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BUCKLING LOAD AND EFFECTIVE LENGTH OF WEB TAPERED BUILT-UP COLUMNS IN PRE-ENGINEERED STEEL BUILDINGS

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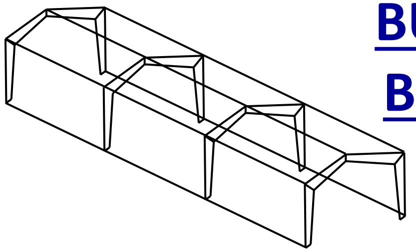
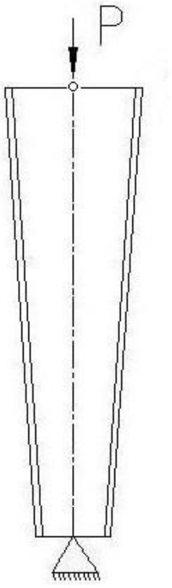


BUCKLING LOAD AND EFFECTIVE LENGTH OF WEB TAPERED BUILT-UP COLUMNS IN PRE-ENGINEERED STEEL BUILDINGS

OBJECTIVE



- No Direct Solutions Yet Available.
- Paper Presents Two Simple Methods
- Direct Equations
- Simple Tool For Practicing Engineers
- Relation Between Pinned and Fixed Base Columns
- Effect Of Height

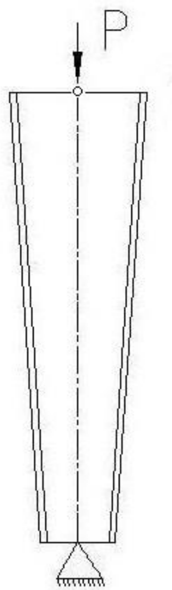
BUCKLING LOAD OF INDIVIDUAL WEB-TAPERED COLUMNS

INTRODUCTION

P-Δ = Effect of loads acting on the displaced location of joints or nodes in a structure.

P-δ = Effect of loads acting on the deflected shape of a member between joints or nodes.

- Stability Design Requirements emphasize P-Δ and P-δ effects on structures.
- Evaluation Of Buckling Load, Pcr is critical in analysis.
- Has direct bearing on Effective Length Factor in Elastic Analysis.



Buckling Load Of Web Tapered Column

Height – 6 meters

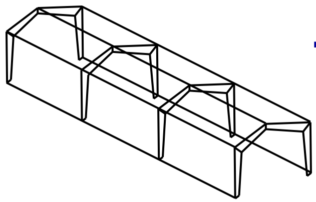
Column Section – Web (300 – 600) x6 mm

Flanges – 180 x 8 mm

Prismatic – P_{TOP} - 20516 kN

- P_{BASE} - 4485 kN

Tapered – $$P_{cr} = \alpha_n \left(\frac{\pi}{kL}\right)^2 EI_{y2}$$



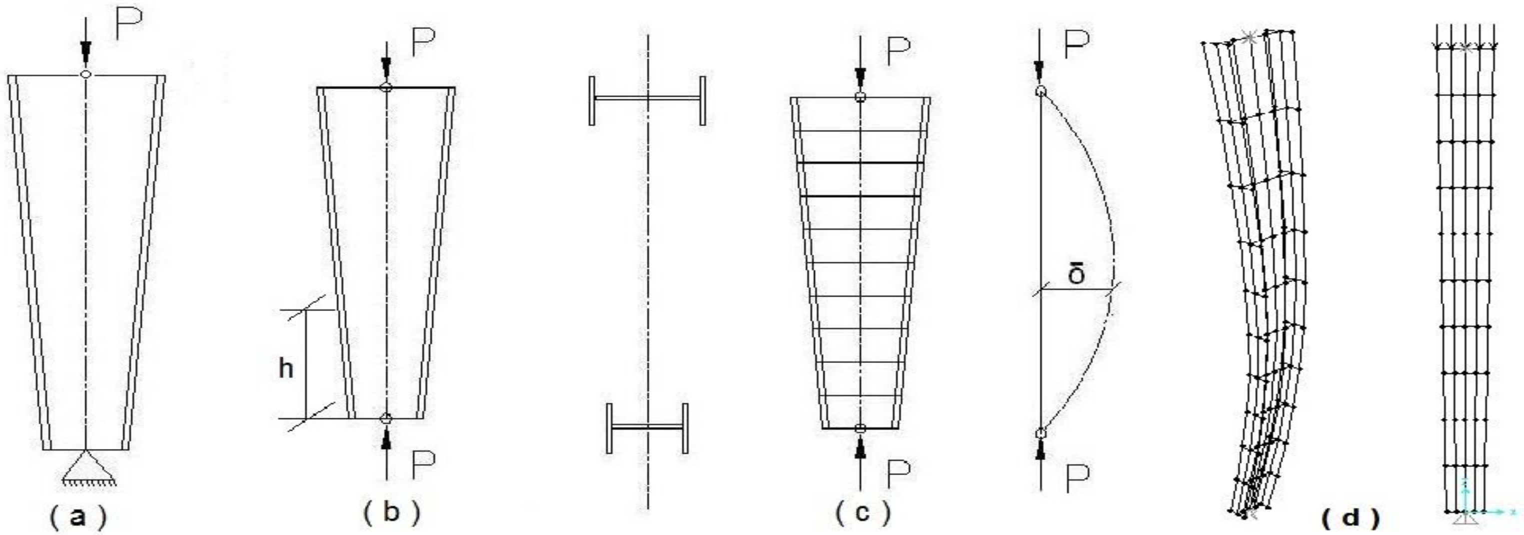
BUCKLING LOAD OF INDIVIDUAL WEB-TAPERED COLUMNS

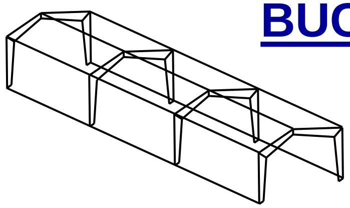
AISC METHODS

- **AISC – DESIGN SERIES 25 – Web Tapered Members**

Recommends Two Methods –

1. Equivalent Moment Of Inertia (EMI) – (b)
2. Newmark Method Of Successive Approximation (MSA) – (c)





BUCKLING LOAD OF WEB-TAPERED COLUMNS - PINNED SUPPORTS

EQUIVALENT MOMENT OF INERTIA (AISC)

Height – 6 meter

Column Section – Web (300 – 600) x6 mm

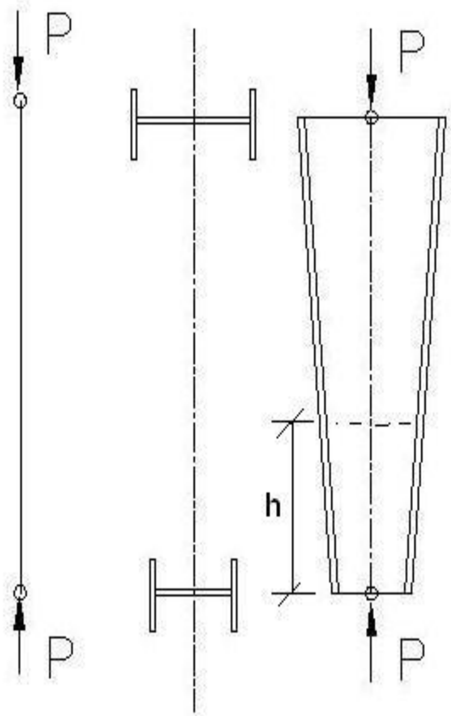
Flanges – 180 x 8 mm

Steps

$$h = 0.5L\left(\frac{I_{small}}{I_{large}}\right)^{0.0732}$$

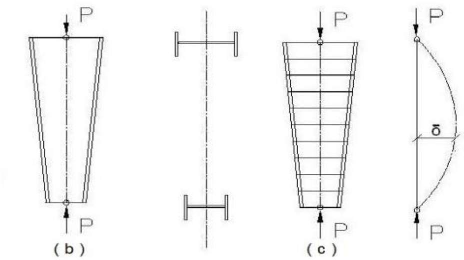
$$P_{eL} = \frac{\pi^2 EI'}{L^2}$$

$$\gamma_{eL} = \frac{P_{eL}}{P_y}$$



BUCKLING LOAD BY EQUIVALENT MOMENT OF INERTIA

SNO	DESCRIPTION	UNIT	NOTATION	VARIABLE	VALUE
1	MODULUS OF ELASTICITY	MPa	E	Elamod	200000
2	FLANGE WIDTH	mm	Bf	flgwid	180
3	FLANGE THICKNESS	mm	tf	flgthk	8
4	WEB THICKNESS	mm	tw	webthk	6
5	WEB DEPTH - SMALL	mm	hsmall	websmall	300
6	WEB DEPTH - LARGE	mm	hlarge	weblarge	600
7	LENGTH OF MEMBER	mm	L	Length	6000
8	AXIAL LOAD	N	αPr	Pralpha	1000
9	MOMENT OF INERTIA - SMALL	mm4	Ismall	Ismall	81802080
10	MOMENT OF INERTIA - LARGE	mm4	Ilarge	Ilarge	374158080
11	AISC 25 FACTOR FOR MI		I - factor	Ifactor	0.073
12	RATIO - Ismall/ Ilarge		I - Ratio	Iratio	0.219
13	AISC25 EQUIVALENT DISTANCE		distequal	distequal	0.447
14	WEB DEPTH - EQUIVALENT	mm	hequal	webequal	434.20
15	MOMENT OF INERTIA- EQUIVALENT		Iel	Iequal	181720741
16	**BUCKLING LOAD**	**KN**	**P_{EMI}**	**Pequal**	**9964**

