.9
10 I	22.00	0.00010	0.00085	0.000752	1.41	68	35.5	0.027	2.36	6.58	8.94	1.94	4.30	10.88	3.8	2.5	8.94	2.5

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
10 A	0.66	13.67
10 B	0.69	13.87
10 C	1.17	13.94
10 D	1.52	10.83
10 E	2.26	11.09
10 F	3.31	11.24
10 G	3.48	9.70
10 H	4.54	9.14
10 I	5.76	8.94

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{req} (k-ft)	check
10 A	69.4	1527	1343	NG
10 B	69.4	1527	1964	OK
10 C	69.4	1527	2544	OK
10 D	72.7	1599	2870	OK
10 E	72.7	1599	4477	OK
10 F	72.7	1599	6080	OK
10 G	76.5	1683	5416	OK
10 H	76.5	1683	8833	OK
10 I	76.5	1683	12082	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
10 A	269	791	Yes
10 B	393	802	Yes
10 C	509	806	Yes
10 D	574	656	Yes
10 E	895	672	No
10 F	1216	681	No
10 G	1083	618	No
10 H	1767	583	No
10 I	2416	570	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
0.98	0.43	0.32	2.16	0.41	L	2.16	0.27	L
0.89	0.48	0.45	1.93	0.45	L	1.93	0.35	L
0.69	0.53	0.58	1.44	0.49	L	1.44	0.43	L
0.60	0.54	0.82	1.23	0.48	L	1.23	0.42	L
0.55	0.64	1.03	1.09	0.55	L	1.09	0.73	L
0.50	0.71	1.53	0.97	0.60	L	0.97	0.88	L
0.43	0.71	1.67	0.81	0.58	L	0.81	0.91	L
0.38	0.81	2.27	0.71	0.63	L	0.71	1.12	L
0.39	0.90	2.80	0.71	0.68	L	0.71	1.29	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 11, M6.50 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	53.31 ft
h_{col} =	50.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
11 A	1950	13829	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
11 B	2040	20168	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 C	2040	27797	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 D	2133	19523	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 E	2133	32923	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 F	2237	28310	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 G	2096	16337	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
11 H	2096	26163	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 I	2096	35165	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 J	2216	31032	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000
11 K	2216	52962	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 L	2216	74019	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Oblong	4.00	6.00	0.03	72	10	91	14.4	23.23	0.62	11524	13829	461	553	1796	1950	418	0	2368	1950	1950
Circular	6.00	6.00	0.02	52	11	81	31.0	63.62	0.49	16807	20168	672	807	1828	2040	418	0	2458	2040	2040
Circular	6.00	6.00	0.03	78	11	122	39.7	63.62	0.62	23164	27797	927	1112	1828	2040	418	0	2458	2040	2040
Circular	7.00	7.00	0.01	36	11	56	39.1	117.86	0.33	16269	19523	651	781	1844	2133	418	0	2551	2133	2133
Circular	7.00	7.00	0.02	72	11	112	57.5	117.86	0.49	27436	32923	1097	1317	1844	2133	418	0	2551	2133	2133
Circular	8.00	8.00	0.01	32	14	72	63.5	201.1	0.32	23592	28310	944	1132	1860	2237	418	0	2655	2237	2237
Oblong	5.50	8.25	0.01	36	11	56	27.9	83.05	0.34	13614	16337	545	653	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.02	72	11	112	41.0	83.05	0.49	21803	26163	872	1047	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.03	108	11	168	50.2	83.05	0.60	29304	35165	1172	1407	1804	2096	418	0	2514	2096	2096
Oblong	7.00	10.50	0.01	40	14	90	66.0	217.9	0.30	25860	31032	1034	1241	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.02	80	14	180	102.7	217.9	0.47	44135	52962	1765	2118	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.03	120	14	270	137.7	217.9	0.63	61682	74019	2467	2961	1744	2216	418	0	2634	2216	2216

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
11 A	2962	2522	2369	7	0.60	0.94	5.00	43.13	0.0052	0.0056	0.0107	0.0072	0.0107	0.0111	3.9	43.56	2.07	1.4	668	350	2.9	0.184	437	2	985	1209	553	0.46
11 B	4072	3632	3257	7	0.60	0.94	3.25	67.13	0.0036	0.0053	0.0089	0.0104	0.0104	0.0110	4.3	67.56	1.68	1.3	660	350	2.2	0.140	455	1	1176	1386	807	0.58
11 C	4072	3632	3257	8	0.79	1.24	3.00	67.00	0.0036	0.0053	0.0102	0.0156	0.0156	0.0157	4.3	67.50	1.72	1.3	943	350	2.3	0.143	466	1	1675	1820	1112	0.61
11 D	5542	5027	4433	8	0.79	1.24	5.50	79.00	0.0031	0.0050	0.0072	0.0072	0.0072	0.0073	4.4	79.50	1.60	1.2	436	350	2.0	0.126	558	1	1076	1389	781	0.56
11 E	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0050	0.0085	0.0144	0.0144	0.0145	4.4	79.50	1.65	1.2	873	350	2.0	0.129	572	1	2152	2316	1317	0.57
11 F	7238	6648	5791	8	0.79	1.24	4.75	91.00	0.0027	0.0048	0.0070	0.0064	0.0070	0.0073	4.4	91.50	1.56	1.2	439	350	1.9	0.117	680	1	1434	1797	1132	0.63
11 G	5599	4964	4479	7	0.60	0.94	5.25	61.13	0.0038	0.0049	0.0072	0.0036	0.0072	0.0075	4.2	61.56	1.78	1.2	449	350	2.2	0.139	623	2	1326	1657	653	0.39
11 H	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0049	0.0085	0.0072	0.0085	0.0087	4.3	61.56	1.75	1.2	524	350	2.2	0.136	611	2	1547	1834	1047	0.57
11 I	5599	4964	4479	7	0.60	0.94	3.50	61.13	0.0038	0.0049	0.0098	0.0108	0.0108	0.0112	4.2	61.56	1.78	1.2	673	350	2.2	0.139	622	2	1989	2219	1407	0.63
11 J	9070	8225	7256	7	0.60	0.94	4.25	79.13	0.0031	0.0046	0.0068	0.0040	0.0068	0.0071	4.4	79.56	1.63	1.2	428	350	1.9	0.119	860	2	2117	2531	1241	0.49
11 K	9070	8225	7256	7	0.60	0.94	3.50	79.13	0.0031	0.0046	0.0081	0.0080	0.0081	0.0087	4.5	79.56	1.54	1.2	520	350	1.8	0.112	814	2	2571	2877	2118	0.74
11 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0094	0.0120	0.0120	0.0123	4.5	79.50	1.47	1.2	738	350	1.7	0.107	780	2	3643	3759	2961	0.79

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
11 A	50.00	0.000121	0.001142	0.001021	1.27	68	37.0	0.038	7.24	21.3	28.49	0.42	7.65	28.90	3.9	3.8	28.49	3.8
11 B	50.00	0.000081	0.000856	0.000775	1.41	68	38.4	0.030	4.87	16.7	21.58	0.52	5.39	22.10	4.4	4.1	21.06	4.0
11 C	50.00	0.000088	0.00099	0.000897	1.41	68	38.4	0.034	5.30	19.3	24.63	0.49	5.80	25.13	4.6	4.3	22.70	4.0
11 D	50.00	0.00006	0.00071	0.000646	1.41	68	38.4	0.025	3.78	13.9	17.71	0.50	4.29	18.21	4.7	4.2	16.65	4.0
11 E	50.00	0.00007	0.00094	0.000868	1.41	68	38.4	0.033	4.33	18.7	23.04	0.52	4.85	23.56	5.3	4.9	18.89	4.0
11 F	50.00	0.00006	0.00067	0.000615	1.693	68	41.3	0.025	3.37	14.2	17.55	0.50	3.88	18.05	5.2	4.7	15.00	4.0
11 G	50.00	0.00007	0.00096	0.000890	1.41	68	38.4	0.034	4.39	19.2	23.57	0.32	4.71	23.90	5.4	5.1	18.53	4.0
11 H	50.00	0.00008	0.00087	0.000791	1.41	68	38.4	0.030	4.80	17.1	21.85	0.41	5.21	22.26	4.6	4.3	20.43	4.0
11 I	50.00	0.00009	0.00094	0.000853	1.41	68	38.4	0.033	5.31	18.4	23.68	0.40	5.70	24.08	4.5	4.2	22.42	4.0
11 J	50.00	0.00006	0.00083	0.000766	1.693	68	41.3	0.032	3.59	17.7	21.25	0.45	4.04	21.71	5.9	5.4	15.70	4.0
11 K	50.00	0.00006	0.00077	0.000704	1.693	68	41.3	0.029	3.87	16.2	20.12	0.60	4.47	20.72	5.2	4.6	17.30	4.0
11 L	50.00	0.00007	0.00069	0.000619	1.693	68	41.3	0.026	4.04	14.3	18.31	0.84	4.88	19.14	4.5	3.9	18.31	3.9

6. Displacement Demand

	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
11 A	>1.01	28.49
11 B	>1.34	21.06
11 C	>1.05	22.70
11 D	>1.49	16.65
11 E	>1.07	18.89
11 F	>1.27	15.00
11 G	>1.02	18.53
11 H	>0.96	20.43
11 I	>0.75	22.42
11 J	>1.07	15.70
11 K	>0.94	17.30
11 L	>0.99	18.31

7. Minimum Lateral Strength Check

	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
11 A	195.0	4876	11524	OK
11 B	204.0	5100	16807	OK
11 C	204.0	5100	23164	OK
11 D	213.3	5332	16269	OK
11 E	213.3	5332	27436	OK
11 F	223.7	5592	23592	OK
11 G	209.6	5239	13614	OK
11 H	209.6	5239	21803	OK
11 I	209.6	5239	29304	OK
11 J	221.6	5541	25860	OK
11 K	221.6	5541	44135	OK
11 L	221.6	5541	61682	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
11 A	2305	2315	Yes
11 B	3361	1834	No
11 C	4633	2094	No
11 D	3254	1574	No
11 E	5487	2047	No
11 F	4718	1636	No
11 G	2723	2058	No
11 H	4361	1908	No
11 I	5861	2068	No
11 J	5172	1963	No
11 K	8827	1858	No
11 L	12336	1691	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.98	>1.0g	>0.58	1.98	> 1.0g	L	1.98	>0.58	L
1.48	>1.0g	>0.80	1.48	> 1.0g	L	1.48	>0.80	L
1.30	>1.0g	>0.89	1.30	> 1.0g	L	1.30	>0.89	L
1.38	>1.0g	>0.84	1.38	> 1.0g	L	1.38	>0.84	L
1.14	>1.0g	>0.96	1.14	> 1.0g	L	1.14	>0.96	L
1.12	>1.0g	>0.96	1.12	> 1.0g	L	1.12	>0.96	L
1.52	>1.0g	>0.77	1.52	> 1.0g	L	1.52	>0.77	L
1.28	>1.0g	>0.89	1.28	> 1.0g	L	1.28	>0.89	L
1.15	>1.0g	>0.95	1.15	> 1.0g	L	1.15	>0.95	L
1.10	>1.0g	>0.96	1.10	> 1.0g	L	1.10	>0.96	L
0.91	>1.0g	>1.06	0.91	> 1.0g	L	0.91	>1.06	L
0.84	>1.0g	>1.10	0.84	> 1.0g	L	0.84	>1.10	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 11, M6.50 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	53.31 ft
h_{col} =	50.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
11 A	1950	14387	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
11 B	2040	20168	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 C	2040	27797	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 D	2133	19523	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 E	2133	32923	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 F	2237	28310	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 G	2096	23776	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
11 H	2096	37804	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 I	2096	51334	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 J	2216	45628	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000
11 K	2216	76203	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 L	2216	107323	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Oblong	4.00	6.00	0.03	72	10	91	29.9	49.13	0.61	11989	14387	225	270	1796	1950	418	0	2368	1950	1950
Circular	6.00	6.00	0.02	52	11	81	31.0	63.62	0.49	16807	20168	315	378	1828	2040	418	0	2458	2040	2040
Circular	6.00	6.00	0.03	78	11	122	39.7	63.62	0.62	23164	27797	435	521	1828	2040	418	0	2458	2040	2040
Circular	7.00	7.00	0.01	36	11	56	39.1	117.86	0.33	16269	19523	305	366	1844	2133	418	0	2551	2133	2133
Circular	7.00	7.00	0.02	72	11	112	57.5	117.86	0.49	27436	32923	515	618	1844	2133	418	0	2551	2133	2133
Circular	8.00	8.00	0.01	32	14	72	63.5	201.1	0.32	23592	28310	443	531	1860	2237	418	0	2655	2237	2237
Oblong	5.50	8.25	0.01	36	11	56	56.5	175.62	0.32	19813	23776	372	446	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.02	72	11	112	82.8	175.62	0.47	31503	37804	591	709	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.03	108	11	168	105.1	175.62	0.60	42779	51334	802	963	1804	2096	418	0	2514	2096	2096
Oblong	7.00	10.50	0.01	40	14	90	133.9	460.8	0.29	38023	45628	713	856	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.02	80	14	180	205.3	460.8	0.45	63502	76203	1191	1429	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.03	120	14	270	271.3	460.8	0.59	89436	107323	1678	2013	1744	2216	418	0	2634	2216	2216

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
11 A	2962	2522	2369	7	0.60	0.94	5.00	43.13	0.0052	0.0056	0.0107	0.0072	0.0107	0.0111	3.3	67.563	2.71	1.4	668	350	3.8	0.242	574	2	1528	1787	270	0.15
11 B	4072	3632	3257	7	0.60	0.94	3.25	67.13	0.0036	0.0053	0.0089	0.0104	0.0104	0.0110	3.8	67.563	2.22	1.3	660	350	2.9	0.185	601	1	1176	1510	378	0.25
11 C	4072	3632	3257	8	0.79	1.24	3.00	67.00	0.0036	0.0053	0.0102	0.0156	0.0156	0.0157	4.0	67.500	2.04	1.3	943	350	2.7	0.170	553	1	1675	1894	521	0.28
11 D	5542	5027	4433	8	0.79	1.24	5.50	79.00	0.0031	0.0050	0.0072	0.0072	0.0072	0.0073	4.0	79.500	2.02	1.2	436	350	2.5	0.158	701	1	1076	1511	366	0.24
11 E	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0050	0.0085	0.0144	0.0144	0.0145	4.1	79.500	1.93	1.2	873	350	2.4	0.152	673	1	2152	2402	618	0.26
11 F	7238	6648	5791	8	0.79	1.24	4.75	91.00	0.0027	0.0048	0.0070	0.0064	0.0070	0.0073	4.1	91.500	1.92	1.2	439	350	2.3	0.145	838	1	1434	1931	531	0.28
11 G	5599	4964	4479	7	0.60	0.94	5.25	61.13	0.0038	0.0049	0.0072	0.0036	0.0072	0.0075	4.1	94.563	1.92	1.2	449	350	2.4	0.150	672	2	2037	2302	446	0.19
11 H	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0049	0.0085	0.0072	0.0085	0.0087	3.7	94.563	2.30	1.2	524	350	2.8	0.180	806	2	2377	2705	709	0.26
11 I	5599	4964	4479	7	0.60	0.94	3.50	61.13	0.0038	0.0049	0.0098	0.0108	0.0108	0.0112	3.6	94.563	2.36	1.2	673	350	2.9	0.184	825	2	3056	3299	963	0.29
11 J	9070	8225	7256	7	0.60	0.94	4.25	79.13	0.0031	0.0046	0.0068	0.0040	0.0068	0.0071	4.1	121.563	1.86	1.2	428	350	2.1	0.136	983	2	3235	3585	856	0.24
11 K	9070	8225	7256	7	0.60	0.94	3.50	79.13	0.0031	0.0046	0.0081	0.0080	0.0081	0.0087	4.0	121.563	2.03	1.2	520	350	2.3	0.148	1075	2	3928	4252	1429	0.34
11 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0094	0.0120	0.0120	0.0123	4.0	121.500	1.96	1.2	738	350	2.3	0.143	1035	2	5567	5612	2013	0.36

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
11 A	53.31	0.000085	0.000769	0.000684	1.27	68	64.1	0.044	11.64	26.64	38.28	0.18	11.82	38.46	3.3	3.3	38.28	3.3
11 B	53.31	0.000081	0.00086	0.000775	1.41	68	65.6	0.051	11.08	30.83	41.91	0.22	11.30	42.13	3.8	3.7	41.91	3.7
11 C	53.31	0.000088	0.00099	0.000897	1.41	68	65.6	0.059	12.06	35.68	47.74	0.22	12.28	47.95	4.0	3.9	47.74	3.9
11 D	53.31	0.00006	0.00071	0.000646	1.41	68	65.6	0.042	8.61	25.70	34.31	0.21	8.82	34.52	4.0	3.9	34.31	3.9
11 E	53.31	0.00007	0.00094	0.000868	1.41	68	65.6	0.057	9.85	34.53	44.38	0.23	10.08	44.61	4.5	4.4	40.09	4.0
11 F	53.31	0.00006	0.00067	0.000615	1.69	68	68.4	0.042	7.67	25.48	33.15	0.22	7.89	33.37	4.3	4.2	31.33	4.0
11 G	53.31	0.00005	0.00066	0.000607	1.41	68	65.6	0.040	7.27	24.14	31.41	0.20	7.47	31.61	4.3	4.2	29.68	4.0
11 H	53.31	0.00006	0.00060	0.000538	1.41	68	65.6	0.035	7.93	21.40	29.33	0.26	8.19	29.59	3.7	3.6	29.33	3.6
11 I	53.31	0.00006	0.00062	0.000558	1.41	68	65.6	0.037	8.41	22.22	30.63	0.26	8.67	30.89	3.6	3.6	30.63	3.6
11 J	53.31	0.00004	0.00056	0.000514	1.69	68	68.4	0.035	5.95	21.32	27.27	0.29	6.24	27.56	4.6	4.4	24.67	4.0
11 K	53.31	0.00005	0.00050	0.000455	1.69	68	68.4	0.031	6.34	18.84	25.18	0.39	6.73	25.57	4.0	3.8	25.18	3.8
11 L	53.31	0.00005	0.00054	0.000494	1.69	68	68.4	0.034	6.72	20.46	27.18	0.55	7.26	27.73	4.0	3.8	27.18	3.8

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
11 A	>1.01	38.28
11 B	>1.34	41.91
11 C	>1.05	47.74
11 D	>1.49	34.31
11 E	>1.07	40.09
11 F	>1.27	31.33
11 G	>1.02	29.68
11 H	>0.96	29.33
11 I	>0.75	30.63
11 J	>1.07	24.67
11 K	>0.94	25.18
11 L	>0.99	27.18

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
11 A	179.6	9574	11989	OK
11 B	182.8	9745	16807	OK
11 C	182.8	9745	23164	OK
11 D	184.4	9830	16269	OK
11 E	184.4	9830	27436	OK
11 F	186.0	9916	23592	OK
11 G	180.4	9617	19813	OK
11 H	180.4	9617	31503	OK
11 I	180.4	9617	42779	OK
11 J	174.4	9297	38023	OK
11 K	174.4	9297	63502	OK
11 L	174.4	9297	89436	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
11 A	2398	5730	Yes
11 B	3361	6384	Yes
11 C	4633	7272	Yes
11 D	3254	5272	Yes
11 E	5487	6160	Yes
11 F	4718	4856	Yes
11 G	3963	4462	Yes
11 H	6301	4410	No
11 I	8556	4604	No
11 J	7605	3585	No
11 K	12700	3659	No
11 L	17887	3950	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.09	>1.0g	>0.54	1.98	> 1.0g	L	1.98	>0.58	L
2.06	>1.0g	>0.54	1.48	> 1.0g	L	1.48	>0.80	L
1.85	>1.0g	>0.63	1.30	> 1.0g	L	1.30	>0.89	L
1.94	>1.0g	>0.59	1.38	> 1.0g	L	1.38	>0.84	L
1.65	>1.0g	>0.70	1.14	> 1.0g	L	1.14	>0.96	L
1.62	>1.0g	>0.71	1.12	> 1.0g	L	1.12	>0.96	L
1.69	>1.0g	>0.69	1.52	> 1.0g	L	1.52	>0.77	L
1.47	>1.0g	>0.78	1.28	> 1.0g	L	1.28	>0.89	L
1.30	>1.0g	>0.85	1.15	> 1.0g	L	1.15	>0.95	L
1.29	>1.0g	>0.84	1.10	> 1.0g	L	1.10	>0.96	L
1.06	>1.0g	>0.94	0.91	> 1.0g	L	0.91	>1.06	L
0.97	>1.0g	>0.99	0.84	> 1.0g	L	0.84	>1.10	L