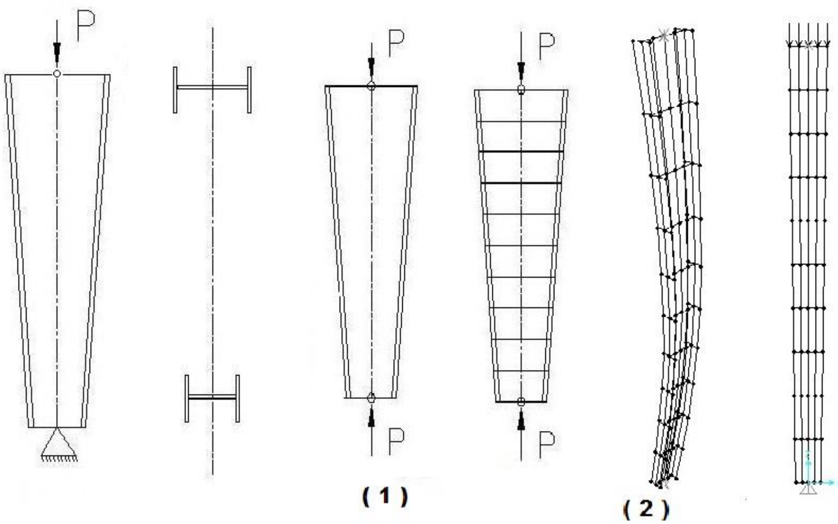


BUCKLING LOAD OF WEB-TAPERED COLUMNS - PINNED ENDS

MEWMARK METHOD OF SUCCESSIVE APPROXIMATIONS

Elamod	flgwid	flgthk	webthk	websmall	weblarge	Length	Pr_{alpha}	I_{bot}	I_{top}	Euler Load, P_{euler}	Ratio = I_{top}/ I_{bot} R_i	Buckling Load, P_{Taper}	P_{Taper}/P_{euler} R_{ppin}
MPa	mm	mm	mm	mm	mm	mm	N	mm4	mm4	KN		KN	
200000	180	8	6	300	600	6000	1000	81802080	374158080	4485.3	4.574	9988	2.227
ITERATION NO	1												
1	2	3	4	5	6	7	8	9	10	11	12	13	14
SNO	NODE	Height from top	Depth	Moment of Inertia	P in N	Assumed defln δ	Pδ/EI rad/mm	Conc Curvature M'/EI rad	(M'/EI)*x in-rad	Average θ rad	δ	γ = y1/y2	Next δ Estimate in
0	0	0	616	3.74E+08	1000	0	0.00E+00				0.00E+00		
1	1	600	586	3.33E+08	1000	100	1.50E-09	9.20E-07	5.52E-04	1.78E-05	1.07E-02	9367	133
2	2	1200	556	2.95E+08	1000	200	3.39E-09	2.06E-06	2.47E-03	1.69E-05	2.08E-02	9616	260
3	3	1800	526	2.60E+08	1000	300	5.78E-09	3.50E-06	6.30E-03	1.48E-05	2.97E-02	10105	371
4	4	2400	496	2.27E+08	1000	400	8.82E-09	5.33E-06	1.28E-02	1.13E-05	3.65E-02	10966	455
5	5	3000	466	1.97E+08	1000	500	1.27E-08	7.39E-06	2.22E-02	5.98E-06	4.01E-02	12480	500
6	6	3600	436	1.69E+08	1000	400	1.18E-08	7.08E-06	2.55E-02	-1.41E-06	3.92E-02	10200	489
7	7	4200	406	1.44E+08	1000	300	1.04E-08	6.22E-06	2.61E-02	-8.49E-06	3.41E-02	8792	426
8	8	4800	376	1.21E+08	1000	200	8.28E-09	4.91E-06	2.36E-02	-1.47E-05	2.53E-02	7907	316
9	9	5400	346	1.00E+08	1000	100	4.99E-09	2.91E-06	1.57E-02	-1.96E-05	1.35E-02	7397	169
10	10	6000	316	8.18E+07	1000	0	0.00E+00			-2.25E-05	0.00E+00		
								4.03E-05	1.35E-01				
ITERATION NO	2												
0	0	0	616	3.74E+08	1000	0	0.00E+00				0.00E+00		
1	1	600	586	3.33E+08	1000	133	2.00E-09	1.22E-06	7.32E-04	2.17E-05	1.30E-02	10217	134
2	2	1200	556	2.95E+08	1000	260	4.40E-09	2.66E-06	3.19E-03	2.05E-05	2.53E-02	10240	260
3	3	1800	526	2.60E+08	1000	371	7.14E-09	4.29E-06	7.72E-03	1.79E-05	3.61E-02	10274	370
4	4	2400	496	2.27E+08	1000	455	1.00E-08	6.01E-06	1.44E-02	1.36E-05	4.42E-02	10298	453
5	5	3000	466	1.97E+08	1000	500	1.27E-08	7.58E-06	2.28E-02	7.55E-06	4.87E-02	10259	500
6	6	3600	436	1.69E+08	1000	489	1.45E-08	8.62E-06	3.10E-02	-2.96E-08	4.87E-02	10046	500
7	7	4200	406	1.44E+08	1000	426	1.48E-08	8.79E-06	3.69E-02	-8.65E-06	4.35E-02	9783	447
8	8	4800	376	1.21E+08	1000	316	1.31E-08	7.69E-06	3.69E-02	-1.74E-05	3.31E-02	9546	339
9	9	5400	346	1.00E+08	1000	169	8.42E-09	4.86E-06	2.63E-02	-2.51E-05	1.80E-02	9377	185
10	10	6000	316	8.18E+07	1000	0	0.00E+00			-3.00E-05	0.00E+00		
								5.17E-05	1.80E-01				
ITERATION NO	8												
0	0	0	616	3.74E+08	1000	0.0	0.00E+00				0.00E+00		
1	1	600	586	3.33E+08	1000	133	1.99E-09	1.21E-06	7.29E-04	2.21E-05	1.33E-02	9988	133
2	2	1200	556	2.95E+08	1000	258	4.38E-09	2.64E-06	3.17E-03	2.09E-05	2.58E-02	9988	258
3	3	1800	526	2.60E+08	1000	368	7.08E-09	4.26E-06	7.67E-03	1.83E-05	3.68E-02	9988	368
4	4	2400	496	2.27E+08	1000	452	9.96E-09	5.97E-06	1.43E-02	1.40E-05	4.52E-02	9988	452
5	5	3000	466	1.97E+08	1000	500	1.27E-08	7.60E-06	2.28E-02	8.06E-06	5.01E-02	9988	500
6	6	3600	436	1.69E+08	1000	503	1.49E-08	8.86E-06	3.19E-02	4.56E-07	5.03E-02	9988	503
7	7	4200	406	1.44E+08	1000	452	1.57E-08	9.33E-06	3.92E-02	-8.41E-06	4.53E-02	9988	452
8	8	4800	376	1.21E+08	1000	346	1.43E-08	8.42E-06	4.04E-02	-1.77E-05	3.46E-02	9988	346
9	9	5400	346	1.00E+08	1000	189	9.45E-09	5.44E-06	2.94E-02	-2.62E-05	1.90E-02	9988	189
10	10	6000	316	8.18E+07	1000	0	0.00E+00			-3.16E-05	0.00E+00		
								5.37E-05	1.90E-01				

BUCKLING LOAD OF WEB-TAPERED COLUMNS – PINNED ENDS
TAPER SYMMETRIC – BASE WIDTH 200,250,300 350
BUCKLING ANALYSIS BY SAP2000 & MSA



DATA

- Height – 6 meter
- Base Web Depth – 200, 250, 300, 350
- Top Web Depth – Upto 120mm Increment 50mm
- Flange Width - 180mm
- Flange Thickness – 6, 8, 10 & 12mm

TWO METHODS IN SAP2000

1. Single Web Tapered Member
2. 3- Plated I section, 10 segments

Results are almost equal in both methods.

Shows variations upto 3% with MSA.

Used as Benchmark for further Analysis.

BUCKLING LOAD OF WEB-TAPERED COLUMNS – PINNED BASE
TAPER SYMMETRIC– BASE WIDTH 200,250,300 350
DATA FOR BUCKLING LOAD FACTOR METHOD

Top Web Depth mm	BASE WEB DEPTH - 200 mm								BASE WEB DEPTH - 250 mm							
	Flange 180 x 6 mm		Flange 180 x 8 mm		Flange 180 x 10 mm		Flange 180 x12 mm		Flange 180 x 6 mm		Flange 180 x 8 mm		Flange 180 x 10 mm		Flange 180 x12 mm	
	Psap KN	PsucApp KN	Psap KN	PsucApp KN	Psap KN	PsucApp KN	Psap KN	PsucApp KN	Psap KN	PsucApp KN	Psap KN	PsucApp KN	Psap KN	PsucApp KN	Psap KN	PsucApp KN
200	1514	1476	1939	1927	2360	2396	2778	2881								
250	1929	1878	2461	2438	2987	3016	3507	3614	2430	2369	3090	3056	3739	3764	4380	4493
300	2373	2309	3016	2983	3651	3677	4278	4392	2965	2893	3756	3713	4532	4556	5298	5422
350	2845	2770	3605	3563	4353	4378	5091	5216	3530	3450	4456	4408	5364	5392	6259	6400
400	3344	3260	4225	4177	5090	5118	5942	6085	4124	4039	5191	5142	6235	6271	7260	7427
450	3869	3778	4876	4825	5862	5898	6832	6997	4745	4661	5959	5913	7141	7193	8302	8502
500	4419	4324	5557	5506	6667	6716	7758	7954	5393	5314	6759	6712	8084	8158	9382	9625
550	4994	4899	6267	6220	7505	7571	8720	8953	6065	6000	7590	7566	9061	9165	10499	10796
600	5593	5501	7005	6968	8375	8465	9716	9995	6760	6717	8451	8448	10071	10213	11652	12013
650	6213	6132	7771	7748	9275	9397	10744	11080	7576	7465	9341	9367	11113	11304	12840	13277
700	6853	6789	8563	8560	10204	10366	11804	12207	8207	8245	10259	10322	12187	12436	14061	14587
750	7511	7475	9381	9405	11162	11372	12895	13376	8948	9055	11203	11313	13290	13608	15313	15944
800	8184	8187	10223	10282	12147	12414	14015	14586	9689	9897	12173	12339	14422	14822	16596	17346
850	8866	8927	11090	11191	13159	13494	15164	15838	10413	10769	13167	13402	15582	16076	17908	18794
900	9548	9695	11978	12132	14197	14611	16339	17132	11085	11672	14184	14500	16768	17371	19248	20287
950	10211	10489	12889	13106	15259	15764	17541	18467	11519	12605	15221	15634	17980	18706	20615	21825
1000	10808	11311	13819	14111	16345	16954	18767	19843	11682	13569	16278	16803	19215	20082	22007	23408
1050	11168	12161	14718	15149	17453	18181	20018	21260	11820	14564	17351	18008	20474	21497	23424	25036
1100	11162	13037	15428	16218	18208	19444	20875	22718	11797	15589	18123	19248	21342	22953	24398	26709
1150	11425	13941	16716	17319	19734	20743	22587	24218	12088	16645	19534	20523	23056	24449	26325	28427
1200	11549	14873	17710	18453	20905	22080	23903	25758	12220	17731	20636	21834	24375	25895	27787	30189

Top Web Depth, mm	BASE WEB DEPTH - 300 mm								BASE WEB DEPTH - 350 mm							
300	3588	3513	4531	4485	5459	5483	6362	6505								
350	4245	4169	5346	5299	6418	6456	7471	7640	4987	4928	6271	6235	7512	7571	8728	8936
400	4933	4861	6196	6155	7421	7477	8623	8827	5765	5726	7237	7216	8649	8736	10030	10287
450	5648	5589	7081	7052	8463	8544	9816	10067	6569	6565	8239	8242	9826	9952	11374	11694
500	6389	6353	8000	7990	9542	9658	11049	11359	7393	7442	9277	9313	11042	11218	12760	13158
550	7152	7153	8951	8968	10657	10818	12321	12702	8230	8358	10347	10428	12295	12534	14185	14676
600	7933	7987	9933	9988	11807	12024	13630	14097	9066	9313	11449	11588	13584	13890	15649	16250
650	8723	8856	10946	11047	12990	13275	14974	15542	9881	10307	12581	12791	14908	15314	17149	17878
700	9513	9761	11986	12147	14206	14572	16353	17037	10641	11339	13741	14038	16264	16778	18684	19560
750	10281	10699	13054	13286	15453	15913	17764	18582	11304	12408	14926	15328	17652	18291	20252	21297
800	10997	11672	14146	14465	16729	17299	19207	20177	11841	13516	16134	16662	19070	19852	21853	23087
850	11616	12679	15262	15683	18034	18730	20680	21822	12257	14661	17362	18038	20517	21461	23484	24930
900	12019	13720	16399	16940	19366	20205	22181	23515	12577	15844	18605	19458	21991	23118	25143	26826
950	12188	14796	17554	18237	20723	21724	23710	25258	12816	17065	19857	20920	23491	24822	26831	28775
1000	12333	15905	18723	19572	22105	23286	25625	27050	12981	18322	21111	22424	25014	26575	28545	30777
1050	12473	17048	19902	20947	23510	24893	26844	28890	13129	19617	22355	23971	26559	28374	30383	32831
1100	12444	18225	20798	22360	24494	26543	27397	30779	13273	20949	23573	25560	28125	30221	32044	34937
1150	12748	19435	22262	23812	26382	28237	30070	32716	13416	22317	24743	27191	29709	32116	33827	37096
1200	12884	20680	23421	25302	27847	29975	31715	34701	13557	23723	25831	28864	31309	34057	35629	39306

DATA AS GENERATED

BUCKLING LOAD FACTOR METHOD - PARAMETERS

1. Moment of Inertia, I_{top}, I_{base} and ratio $R_i = I_{top} / I_{base}$
2. Ratio Of Buckling Loads, $Rppin = P_{SUCAPP} / P_{EULER}$