Column Design, Displacement Capacity, and Displacement Demand for Model No. 11, M7.25 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	53.31 ft
h_{col} =	50.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
11 A	1950	13829	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
11 B	2040	20168	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 C	2040	27797	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 D	2133	19523	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 E	2133	32923	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 F	2237	28310	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 G	2096	16337	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
11 H	2096	26163	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 I	2096	35165	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 J	2216	31032	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000
11 K	2216	52962	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 L	2216	74019	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Oblong	4.00	6.00	0.03	72	10	91	14.4	23.23	0.62	11524	13829	461	553	1796	1950	418	0	2368	1950	1950
Circular	6.00	6.00	0.02	52	11	81	31.0	63.62	0.49	16807	20168	672	807	1828	2040	418	0	2458	2040	2040
Circular	6.00	6.00	0.03	78	11	122	39.7	63.62	0.62	23164	27797	927	1112	1828	2040	418	0	2458	2040	2040
Circular	7.00	7.00	0.01	36	11	56	39.1	117.86	0.33	16269	19523	651	781	1844	2133	418	0	2551	2133	2133
Circular	7.00	7.00	0.02	72	11	112	57.5	117.86	0.49	27436	32923	1097	1317	1844	2133	418	0	2551	2133	2133
Circular	8.00	8.00	0.01	32	14	72	63.5	201.1	0.32	23592	28310	944	1132	1860	2237	418	0	2655	2237	2237
Oblong	5.50	8.25	0.01	36	11	56	27.9	83.05	0.34	13614	16337	545	653	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.02	72	11	112	41.0	83.05	0.49	21803	26163	872	1047	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.03	108	11	168	50.2	83.05	0.60	29304	35165	1172	1407	1804	2096	418	0	2514	2096	2096
Oblong	7.00	10.50	0.01	40	14	90	66.0	217.9	0.30	25860	31032	1034	1241	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.02	80	14	180	102.7	217.9	0.47	44135	52962	1765	2118	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.03	120	14	270	137.7	217.9	0.63	61682	74019	2467	2961	1744	2216	418	0	2634	2216	2216

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
11 A	2962	2522	2369	7	0.60	0.94	5.00	43.13	0.0052	0.0056	0.0107	0.0072	0.0107	0.0111	3.9	43.56	2.07	1.4	668	350	2.9	0.184	437	2	985	1209	553	0.46
11 B	4072	3632	3257	7	0.60	0.94	3.25	67.13	0.0036	0.0053	0.0089	0.0104	0.0104	0.0110	4.3	67.56	1.68	1.3	660	350	2.2	0.140	455	1	1176	1386	807	0.58
11 C	4072	3632	3257	8	0.79	1.24	3.00	67.00	0.0036	0.0053	0.0102	0.0156	0.0156	0.0157	4.3	67.50	1.72	1.3	943	350	2.3	0.143	466	1	1675	1820	1112	0.61
11 D	5542	5027	4433	8	0.79	1.24	5.50	79.00	0.0031	0.0050	0.0072	0.0072	0.0072	0.0073	4.4	79.50	1.60	1.2	436	350	2.0	0.126	558	1	1076	1389	781	0.56
11 E	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0050	0.0085	0.0144	0.0144	0.0145	4.4	79.50	1.65	1.2	873	350	2.0	0.129	572	1	2152	2316	1317	0.57
11 F	7238	6648	5791	8	0.79	1.24	4.75	91.00	0.0027	0.0048	0.0070	0.0064	0.0070	0.0073	4.4	91.50	1.56	1.2	439	350	1.9	0.117	680	1	1434	1797	1132	0.63
11 G	5599	4964	4479	7	0.60	0.94	5.25	61.13	0.0038	0.0049	0.0072	0.0036	0.0072	0.0075	4.2	61.56	1.78	1.2	449	350	2.2	0.139	623	2	1326	1657	653	0.39
11 H	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0049	0.0085	0.0072	0.0085	0.0087	4.3	61.56	1.75	1.2	524	350	2.2	0.136	611	2	1547	1834	1047	0.57
11 I	5599	4964	4479	7	0.60	0.94	3.50	61.13	0.0038	0.0049	0.0098	0.0108	0.0108	0.0112	4.2	61.56	1.78	1.2	673	350	2.2	0.139	622	2	1989	2219	1407	0.63
11 J	9070	8225	7256	7	0.60	0.94	4.25	79.13	0.0031	0.0046	0.0068	0.0040	0.0068	0.0071	4.4	79.56	1.63	1.2	428	350	1.9	0.119	860	2	2117	2531	1241	0.49
11 K	9070	8225	7256	7	0.60	0.94	3.50	79.13	0.0031	0.0046	0.0081	0.0080	0.0081	0.0087	4.5	79.56	1.54	1.2	520	350	1.8	0.112	814	2	2571	2877	2118	0.74
11 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0094	0.0120	0.0120	0.0123	4.5	79.50	1.47	1.2	738	350	1.7	0.107	780	2	3643	3759	2961	0.79

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
11 A	50.00	0.000121	0.001142	0.001021	1.27	68	37.0	0.038	7.24	21.3	28.49	0.42	7.65	28.90	3.9	3.8	28.49	3.8
11 B	50.00	0.000081	0.000856	0.000775	1.41	68	38.4	0.030	4.87	16.7	21.58	0.52	5.39	22.10	4.4	4.1	21.06	4.0
11 C	50.00	0.000088	0.00099	0.000897	1.41	68	38.4	0.034	5.30	19.3	24.63	0.49	5.80	25.13	4.6	4.3	22.70	4.0
11 D	50.00	0.00006	0.00071	0.000646	1.41	68	38.4	0.025	3.78	13.9	17.71	0.50	4.29	18.21	4.7	4.2	16.65	4.0
11 E	50.00	0.00007	0.00094	0.000868	1.41	68	38.4	0.033	4.33	18.7	23.04	0.52	4.85	23.56	5.3	4.9	18.89	4.0
11 F	50.00	0.00006	0.00067	0.000615	1.693	68	41.3	0.025	3.37	14.2	17.55	0.50	3.88	18.05	5.2	4.7	15.00	4.0
11 G	50.00	0.00007	0.00096	0.000890	1.41	68	38.4	0.034	4.39	19.2	23.57	0.32	4.71	23.90	5.4	5.1	18.53	4.0
11 H	50.00	0.00008	0.00087	0.000791	1.41	68	38.4	0.030	4.80	17.1	21.85	0.41	5.21	22.26	4.6	4.3	20.43	4.0
11 I	50.00	0.00009	0.00094	0.000853	1.41	68	38.4	0.033	5.31	18.4	23.68	0.40	5.70	24.08	4.5	4.2	22.42	4.0
11 J	50.00	0.00006	0.00083	0.000766	1.693	68	41.3	0.032	3.59	17.7	21.25	0.45	4.04	21.71	5.9	5.4	15.70	4.0
11 K	50.00	0.00006	0.00077	0.000704	1.693	68	41.3	0.029	3.87	16.2	20.12	0.60	4.47	20.72	5.2	4.6	17.30	4.0
11 L	50.00	0.00007	0.00069	0.000619	1.693	68	41.3	0.026	4.04	14.3	18.31	0.84	4.88	19.14	4.5	3.9	18.31	3.9

6. Displacement Demand

Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1.30	28.49
1.79	21.06
2.02	22.70
1.25	16.65
1.31	18.89
0.85	18.53
1.21	20.43
1.36	22.42
1.58	15.70
1.66	17.30
2.08	18.31

7. Minimum Lateral Strength Check

$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
195.0	4876	11524	OK
204.0	5100	16807	OK
204.0	5100	23164	OK
213.3	5332	16269	OK
213.3	5332	27436	OK
223.7	5592	23592	OK
209.6	5239	13614	OK
209.6	5239	21803	OK
209.6	5239	29304	OK
221.6	5541	25860	OK
221.6	5541	44135	OK
221.6	5541	61682	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
11 A	2305	2315	Yes
11 B	3361	1834	No
11 C	4633	2094	No
11 D	3254	1574	No
11 E	5487	2047	No
11 F	4718	1636	No
11 G	2723	2058	No
11 H	4361	1908	No
11 I	5861	2068	No
11 J	5172	1963	No
11 K	8827	1858	No
11 L	12336	1691	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.98	0.75	0.76	1.98	0.75	L	1.98	0.76	L
1.48	0.74	1.02	1.48	0.74	L	2.06	0.93	T
1.30	0.81	1.42	1.30	0.81	L	1.85	1.28	T
1.38	0.69	0.93	1.38	0.69	L	1.94	0.83	T
1.14	0.80	1.53	1.14	0.80	L	1.65	1.28	T
1.12	0.72	1.26	1.12	0.72	L	1.62	1.02	T
1.52	0.69	0.82	1.52	0.69	L	1.52	0.82	L
1.28	0.77	1.28	1.28	0.77	L	1.47	1.17	T
1.15	0.85	1.72	1.15	0.85	L	1.30	1.51	T
1.10	0.74	1.32	1.10	0.74	L	1.29	1.20	T
0.91	0.88	2.15	1.06	0.86	T	1.06	1.78	T
0.84	1.00	2.79	0.97	0.95	T	0.97	2.31	T

Column Design, Displacement Capacity, and Displacement Demand for Model No. 11, M7.25 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	53.31 ft
h_{col} =	50.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
11 A	1950	20213	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
11 B	2040	20168	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 C	2040	27797	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 D	2133	19523	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 E	2133	32923	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 F	2237	28310	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 G	2096	23776	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
11 H	2096	37804	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 I	2096	51334	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 J	2216	45628	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000
11 K	2216	76203	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 L	2216	107323	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Oblong	4.00	6.00	0.03	72	10	91	30.0	49.13	0.61	16844	20213	316	379	1796	1950	418	0	2368	1950	1950
Circular	6.00	6.00	0.02	52	11	81	31.0	63.62	0.49	16807	20168	315	378	1828	2040	418	0	2458	2040	2040
Circular	6.00	6.00	0.03	78	11	122	39.7	63.62	0.62	23164	27797	435	521	1828	2040	418	0	2458	2040	2040
Circular	7.00	7.00	0.01	36	11	56	39.1	117.86	0.33	16269	19523	305	366	1844	2133	418	0	2551	2133	2133
Circular	7.00	7.00	0.02	72	11	112	57.5	117.86	0.49	27436	32923	515	618	1844	2133	418	0	2551	2133	2133
Circular	8.00	8.00	0.01	32	14	72	63.5	201.1	0.32	23592	28310	443	531	1860	2237	418	0	2655	2237	2237
Oblong	5.50	8.25	0.01	36	11	56	56.5	175.62	0.32	19813	23776	372	446	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.02	72	11	112	82.8	175.62	0.47	31503	37804	591	709	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.03	108	11	168	105.1	175.62	0.60	42779	51334	802	963	1804	2096	418	0	2514	2096	2096
Oblong	7.00	10.50	0.01	40	14	90	133.9	460.8	0.29	38023	45628	713	856	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.02	80	14	180	205.3	460.8	0.45	63502	76203	1191	1429	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.03	120	14	270	271.3	460.8	0.59	89436	107323	1678	2013	1744	2216	418	0	2634	2216	2216

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
11 A	2962	2522	2369	7	0.60	0.94	5.00	43.13	0.0052	0.0056	0.0107	0.0072	0.0107	0.0111	3.3	67.563	2.72	1.4	668	350	3.8	0.243	576	2	1528	1789	379	0.21
11 B	4072	3632	3257	7	0.60	0.94	3.25	67.13	0.0036	0.0053	0.0089	0.0104	0.0104	0.0110	3.8	67.563	2.22	1.3	660	350	2.9	0.185	601	1	1176	1510	378	0.25
11 C	4072	3632	3257	8	0.79	1.24	3.00	67.00	0.0036	0.0053	0.0102	0.0156	0.0156	0.0157	4.0	67.500	2.04	1.3	943	350	2.7	0.170	553	1	1675	1894	521	0.28
11 D	5542	5027	4433	8	0.79	1.24	5.50	79.00	0.0031	0.0050	0.0072	0.0072	0.0072	0.0073	4.0	79.500	2.02	1.2	436	350	2.5	0.158	701	1	1076	1511	366	0.24
11 E	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0050	0.0085	0.0144	0.0144	0.0145	4.1	79.500	1.93	1.2	873	350	2.4	0.152	673	1	2152	2402	618	0.26
11 F	7238	6648	5791	8	0.79	1.24	4.75	91.00	0.0027	0.0048	0.0070	0.0064	0.0070	0.0073	4.1	91.500	1.92	1.2	439	350	2.3	0.145	838	1	1434	1931	531	0.28
11 G	5599	4964	4479	7	0.60	0.94	5.25	61.13	0.0038	0.0049	0.0072	0.0036	0.0072	0.0075	4.1	94.563	1.92	1.2	449	350	2.4	0.150	672	2	2037	2302	446	0.19
11 H	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0049	0.0085	0.0072	0.0085	0.0087	3.7	94.563	2.30	1.2	524	350	2.8	0.180	806	2	2377	2705	709	0.26
11 I	5599	4964	4479	7	0.60	0.94	3.50	61.13	0.0038	0.0049	0.0098	0.0108	0.0108	0.0112	3.6	94.563	2.36	1.2	673	350	2.9	0.184	825	2	3056	3299	963	0.29
11 J	9070	8225	7256	7	0.60	0.94	4.25	79.13	0.0031	0.0046	0.0068	0.0040	0.0068	0.0071	4.1	121.563	1.86	1.2	428	350	2.1	0.136	983	2	3235	3585	856	0.24
11 K	9070	8225	7256	7	0.60	0.94	3.50	79.13	0.0031	0.0046	0.0081	0.0080	0.0081	0.0087	4.0	121.563	2.03	1.2	520	350	2.3	0.148	1075	2	3928	4252	1429	0.34
11 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0094	0.0120	0.0120	0.0123	4.0	121.500	1.96	1.2	738	350	2.3	0.143	1035	2	5567	5612	2013	0.36

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
11 A	53.31	0.000085	0.000762	0.000677	1.27	68	64.1	0.043	11.58	26.39	37.97	0.25	11.83	38.22	3.3	3.2	37.97	3.2
11 B	53.31	0.000081	0.00086	0.000775	1.41	68	65.6	0.051	11.08	30.83	41.91	0.22	11.30	42.13	3.8	3.7	41.91	3.7
11 C	53.31	0.000088	0.00099	0.000897	1.41	68	65.6	0.059	12.06	35.68	47.74	0.22	12.28	47.95	4.0	3.9	47.74	3.9
11 D	53.31	0.00006	0.00071	0.000646	1.41	68	65.6	0.042	8.61	25.70	34.31	0.21	8.82	34.52	4.0	3.9	34.31	3.9
11 E	53.31	0.00007	0.00094	0.000868	1.41	68	65.6	0.057	9.85	34.53	44.38	0.23	10.08	44.61	4.5	4.4	40.09	4.0
11 F	53.31	0.00006	0.00067	0.000615	1.69	68	68.4	0.042	7.67	25.48	33.15	0.22	7.89	33.37	4.3	4.2	31.33	4.0
11 G	53.31	0.00005	0.00066	0.000607	1.41	68	65.6	0.040	7.27	24.14	31.41	0.20	7.47	31.61	4.3	4.2	29.68	4.0
11 H	53.31	0.00006	0.00060	0.000538	1.41	68	65.6	0.035	7.93	21.40	29.33	0.26	8.19	29.59	3.7	3.6	29.33	3.6
11 I	53.31	0.00006	0.00062	0.000558	1.41	68	65.6	0.037	8.41	22.22	30.63	0.26	8.67	30.89	3.6	3.6	30.63	3.6
11 J	53.31	0.00004	0.00056	0.000514	1.69	68	68.4	0.035	5.95	21.32	27.27	0.29	6.24	27.56	4.6	4.4	24.67	4.0
11 K	53.31	0.00005	0.00050	0.000455	1.69	68	68.4	0.031	6.34	18.84	25.18	0.39	6.73	25.57	4.0	3.8	25.18	3.8
11 L	53.31	0.00005	0.00054	0.000494	1.69	68	68.4	0.034	6.72	20.46	27.18	0.55	7.26	27.73	4.0	3.8	27.18	3.8

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
11 A	1.73	37.97
11 B	1.40	41.91
11 C	1.40	47.74
11 D	1.04	34.31
11 E	1.03	40.09
11 F	0.90	31.33
11 G	1.03	29.68
11 H	1.53	29.33
11 I	1.11	30.63
11 J	1.18	24.67
11 K	1.54	25.18
11 L	2.16	27.18

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
11 A	179.6	9574	16844	OK
11 B	182.8	9745	16807	OK
11 C	182.8	9745	23164	OK
11 D	184.4	9830	16269	OK
11 E	184.4	9830	27436	OK
11 F	186.0	9916	23592	OK
11 G	180.4	9617	19813	OK
11 H	180.4	9617	31503	OK
11 I	180.4	9617	42779	OK
11 J	174.4	9297	38023	OK
11 K	174.4	9297	63502	OK
11 L	174.4	9297	89436	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
11 A	3369	5682	Yes
11 B	3361	6384	Yes
11 C	4633	7272	Yes
11 D	3254	5272	Yes
11 E	5487	6160	Yes
11 F	4718	4856	Yes
11 G	3963	4462	Yes
11 H	6301	4410	No
11 I	8556	4604	No
11 J	7605	3585	No
11 K	12700	3659	No
11 L	17887	3950	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.09	0.81	0.83	1.98	0.75	L	1.98	0.76	L
2.06	0.84	0.93	1.48	0.74	L	2.06	0.93	T
1.85	0.93	1.28	1.30	0.81	L	1.85	1.28	T
1.94	0.79	0.83	1.38	0.69	L	1.94	0.83	T
1.65	0.89	1.28	1.14	0.80	L	1.65	1.28	T
1.62	0.80	1.02	1.12	0.72	L	1.62	1.02	T
1.69	0.77	0.91	1.52	0.69	L	1.52	0.82	L
1.47	0.80	1.17	1.28	0.77	L	1.47	1.17	T
1.30	0.85	1.51	1.15	0.85	L	1.30	1.51	T
1.29	0.77	1.20	1.10	0.74	L	1.29	1.20	T
1.06	0.86	1.78	1.06	0.86	T	1.06	1.78	T
0.97	0.95	2.31	0.97	0.95	T	0.97	2.31	T