Flange	Top Web Depth	BASE 200		BASE 250		BASE 300		BASE 350	
		Ri	Rppin	Ri	Rppin	Ri	Rppin	Ri	Rppin
180x6	200	1.0000	1.0000						
	250	1.6050	1.2724	1.0000	1.0000				
	300	2.3798	1.5650	1.4828	1.2212	1.0000	1.0000		
	350	3.3386	1.8767	2.0802	1.4563	1.4029	1.1867	1.0000	1.0000
	400	4.4951	2.2087	2.8008	1.7049	1.8888	1.3837	1.3464	1.1621
	450	5.8634	2.5596	3.6533	1.9675	2.4638	1.5912	1.7563	1.3322
	500	7.4573	2.9302	4.6465	2.2436	3.1335	1.8087	2.2337	1.5101
	550	9.2908	3.3191	5.7889	2.5327	3.9040	2.0362	2.7829	1.6962
	600	11.3779	3.7276	7.0892	2.8354	4.7809	2.2736	3.4080	1.8900
	650	13.7323	4.1545	8.5562	3.1515	5.7703	2.5212	4.1132	2.0915
	700	16.3681	4.6003	10.1985	3.4804	6.8778	2.7785	4.9027	2.3009
	750	19.2993	5.0644	12.0248	3.8227	8.1095	3.0458	5.7807	2.5181
	800	22.5396	5.5474	14.0438	4.1777	9.4711	3.3225	6.7512	2.7427
	850	26.1031	6.0488	16.2641	4.5458	10.9684	3.6095	7.8186	2.9752
	900	30.0037	6.5684	18.6945	4.9270	12.6074	3.9058	8.9869	3.2153
	950	34.2553	7.1070	21.3435	5.3212	14.3940	4.2118	10.2604	3.4629
	1000	38.8719	7.6640	24.2200	5.7282	16.3338	4.5278	11.6432	3.7179
	1050	43.8673	8.2392	27.3325	6.1477	18.4329	4.8531	13.1394	3.9807
	1100	49.2555	8.8333	30.6897	6.5808	20.6970	5.1879	14.7534	4.2510
	1150	55.0505	9.4458	34.3004	7.0262	23.1320	5.5326	16.4891	4.5288
	1200	61.2661	10.0772	38.1732	7.4846	25.7438	5.8867	18.3509	4.8139
180x8	200	1.0000	1.0000						
	250	1.5855	1.2645	1.0000	1.0000				
	300	2.3266	1.5477	1.4675	1.2149	1.0000	1.0000		
	350	3.2342	1.8485	2.0399	1.4423	1.3901	1.1815	1.0000	1.0000
	400	4.3187	2.1670	2.7239	1.6824	1.8562	1.3720	1.3353	1.1573
	450	5.5909	2.5031	3.5264	1.9346	2.4030	1.5720	1.7287	1.3218
	500	7.0615	2.8563	4.4539	2.1989	3.0351	1.7811	2.1834	1.4936
	550	8.7411	3.2267	5.5132	2.4753	3.7570	1.9993	2.7027	1.6724
	600	10.6404	3.6146	6.7112	2.7638	4.5733	2.2267	3.2900	1.8582
	650	12.7700	4.0192	8.0544	3.0644	5.4886	2.4628	3.9485	2.0513
	700	15.1406	4.4404	9.5496	3.3768	6.5075	2.7080	4.6814	2.2513
	750	17.7629	4.8786	11.2035	3.7010	7.6345	2.9619	5.4923	2.4581
	800	20.6475	5.3335	13.0229	4.0370	8.8744	3.2247	6.3842	2.6721
	850	23.8051	5.8050	15.0145	4.3844	10.2315	3.4962	7.3605	2.8927
	900	27.2463	6.2936	17.1850	4.7435	11.7106	3.7766	8.4245	3.1204
	950	30.9819	6.7982	19.5411	5.1145	13.3161	4.0655	9.5796	3.3549
	1000	35.0225	7.3190	22.0896	5.4969	15.0528	4.3634	10.8289	3.5961
	1050	39.3787	7.8579	24.8372	5.8911	16.9251	4.6696	12.1758	3.8441
	1100	44.0613	8.4123	27.7906	6.2967	18.9377	4.9846	13.6237	4.0989
	1150	49.0808	8.9839	30.9565	6.7138	21.0951	5.3083	15.1757	4.3605
	1200	54.4479	9.5716	34.3417	7.1426	23.4019	5.6404	16.8352	4.6288

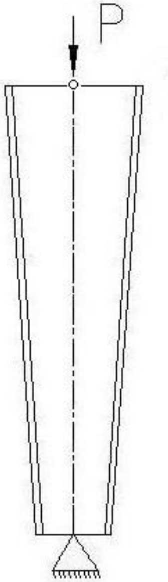
Flange	Top Web Depth	BASE 200		BASE 250		BASE 300		BASE 350	
		Ri	Rppin	Ri	Rppin	Ri	Rppin	Ri	Rppin
180x10	200	1.0000	1.0000						
	250	1.5710	1.2591	1.0000	1.0000				
	300	2.2877	1.5348	1.4563	1.2103	1.0000	1.0000		
	350	3.1589	1.8273	2.0108	1.4323	1.3808	1.1776	1.0000	1.0000
	400	4.1930	2.1360	2.6691	1.6657	1.8328	1.3636	1.3274	1.1540
	450	5.3987	2.4610	3.4366	1.9105	2.3599	1.5584	1.7090	1.3146
	500	6.7845	2.8023	4.3187	2.1668	2.9656	1.7615	2.1477	1.4818
	550	8.3590	3.1594	5.3210	2.4341	3.6538	1.9730	2.6462	1.6556
	600	10.1308	3.5323	6.4488	2.7124	4.4283	2.1929	3.2071	1.8358
	650	12.1085	3.9212	7.7077	3.0021	5.2928	2.4210	3.8331	2.0227
	700	14.3005	4.3254	9.1030	3.3027	6.2509	2.6575	4.5271	2.2161
	750	16.7156	4.7451	10.6404	3.6142	7.3066	2.9021	5.2916	2.4157
	800	19.3623	5.1802	12.3251	3.9363	8.4635	3.1548	6.1294	2.6219
	850	22.2491	5.6308	14.1627	4.2695	9.7254	3.4158	7.0433	2.8344
	900	25.3847	6.0964	16.1587	4.6131	11.0960	3.6847	8.0359	3.0534
	950	28.7776	6.5778	18.3185	4.9679	12.5791	3.9617	9.1100	3.2784
	1000	32.4364	7.0743	20.6475	5.3330	14.1784	4.2467	10.2682	3.5099
	1050	36.3697	7.5857	23.1512	5.7090	15.8976	4.5396	11.5134	3.7476
	1100	40.5860	8.1131	25.8351	6.0956	17.7407	4.8406	12.8481	3.9915
	1150	45.0940	8.6550	28.7047	6.4928	19.7111	5.1495	14.2752	4.2417
	1200	49.9021	9.2128	31.7653	6.9007	21.8128	5.4663	15.7973	4.4980
180x12	200	1.0000	1.0000						
	250	1.5592	1.2538	1.0000	1.0000				
	300	2.2567	1.5239	1.4474	1.2066	1.0000	1.0000		
	350	3.0997	1.8096	1.9880	1.4242	1.3735	1.1744	1.0000	1.0000
	400	4.0953	2.1110	2.6265	1.6526	1.8147	1.3570	1.3212	1.1513
	450	5.2506	2.4275	3.3675	1.8917	2.3266	1.5476	1.6939	1.3087
	500	6.5727	2.7590	4.2155	2.1415	2.9125	1.7461	2.1204	1.4725
	550	8.0688	3.1058	5.1750	2.4019	3.5755	1.9525	2.6031	1.6423
	600	9.7461	3.4671	6.2507	2.6726	4.3187	2.1669	3.1442	1.8184
	650	11.6116	3.8433	7.4472	2.9537	5.1454	2.3890	3.7460	2.0006
	700	13.6724	4.2340	8.7689	3.2453	6.0586	2.6187	4.4109	2.1889
	750	15.9358	4.6394	10.2206	3.5469	7.0615	2.8563	5.1411	2.3831
	800	18.4088	5.0589	11.8066	3.8590	8.1574	3.1014	5.9389	2.5834
	850	21.0986	5.4934	13.5318	4.1808	9.3493	3.3541	6.8067	2.7896
	900	24.0122	5.9417	15.4005	4.5129	10.6404	3.6144	7.7467	3.0017
	950	27.1569	6.4046	17.4173	4.8552	12.0339	3.8823	8.7612	3.2197
	1000	30.5398	6.8818	19.5870	5.2073	13.5329	4.1575	9.8525	3.4437
	1050	34.1679	7.3734	21.9139	5.5694	15.1406	4.4404	11.0230	3.6735
	1100	38.0484	7.8790	24.4027	5.9415	16.8602	4.7308	12.2749	3.9093
	1150	42.1885	8.3991	27.0580	6.3236	18.6947	5.0284	13.6106	4.1508
	1200	46.5953	8.9331	29.8843	6.7155	20.6475	5.3336	15.0323	4.3981

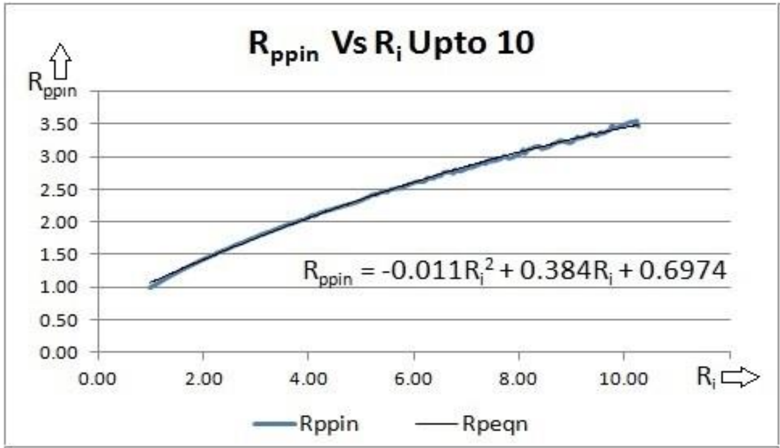
BUCKLING LOAD FACTOR METHOD - PARAMETERS

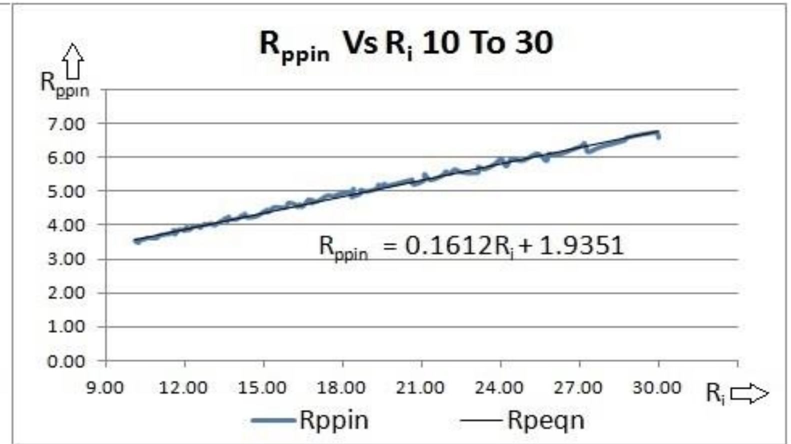
DATA SORTED With Respect to Ri

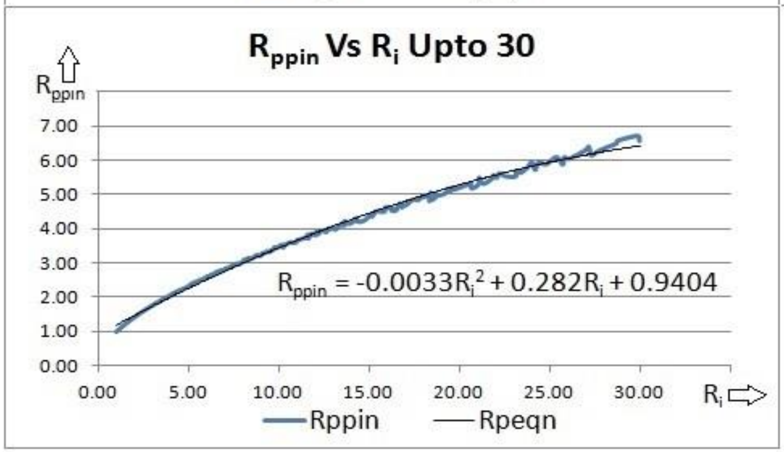
Ri	Rppin	Ri	Rppin	Ri	Rppin	Ri	Rppin	Ri	Rppin	Ri	Rppin	Ri	Rppin	Ri	Rppin
1.0000	1.0000	1.9880	1.4242	3.6533	1.9675	5.9389	2.5834	9.1030	3.3027	13.0229	4.0370	18.3509	4.8139	28.7047	6.4928
1.0000	1.0000	2.0108	1.4323	3.6538	1.9730	6.0586	2.6187	9.1100	3.2784	13.1394	3.9807	18.4088	5.0589	28.7776	6.5778
1.0000	1.0000	2.0399	1.4423	3.7460	2.0006	6.1294	2.6219	9.2908	3.3191	13.3161	4.0655	18.4329	4.8531	29.8843	6.7155
1.0000	1.0000	2.0802	1.4563	3.7570	1.9993	6.2507	2.6726	9.3493	3.3541	13.5318	4.1808	18.6945	4.9270	30.0037	6.5684
1.0000	1.0000	2.1204	1.4725	3.8331	2.0227	6.2509	2.6575	9.4711	3.3225	13.5329	4.1575	18.6947	5.0284	30.5398	6.8818
1.0000	1.0000	2.1477	1.4818	3.9040	2.0362	6.3842	2.6721	9.5496	3.3768	13.6106	4.1508	18.9377	4.9846	30.6897	6.5808
1.0000	1.0000	2.1834	1.4936	3.9485	2.0513	6.4488	2.7124	9.5796	3.3549	13.6237	4.0989	19.2993	5.0644	30.9565	6.7138
1.0000	1.0000	2.2337	1.5101	4.0953	2.1110	6.5075	2.7080	9.7254	3.4158	13.6724	4.2340	19.3623	5.1802	30.9819	6.7982
1.0000	1.0000	2.2567	1.5239	4.1132	2.0915	6.5727	2.7590	9.7461	3.4671	13.7323	4.1545	19.5411	5.1145	31.7653	6.9007
1.0000	1.0000	2.2877	1.5348	4.1930	2.1360	6.7112	2.7638	9.8525	3.4437	14.0438	4.1777	19.5870	5.2073	32.4364	7.0743
1.0000	1.0000	2.3266	1.5477	4.2155	2.1415	6.7512	2.7427	10.1308	3.5323	14.1627	4.2695	19.7111	5.1495	34.1679	7.3734
1.0000	1.0000	2.3266	1.5476	4.3187	2.1670	6.7845	2.8023	10.1985	3.4804	14.1784	4.2467	20.6475	5.3335	34.2553	7.1070
1.0000	1.0000	2.3599	1.5584	4.3187	2.1668	6.8067	2.7896	10.2206	3.5469	14.2752	4.2417	20.6475	5.3330	34.3004	7.0262
1.0000	1.0000	2.3798	1.5650	4.3187	2.1669	6.8778	2.7785	10.2315	3.4962	14.3005	4.3254	20.6475	5.3336	34.3417	7.1426
1.0000	1.0000	2.4030	1.5720	4.4109	2.1889	7.0433	2.8344	10.2604	3.4629	14.3940	4.2118	20.6970	5.1879	35.0225	7.3190
1.0000	1.0000	2.4638	1.5912	4.4283	2.1929	7.0615	2.8563	10.2682	3.5099	14.7534	4.2510	21.0951	5.3083	36.3697	7.5857
1.3212	1.1513	2.6031	1.6423	4.4539	2.1989	7.0615	2.8563	10.6404	3.6146	15.0145	4.3844	21.0986	5.4934	38.0484	7.8790
1.3274	1.1540	2.6265	1.6526	4.4951	2.2087	7.0892	2.8354	10.6404	3.6142	15.0323	4.3981	21.3435	5.3212	38.1732	7.4846
1.3353	1.1573	2.6462	1.6556	4.5271	2.2161	7.3066	2.9021	10.6404	3.6144	15.0528	4.3634	21.8128	5.4663	38.8719	7.6640
1.3464	1.1621	2.6691	1.6657	4.5733	2.2267	7.3605	2.8927	10.8289	3.5961	15.1406	4.4404	21.9139	5.5694	39.3787	7.8579
1.3735	1.1744	2.7027	1.6724	4.6465	2.2436	7.4472	2.9537	10.9684	3.6095	15.1406	4.4404	22.0896	5.4969	40.5860	8.1131
1.3808	1.1776	2.7239	1.6824	4.6814	2.2513	7.4573	2.9302	11.0230	3.6735	15.1757	4.3605	22.2491	5.6308	42.1885	8.3991
1.3901	1.1815	2.7829	1.6962	4.7809	2.2736	7.6345	2.9619	11.0960	3.6847	15.4005	4.5129	22.5396	5.5474	43.8673	8.2392
1.4029	1.1867	2.8008	1.7049	4.9027	2.3009	7.7077	3.0021	11.2035	3.7010	15.7973	4.4980	23.1320	5.5326	44.0613	8.4123
1.4474	1.2066	2.9125	1.7461	5.1411	2.3831	7.7467	3.0017	11.3779	3.7276	15.8976	4.5396	23.1512	5.7090	45.0940	8.6550
1.4563	1.2103	2.9656	1.7615	5.1454	2.3890	7.8186	2.9752	11.5134	3.7476	15.9358	4.6394	23.4019	5.6404	46.5953	8.9331
1.4675	1.2149	3.0351	1.7811	5.1750	2.4019	8.0359	3.0534	11.6116	3.8433	16.1587	4.6131	23.8051	5.8050	49.0808	8.9839
1.4828	1.2212	3.0997	1.8096	5.2506	2.4275	8.0544	3.0644	11.6432	3.7179	16.2641	4.5458	24.0122	5.9417	49.2555	8.8333
1.5592	1.2538	3.1335	1.8087	5.2916	2.4157	8.0688	3.1058	11.7106	3.7766	16.3338	4.5278	24.2200	5.7282	49.9021	9.2128
1.5710	1.2591	3.1442	1.8184	5.2928	2.4210	8.1095	3.0458	11.8066	3.8590	16.3681	4.6003	24.4027	5.9415	54.4479	9.5716
1.5855	1.2645	3.1589	1.8273	5.3210	2.4341	8.1574	3.1014	12.0248	3.8227	16.4891	4.5288	24.8372	5.8911	55.0505	9.4458
1.6050	1.2724	3.2071	1.8358	5.3987	2.4610	8.3590	3.1594	12.0339	3.8823	16.7156	4.7451	25.3847	6.0964	61.2661	10.0772
1.6939	1.3087	3.2342	1.8485	5.4886	2.4628	8.4245	3.1204	12.1085	3.9212	16.8352	4.6288	25.7438	5.8867		
1.7090	1.3146	3.2900	1.8582	5.4923	2.4581	8.4635	3.1548	12.1758	3.8441	16.8602	4.7308	25.8351	6.0956		
1.7287	1.3218	3.3386	1.8767	5.5132	2.4753	8.5562	3.1515	12.2749	3.9093	16.9251	4.6696	26.1031	6.0488		
1.7563	1.3322	3.3675	1.8917	5.5909	2.5031	8.7411	3.2267	12.3251	3.9363	17.1850	4.7435	27.0580	6.3236		
1.8147	1.3570	3.4080	1.8900	5.7703	2.5212	8.7612	3.2197	12.5791	3.9617	17.4173	4.8552	27.1569	6.4046		
1.8328	1.3636	3.4366	1.9105	5.7807	2.5181	8.7689	3.2453	12.6074	3.9058	17.7407	4.8406	27.2463	6.2936		
1.8562	1.3720	3.5264	1.9346	5.7889	2.5327	8.8744	3.2247	12.7700	4.0192	17.7629	4.8786	27.3325	6.1477		
1.8888	1.3837	3.5755	1.9525	5.8634	2.5596	8.9869	3.2153	12.8481	3.9915	18.3185	4.9679	27.7906	6.2967		