Column Design, Displacement Capacity, and Displacement Demand for Model No. 11, M8.00 Earthquake - LONGITUDINAL DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	53.31 ft
h_{col} =	50.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft)	14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_θ (k/rad)
11 A	1950	13829	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
11 B	2040	20168	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 C	2040	27797	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 D	2133	19523	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 E	2133	32923	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 F	2237	28310	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 G	2096	16337	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
11 H	2096	26163	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 I	2096	35165	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 J	2216	31032	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000
11 K	2216	52962	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 L	2216	74019	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	P_{DL_TOP} (k)	P_{DL_BOT} (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Oblong	4.00	6.00	0.03	72	10	91	14.4	23.23	0.62	11524	13829	461	553	1796	1950	418	0	2368	1950	1950
Circular	6.00	6.00	0.02	52	11	81	31.0	63.62	0.49	16807	20168	672	807	1828	2040	418	0	2458	2040	2040
Circular	6.00	6.00	0.03	78	11	122	39.7	63.62	0.62	23164	27797	927	1112	1828	2040	418	0	2458	2040	2040
Circular	7.00	7.00	0.01	36	11	56	39.1	117.86	0.33	16269	19523	651	781	1844	2133	418	0	2551	2133	2133
Circular	7.00	7.00	0.02	72	11	112	57.5	117.86	0.49	27436	32923	1097	1317	1844	2133	418	0	2551	2133	2133
Circular	8.00	8.00	0.01	32	14	72	63.5	201.1	0.32	23592	28310	944	1132	1860	2237	418	0	2655	2237	2237
Oblong	5.50	8.25	0.01	36	11	56	27.9	83.05	0.34	13614	16337	545	653	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.02	72	11	112	41.0	83.05	0.49	21803	26163	872	1047	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.03	108	11	168	50.2	83.05	0.60	29304	35165	1172	1407	1804	2096	418	0	2514	2096	2096
Oblong	7.00	10.50	0.01	40	14	90	66.0	217.9	0.30	25860	31032	1034	1241	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.02	80	14	180	102.7	217.9	0.47	44135	52962	1765	2118	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.03	120	14	270	137.7	217.9	0.63	61682	74019	2467	2961	1744	2216	418	0	2634	2216	2216

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	$d_{,shear}$ (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
11 A	2962	2522	2369	7	0.60	0.94	5.00	43.13	0.0052	0.0056	0.0107	0.0072	0.0107	0.0111	3.9	43.56	2.07	1.4	668	350	2.9	0.184	437	2	985	1209	553	0.46
11 B	4072	3632	3257	7	0.60	0.94	3.25	67.13	0.0036	0.0053	0.0089	0.0104	0.0104	0.0110	4.3	67.56	1.68	1.3	660	350	2.2	0.140	455	1	1176	1386	807	0.58
11 C	4072	3632	3257	8	0.79	1.24	3.00	67.00	0.0036	0.0053	0.0102	0.0156	0.0156	0.0157	4.3	67.50	1.72	1.3	943	350	2.3	0.143	466	1	1675	1820	1112	0.61
11 D	5542	5027	4433	8	0.79	1.24	5.50	79.00	0.0031	0.0050	0.0072	0.0072	0.0072	0.0073	4.4	79.50	1.60	1.2	436	350	2.0	0.126	558	1	1076	1389	781	0.56
11 E	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0050	0.0085	0.0144	0.0144	0.0145	4.4	79.50	1.65	1.2	873	350	2.0	0.129	572	1	2152	2316	1317	0.57
11 F	7238	6648	5791	8	0.79	1.24	4.75	91.00	0.0027	0.0048	0.0070	0.0064	0.0070	0.0073	4.4	91.50	1.56	1.2	439	350	1.9	0.117	680	1	1434	1797	1132	0.63
11 G	5599	4964	4479	7	0.60	0.94	5.25	61.13	0.0038	0.0049	0.0072	0.0036	0.0072	0.0075	4.2	61.56	1.78	1.2	449	350	2.2	0.139	623	2	1326	1657	653	0.39
11 H	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0049	0.0085	0.0072	0.0085	0.0087	4.3	61.56	1.75	1.2	524	350	2.2	0.136	611	2	1547	1834	1047	0.57
11 I	5599	4964	4479	7	0.60	0.94	3.50	61.13	0.0038	0.0049	0.0098	0.0108	0.0108	0.0112	4.2	61.56	1.78	1.2	673	350	2.2	0.139	622	2	1989	2219	1407	0.63
11 J	9070	8225	7256	7	0.60	0.94	4.25	79.13	0.0031	0.0046	0.0068	0.0040	0.0068	0.0071	4.4	79.56	1.63	1.2	428	350	1.9	0.119	860	2	2117	2531	1241	0.49
11 K	9070	8225	7256	7	0.60	0.94	3.50	79.13	0.0031	0.0046	0.0081	0.0080	0.0081	0.0087	4.5	79.56	1.54	1.2	520	350	1.8	0.112	814	2	2571	2877	2118	0.74
11 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0094	0.0120	0.0120	0.0123	4.5	79.50	1.47	1.2	738	350	1.7	0.107	780	2	3643	3759	2961	0.79

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Usable System Ductility Demand μ_D
11 A	50.00	0.000121	0.001142	0.001021	1.27	68	37.0	0.038	7.24	21.3	28.49	0.42	7.65	28.90	3.9	3.8	28.49	3.8
11 B	50.00	0.000081	0.000856	0.000775	1.41	68	38.4	0.030	4.87	16.7	21.58	0.52	5.39	22.10	4.4	4.1	21.06	4.0
11 C	50.00	0.000088	0.00099	0.000897	1.41	68	38.4	0.034	5.30	19.3	24.63	0.49	5.80	25.13	4.6	4.3	22.70	4.0
11 D	50.00	0.00006	0.00071	0.000646	1.41	68	38.4	0.025	3.78	13.9	17.71	0.50	4.29	18.21	4.7	4.2	16.65	4.0
11 E	50.00	0.00007	0.00094	0.000868	1.41	68	38.4	0.033	4.33	18.7	23.04	0.52	4.85	23.56	5.3	4.9	18.89	4.0
11 F	50.00	0.00006	0.00067	0.000615	1.693	68	41.3	0.025	3.37	14.2	17.55	0.50	3.88	18.05	5.2	4.7	15.00	4.0
11 G	50.00	0.00007	0.00096	0.000890	1.41	68	38.4	0.034	4.39	19.2	23.57	0.32	4.71	23.90	5.4	5.1	18.53	4.0
11 H	50.00	0.00008	0.00087	0.000791	1.41	68	38.4	0.030	4.80	17.1	21.85	0.41	5.21	22.26	4.6	4.3	20.43	4.0
11 I	50.00	0.00009	0.00094	0.000853	1.41	68	38.4	0.033	5.31	18.4	23.68	0.40	5.70	24.08	4.5	4.2	22.42	4.0
11 J	50.00	0.00006	0.00083	0.000766	1.693	68	41.3	0.032	3.59	17.7	21.25	0.45	4.04	21.71	5.9	5.4	15.70	4.0
11 K	50.00	0.00006	0.00077	0.000704	1.693	68	41.3	0.029	3.87	16.2	20.12	0.60	4.47	20.72	5.2	4.6	17.30	4.0
11 L	50.00	0.00007	0.00069	0.000619	1.693	68	41.3	0.026	4.04	14.3	18.31	0.84	4.88	19.14	4.5	3.9	18.31	3.9

6. Displacement Demand

Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
1.52	28.49
1.94	21.06
1.94	22.70
1.63	16.65
2.07	15.00
1.13	18.53
1.32	20.43
1.34	22.42
1.70	15.70
1.67	17.30
>2.50	18.31

7. Minimum Lateral Strength Check

$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ns} (k-ft)	check
195.0	4876	11524	OK
204.0	5100	16807	OK
204.0	5100	23164	OK
213.3	5332	16269	OK
213.3	5332	27436	OK
223.7	5592	23592	OK
209.6	5239	13614	OK
209.6	5239	21803	OK
209.6	5239	29304	OK
221.6	5541	25860	OK
221.6	5541	44135	OK
221.6	5541	61682	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
11 A	2305	2315	Yes
11 B	3361	1834	No
11 C	4633	2094	No
11 D	3254	1574	No
11 E	5487	2047	No
11 F	4718	1636	No
11 G	2723	2058	No
11 H	4361	1908	No
11 I	5861	2068	No
11 J	5172	1963	No
11 K	8827	1858	No
11 L	12336	1691	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Longitudinal Response T_{long} (s)	PGA_{long} (g)	$S_{A,long}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
1.98	0.72	0.76	1.98	0.72	L	1.98	0.76	L
1.48	0.72	1.02	1.48	0.72	L	2.06	0.93	T
1.30	0.81	1.42	1.30	0.81	L	1.85	1.28	T
1.38	0.65	0.93	1.38	0.65	L	1.94	0.83	T
1.14	0.79	1.53	1.14	0.79	L	1.65	1.28	T
1.12	0.70	1.26	1.12	0.70	L	1.62	1.02	T
1.52	0.64	0.82	1.52	0.64	L	1.52	0.82	L
1.28	0.76	1.28	1.28	0.76	L	1.47	1.17	T
1.15	0.86	1.72	1.15	0.86	L	1.30	1.51	T
1.10	0.72	1.32	1.10	0.72	L	1.29	1.20	T
0.91	0.88	2.15	1.06	0.86	T	1.06	1.79	T
0.84	>1.0g	>2.77	0.97	0.96	T	0.97	2.32	T

Column Design, Displacement Capacity, and Displacement Demand for Model No. 11, M8.00 Earthquake - TRANSVERSE DIRECTION

1. Material Properties, Frame Geometry

f'_c =	4000 psi
f'_{ce} =	5200 psi
f_y =	60 ksi
f_{ye} =	68 ksi
h_{bent} =	53.31 ft
h_{col} =	50.00 ft

2. Footing Design

Model	Column Load (k)	M_o (k-ft) 14x89 H-Pile	24" Pipe Pile	36" CIDH	K (k/in)	K (k/ft)	K_{ij} (k/rad)
11 A	1950	14387	5 x 4	3 x 3 +10ft	3 x 3 -10ft	1250	15000	5,700,000
11 B	2040	20168	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 C	2040	27797	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 D	2133	19523	6 x 4	4 x 3	3 x 3	1430	17160	8,000,000
11 E	2133	32923	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 F	2237	28310	6 x 6	4 x 4 +5ft	4 x 3	2000	24000	18,000,000
11 G	2096	23776	6 x 5	4 x 4	4 x 3 -10ft	1865	22380	10,500,000
11 H	2096	37804	7 x 6	5 x 4	4 x 4 -5ft	2285	27420	18,000,000
11 I	2096	51334	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 J	2216	45628	7 x 6	6 x 4	4 x 4	2485	29820	18,000,000
11 K	2216	76203	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000
11 L	2216	107323	8 x 7	6 x 5	5 x 4	3065	36780	45,000,000

3. Column Main Bar Design and Design Forces

Column Type	Column Dim1. (ft)	Column Dim2. (ft)	ρ	N_{bars}	Main Bar Size	$A_{s,prov}$ (in^2)	I_{cr} (ft^4)	I_g (ft^4)	I_{cr} / I_g	M_p (k-ft)	M_o (k-ft)	V_p (k)	V_o (k)	$P_{DL,TOP}$ (k)	$P_{DL,BOT}$ (k)	P_{LL} (k)	P_{EQ} (k)	$P_{DL+LL,BOT}$ (k)	$P_{DL+EQ,BOT}$ (k)	$P_{DL-EQ,BOT}$ (k)
Oblong	4.00	6.00	0.03	72	10	91	29.9	49.13	0.61	11989	14387	225	270	1796	1950	418	0	2368	1950	1950
Circular	6.00	6.00	0.02	52	11	81	31.0	63.62	0.49	16807	20168	315	378	1828	2040	418	0	2458	2040	2040
Circular	6.00	6.00	0.03	78	11	122	39.7	63.62	0.62	23164	27797	435	521	1828	2040	418	0	2458	2040	2040
Circular	7.00	7.00	0.01	36	11	56	39.1	117.86	0.33	16269	19523	305	366	1844	2133	418	0	2551	2133	2133
Circular	7.00	7.00	0.02	72	11	112	57.5	117.86	0.49	27436	32923	515	618	1844	2133	418	0	2551	2133	2133
Circular	8.00	8.00	0.01	32	14	72	63.5	201.1	0.32	23592	28310	443	531	1860	2237	418	0	2655	2237	2237
Oblong	5.50	8.25	0.01	36	11	56	56.5	175.62	0.32	19813	23776	372	446	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.02	72	11	112	82.8	175.62	0.47	31503	37804	591	709	1804	2096	418	0	2514	2096	2096
Oblong	5.50	8.25	0.03	108	11	168	105.1	175.62	0.60	42779	51334	802	963	1804	2096	418	0	2514	2096	2096
Oblong	7.00	10.50	0.01	40	14	90	133.9	460.8	0.29	38023	45628	713	856	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.02	80	14	180	205.3	460.8	0.45	63502	76203	1191	1429	1744	2216	418	0	2634	2216	2216
Oblong	7.00	10.50	0.03	120	14	270	271.3	460.8	0.59	89436	107323	1678	2013	1744	2216	418	0	2634	2216	2216

4. Column Lateral Reinforcement Design

Model	A_g (in^2)	A_c (in^2)	A_e (in^2)	Hoop Bar Size	A_b (in^2)	A_v (in^2)	s_{min} (in)	used for confinement calculation D' (in)	BDS eqn 8-62 ρ_s	BDS eqn 8-62B ρ_s	Priestley eqn 5.47 ρ_s	Priestley eqn 5.56 ρ_s	<=Max of $\rho_{s,req't}$	$\rho_{s,prov}$	$\mu_d = \mu_c$	used for shear calculation d_{shear} (in)	SDC 3.62 Fact 1	SDC 3.62 Fact 2	$\rho_s F_y$	For shear calculation $\rho_s F_y$	sqrt f'c	v_c (ksi)	V_c (k)	n_{cores}	V_s (k)	ϕV_n (k)	V_u (k)	D/C Ratio
11 A	2962	2522	2369	7	0.60	0.94	5.00	43.13	0.0052	0.0056	0.0107	0.0072	0.0107	0.0111	3.3	67.563	2.71	1.4	668	350	3.8	0.242	574	2	1528	1787	270	0.15
11 B	4072	3632	3257	7	0.60	0.94	3.25	67.13	0.0036	0.0053	0.0089	0.0104	0.0104	0.0110	3.8	67.563	2.22	1.3	660	350	2.9	0.185	601	1	1176	1510	378	0.25
11 C	4072	3632	3257	8	0.79	1.24	3.00	67.00	0.0036	0.0053	0.0102	0.0156	0.0156	0.0157	4.0	67.500	2.04	1.3	943	350	2.7	0.170	553	1	1675	1894	521	0.28
11 D	5542	5027	4433	8	0.79	1.24	5.50	79.00	0.0031	0.0050	0.0072	0.0072	0.0072	0.0073	4.0	79.500	2.02	1.2	436	350	2.5	0.158	701	1	1076	1511	366	0.24
11 E	5542	5027	4433	8	0.79	1.24	2.75	79.00	0.0031	0.0050	0.0085	0.0144	0.0144	0.0145	4.1	79.500	1.93	1.2	873	350	2.4	0.152	673	1	2152	2402	618	0.26
11 F	7238	6648	5791	8	0.79	1.24	4.75	91.00	0.0027	0.0048	0.0070	0.0064	0.0070	0.0073	4.1	91.500	1.92	1.2	439	350	2.3	0.145	838	1	1434	1931	531	0.28
11 G	5599	4964	4479	7	0.60	0.94	5.25	61.13	0.0038	0.0049	0.0072	0.0036	0.0072	0.0075	4.1	94.563	1.92	1.2	449	350	2.4	0.150	672	2	2037	2302	446	0.19
11 H	5599	4964	4479	7	0.60	0.94	4.50	61.13	0.0038	0.0049	0.0085	0.0072	0.0085	0.0087	3.7	94.563	2.30	1.2	524	350	2.8	0.180	806	2	2377	2705	709	0.26
11 I	5599	4964	4479	7	0.60	0.94	3.50	61.13	0.0038	0.0049	0.0098	0.0108	0.0108	0.0112	3.6	94.563	2.36	1.2	673	350	2.9	0.184	825	2	3056	3299	963	0.29
11 J	9070	8225	7256	7	0.60	0.94	4.25	79.13	0.0031	0.0046	0.0068	0.0040	0.0068	0.0071	4.1	121.563	1.86	1.2	428	350	2.1	0.136	983	2	3235	3585	856	0.24
11 K	9070	8225	7256	7	0.60	0.94	3.50	79.13	0.0031	0.0046	0.0081	0.0080	0.0081	0.0087	4.0	121.563	2.03	1.2	520	350	2.3	0.148	1075	2	3928	4252	1429	0.34
11 L	9070	8225	7256	8	0.79	1.24	3.25	79.00	0.0031	0.0046	0.0094	0.0120	0.0120	0.0123	4.0	121.500	1.96	1.2	738	350	2.3	0.143	1035	2	5567	5612	2013	0.36

= calculated by hand

5. Column Displacement Capacity

Model	L (ft)	ϕ_y (in^{-1})	ϕ_u (in^{-1})	ϕ_p (in^{-1})	d_{bl} (in)	f_{ye} (ksi)	L_p (in)	θ_p (rad)	$\Delta_{y,col}$ (in)	$\Delta_{p,col}$ (in)	$\Delta_{c,col}$ (in)	$\Delta_{c,foot}$ (in)	$\Delta_{y,system}$ (in)	$\Delta_{C,system}$ (in)	Column Ductility Capacity μ_c	System Ductility Demand μ_D	Usable Col Disp with μ_D = 4 Δ_c	Restricted System Ductility Demand μ_D
11 A	53.31	0.000085	0.000769	0.000684	1.27	68	64.1	0.044	11.64	26.64	38.28	0.18	11.82	38.46	3.3	3.3	38.28	3.3
11 B	53.31	0.000081	0.00086	0.000775	1.41	68	65.6	0.051	11.08	30.83	41.91	0.22	11.30	42.13	3.8	3.7	41.91	3.7
11 C	53.31	0.000088	0.00099	0.000897	1.41	68	65.6	0.059	12.06	35.68	47.74	0.22	12.28	47.95	4.0	3.9	47.74	3.9
11 D	53.31	0.00006	0.00071	0.000646	1.41	68	65.6	0.042	8.61	25.70	34.31	0.21	8.82	34.52	4.0	3.9	34.31	3.9
11 E	53.31	0.00007	0.00094	0.000868	1.41	68	65.6	0.057	9.85	34.53	44.38	0.23	10.08	44.61	4.5	4.4	40.09	4.0
11 F	53.31	0.00006	0.00067	0.000615	1.69	68	68.4	0.042	7.67	25.48	33.15	0.22	7.89	33.37	4.3	4.2	31.33	4.0
11 G	53.31	0.00005	0.00066	0.000607	1.41	68	65.6	0.040	7.27	24.14	31.41	0.20	7.47	31.61	4.3	4.2	29.68	4.0
11 H	53.31	0.00006	0.00060	0.000538	1.41	68	65.6	0.035	7.93	21.40	29.33	0.26	8.19	29.59	3.7	3.6	29.33	3.6
11 I	53.31	0.00006	0.00062	0.000558	1.41	68	65.6	0.037	8.41	22.22	30.63	0.26	8.67	30.89	3.6	3.6	30.63	3.6
11 J	53.31	0.00004	0.00056	0.000514	1.69	68	68.4	0.035	5.95	21.32	27.27	0.29	6.24	27.56	4.6	4.4	24.67	4.0
11 K	53.31	0.00005	0.00050	0.000455	1.69	68	68.4	0.031	6.34	18.84	25.18	0.39	6.73	25.57	4.0	3.8	25.18	3.8
11 L	53.31	0.00005	0.00054	0.000494	1.69	68	68.4	0.034	6.72	20.46	27.18	0.55	7.26	27.73	4.0	3.8	27.18	3.8

6. Displacement Demand

Model	Δ_{FOOT} (in)	$\Delta_{u,COL}$ (in)
11 A	1.14	38.28
11 B	1.45	41.91
11 C	1.30	47.74
11 D	1.23	34.31
11 E	1.49	40.09
11 F	1.03	31.33
11 G	1.17	29.68
11 H	0.98	29.33
11 I	1.06	30.63
11 J	1.28	24.67
11 K	1.52	25.18
11 L	2.04	27.18