BUCKLING LOAD FACTOR METHOD – PINNED BASE
EQUATIONS BY CURVE FITTING









EQUATIONS

- **For R_i Upto 10**

  $R_{ppin} = -0.011R_i^2 + 0.384R_i + 0.6974$ ...(6)

- **For R_i 10 To 30**

  $R_{ppin} = 0.1612R_i + 1.9351$ ...(7)

- **For R_i Upto 30**

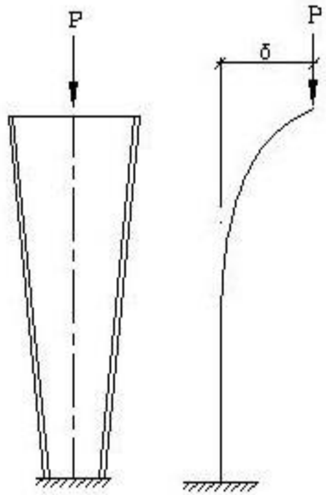
  $R_{ppin} = -0.0033R_i^2 + 0.282R_i + 0.9404$ ...(8)

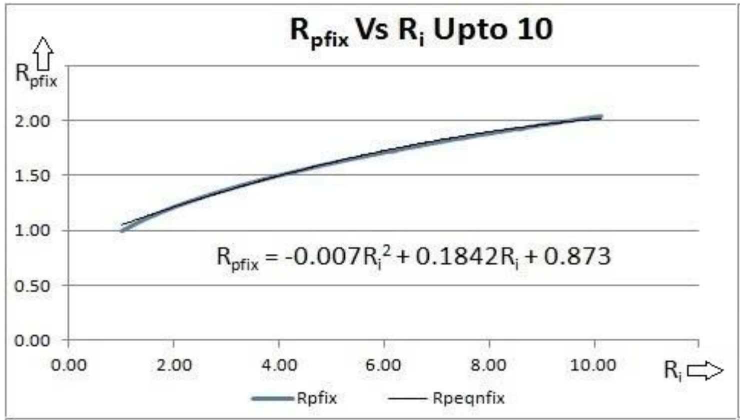
Procedure

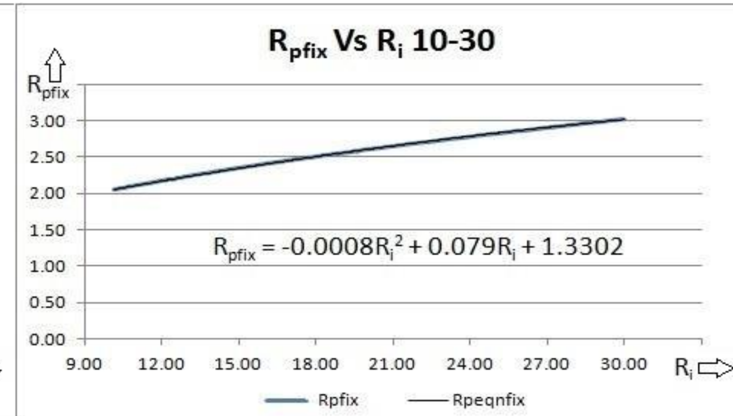
1. Calculate Moment of Inertia, I_{top}, I_{base} and ratio $\mathbf{R_i = I_{top} / I_{base}}$
2. Buckling Load For Prismatic Column with Base Section, $\mathbf{P_{EULER} = \pi^2 E I_{BASE} / L^2}$
3. Buckling Load Of Tapered Column, $\mathbf{P_{TAPER} = R_{ppin} * P_{EULER}}$

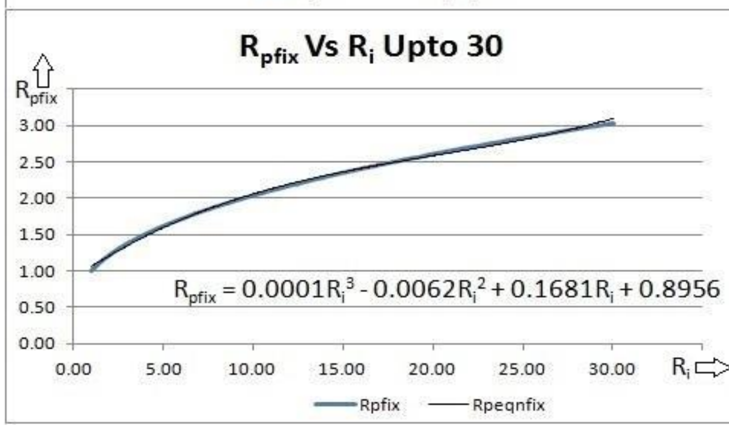
$\mathbf{R_{ppin}}$ to be calculated from graph and equations above.

BUCKLING LOAD FACTOR METHOD – FIXED BASE FREE TOP EQUATIONS BY CURVE FITTING









EQUATIONS

- **For R_i Upto 10**

  $R_{pfix} = -0.007R_i^2 + 0.1842R_i + 0.873$ ...(9)

- **For R_i 10-30**

  $R_{pfix} = -0.0008R_i^2 + 0.079R_i + 1.3302$ ...(10)

- **For R_i Upto 30**

  $R_{pfix} = 0.0001R_i^3 - 0.0062R_i^2 + 0.1681R_i + 0.8956$ ...(11)

Procedure

1. Calculate Moment of Inertia, I_{top}, I_{base} and ratio **$R_i = I_{top} / I_{base}$**
2. Buckling Load For Prismatic Column with Base Section, **$P_{EULER} = \pi^2 E I_{BASE} / L^2$**
3. Buckling Load Of Tapered Column, **$P_{TAPER} = R_{pfix} * P_{EULER}$**

R_{pfix} to be calculated from graph and equations above.

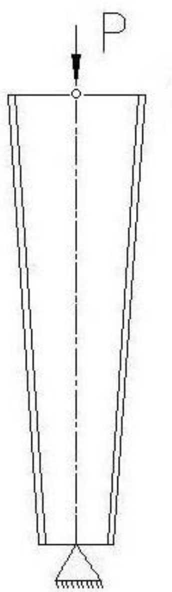
BUCKLING LOAD FACTOR METHOD

ILLUSTRATION

Height – 6 meter

Column Section – Web (300 – 600) x6 mm

Flanges – 180 x 8 mm



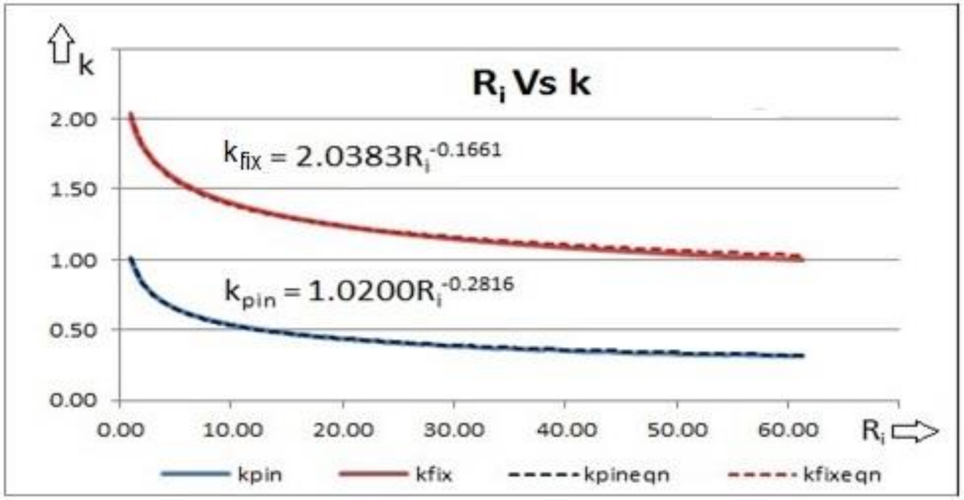
Flange mm	Top Width mm	Mom Inertia mm^4	Psap KN	PsucApp KN	% Var	R_i	R_{ppin}	Buckling Load Factor Method,			
								P_{10}/P_{10-30}, KN	% Var	P_{ALL}, KN	% Var
	300	8.18E+07	4531	4485	1.02%	1.0000	1.0000	4485		4485	
	350	1.14E+08	5346	5299	0.88%	1.3901	1.1815	5427	-2.41%	5947	-12.23%
	400	1.52E+08	6196	6155	0.66%	1.8564	1.3724	6155	0.00%	6515	-5.84%
	450	1.97E+08	7081	7052	0.41%	2.4033	1.5724	6982	0.99%	7172	-1.70%
	500	2.48E+08	8000	7990	0.13%	3.0354	1.7815	7901	1.11%	7920	0.87%
	550	3.07E+08	8951	8968	-0.19%	3.7575	1.9996	8903	0.73%	8761	2.31%
	600	3.74E+08	9933	9988	-0.55%	4.5739	2.2270	9973	0.15%	9693	2.95%
	650	4.49E+08	10946	11047	-0.92%	5.4894	2.4631	11095	-0.44%	10715	3.01%
	700	5.32E+08	11986	12147	-1.34%	6.5085	2.7084	12247	-0.82%	11823	2.67%
180x08	750	6.25E+08	13054	13286	-1.78%	7.6358	2.9623	13402	-0.87%	13012	2.06%
	800	7.26E+08	14146	14465	-2.26%	8.8758	3.2252	14528	-0.43%	14278	1.30%
	850	8.37E+08	15262	15683	-2.76%	10.2332	3.4968	16077	-2.51%	15610	0.46%
	900	9.58E+08	16399	16940	-3.30%	11.7126	3.7770	17147	-1.22%	17001	-0.36%
	950	1.09E+09	17554	18237	-3.89%	13.3185	4.0662	18308	-0.39%	18437	-1.10%
	1000	1.23E+09	18723	19572	-4.53%	15.0554	4.3639	19564	0.04%	19905	-1.70%
	1050	1.38E+09	19902	20947	-5.25%	16.9281	4.6705	20918	0.14%	21387	-2.10%
	1100	1.55E+09	20798	22360	-7.51%	18.9411	4.9855	22373	-0.06%	22864	-2.25%
	1150	1.73E+09	22262	23812	-6.96%	21.0989	5.3093	23933	-0.51%	24314	-2.11%
	1200	1.91E+09	23421	25302	-8.03%	23.4061	5.6415	25601	-1.18%	25713	-1.62%

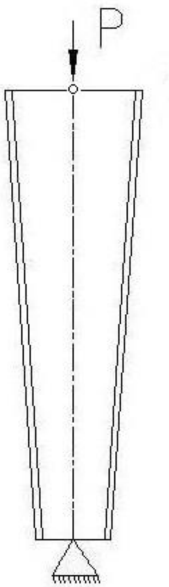
Psap - Using SAP2000; Psucp - Using MSA; $P_{10}/P_{10-30}/P_{ALL}$ - Using Buckling Load Factor Method

Error is less than 3% as compared with results from MSA.

EFFECTIVE LENGTH FACTOR METHOD

- **Buckling Load increases with increase in web depth at top.**
- **Conversely, Effective Length Factor reduces as per Euler's Eqn.**





Procedure

1. Calculate Moment of Inertia, I_{top}, I_{base} and ratio **$R_i = I_{top} / I_{base}$**
2. Calculate Effective Length Factor **k_{pin}** or **k_{fix}** respectively