7. Minimum Lateral Strength Check

Model	$0.1P_{DL}$ (k)	$M_{0.1PDL}$ (k-ft)	M_{ne} (k-ft)	check
11 A	179.6	9574	11989	OK
11 B	182.8	9745	16807	OK
11 C	182.8	9745	23164	OK
11 D	184.4	9830	16269	OK
11 E	184.4	9830	27436	OK
11 F	186.0	9916	23592	OK
11 G	180.4	9617	19813	OK
11 H	180.4	9617	31503	OK
11 I	180.4	9617	42779	OK
11 J	174.4	9297	38023	OK
11 K	174.4	9297	63502	OK
11 L	174.4	9297	89436	OK

8. P-delta Check

Model	$0.2M_p$	$P_{DL}\ \Delta_r$	P-Δ
11 A	2398	5730	Yes
11 B	3361	6384	Yes
11 C	4633	7272	Yes
11 D	3254	5272	Yes
11 E	5487	6160	Yes
11 F	4718	4856	Yes
11 G	3963	4462	Yes
11 H	6301	4410	No
11 I	8556	4604	No
11 J	7605	3585	No
11 K	12700	3659	No
11 L	17887	3950	No

9. Ground Motion Corresponding to Displacement Capacity and Controlling Response

Transverse Response T_{tran} (s)	PGA_{tran} (g)	$S_{A,tran}$ (g)	Controlling Response T (s)	PGA (g)	Dir	T (s)	S_A (g)	Dir
2.09	0.79	0.83	1.98	0.72	L	1.98	0.76	L
2.06	0.84	0.93	1.48	0.72	L	2.06	0.93	T
1.85	0.95	1.28	1.30	0.81	L	1.85	1.28	T
1.94	0.76	0.83	1.38	0.65	L	1.94	0.83	T
1.65	0.90	1.28	1.14	0.79	L	1.65	1.28	T
1.62	0.78	1.02	1.12	0.70	L	1.62	1.02	T
1.69	0.74	0.91	1.52	0.64	L	1.52	0.82	L
1.47	0.80	1.17	1.28	0.76	L	1.47	1.17	T
1.30	0.87	1.51	1.15	0.86	L	1.30	1.51	T
1.29	0.76	1.20	1.10	0.72	L	1.29	1.20	T
1.06	0.86	1.79	1.06	0.86	T	1.06	1.79	T
0.97	0.96	2.32	0.97	0.96	T	0.97	2.32	T

APPENDIX D: QUANTITY AND COST SUMMARY

Quantity and Probable Cost Summary for Model No. 1

			Quantity											
ITEM	Unit	Price	A	B	C	D	E	F	G	H	I	J	K	L
Structure Excavation (Bridge)	CY	$50	690	773	773	773	773	927	1,068	773	927	1,068	1,292	1,356
Structure Backfill (Bridge)	CY	$65	385	419	419	419	419	478	525	419	478	525	600	622
Furnish Piling (Caltrans Ave. Fdn. Cost*)	EA	varies	71,352	98,685	98,685	98,685	98,685	149,113	177,700	100,072	149,113	177,700	245,397	276,651
Drive Pile (Caltrans Ave. Fdn. Cost*)	EA	varies	74,208	103,752	103,752	103,752	103,752	160,827	191,408	105,832	160,827	191,408	268,747	302,363
Prestressing Cast-in-Place Concrete	LB	$1.05	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730
Structural Concrete, Bridge Footing	CY	$310	81	130	130	130	130	225	318	130	225	318	467	510
Structural Concrete, Bridge	CY	$445	1887	1887	1925	1913	1913	1936	1925	1969	2017	1996	2019	2097
Joint Seal (Type B - MR 2")	FT	$50	136	136	136	136	136	136	136	136	136	136	136	136
Bar Reinforcing Steel	LB	$0.65	444,282	466,618	460,850	456,686	475,291	528,621	530,042	479,776	527,888	543,116	644,047	664,883
Concrete Barrier (Type 732)	FT	$75	920	920	920	920	920	920	920	920	920	920	920	920

	Amount											
ITEM	A	B	C	D	E	F	G	H	I	J	K	L
Structure Excavation (Bridge)	$82,795	$92,779	$92,779	$92,779	$92,779	$111,218	$128,145	$92,779	$111,218	$128,145	$155,032	$162,737
Structure Backfill (Bridge)	$61,540	$67,028	$67,028	$67,028	$67,028	$76,413	$84,029	$67,028	$76,413	$84,029	$96,043	$99,456
Furnish Piling (Caltrans Ave. Fdn. Cost*)	$71,352	$98,685	$98,685	$98,685	$98,685	$149,113	$177,700	$100,072	$149,113	$177,700	$245,397	$276,651
Drive Pile (Caltrans Ave. Fdn. Cost*)	$74,208	$103,752	$103,752	$103,752	$103,752	$160,827	$191,408	$105,832	$160,827	$191,408	$268,747	$302,363
Prestressing Cast-in-Place Concrete	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000
Structural Concrete, Bridge Footing	$32,000	$52,000	$52,000	$52,000	$52,000	$90,000	$127,000	$52,000	$90,000	$127,000	$187,000	$204,000
Structural Concrete, Bridge	$1,132,000	$1,132,000	$1,155,000	$1,148,000	$1,148,000	$1,162,000	$1,155,000	$1,181,000	$1,210,000	$1,197,000	$1,211,000	$1,258,000
Joint Seal (Type B - MR 2")	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800
Bar Reinforcing Steel	$311,000	$327,000	$323,000	$320,000	$333,000	$370,000	$371,000	$336,000	$370,000	$380,000	$451,000	$465,000
Concrete Barrier (Type 732)	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200
Subtotal	$2,028,895	$2,137,244	$2,156,244	$2,146,244	$2,159,244	$2,383,571	$2,498,283	$2,198,711	$2,431,571	$2,549,283	$2,723,187	$2,770,014
Mobilization (10%)	$202,890	$213,724	$215,624	$214,624	$215,924	$238,357	$249,828	$219,871	$243,157	$254,928	$272,319	$277,001
Subtotal	$2,231,785	$2,350,968	$2,371,868	$2,360,868	$2,375,168	$2,621,928	$2,748,111	$2,418,582	$2,674,728	$2,804,211	$2,995,506	$3,047,016
Contingencies (5%)	$111,589	$117,548	$118,593	$118,043	$118,758	$131,096	$137,406	$120,929	$133,736	$140,211	$149,775	$152,351
Total Probable Cost	$2,343,374	$2,468,517	$2,490,462	$2,478,912	$2,493,927	$2,753,025	$2,885,517	$2,539,511	$2,808,465	$2,944,422	$3,145,281	$3,199,366
Cost per Square Foot Deck Area	$87.08	$91.73	$92.55	$92.12	$92.68	$102.30	$107.23	$94.37	$104.37	$109.42	$116.88	$118.89

* Caltrans Average Foundation Cost is a weighted cost average = 0.13 * H-Pile Cost + 0.33 * Pipe Pile Cost + 0.34 * CIDH Pile Cost + 0.20 * Concrete Pile Cost

Quantity and Probable Cost Summary for Model No. 3

			Quantity									
ITEM	Unit	Price	A	B	C	D	E	F	G	H	I	J
Structure Excavation (Bridge)	CY	$50	658	690	746	773	844	927	737	833	1,068	1,292
Structure Backfill (Bridge)	CY	$65	370	385	406	419	448	478	403	443	525	600
Furnish Piling (Caltrans Ave. Fdn. Cost*)	EA	varies	57,539	75,956	80,390	98,685	125,273	149,113	79,510	124,643	177,700	245,397
Drive Pile (Caltrans Ave. Fdn. Cost*)	EA	varies	59,524	78,496	85,406	103,752	126,109	160,827	82,366	123,069	191,408	268,747
Prestressing Cast-in-Place Concrete	LB	$1.05	34,486	34,486	34,486	34,486	34,486	34,486	34,486	34,486	34,486	37,935
Structural Concrete, Bridge Footing	CY	$310	63	81	115	130	172	225	110	166	318	467
Structural Concrete, Bridge	CY	$445	1248	1248	1248	1274	1301	1350	1282	1298	1350	1530
Joint Seal (Type B - MR 2")	FT	$50	136	136	136	136	136	136	136	136	136	136
Bar Reinforcing Steel	LB	$0.65	280,305	294,797	312,716	304,581	340,831	393,187	302,375	340,434	395,696	535,635
Concrete Barrier (Type 732)	FT	$75	920	920	920	920	920	920	920	920	920	920
			Amount									
ITEM			A	B	C	D	E	F	G	H	I	J
Structure Excavation (Bridge)			$32,899	$34,498	$37,280	$38,658	$42,205	$46,341	$36,838	$41,654	$53,394	$64,597
Structure Backfill (Bridge)			$24,066	$25,001	$26,420	$27,230	$29,089	$31,043	$26,164	$28,802	$34,137	$39,017
Furnish Piling (Caltrans Ave. Fdn. Cost*)			$57,539	$75,956	$80,390	$98,685	$125,273	$149,113	$79,510	$124,643	$177,700	$245,397
Drive Pile (Caltrans Ave. Fdn. Cost*)			$59,524	$78,496	$85,406	$103,752	$126,109	$160,827	$82,366	$123,069	$191,408	$268,747
Prestressing Cast-in-Place Concrete			$36,211	$36,211	$36,211	$36,211	$36,211	$36,211	$36,211	$36,211	$36,211	$39,832
Structural Concrete, Bridge Footing			$19,633	$25,089	$35,567	$40,249	$53,374	$69,699	$34,048	$51,328	$98,671	$144,853
Structural Concrete, Bridge			$555,240	$555,240	$555,240	$566,843	$578,767	$600,580	$570,494	$577,416	$600,912	$680,755
Joint Seal (Type B - MR 2")			$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800
Bar Reinforcing Steel			$182,198	$191,618	$203,266	$197,978	$221,540	$255,571	$196,544	$221,282	$257,203	$348,163
Concrete Barrier (Type 732)			$69,000	$69,000	$69,000	$69,000	$69,000	$69,000	$69,000	$69,000	$69,000	$69,000
Subtotal			$1,043,110	$1,097,908	$1,135,579	$1,185,405	$1,288,368	$1,425,184	$1,137,974	$1,280,204	$1,525,435	$1,907,160
Mobilization (10%)			$104,311	$109,791	$113,558	$118,541	$128,837	$142,518	$113,797	$128,020	$152,544	$190,716
Subtotal			$1,147,421	$1,207,699	$1,249,137	$1,303,946	$1,417,205	$1,567,702	$1,251,772	$1,408,225	$1,677,979	$2,097,876
Contingencies (5%)			$57,371	$60,385	$62,457	$65,197	$70,860	$78,385	$62,589	$70,411	$83,899	$104,894
Total Probable Cost			$1,204,792	$1,268,083	$1,311,594	$1,369,143	$1,488,065	$1,646,087	$1,314,360	$1,478,636	$1,761,878	$2,202,770
Cost per Square Foot Deck Area			$67.16	$70.68	$73.11	$76.32	$82.95	$91.76	$73.26	$82.42	$98.21	$122.79

* Caltrans Average Foundation Cost is a weighted cost average = 0.13 * H-Pile Cost + 0.33 * Pipe Pile Cost + 0.34 * CIDH Pile Cost + 0.20 * Concrete Pile Cost

Quantity and Probable Cost Summary for Model No. 4

			Quantity								
ITEM	Unit	Price	A	B	C	D	E	F	G	H	I
Structure Excavation (Bridge)	CY	$50	1,230	1,230	1,230	1,230	1,230	1,248	1,248	1,275	1,335
Structure Backfill (Bridge)	CY	$65	687	687	687	687	687	696	696	708	733
Furnish Piling (Caltrans Ave. Fdn. Cost*)	EA	varies	155,645	155,645	155,645	155,645	155,645	159,470	159,470	163,115	201,559
Drive Pile (Caltrans Ave. Fdn. Cost*)	EA	varies	158,280	158,280	158,280	158,280	158,280	165,120	165,120	171,960	212,424
Prestressing Cast-in-Place Concrete	LB	$1.05	54,083	54,083	54,083	54,083	54,083	54,083	54,083	54,083	54,083
Structural Concrete, Bridge Footing	CY	$310	181	181	181	181	181	190	190	205	240
Structural Concrete, Bridge	CY	$445	2196	2196	2196	2271	2271	2271	2362	2362	2362
Joint Seal (Type B - MR 2")	FT	$50	136	136	136	136	136	136	136	136	136
Bar Reinforcing Steel	LB	$0.65	501,679	518,768	537,824	532,751	571,876	619,703	582,110	684,829	782,587
Chain Link Railing (Type 7)	FT	$40	920	920	920	920	920	920	920	920	920
Concrete Barrier (Type 26)	FT	$85	920	920	920	920	920	920	920	920	920
			Amount								
ITEM			A	B	C	D	E	F	G	H	I
Structure Excavation (Bridge)			$61,484	$61,484	$61,484	$61,484	$61,484	$62,418	$62,418	$63,764	$66,744
Structure Backfill (Bridge)			$44,630	$44,630	$44,630	$44,630	$44,630	$45,237	$45,237	$45,991	$47,622
Furnish Piling (Caltrans Ave. Fdn. Cost*)			$155,645	$155,645	$155,645	$155,645	$155,645	$159,470	$159,470	$163,115	$201,559
Drive Pile (Caltrans Ave. Fdn. Cost*)			$158,280	$158,280	$158,280	$158,280	$158,280	$165,120	$165,120	$171,960	$212,424
Prestressing Cast-in-Place Concrete			$56,787	$56,787	$56,787	$56,787	$56,787	$56,787	$56,787	$56,787	$56,787
Structural Concrete, Bridge Footing			$56,007	$56,007	$56,007	$56,007	$56,007	$58,900	$58,900	$63,653	$74,348
Structural Concrete, Bridge			$977,092	$977,092	$977,092	$1,010,740	$1,010,740	$1,010,740	$1,051,223	$1,051,223	$1,051,223
Joint Seal (Type B - MR 2")			$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800
Bar Reinforcing Steel			$326,092	$337,199	$349,585	$346,288	$371,719	$402,807	$378,371	$445,139	$508,682
Chain Link Railing (Type 7)			$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800
Concrete Barrier (Type 26)			$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200
Subtotal			$1,957,817	$1,968,925	$1,981,311	$2,011,662	$2,037,093	$2,083,279	$2,099,326	$2,183,433	$2,341,189
Mobilization (10%)			$195,782	$196,892	$198,131	$201,166	$203,709	$208,328	$209,933	$218,343	$234,119
Subtotal			$2,153,599	$2,165,817	$2,179,442	$2,212,828	$2,240,802	$2,291,607	$2,309,259	$2,401,776	$2,575,308
Contingencies (20%)			$430,720	$433,163	$435,888	$442,566	$448,160	$458,321	$461,852	$480,355	$515,062
Total Probable Cost			$2,584,318	$2,598,981	$2,615,330	$2,655,393	$2,688,963	$2,749,928	$2,771,111	$2,882,131	$3,090,369
Cost per Square Foot Deck Area			$82.62	$83.09	$83.61	$84.89	$85.96	$87.91	$88.59	$92.14	$98.80

* Caltrans Average Foundation Cost is a weighted cost average = 0.13 * H-Pile Cost + 0.33 * Pipe Pile Cost + 0.34 * CIDH Pile Cost + 0.20 * Concrete Pile Cost

Quantity and Probable Cost Summary for Model No. 6

			Quantity									
ITEM	Unit	Price	A	B	C	D	E	F	G	H	I	J
Structure Excavation (Bridge)	CY	$50	1,218	1,230	1,230	1,248	1,485	1,344	1,594	1,722	1,594	2,055
Structure Backfill (Bridge)	CY	$65	681	687	687	696	793	739	842	909	842	1,018
Furnish Piling (Caltrans Ave. Fdn. Cost*)	EA	varies	148,628	148,628	160,329	180,738	238,531	214,057	296,055	378,582	296,055	447,339
Drive Pile (Caltrans Ave. Fdn. Cost*)	EA	varies	151,262	151,262	162,960	178,572	247,098	222,624	311,256	381,090	311,256	482,481
Furnish Precast Prestressed Concrete Girder	FT	$145	4,019	4,019	4,019	4,019	4,019	4,019	4,019	4,019	4,019	4,019
Erect Precast Prestressed Concrete Girder	EA	$2,000	45	45	45	45	45	45	45	45	45	45
Structural Concrete, Bridge Footing	CY	$310	175	181	181	190	330	243	390	450	390	675
Structural Concrete, Bridge	CY	$445	1759	1759	1813	1813	1813	1980	1980	1980	2162	2162
Joint Seal (Type B - MR 2")	FT	$50	136	136	136	136	136	136	136	136	136	136
Bar Reinforcing Steel	LB	$0.65	366,665	380,046	369,052	399,145	456,842	426,076	511,543	559,748	510,181	673,236
Chain Link Railing (Type 7)	FT	$40	920	920	920	920	920	920	920	920	920	920
Concrete Barrier (Type 26)	FT	$85	920	920	920	920	920	920	920	920	920	920
			Amount									
ITEM			A	B	C	D	E	F	G	H	I	J
Structure Excavation (Bridge)			$60,878	$61,484	$61,484	$62,418	$74,233	$67,214	$79,694	$86,086	$79,694	$102,742
Structure Backfill (Bridge)			$44,236	$44,630	$44,630	$45,237	$51,530	$48,040	$54,728	$59,099	$54,728	$66,166
Furnish Piling (Caltrans Ave. Fdn. Cost*)			$148,628	$148,628	$160,329	$180,738	$238,531	$214,057	$296,055	$378,582	$296,055	$447,339
Drive Pile (Caltrans Ave. Fdn. Cost*)			$151,262	$151,262	$162,960	$178,572	$247,098	$222,624	$311,256	$381,090	$311,256	$482,481
Furnish Precast Prestressed Concrete Girder			$582,683	$582,683	$582,683	$582,683	$582,683	$582,683	$582,683	$582,683	$582,683	$582,683
Erect Precast Prestressed Concrete Girder			$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000
Structural Concrete, Bridge Footing			$54,126	$56,007	$56,007	$58,900	$102,145	$75,268	$120,747	$139,533	$120,747	$209,096
Structural Concrete, Bridge			$782,976	$782,976	$806,897	$806,897	$806,897	$881,066	$881,066	$881,066	$962,069	$962,085
Joint Seal (Type B - MR 2")			$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800
Bar Reinforcing Steel			$238,332	$247,030	$239,884	$259,444	$296,947	$276,949	$332,503	$363,836	$331,617	$437,603
Chain Link Railing (Type 7)			$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800
Concrete Barrier (Type 26)			$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200
Subtotal			$2,274,920	$2,286,499	$2,326,674	$2,386,689	$2,611,864	$2,579,700	$2,870,531	$3,083,774	$2,950,648	$3,501,996
Mobilization (10%)			$227,492	$228,650	$232,667	$238,669	$261,186	$257,970	$287,053	$308,377	$295,065	$350,200
Subtotal			$2,502,412	$2,515,149	$2,559,341	$2,625,358	$2,873,051	$2,837,670	$3,157,584	$3,392,151	$3,245,713	$3,852,196
Contingencies (5%)			$125,121	$125,757	$127,967	$131,268	$143,653	$141,884	$157,879	$169,608	$162,286	$192,610
Total Probable Cost			$2,627,533	$2,640,907	$2,687,309	$2,756,626	$3,016,703	$2,979,554	$3,315,463	$3,561,759	$3,407,999	$4,044,805
Cost per Square Foot Deck Area			$84.00	$84.43	$85.91	$88.13	$96.44	$95.25	$105.99	$113.87	$108.95	$129.31

* Caltrans Average Foundation Cost is a weighted cost average = 0.13 * H-Pile Cost + 0.33 * Pipe Pile Cost + 0.34 * CIDH Pile Cost + 0.20 * Concrete Pile Cost

Quantity and Probable Cost Summary for Model No. 9

			Quantity											
ITEM	Unit	Price	A	B	C	D	E	F	G	H	I	J	K	L
Structure Excavation (Bridge)	CY	$120	558	641	641	641	641	795	936	694	795	936	1,160	1,224
Structure Backfill (Bridge)	CY	$160	313	347	347	347	347	406	453	368	406	453	528	550
Furnish Piling (Caltrans Ave. Fdn. Cost*)	EA	varies	71,352	98,685	98,685	98,685	98,685	149,113	177,700	130,467	149,113	177,700	245,397	276,651
Drive Pile (Caltrans Ave. Fdn. Cost*)	EA	varies	74,208	103,752	103,752	103,752	103,752	160,827	191,408	136,227	160,827	191,408	268,747	302,363
Prestressing Cast-in-Place Concrete	LB	$2.50	55,890	55,890	55,890	55,890	55,890	55,890	55,890	55,890	55,890	55,890	55,890	55,890
Structural Concrete, Bridge Footing	CY	$400	81	130	130	130	130	225	318	161	225	318	467	510
Structural Concrete, Bridge	CY	$600	1242	1242	1273	1268	1268	1276	1273	1309	1350	1340	1351	1430
Joint Seal (Type B - MR 2")	FT	$50	136	136	136	136	136	136	136	136	136	136	136	136
Bar Reinforcing Steel	LB	$0.70	292,014	314,349	307,089	304,417	323,023	372,613	376,281	333,312	371,143	388,609	483,310	504,324
Concrete Barrier (Type 732)	FT	$50	920	920	920	920	920	920	920	920	920	920	920	920

	Amount											
ITEM	A	B	C	D	E	F	G	H	I	J	K	L
Structure Excavation (Bridge)	$66,918	$76,902	$76,902	$76,902	$76,902	$95,341	$112,268	$83,233	$95,341	$112,268	$139,155	$146,860
Structure Backfill (Bridge)	$50,020	$55,508	$55,508	$55,508	$55,508	$64,893	$72,509	$58,917	$64,893	$72,509	$84,523	$87,936
Furnish Piling (Caltrans Ave. Fdn. Cost*)	$71,352	$98,685	$98,685	$98,685	$98,685	$149,113	$177,700	$130,467	$149,113	$177,700	$245,397	$276,651
Drive Pile (Caltrans Ave. Fdn. Cost*)	$74,208	$103,752	$103,752	$103,752	$103,752	$160,827	$191,408	$136,227	$160,827	$191,408	$268,747	$302,363
Prestressing Cast-in-Place Concrete	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000
Structural Concrete, Bridge Footing	$32,000	$52,000	$52,000	$52,000	$52,000	$90,000	$127,000	$65,000	$90,000	$127,000	$187,000	$204,000
Structural Concrete, Bridge	$745,000	$745,000	$764,000	$761,000	$761,000	$766,000	$764,000	$785,000	$810,000	$804,000	$811,000	$858,000
Joint Seal (Type B - MR 2")	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800
Bar Reinforcing Steel	$204,000	$220,000	$215,000	$213,000	$226,000	$261,000	$263,000	$233,000	$260,000	$272,000	$338,000	$353,000
Concrete Barrier (Type 732)	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200
Subtotal	$1,445,499	$1,553,847	$1,567,847	$1,562,847	$1,575,847	$1,789,174	$1,909,886	$1,693,844	$1,832,174	$1,958,886	$2,136,667	$2,196,014
Mobilization (10%)	$144,550	$155,385	$156,785	$156,285	$157,585	$178,917	$190,989	$169,384	$183,217	$195,889	$213,667	$219,601
Subtotal	$1,590,048	$1,709,232	$1,724,632	$1,719,132	$1,733,432	$1,968,092	$2,100,875	$1,863,228	$2,015,392	$2,154,775	$2,350,334	$2,415,616
Contingencies (5%)	$79,502	$85,462	$86,232	$85,957	$86,672	$98,405	$105,044	$93,161	$100,770	$107,739	$117,517	$120,781
Total Probable Cost	$1,669,551	$1,794,693	$1,810,863	$1,805,088	$1,820,103	$2,066,496	$2,205,918	$1,956,389	$2,116,161	$2,262,513	$2,467,851	$2,536,396
Cost per Square Foot Deck Area	$89.62	$96.33	$97.20	$96.89	$97.70	$110.92	$118.41	$105.01	$113.59	$121.44	$132.47	$136.15

* Caltrans Average Foundation Cost is a weighted cost average = 0.13 * H-Pile Cost + 0.33 * Pipe Pile Cost + 0.34 * CIDH Pile Cost + 0.20 * Concrete Pile Cost

Quantity and Probable Cost Summary for Model No. 10

			Quantity								
ITEM	Unit	Price	A	B	C	D	E	F	G	H	I
Structure Excavation (Bridge)	CY	$50	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,371	1,443
Structure Backfill (Bridge)	CY	$65	739	739	739	739	739	739	739	760	791
Furnish Piling (Caltrans Ave. Fdn. Cost*)	EA	varies	155,645	155,645	155,645	155,645	155,645	155,645	155,645	163,115	200,085
Drive Pile (Caltrans Ave. Fdn. Cost*)	EA	varies	158,280	158,280	158,280	158,280	158,280	158,280	158,280	171,960	212,424
Prestressing Cast-in-Place Concrete	LB	$1.05	54,083	54,083	54,083	54,083	54,083	54,083	54,083	54,083	54,083
Structural Concrete, Bridge Footing	CY	$310	175	175	175	175	175	175	175	199	240
Structural Concrete, Bridge	CY	$445	2285	2285	2285	2366	2366	2366	2463	2463	2463
Joint Seal (Type B - MR 2")	FT	$50	136	136	136	136	136	136	136	136	136
Bar Reinforcing Steel	LB	$0.65	543,039	560,828	580,938	576,612	618,225	668,254	629,169	740,853	844,120
Chain Link Railing (Type 7)	FT	$40	920	920	920	920	920	920	920	920	920
Concrete Barrier (Type 26)	FT	$85	920	920	920	920	920	920	920	920	920
			Amount								
ITEM			A	B	C	D	E	F	G	H	I
Structure Excavation (Bridge)			$66,275	$66,275	$66,275	$66,275	$66,275	$66,275	$66,275	$68,555	$72,141
Structure Backfill (Bridge)			$48,060	$48,060	$48,060	$48,060	$48,060	$48,060	$48,060	$49,420	$51,445
Furnish Piling (Caltrans Ave. Fdn. Cost*)			$155,645	$155,645	$155,645	$155,645	$155,645	$155,645	$155,645	$163,115	$200,085
Drive Pile (Caltrans Ave. Fdn. Cost*)			$158,280	$158,280	$158,280	$158,280	$158,280	$158,280	$158,280	$171,960	$212,424
Prestressing Cast-in-Place Concrete			$56,787	$56,787	$56,787	$56,787	$56,787	$56,787	$56,787	$56,787	$56,787
Structural Concrete, Bridge Footing			$54,126	$54,126	$54,126	$54,126	$54,126	$54,126	$54,126	$61,773	$74,348
Structural Concrete, Bridge			$1,016,789	$1,016,789	$1,016,789	$1,052,961	$1,052,961	$1,052,961	$1,095,967	$1,095,967	$1,095,967
Joint Seal (Type B - MR 2")			$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800
Bar Reinforcing Steel			$352,976	$364,538	$377,610	$374,798	$401,846	$434,365	$408,960	$481,555	$548,678
Chain Link Railing (Type 7)			$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800	$36,800
Concrete Barrier (Type 26)			$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200	$78,200
Subtotal			$2,030,737	$2,042,300	$2,055,371	$2,088,731	$2,115,780	$2,148,298	$2,165,900	$2,270,932	$2,433,676
Mobilization (10%)			$203,074	$204,230	$205,537	$208,873	$211,578	$214,830	$216,590	$227,093	$243,368
Subtotal			$2,233,811	$2,246,530	$2,260,909	$2,297,605	$2,327,358	$2,363,128	$2,382,490	$2,498,025	$2,677,044
Contingencies (20%)			$446,762	$449,306	$452,182	$459,521	$465,472	$472,626	$476,498	$499,605	$535,409
Total Probable Cost			$2,680,573	$2,695,836	$2,713,090	$2,757,125	$2,792,829	$2,835,754	$2,858,987	$2,997,630	$3,212,452
Cost per Square Foot Deck Area			$85.70	$86.18	$86.74	$88.14	$89.28	$90.66	$91.40	$95.83	$102.70

* Caltrans Average Foundation Cost is a weighted cost average = 0.13 * H-Pile Cost + 0.33 * Pipe Pile Cost + 0.34 * CIDH Pile Cost + 0.20 * Concrete Pile Cost

Quantity and Probable Cost Summary for Model No. 11

			Quantity											
ITEM	Unit	Price	A	B	C	D	E	F	G	H	I	J	K	L
Structure Excavation (Bridge)	CY	$50	844	927	1,105	927	1,292	1,105	1,068	1,292	1,690	1,356	1,690	1,690
Structure Backfill (Bridge)	CY	$65	448	478	537	478	600	537	525	600	718	622	718	718
Furnish Piling (Caltrans Ave. Fdn. Cost*)	EA	varies	125,273	149,113	204,965	149,113	245,397	204,965	177,700	245,397	347,300	276,651	347,300	372,810
Drive Pile (Caltrans Ave. Fdn. Cost*)	EA	varies	126,109	160,827	216,632	160,827	268,747	216,632	191,408	268,747	384,450	302,363	384,450	399,070
Prestressing Cast-in-Place Concrete	LB	$1.05	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730	80,730
Structural Concrete, Bridge Footing	CY	$310	172	225	344	225	467	344	318	467	747	510	747	747
Structural Concrete, Bridge	CY	$445	2014	2086	2105	2177	2177	2280	2157	2172	2240	2359	2451	2724
Joint Seal (Type B - MR 2")	FT	$50	136	136	136	136	136	136	136	136	136	136	136	136
Bar Reinforcing Steel	LB	$0.65	516,713	536,840	617,549	529,435	669,402	586,731	554,368	637,202	795,387	666,384	883,775	1,029,173
Concrete Barrier (Type 732)	FT	$75	920	920	920	920	920	920	920	920	920	920	920	920

	Amount											
ITEM	A	B	C	D	E	F	G	H	I	J	K	L
Structure Excavation (Bridge)	$101,292	$111,218	$132,633	$111,218	$155,032	$132,633	$128,145	$155,032	$202,757	$162,737	$202,757	$202,757
Structure Backfill (Bridge)	$71,604	$76,413	$85,844	$76,413	$96,043	$85,844	$84,029	$96,043	$114,875	$99,456	$114,875	$114,875
Furnish Piling (Caltrans Ave. Fdn. Cost*)	$125,273	$149,113	$204,965	$149,113	$245,397	$204,965	$177,700	$245,397	$347,300	$276,651	$347,300	$372,810
Drive Pile (Caltrans Ave. Fdn. Cost*)	$126,109	$160,827	$216,632	$160,827	$268,747	$216,632	$191,408	$268,747	$384,450	$302,363	$384,450	$399,070
Prestressing Cast-in-Place Concrete	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000	$202,000
Structural Concrete, Bridge Footing	$69,000	$90,000	$138,000	$90,000	$187,000	$138,000	$127,000	$187,000	$299,000	$204,000	$299,000	$299,000
Structural Concrete, Bridge	$1,208,000	$1,252,000	$1,263,000	$1,306,000	$1,306,000	$1,368,000	$1,294,000	$1,303,000	$1,344,000	$1,415,000	$1,471,000	$1,634,000
Joint Seal (Type B - MR 2")	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800	$6,800
Bar Reinforcing Steel	$362,000	$376,000	$432,000	$371,000	$469,000	$411,000	$388,000	$446,000	$557,000	$466,000	$619,000	$720,000
Concrete Barrier (Type 732)	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200	$55,200
Subtotal	$2,327,278	$2,479,571	$2,737,075	$2,528,571	$2,991,219	$2,821,075	$2,654,283	$2,965,219	$3,513,382	$3,190,207	$3,499,626	$3,688,880
Mobilization (10%)	$232,728	$247,957	$273,707	$252,857	$299,122	$282,107	$265,428	$296,522	$351,338	$319,021	$349,963	$368,888
Subtotal	$2,560,006	$2,727,528	$3,010,782	$2,781,428	$3,290,341	$3,103,182	$2,919,711	$3,261,741	$3,864,721	$3,509,228	$3,849,588	$4,057,768
Contingencies (5%)	$128,000	$136,376	$150,539	$139,071	$164,517	$155,159	$145,986	$163,087	$193,236	$175,461	$192,479	$202,888
Total Probable Cost	$2,688,007	$2,863,905	$3,161,321	$2,920,500	$3,454,858	$3,258,341	$3,065,697	$3,424,828	$4,057,957	$3,684,690	$4,042,068	$4,260,657
Cost per Square Foot Deck Area	$99.89	$106.43	$117.48	$108.53	$128.39	$121.08	$113.92	$127.27	$150.80	$136.93	$150.21	$158.33

* Caltrans Average Foundation Cost is a weighted cost average = 0.13 * H-Pile Cost + 0.33 * Pipe Pile Cost + 0.34 * CIDH Pile Cost + 0.20 * Concrete Pile Cost

APPENDIX E: COST CURVES

Cost Curve for Model No. 1 (CIP P/S box girder, 150' span, 39' wide, 6' deep)

Cost Curve 1: 6.5M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.79	0.44	$73.25
A	4.00	4.00	0.02	0.93	0.99	$87.08
C	5.00	5.00	0.01	0.98	0.95	$92.55
D ***	4.00	6.00	0.01	0.84	0.90	$92.12
B **	4.00	4.00	0.03	> 1.0g	>1.09	$91.73
E **	4.00	6.00	0.02	> 1.0g	>1.21	$92.68
F **	4.00	6.00	0.03	> 1.0g	>1.27	$102.30
G **	5.00	5.00	0.02	> 1.0g	>1.21	$107.23
H **	6.00	6.00	0.01	> 1.0g	>1.31	$94.37
I **	7.00	7.00	0.01	> 1.0g	>1.38	$104.37
J **	5.50	8.25	0.01	> 1.0g	>1.38	$109.42
K **	5.50	8.25	0.02	> 1.0g	>1.43	$116.88
L **	7.00	10.50	0.01	> 1.0g	>1.48	$118.89

Cost Curve 2: 7.25M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	0 r	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.49	0.44	$73.25
A	4.00	4.00	0.02	0.60	0.99	$87.08
B	4.00	4.00	0.03	0.66	1.23	$91.73
E	4.00	6.00	0.02	0.69	1.39	$92.68
F	4.00	6.00	0.03	0.75	1.69	$102.30
K	5.50	8.25	0.02	0.89	2.36	$116.88
L	7.00	10.50	0.01	0.90	2.38	$118.89
C ***	5.00	5.00	0.01	0.62	0.96	$92.55
D ***	4.00	6.00	0.01	0.57	0.91	$92.12
G ***	5.00	5.00	0.02	0.69	1.25	$107.23
H ***	6.00	6.00	0.01	0.64	1.21	$94.37
I ***	7.00	7.00	0.01	0.68	1.43	$104.37
J ***	5.50	8.25	0.01	0.69	1.53	$109.42

Cost Curve 3: 8.0M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	0 r	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.45	0.44	$73.25
A	4.00	4.00	0.02	0.56	0.99	$87.08
B	4.00	4.00	0.03	0.63	1.23	$91.73
E	4.00	6.00	0.02	0.67	1.38	$92.68
F	4.00	6.00	0.03	0.74	1.69	$102.30
K	5.50	8.25	0.02	0.87	2.38	$116.88
L	7.00	10.50	0.01	0.88	2.40	$118.89
C ***	5.00	5.00	0.01	0.58	0.96	$92.55
D ***	4.00	6.00	0.01	0.52	0.90	$92.12
G ***	5.00	5.00	0.02	0.67	1.25	$107.23
H ***	6.00	6.00	0.01	0.62	1.20	$94.37
I ***	7.00	7.00	0.01	0.66	1.42	$104.37
J ***	5.50	8.25	0.01	0.67	1.53	$109.42

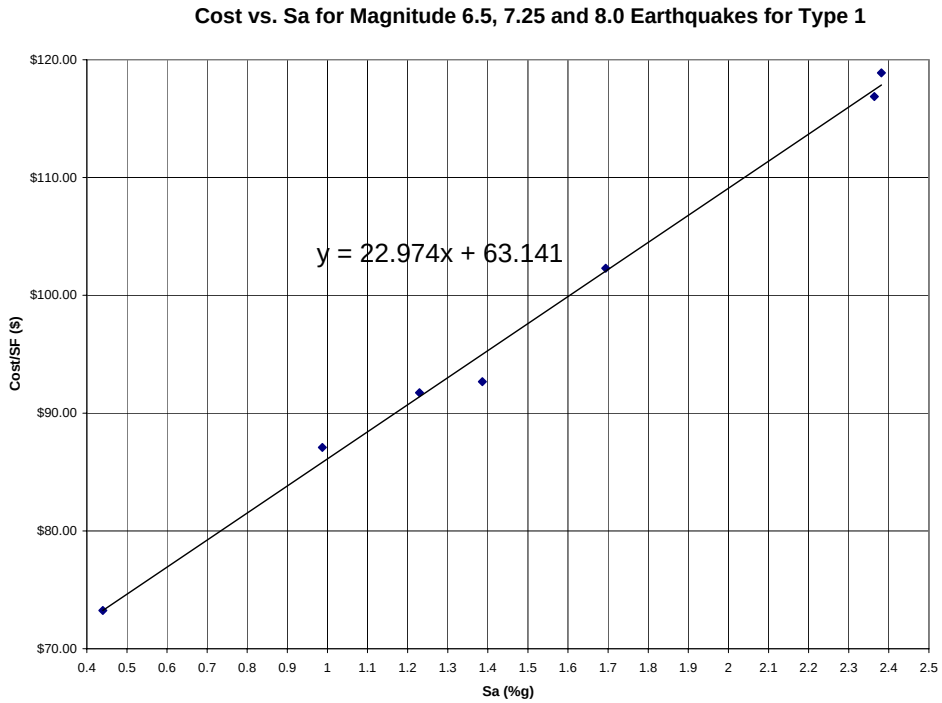
NOTES:

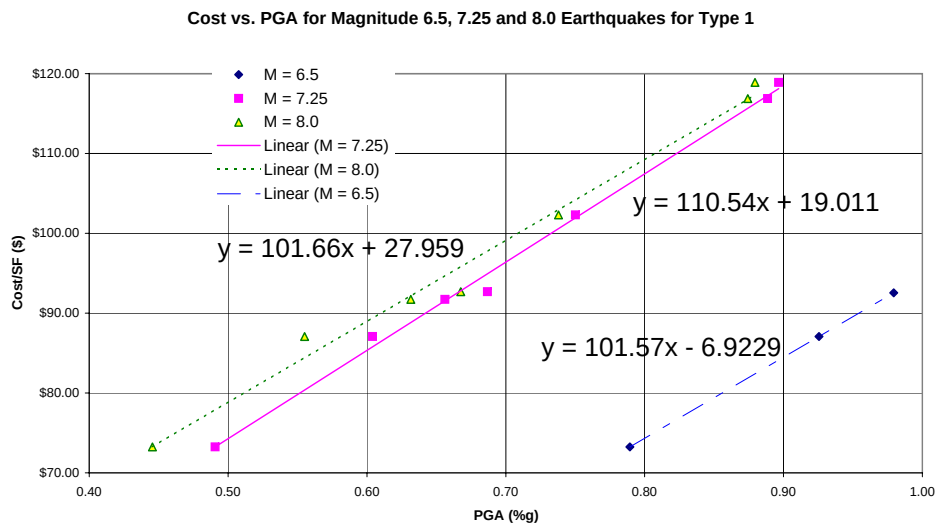
* The minimum and maximum column sizes were determined by the guideline that 0.67 < Dc/Ds < 1.33 per SDC Section 7.6.1.

** These costs were not plotted since the associated PGA's exceed 1.0g.

*** These costs were not plotted since other models provide similar seismic resistance at lower cost.

**** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.





Cost Curve for Model No. 3 (CIP P/S box girder, 100' span, 39' wide, 4' deep)

Cost Curve 1: 6.5M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****					0.32	$57.94
A	4.00	4.00	0.01	0.76	0.87	$67.16
B **	4.00	4.00	0.02	> 1.0g	>1.14	$70.68
C **	4.00	4.00	0.03	> 1.0g	>1.18	$73.11
D **	4.00	6.00	0.01	> 1.0g	>1.22	$76.32
E **	4.00	6.00	0.02	> 1.0g	>1.33	$82.95
F **	4.00	6.00	0.03	> 1.0g	>1.40	$91.76
G **	5.00	5.00	0.01	> 1.0g	>1.26	$73.26
H **	5.00	5.00	0.02	> 1.0g	>1.38	$82.42
I **	5.50	8.25	0.01	> 1.0g	>1.51	$98.21
J **	5.50	8.25	0.02	> 1.0g	>1.62	$122.79

Cost Curve 2: 7.25M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.43	0.32	$57.94
A	4.00	4.00	0.01	0.54	0.87	$67.16
B	4.00	4.00	0.02	0.66	1.33	$70.68
C	4.00	4.00	0.03	0.76	1.81	$73.11
E	4.00	6.00	0.02	0.83	2.21	$82.95
F	4.00	6.00	0.03	0.97	2.83	$91.76
H	5.00	5.00	0.02	0.83	2.17	$82.42
J **	5.50	8.25	0.02	> 1.0g	>2.76	$122.79
D ***	4.00	6.00	0.01	0.63	1.32	$76.32
I ***	5.50	8.25	0.01	0.90	2.44	$98.21
G ***	5.00	5.00	0.01	0.71	1.49	$73.26

Cost Curve 3: 8.0M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.37	0.32	$57.94
A	4.00	4.00	0.01	0.49	0.87	$67.16
B	4.00	4.00	0.02	0.64	1.33	$70.68
C	4.00	4.00	0.03	0.75	1.81	$73.11
E	4.00	6.00	0.02	0.82	2.21	$82.95
F	4.00	6.00	0.03	0.95	2.84	$91.76
H	5.00	5.00	0.02	0.83	2.17	$82.42
J **	5.50	8.25	0.02	> 1.0g	>2.95	$122.79
D ***	4.00	6.00	0.01	0.61	1.32	$76.32
I ***	5.50	8.25	0.01	0.88	2.44	$98.21
G ***	5.00	5.00	0.01	0.69	1.49	$73.26

NOTES:

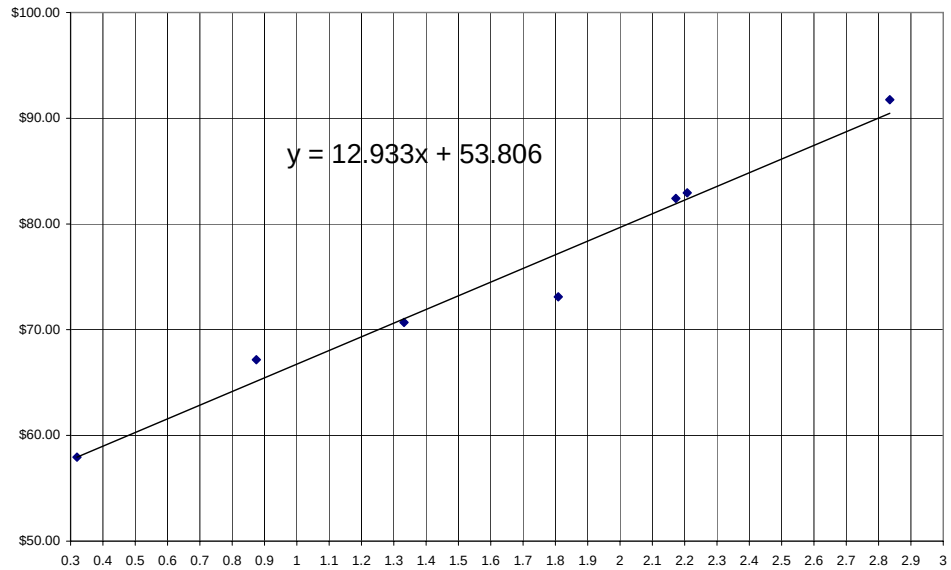
* The minimum and maximum column sizes were determined by the guideline that 0.67 < Dc/Ds < 1.33 per SDC Section 7.6.1.

** These costs were not plotted since the associated PGA's exceed 1.0g.

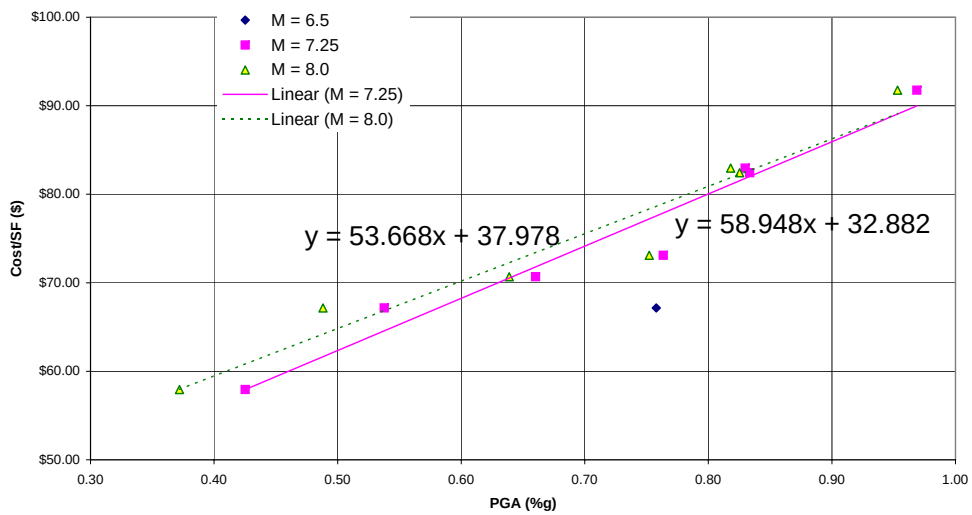
*** These costs were not plotted since other models provide similar seismic resistance at lower cost.

**** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.

Cost vs. Sa for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 3



Cost vs. PGA for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 3



Cost Curve for Model No. 4 (CIP P/S box girder, 100' span, 68' wide, 4' deep)

Cost Curve 1: Average CIDH-HP-PP stiffness, 6.5 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
4A **	3.0	0.01		0.26	$82.62
*****			0.69	0.28	$82.72
4B	3.0	0.02	0.71	0.35	$83.09
4C	3.0	0.03	0.75	0.42	$83.61
4E	4.0	0.02	0.89	0.78	$85.96
4F	4.0	0.03	1.00	0.94	$87.91
4G ***	5.0	0.01	> 1.0g	>0.97	$88.59
4H ***	5.0	0.02	> 1.0g	>1.02	$92.14
4I ***	5.0	0.03	> 1.0g	>1.04	$98.80
4D ****	4.0	0.01	0.73	0.54	$84.89

Cost Curve 2: Average CIDH-HP-PP stiffness, 7.25 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
4A **	3.0	0.01			$82.62
*****			0.54	0.28	$82.72
4B	3.0	0.02	0.55	0.35	$83.09
4C	3.0	0.03	0.56	0.42	$83.61
4E	4.0	0.02	0.62	0.78	$85.96
4F	4.0	0.03	0.66	0.95	$87.91
4H	5.0	0.02	0.69	1.24	$92.14
4I	5.0	0.03	0.72	1.44	$98.80
4D ****	4.0	0.01	0.55	0.54	$84.89
4G ****	5.0	0.01	0.65	1.00	$88.59

Cost Curve 3: Average CIDH-HP-PP stiffness, 8.0 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
4A **	3.0	0.01			$82.62
*****			0.43	0.28	$82.72
4B	3.0	0.02	0.44	0.35	$83.09
4C	3.0	0.03	0.47	0.42	$83.61
4E	4.0	0.02	0.55	0.78	$85.96
4F	4.0	0.03	0.61	0.95	$87.91
4H	5.0	0.02	0.66	1.24	$92.14
4I	5.0	0.03	0.70	1.44	$98.80
4D ****	4.0	0.01	0.46	0.54	$84.89
4G ****	5.0	0.01	0.61	1.00	$88.59

NOTES:

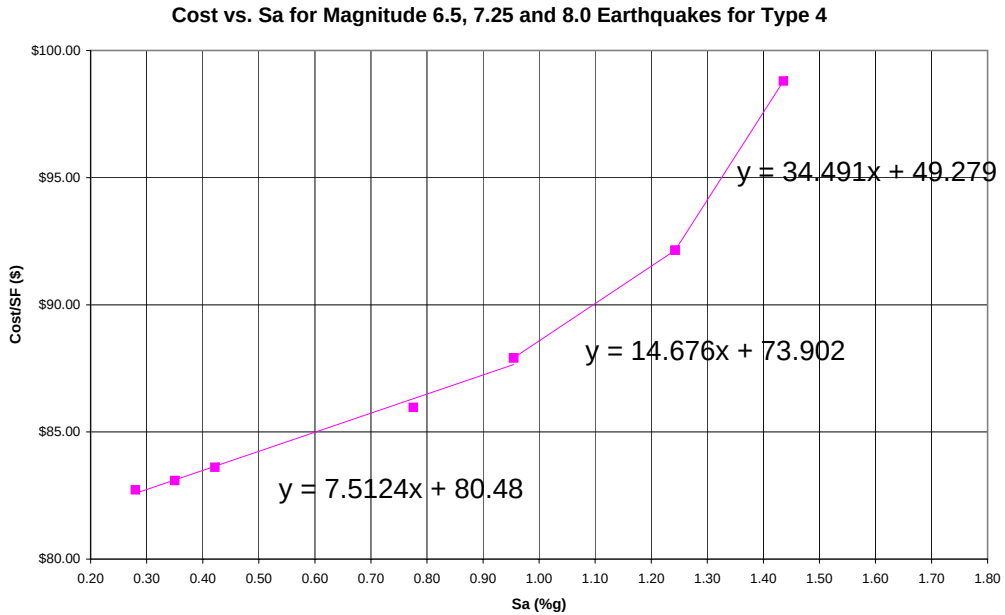
* The minimum and maximum column sizes were determined by the guideline that 0.67 < Dc/Ds < 1.33 per SDC Section 7.6.1.

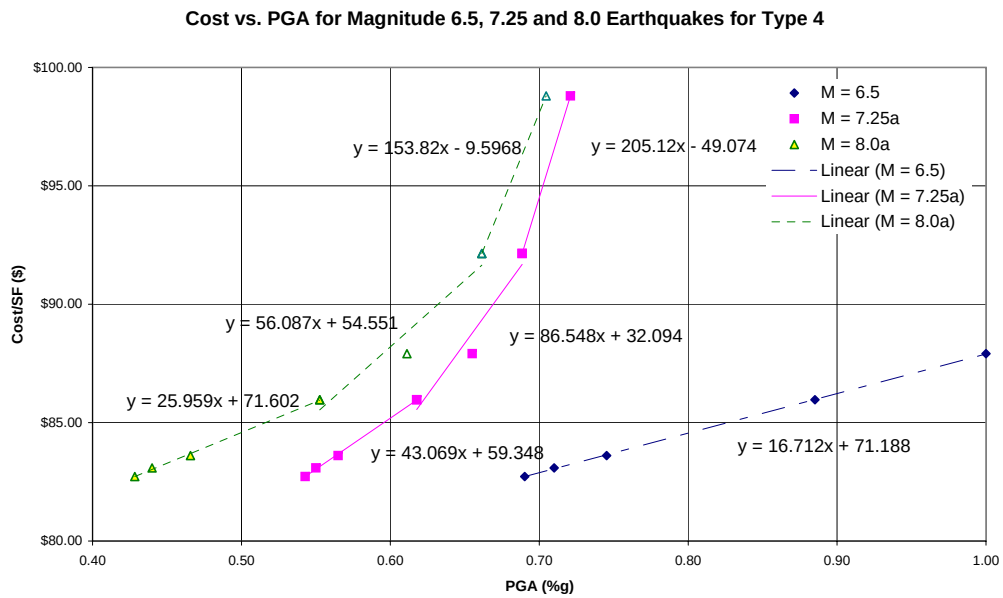
** These costs were not plotted since these models do not meet the minimum lateral load requirement of SDC Section 3.5.

*** These costs were not plotted since the associated PGA's exceed 1.0g.

**** These costs were not plotted since other models provide similar seismic resistance at lower cost.

***** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.





Cost Curve for Model No. 6 (PC/PS I girder, 100' span, 68' wide, 4.5' girder)

Cost Curve 1: Average CIDH-HP-PP stiffness, 6.5 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****			0.64	0.29	$82.74
A	3.0	0.02	0.67	0.32	$84.00
B	3.0	0.03	0.71	0.39	$84.43
C	4.0	0.01	0.73	0.59	$85.91
D **	4.0	0.02	> 1.0g	>0.95	$88.13
E **	4.0	0.03	> 1.0g	>1.02	$96.44
F **	5.0	0.01	> 1.0g	>1.11	$95.25
G **	5.0	0.02	> 1.0g	>1.22	$105.99
H **	5.0	0.03	> 1.0g	>1.30	$113.87
I **	6.0	0.01	> 1.0g	>1.33	$108.95
J **	6.0	0.02	> 1.0g	>1.47	$129.31

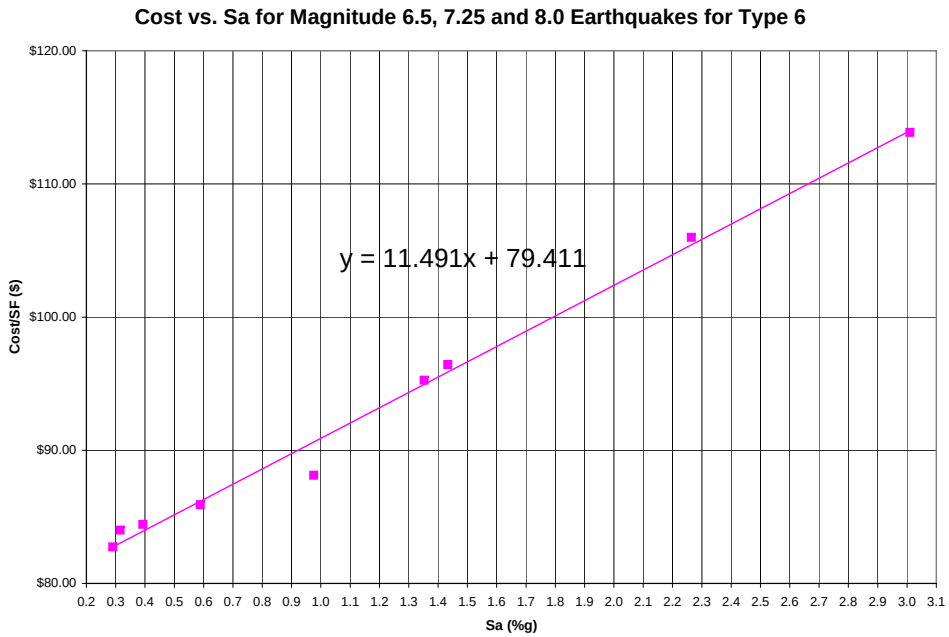
Cost Curve 2: Average CIDH-HP-PP stiffness, 7.25 EQ

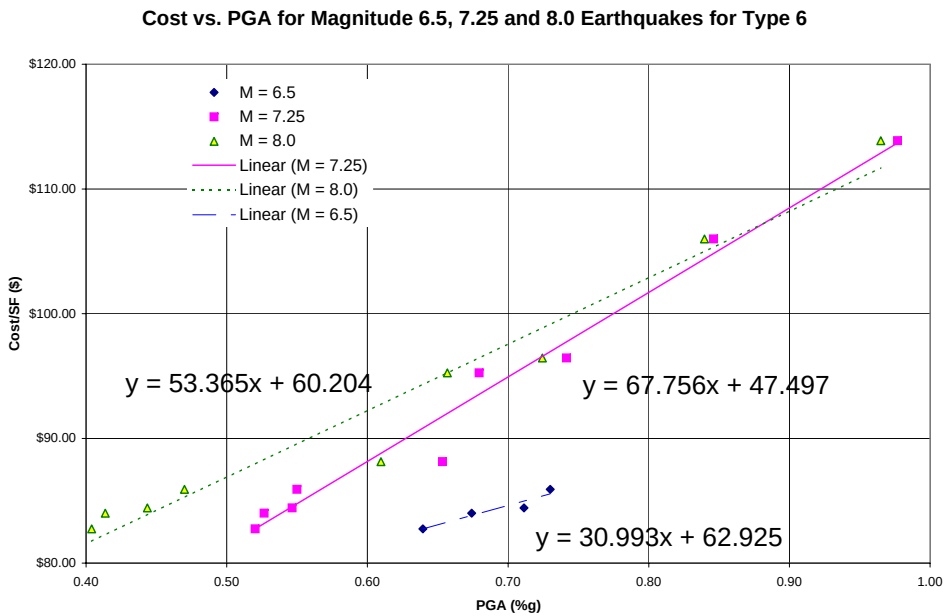
Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****			0.52	0.29	$82.74
A	3.0	0.02	0.53	0.32	$84.00
B	3.0	0.03	0.55	0.39	$84.43
C	4.0	0.01	0.55	0.59	$85.91
D	4.0	0.02	0.65	0.98	$88.13
E	4.0	0.03	0.74	1.43	$96.44
F	5.0	0.01	0.68	1.35	$95.25
G	5.0	0.02	0.85	2.26	$105.99
H	5.0	0.03	0.98	3.01	$113.87
J **	6.0	0.02	> 1.0g	>3.14	$129.31
I ***	6.0	0.01	0.84	2.37	$108.95

Cost Curve 3: Average CIDH-HP-PP stiffness, 8.0 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****			0.40	0.29	$82.74
A	3.0	0.02	0.41	0.32	$84.00
B	3.0	0.03	0.44	0.39	$84.43
C	4.0	0.01	0.47	0.59	$85.91
D	4.0	0.02	0.61	0.98	$88.13
E	4.0	0.03	0.72	1.43	$96.44
F	5.0	0.01	0.66	1.35	$95.25
G	5.0	0.02	0.84	2.26	$105.99
H	5.0	0.03	0.96	3.01	$113.87
J **	6.0	0.02	> 1.0g	>3.25	$129.31
I ***	6.0	0.01	0.83	2.37	$108.95

NOTES:
* The minimum and maximum column sizes were determined by the guideline that 0.67 < Dc/Ds < 1.33 per SDC Section 7.6.1.
** These costs were not plotted since the associated PGA's exceed 1.0g.
*** These costs were not plotted since other models provide similar seismic resistance at lower cost.
**** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.





Cost Curve for Model No. 9 (CIP P/S box girder, 150' span, 27' wide, 6' deep, 1000' curve)

Cost Curve 1: 6.5M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
A **	4.00	4.00	0.02	> 1.0g	>1.13	$89.62
B **	4.00	4.00	0.03	> 1.0g	>1.17	$96.33
C **	5.00	5.00	0.01	> 1.0g	>1.21	$97.20
D	4.00	6.00	0.01	0.99	1.02	$96.89
E **	4.00	6.00	0.02	> 1.0g	>1.23	$97.70
F **	4.00	6.00	0.03	> 1.0g	>1.28	$110.92
G **	5.00	5.00	0.02	> 1.0g	>1.26	$118.41
H **	6.00	6.00	0.01	> 1.0g	>1.33	$105.01
I **	7.00	7.00	0.01	> 1.0g	>1.34	$113.59
J **	5.50	8.25	0.01	> 1.0g	>1.30	$121.44
K **	5.50	8.25	0.02	> 1.0g	>1.29	$132.47
L **	7.00	10.50	0.01	> 1.0g	>1.28	$136.15

Cost Curve 2: 7.25M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.58	0.49	$74.96
A	4.00	4.00	0.02	0.68	1.14	$89.62
B	4.00	4.00	0.03	0.74	1.32	$96.33
F	4.00	6.00	0.03	0.83	1.99	$110.92
C ***	5.00	5.00	0.01	0.65	1.05	$97.20
D ***	4.00	6.00	0.01	0.61	1.03	$96.89
E ***	4.00	6.00	0.02	0.74	1.61	$97.70
G ***	5.00	5.00	0.02	0.73	1.40	$118.41
H ***	6.00	6.00	0.01	0.70	1.39	$105.01
I ***	7.00	7.00	0.01	0.76	1.69	$113.59
J ***	5.50	8.25	0.01	0.78	1.83	$121.44
K **	5.50	8.25	0.02	> 1.0g	>2.32	$132.47
L **	7.00	10.50	0.01	> 1.0g	>2.14	$136.15

Cost Curve 3: 8.0M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.56	0.49	$74.96
A	4.00	4.00	0.02	0.66	1.14	$89.62
B	4.00	4.00	0.03	0.73	1.32	$96.33
F	4.00	6.00	0.03	0.82	2.00	$110.92
C ***	5.00	5.00	0.01	0.62	1.05	$97.20
D ***	4.00	6.00	0.01	0.58	1.02	$96.89
E ***	4.00	6.00	0.02	0.73	1.61	$97.70
G ***	5.00	5.00	0.02	0.71	1.40	$118.41
H ***	6.00	6.00	0.01	0.68	1.39	$105.01
I ***	7.00	7.00	0.01	0.75	1.69	$113.59
J ***	5.50	8.25	0.01	0.77	1.84	$121.44
K **	5.50	8.25	0.02	> 1.0g	>2.46	$132.47
L **	7.00	10.50	0.01	> 1.0g	>2.29	$136.15

NOTES:

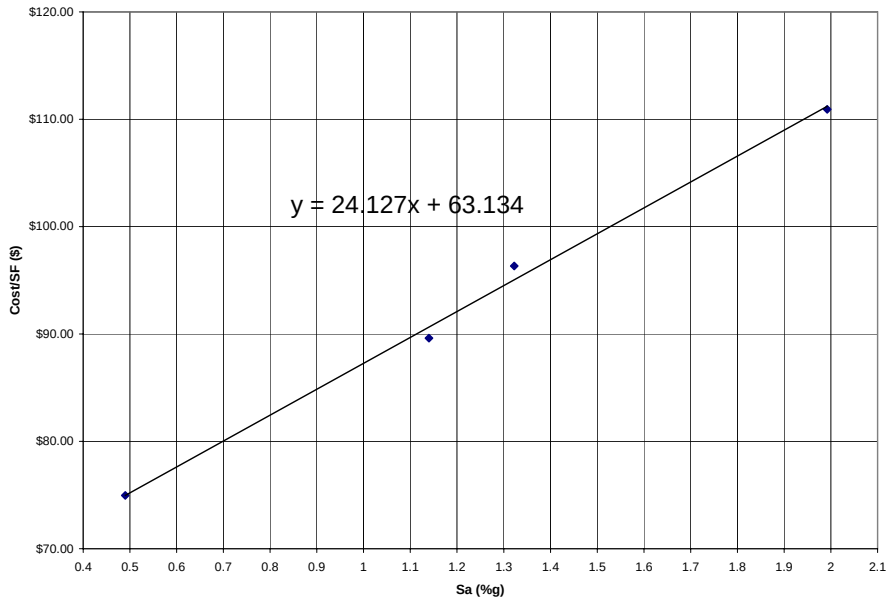
* The minimum and maximum column sizes were determined by the guideline that 0.67 < Dc/Ds < 1.33 per SDC Section 7.6.1.

** These costs were not plotted since the associated PGA's exceed 1.0g.

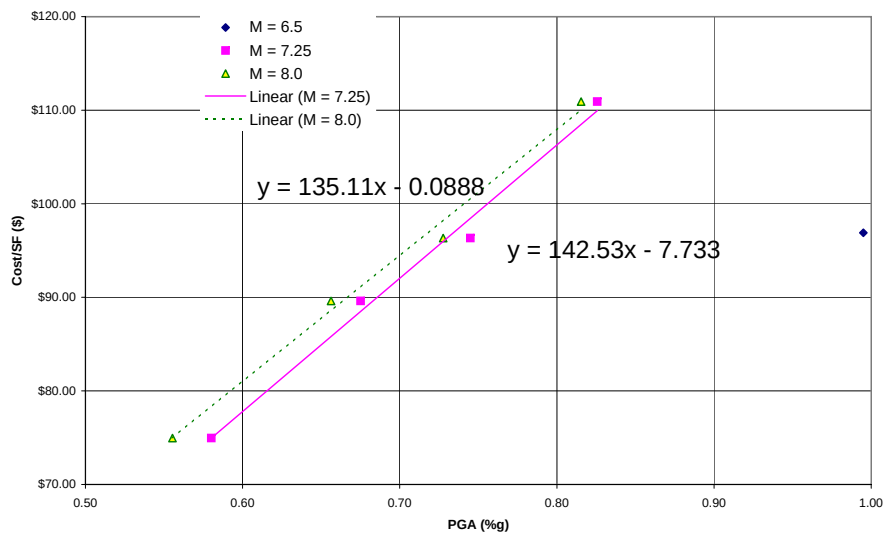
*** These costs were not plotted since other models provide similar seismic resistance at lower cost.

**** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.

Cost vs. Sa for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 9



Cost vs. PGA for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 9



Cost Curve for Model No. 10 (CIP P/S box girder, 100' span, 68' wide, 4' deep, 30° skew)

Cost Curve 1: Average CIDH-HP-PP stiffness, 6.5 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
A **	3.0	0.01	0.68	0.27	$85.70
*****			0.70	0.29	$85.84
B	3.0	0.02	0.73	0.35	$86.18
C	3.0	0.03	0.78	0.43	$86.74
E	4.0	0.02	0.87	0.73	$89.28
F	4.0	0.03	0.99	0.88	$90.66
H ***	5.0	0.02	> 1.0g	>0.99	$95.83
I ***	5.0	0.03	> 1.0g	>1.01	$102.70
D ****	4.0	0.01	0.75	0.41	$88.14
G ****	5.0	0.01	0.96	0.91	$91.40

Cost Curve 2: Average CIDH-HP-PP stiffness, 7.25 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
A **	3.0	0.01	0.53	0.27	$85.70
*****			0.54	0.29	$85.84
B	3.0	0.02	0.56	0.35	$86.18
C	3.0	0.03	0.58	0.43	$86.74
E	4.0	0.02	0.62	0.73	$89.28
F	4.0	0.03	0.65	0.88	$90.66
H	5.0	0.02	0.66	1.12	$95.83
I	5.0	0.03	0.70	1.29	$102.70
D ****	4.0	0.01	0.56	0.40	$88.14
G ****	5.0	0.01	0.63	0.91	$91.40

Cost Curve 3: Average CIDH-HP-PP stiffness, 8.0 EQ

Model	Column Diam.(ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
A **	3.0	0.01	0.41	0.27	$85.70
*****			0.43	0.29	$85.84
B	3.0	0.02	0.45	0.35	$86.18
C	3.0	0.03	0.49	0.43	$86.74
E	4.0	0.02	0.55	0.73	$89.28
F	4.0	0.03	0.60	0.88	$90.66
H	5.0	0.02	0.63	1.12	$95.83
I	5.0	0.03	0.68	1.29	$102.70
D ****	4.0	0.01	0.48	0.42	$88.14
G ****	5.0	0.01	0.58	0.91	$91.40

NOTES:

* The minimum and maximum column sizes were determined by the guideline that 0.67 < Dc/Ds < 1.33 per SDC Section 7.6.1.

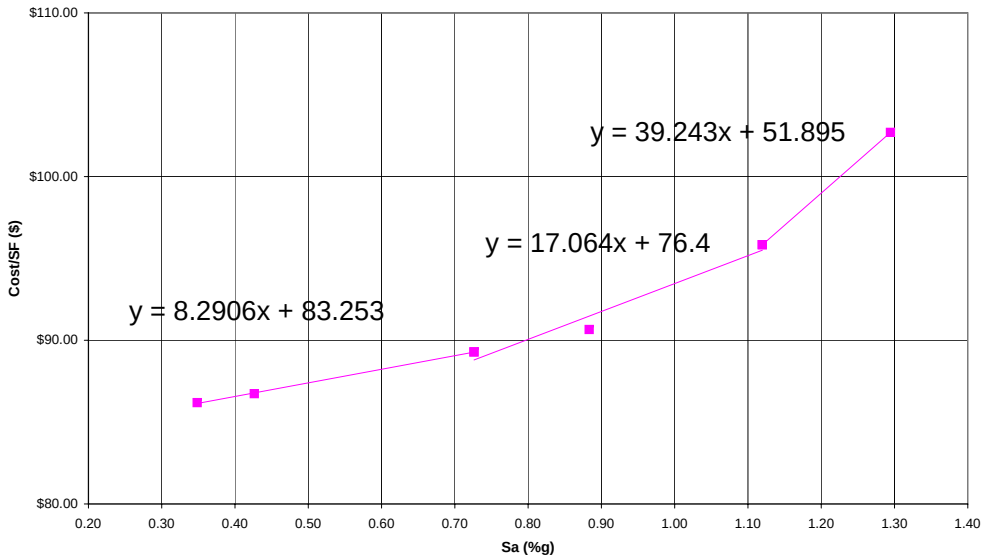
** These costs were not plotted since these models do not meet the minimum lateral load requirement of SDC Section 3.5.

*** These costs were not plotted since the associated PGA's exceed 1.0g.

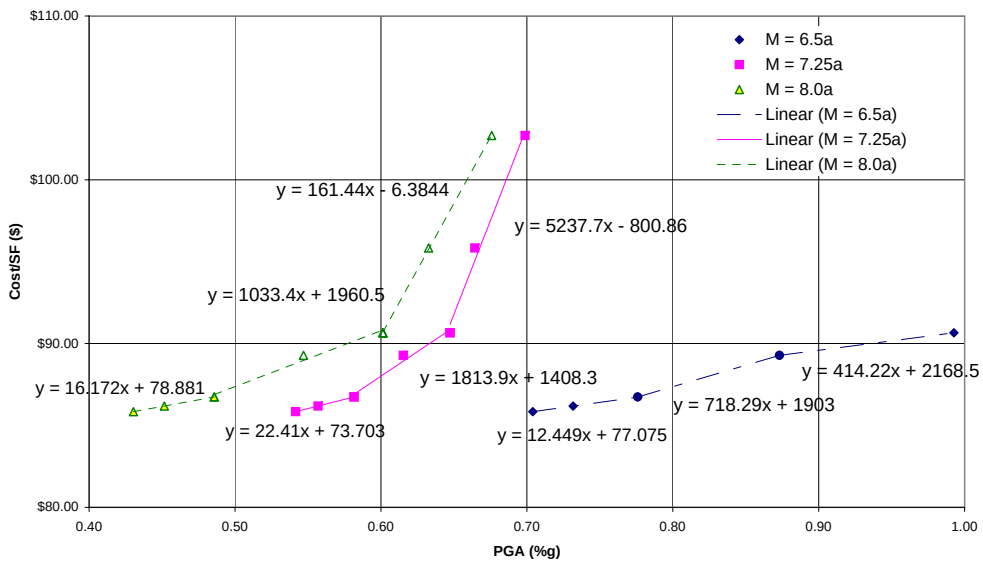
**** These costs were not plotted since other models provide similar seismic resistance at lower cost.

***** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.

Cost vs. Sa for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 10



Cost vs. PGA for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 10



Cost Curve for Model No. 11 (CIP P/S box girder, 150' span, 39' wide, 6' deep, 50' column height)

Cost Curve 1: 6.5M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
A **	4.00	6.00	0.03	> 1.0g	>0.58	$99.89
B **	6.00	6.00	0.02	> 1.0g	>0.80	$106.43
C **	6.00	6.00	0.03	> 1.0g	>0.89	$117.48
D **	7.00	7.00	0.01	> 1.0g	>0.84	$108.53
E **	7.00	7.00	0.02	> 1.0g	>0.96	$128.39
F **	8.00	8.00	0.01	> 1.0g	>0.96	$121.08
G **	5.50	8.25	0.01	> 1.0g	>0.77	$113.92
H **	5.50	8.25	0.02	> 1.0g	>0.89	$127.27
I **	5.50	8.25	0.03	> 1.0g	>0.95	$150.80
J **	7.00	10.50	0.01	> 1.0g	>0.96	$136.93
K **	7.00	10.50	0.02	> 1.0g	>1.06	$150.21
L **	7.00	10.50	0.03	> 1.0g	>1.10	$158.33

Cost Curve 2: 7.25M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.69	0.43	$89.18
A	4.00	6.00	0.03	0.75	0.76	$99.89
B	6.00	6.00	0.02	0.74	0.93	$106.43
C	6.00	6.00	0.03	0.81	1.28	$117.48
I	5.50	8.25	0.03	0.85	1.51	$150.80
K	7.00	10.50	0.02	0.86	1.78	$150.21
L	7.00	10.50	0.03	0.95	2.31	$158.33
D ***	7.00	7.00	0.01	0.69	0.83	$108.53
E ***	7.00	7.00	0.02	0.80	1.28	$128.39
F ***	8.00	8.00	0.01	0.72	1.02	$121.08
G ***	5.50	8.25	0.01	0.69	0.82	$113.92
H ***	5.50	8.25	0.02	0.77	1.17	$127.27
J ***	7.00	10.50	0.01	0.74	1.20	$136.93

Cost Curve 3: 8.0M Earthquake

Model	Column Dim1. (ft)*	Column Dim2. (ft)*	ρ	PGA (%g)	Sa (%g)	Estimated Cost / SF
****				0.66	0.43	$89.18
A	4.00	6.00	0.03	0.72	0.76	$99.89
B	6.00	6.00	0.02	0.72	0.93	$106.43
C	6.00	6.00	0.03	0.81	1.28	$117.48
I	5.50	8.25	0.03	0.86	1.51	$150.80
K	7.00	10.50	0.02	0.86	1.79	$150.21
L	7.00	10.50	0.03	0.96	2.32	$158.33
D ***	7.00	7.00	0.01	0.65	0.83	$108.53
E ***	7.00	7.00	0.02	0.79	1.28	$128.39
F ***	8.00	8.00	0.01	0.70	1.02	$121.08
G ***	5.50	8.25	0.01	0.64	0.82	$113.92
H ***	5.50	8.25	0.02	0.76	1.17	$127.27
J ***	7.00	10.50	0.01	0.72	1.20	$136.93

NOTES:

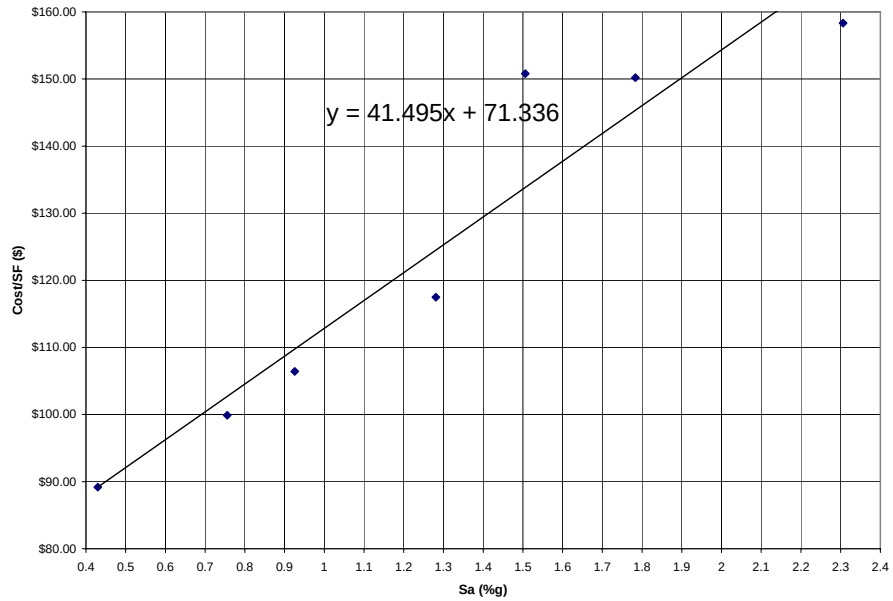
* The minimum and maximum column sizes were determined by the guideline that 0.67 < Dc/Ds < 1.33 per SDC Section 7.6.1.

** These costs were not plotted since the associated PGA's exceed 1.0g.

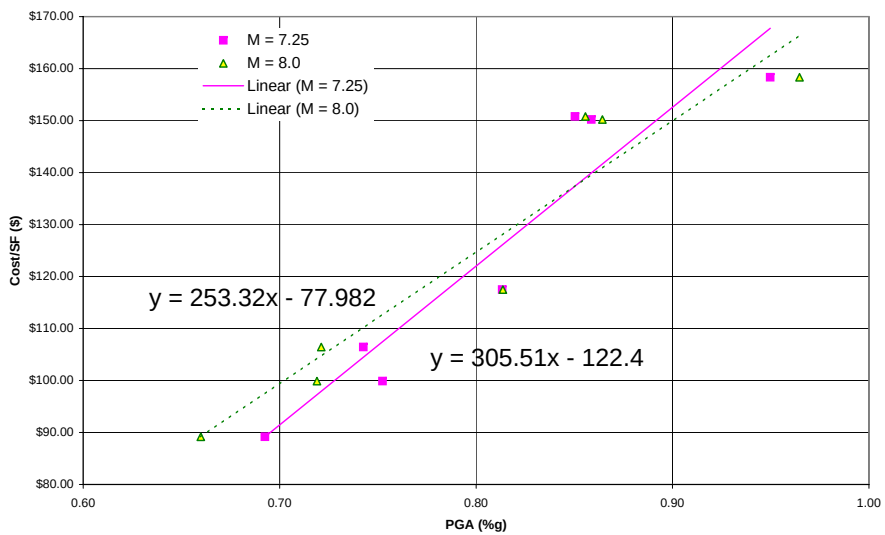
*** These costs were not plotted since other models provide similar seismic resistance at lower cost.

**** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.

Cost vs. Sa for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 11



Cost vs. PGA for Magnitude 6.5, 7.25 and 8.0 Earthquakes for Type 11



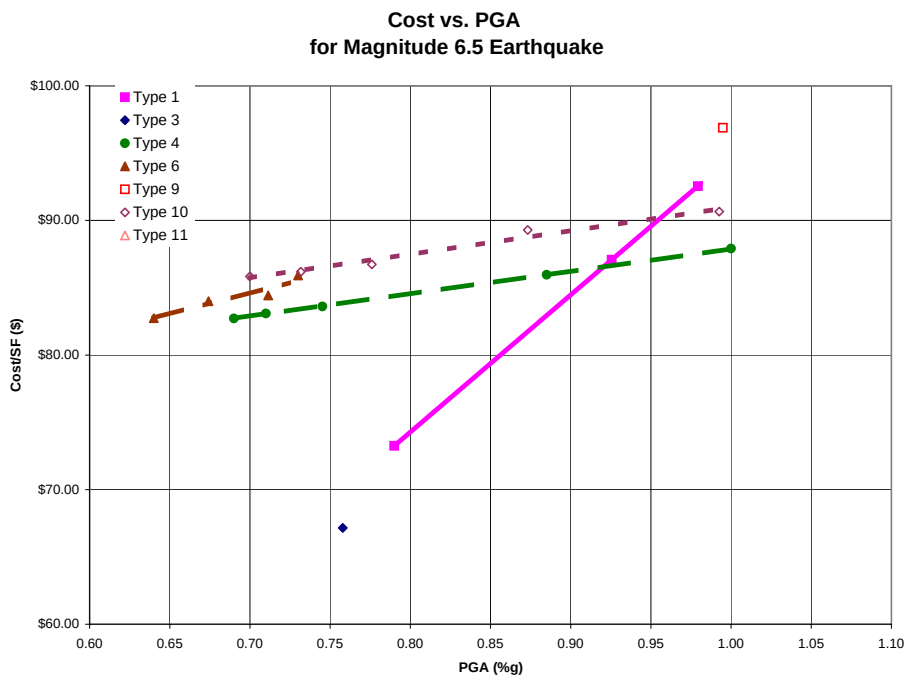
PEERC Bridge Cost Research

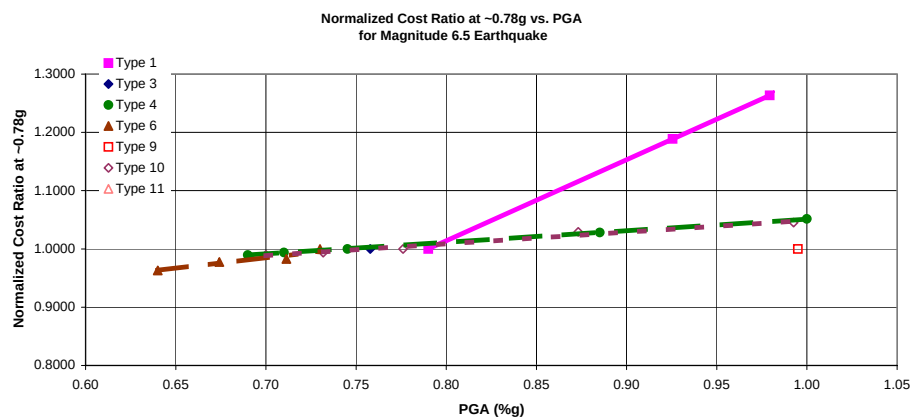
Cost vs. PGA for All Models for M6.5 Earthquake

Cost Curve: use 6.5M Earthquake

Type	Model	Column Dim1. (ft)	Column Dim2. (ft)	ρ	PGA (%g)	Sa (%g)	Estimated Cost / 1000	Estimated Cost / SF	Normalized Cost Ratio*
1	**				0.79	0.44	$1,971	$73.25	1.0000
	A	4.00	4.00	0.02	0.93	0.99	$2,343	$87.08	1.1888
	C	5.00	5.00	0.01	0.98	0.95	$3,199	$92.55	1.2635
3	**					0.32	$1,039	$57.94	0.8628
	A	4.00	4.00	0.01	0.76	0.87	$1,205	$67.16	1.0000
4	**				0.69	0.28	$2,587	$82.72	0.9894
	B	3.00	3.00	0.02	0.71	0.35	$2,599	$83.09	0.9938
	C	3.00	3.00	0.03	0.75	0.42	$2,615	$83.61	1.0000
	E	4.00	4.00	0.02	0.89	0.78	$2,689	$85.96	1.0282
	F	4.00	4.00	0.03	1.00	0.94	$2,750	$87.91	1.0515
6	**				0.64	0.29	$2,588	$82.74	0.9631
	A	3.00	3.00	0.02	0.67	0.32	$2,628	$84.00	0.9778
	B	3.00	3.00	0.03	0.71	0.39	$2,641	$84.43	0.9827
	C	4.00	4.00	0.01	0.73	0.59	$2,687	$85.91	1.0000
9	D	4.00	6.00	0.01	0.99	1.02	$2,088	$96.89	1.0000
10	**				0.70	0.29	$2,685	$85.84	0.9897
	B	3.00	3.00	0.02	0.73	0.35	$2,696	$86.18	0.9936
	C	3.00	3.00	0.03	0.78	0.43	$2,713	$86.74	1.0000
	E	4.00	4.00	0.02	0.87	0.73	$2,793	$89.28	1.0294
	F	4.00	4.00	0.03	0.99	0.88	$2,836	$90.66	1.0452
11									

* Normalized for cost at about 0.78g PGA.
** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.





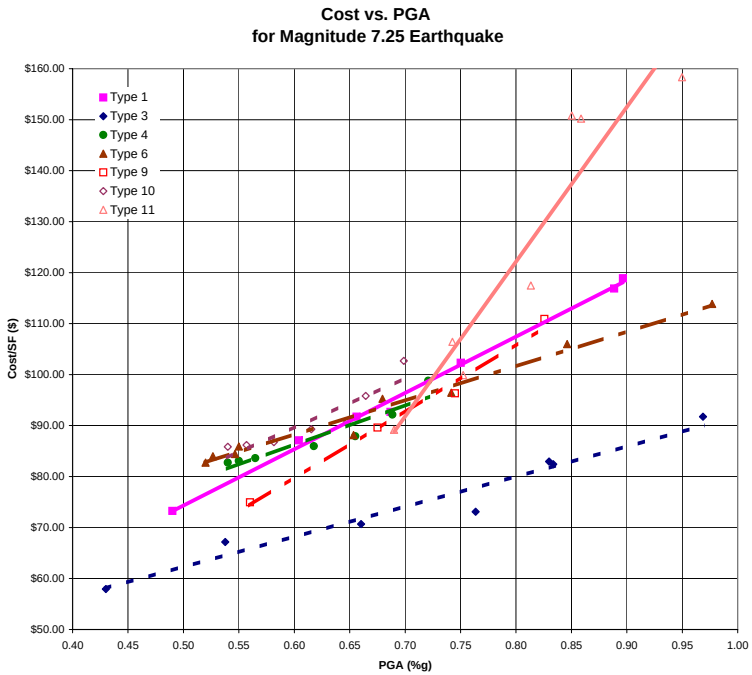
PEERC Bridge Cost Research

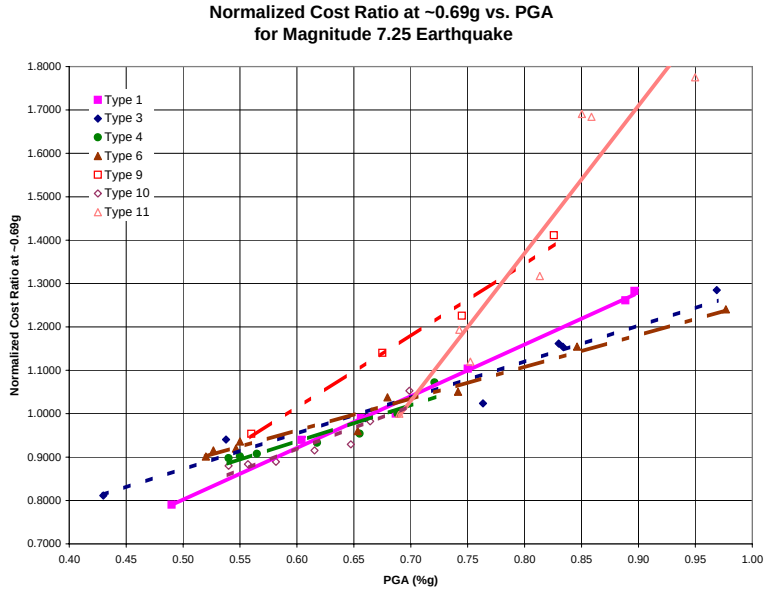
Cost vs. PGA for All Models for M7.25 Earthquake

Cost Curve: use 7.25M Earthquake

Type	Model	Column Dim1. (ft)	Column Dim2. (ft)	ρ	PGA (%g)	Sa (%g)	Estimated Cost / 1000	Estimated Cost / SF	Normalized Cost Ratio*
1	**				0.49	0.44	$1,971	$73.25	0.7904
	A	4.00	4.00	0.02	0.60	0.99	$2,343	$87.08	0.9396
	B	4.00	4.00	0.03	0.66	1.23	$2,469	$91.73	0.9898
	E	4.00	6.00	0.02	0.69	1.39	$2,494	$92.68	1.0000
	F	4.00	6.00	0.03	0.75	1.69	$2,753	$102.30	1.1039
	K	5.50	8.25	0.02	0.89	2.36	$3,145	$116.88	1.2612
	L	7.00	10.50	0.01	0.90	2.38	$3,199	$118.89	1.2829
3	**				0.43	0.32	$1,039	$57.94	0.8113
	A	4.00	4.00	0.01	0.54	0.87	$1,205	$67.16	0.9404
	B	4.00	4.00	0.02	0.66	1.33	$1,268	$70.68	0.9898
	C	4.00	4.00	0.03	0.76	1.81	$1,312	$73.11	1.0238
	E	4.00	6.00	0.02	0.83	2.21	$1,488	$82.95	1.1615
	F	4.00	6.00	0.03	0.97	2.83	$1,646	$91.76	1.2849
	H	5.00	5.00	0.02	0.83	2.17	$1,479	$82.42	1.1542
4	**				0.54	0.28	$2,587	$82.72	0.8978
	4B	3.00	3.00	0.02	0.55	0.35	$2,599	$83.09	0.9018
	4C	3.00	3.00	0.03	0.56	0.42	$2,615	$83.61	0.9074
	4E	4.00	4.00	0.02	0.62	0.78	$2,689	$85.96	0.9330
	4F	4.00	4.00	0.03	0.66	0.95	$2,750	$87.91	0.9541
	4H	5.00	5.00	0.02	0.69	1.24	$2,882	$92.14	1.0000
	4I	5.00	5.00	0.03	0.72	1.44	$3,090	$98.80	1.0723
6	**				0.52	0.29	$2,588	$82.74	0.9014
	A	3.00	3.00	0.02	0.53	0.32	$2,628	$84.00	0.9152
	B	3.00	3.00	0.03	0.55	0.39	$2,641	$84.43	0.9198
	C	4.00	4.00	0.01	0.55	0.59	$2,687	$85.91	0.9360
	D	4.00	4.00	0.02	0.65	0.98	$2,757	$88.13	0.9601
	E	4.00	4.00	0.03	0.74	1.43	$3,017	$96.44	1.0507
	F	5.00	5.00	0.01	0.68	1.35	$2,980	$95.25	1.0378
	G	5.00	5.00	0.02	0.85	2.26	$3,315	$105.99	1.1548
	H	5.00	5.00	0.03	0.98	3.01	$1,670	$113.87	1.2406
9	**				0.56	0.49	$1,501	$74.96	0.9538
	A	4.00	4.00	0.02	0.68	1.14	$1,795	$89.62	1.1403
	B	4.00	4.00	0.03	0.74	1.32	$2,066	$96.33	1.2257
	F	4.00	6.00	0.03	0.83	1.99	$2,088	$110.92	1.4114
10	**				0.54	0.29	$2,685	$85.84	0.8800
	B	3.00	3.00	0.02	0.56	0.35	$2,696	$86.18	0.8835
	C	3.00	3.00	0.03	0.58	0.43	$2,713	$86.74	0.8891
	E	4.00	4.00	0.02	0.62	0.73	$2,793	$89.28	0.9153
	F	4.00	4.00	0.03	0.65	0.88	$2,836	$90.66	0.9293
	H	5.00	5.00	0.02	0.66	1.12	$2,998	$95.83	0.9824
	I	5.00	5.00	0.03	0.70	1.29	$3,212	$102.70	1.0528
11	**				0.69	0.43	$2,400	$89.18	1.0000
	A	4.00	6.00	0.03	0.75	0.76	$2,688	$99.89	1.1201
	B	6.00	6.00	0.02	0.74	0.93	$2,864	$106.43	1.1934
	C	6.00	6.00	0.03	0.81	1.28	$3,161	$117.48	1.3173
	I	5.50	8.25	0.03	0.85	1.51	$4,058	$150.80	1.6909
	K	7.00	10.50	0.02	0.86	1.78	$4,042	$150.21	1.6843
	L	7.00	10.50	0.03	0.95	2.31	$4,261	$158.33	1.7754

* Normalized for cost at about 0.69g PGA.
** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.

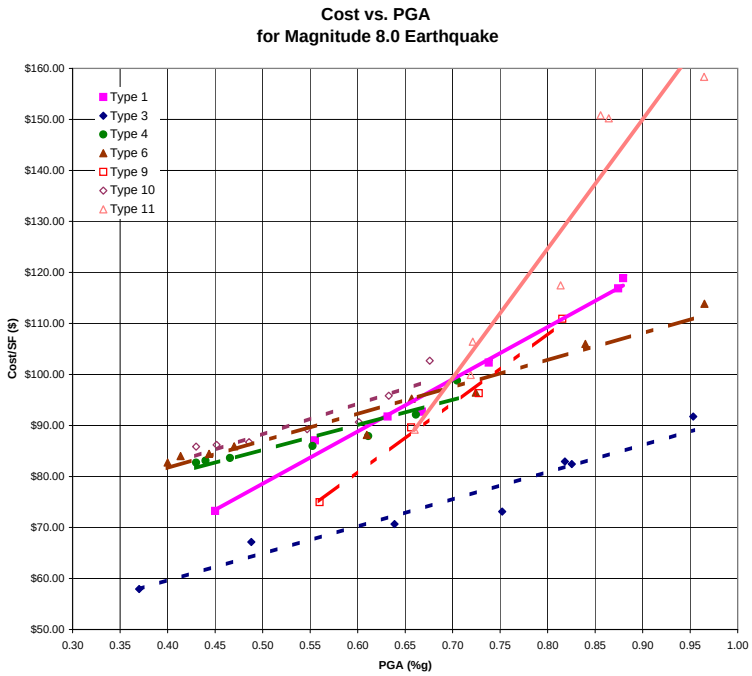
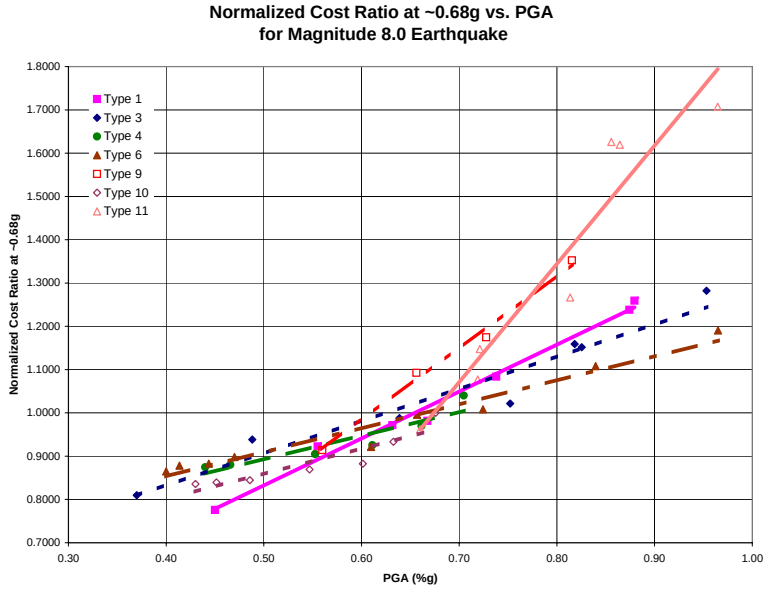




PEERC Bridge Cost Research

Cost vs. PGA for All Models for M8.0 Earthquake

Cost Curve: use 8.0M Earthquake

Type	Model	Column Dim1. (ft)	Column Dim2. (ft)	ρ	PGA (%g)	Sa (%g)	Estimated Cost / 1000	Estimated Cost / SF	Normalized Cost Ratio*
1	**				0.45	0.44	$1,971	$73.25	0.7759
	A	4.00	4.00	0.02	0.56	0.99	$2,343	$87.08	0.9224
	B	4.00	4.00	0.03	0.63	1.23	$2,469	$91.73	0.9716
	E	4.00	6.00	0.02	0.67	1.39	$2,494	$92.68	0.9816
	F	4.00	6.00	0.03	0.74	1.69	$2,753	$102.30	1.0836
	K	5.50	8.25	0.02	0.87	2.36	$3,145	$116.88	1.2380
	L	7.00	10.50	0.01	0.88	2.38	$3,199	$118.89	1.2593
3	**				0.37	0.32	$1,039	$57.94	0.8097
	A	4.00	4.00	0.01	0.49	0.87	$1,205	$67.16	0.9385
	B	4.00	4.00	0.02	0.64	1.33	$1,268	$70.68	0.9878
	C	4.00	4.00	0.03	0.75	1.81	$1,312	$73.11	1.0217
	E	4.00	6.00	0.02	0.82	2.21	$1,488	$82.95	1.1592
	F	4.00	6.00	0.03	0.95	2.83	$1,646	$91.76	1.2823
	H	5.00	5.00	0.02	0.83	2.17	$1,479	$82.42	1.1518
4	**				0.43	0.28	$2,587	$82.72	0.8707
	4B	3.00	3.00	0.02	0.44	0.35	$2,599	$83.09	0.8746
	4C	3.00	3.00	0.03	0.47	0.42	$2,615	$83.61	0.8801
	4E	4.00	4.00	0.02	0.55	0.78	$2,689	$85.96	0.9049
	4F	4.00	4.00	0.03	0.61	0.95	$2,750	$87.91	0.9254
	4H	5.00	5.00	0.02	0.66	1.24	$2,882	$92.14	0.9699
	4I	5.00	5.00	0.03	0.70	1.44	$3,090	$98.80	1.0399
6	**				0.40	0.29	$2,588	$82.74	0.8650
	A	3.00	3.00	0.02	0.41	0.32	$2,628	$84.00	0.8781
	B	3.00	3.00	0.03	0.44	0.39	$2,641	$84.43	0.8826
	C	4.00	4.00	0.01	0.47	0.59	$2,687	$85.91	0.8981
	D	4.00	4.00	0.02	0.61	0.98	$2,757	$88.13	0.9213
	E	4.00	4.00	0.03	0.72	1.43	$3,017	$96.44	1.0082
	F	5.00	5.00	0.01	0.66	1.35	$2,980	$95.25	0.9958
	G	5.00	5.00	0.02	0.84	2.26	$3,315	$105.99	1.1080
	H	5.00	5.00	0.03	0.96	3.01	$1,670	$113.87	1.1904
9	**				0.56	0.49	$1,501	$74.96	0.9140
	A	4.00	4.00	0.02	0.66	1.14	$1,795	$89.62	1.0927
	B	4.00	4.00	0.03	0.73	1.32	$2,066	$96.33	1.1746
	F	4.00	6.00	0.03	0.82	1.99	$2,088	$110.92	1.3525
10	**				0.43	0.29	$2,685	$85.84	0.8358
	B	3.00	3.00	0.02	0.45	0.35	$2,696	$86.18	0.8392
	C	3.00	3.00	0.03	0.49	0.43	$2,713	$86.74	0.8446
	E	4.00	4.00	0.02	0.55	0.73	$2,793	$89.28	0.8694
	F	4.00	4.00	0.03	0.60	0.88	$2,836	$90.66	0.8827
	H	5.00	5.00	0.02	0.63	1.12	$2,998	$95.83	0.9331
	I	5.00	5.00	0.03	0.68	1.29	$3,212	$102.70	1.0000
11	**				0.66	0.43	$2,400	$89.18	0.9615
	A	4.00	6.00	0.03	0.72	0.76	$2,688	$99.89	1.0770
	B	6.00	6.00	0.02	0.72	0.93	$2,864	$106.43	1.1474
	C	6.00	6.00	0.03	0.81	1.28	$3,161	$117.48	1.2666
	I	5.50	8.25	0.03	0.86	1.51	$4,058	$150.80	1.6259
	K	7.00	10.50	0.02	0.86	1.78	$4,042	$150.21	1.6195
	L	7.00	10.50	0.03	0.96	2.31	$4,261	$158.33	1.7071

* Normalized for cost at about 0.68g PGA.
** The cost, PGA and Sa associated with the minimum lateral load requirement of SDC Section 3.5.