For Pinned End column, $k_{pin} = 1.0200\, R_i^{-0.2816}$

For Fixed Base column , $k_{fix} = 2.0383\, R_i^{-0.1661}$

3. Buckling Load Of Tapered Column, $P_{TAPER} = \dfrac{\pi^2 E I_{base}}{(kL)^2}$

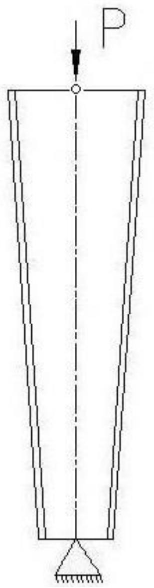
EFFECTIVE LENGTH FACTOR METHOD

ILLUSTRATION

Height – 6 meter

Column Section – Web (300 – 600) x6 mm

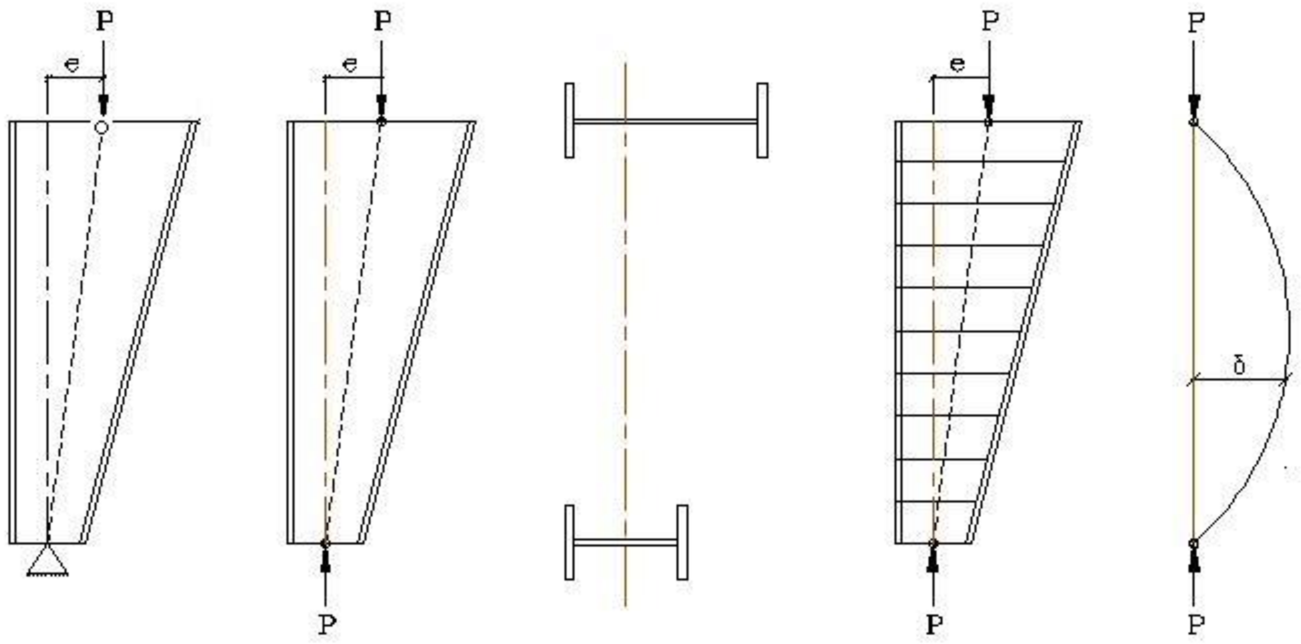
Flanges – 180 x 8 mm



Flange mm	Top Width mm	Mom Inertia mm^4	Psap KN	PsucApp KN	% Var	R_i	R_{ppin}	Effective Length Factor Method			
								k	keqn	Peff, KN	%Var
180x08	300	8.18E+07	4531	4485	1.02%	1.0000	1.0000	1.0000			
	350	1.14E+08	5346	5299	0.88%	1.3901	1.1815	0.9200	0.9296	5190	2.06%
	400	1.52E+08	6196	6155	0.66%	1.8564	1.3724	0.8537	0.8569	6108	0.76%
	450	1.97E+08	7081	7052	0.41%	2.4033	1.5724	0.7975	0.7968	7064	-0.17%
	500	2.48E+08	8000	7990	0.13%	3.0354	1.7815	0.7492	0.7461	8057	-0.84%
	550	3.07E+08	8951	8968	-0.19%	3.7575	1.9996	0.7072	0.7026	9086	-1.32%
	600	3.74E+08	9933	9988	-0.55%	4.5739	2.2270	0.6701	0.6648	10150	-1.62%
	650	4.49E+08	10946	11047	-0.92%	5.4894	2.4631	0.6372	0.6315	11248	-1.82%
	700	5.32E+08	11986	12147	-1.34%	6.5085	2.7084	0.6077	0.6019	12381	-1.92%
	750	6.25E+08	13054	13286	-1.78%	7.6358	2.9623	0.5810	0.5754	13546	-1.96%
	800	7.26E+08	14146	14465	-2.26%	8.8758	3.2252	0.5568	0.5515	14744	-1.93%
	850	8.37E+08	15262	15683	-2.76%	10.2332	3.4968	0.5348	0.5299	15975	-1.86%
	900	9.58E+08	16399	16940	-3.30%	11.7126	3.7770	0.5146	0.5101	17237	-1.75%
	950	1.09E+09	17554	18237	-3.89%	13.3185	4.0662	0.4959	0.4920	18530	-1.61%
	1000	1.23E+09	18723	19572	-4.53%	15.0554	4.3639	0.4787	0.4753	19855	-1.45%
	1050	1.38E+09	19902	20947	-5.25%	16.9281	4.6705	0.4627	0.4599	21210	-1.26%
	1100	1.55E+09	20798	22360	-7.51%	18.9411	4.9855	0.4479	0.4455	22596	-1.05%
	1150	1.73E+09	22262	23812	-6.96%	21.0989	5.3093	0.4340	0.4322	24011	-0.84%
	1200	1.91E+09	23421	25302	-8.03%	23.4061	5.6415	0.4210	0.4198	25456	-0.61%
	Psap - Using SAP2000; Psucapp - Using MSA; Peff - Using Effective Length Factor										

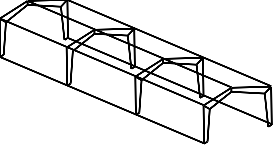
Error is less than 2% as compared with results from MSA.

BUCKLING LOAD OF ONE SIDE WEB-TAPERED COLUMN



- Most PEB buildings have One Side Web Tapered Columns.
- Same data is used as earlier.
- Buckling Analysis done by SAP2000 with 3 plated sections.

BUCKLING LOAD OF SINGLE SIDE WEB TAPERED COLUMN HAS VARIATION OF 1% WITH RESPECT TO SYMMETRIC TAPER.



BUCKLING LOAD OF WEB TAPERED COLUMNS
COMPARISON OF METHODS

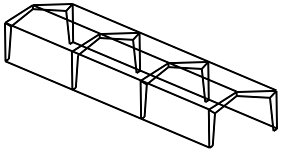
- Method of equivalent moment of inertia (EMI) offers results with errors about 1%.

- Method of successive approximation (MSA) can be used for all the configurations of structure and supports as comprehensive tool for benchmark problems with sufficient number of segments.

- Buckling load factor method offers direct and effective tool for quick assessment of buckling load for web tapered columns with both ends pinned as well as fixed base. Using separate equations for R_i upto 10 and R_i between 10 and 30, shows maximum error upto 3.0%. Single equation for R_i upto 30, shows maximum error upto 5% for R_i above 2.

- Effective length factor method offers direct and effective tool for buckling load of tapered columns and to assess behavior of tapered column in terms effective length. Results show error below 2% for R_i upto 30.

- Buckling Load of one side web tapered column has variation of @1% with respect to Symmetric Taper.



BUCKLING LOAD FACTOR METHOD

EFFECT OF HEIGHT

COLUMN WITH PINNED ENDS

HEIGHT , M	P_{EULER}, KN	P_{TAPER}, KN	R_{PPIN}	P_{TAPER}, KN	R_{PPIN}	P_{TAPER}, KN	R_{PPIN}	P_{TAPER}, KN	R_{PPIN}	P_{TAPER}, KN	R_{PPIN}
Top Web Depth, mm -->		**300**		**350**		**400**		**450**		**500**	
4.0	10092	10092	**1.00**	11923	**1.18**	13848	**1.37**	15866	**1.57**	17977	**1.78**
5.0	6459	6459	**1.00**	7631	**1.18**	8863	**1.37**	10154	**1.57**	11505	**1.78**
6.0	4485	4485	**1.00**	5299	**1.18**	6155	**1.37**	7052	**1.57**	7990	**1.78**
7.0	3295	3295	**1.00**	3893	**1.18**	4522	**1.37**	5181	**1.57**	5870	**1.78**
8.0	2523	2523	**1.00**	2981	**1.18**	3462	**1.37**	3966	**1.57**	4494	**1.78**
9.0	1994	1994	**1.00**	2355	**1.18**	2735	**1.37**	3134	**1.57**	3551	**1.78**
Top Web Depth, mm -->		**550**		**600**		**650**		**700**		**750**	
4.0	10092	20179	**2.00**	22472	**2.23**	24856	**2.46**	27330	**2.71**	29894	**2.96**
5.0	6459	12915	**2.00**	14382	**2.23**	15908	**2.46**	17491	**2.71**	19132	**2.96**
6.0	4485	8968	**2.00**	9988	**2.23**	11047	**2.46**	12147	**2.71**	13286	**2.96**
7.0	3295	6589	**2.00**	7338	**2.23**	8116	**2.46**	8924	**2.71**	9761	**2.96**
8.0	2523	5045	**2.00**	5618	**2.23**	6214	**2.46**	6833	**2.71**	7473	**2.96**
9.0	1994	3988	**2.00**	4439	**2.23**	4910	**2.46**	5399	**2.71**	5905	**2.96**

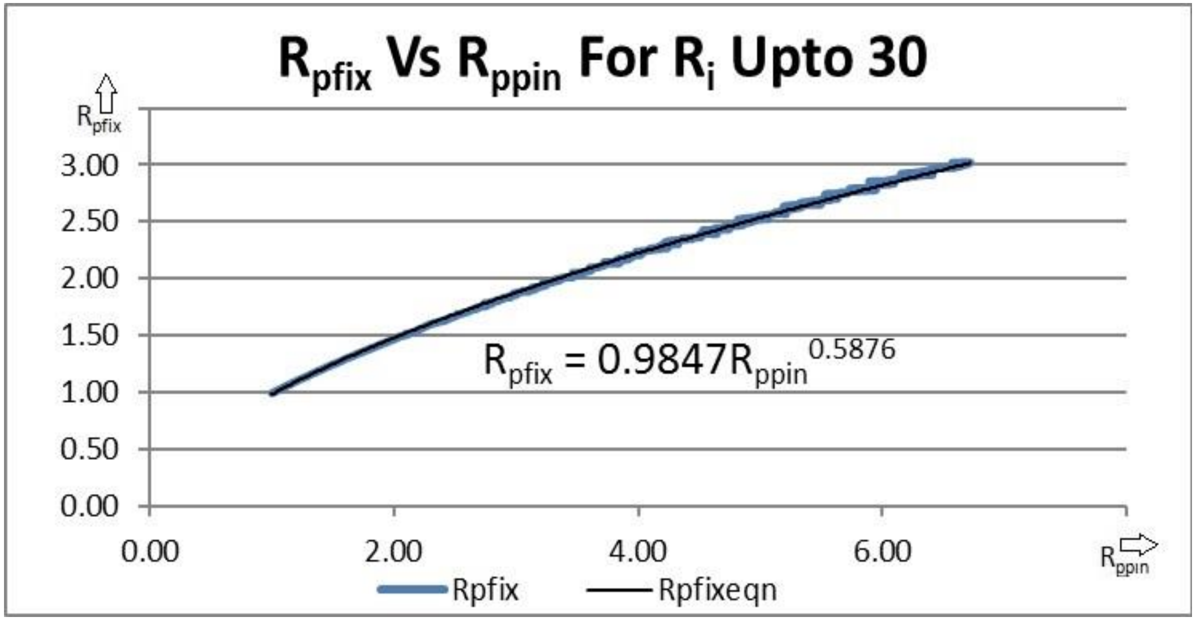
COLUMN WITH FIXED BASE & FREE TOP

HEIGHT , M	P_{EULER}, KN	P_{TAPER}, KN	R_{PFIX}	P_{TAPER}, KN	R_{PFIX}	P_{TAPER}, KN	R_{PFIX}	P_{TAPER}, KN	R_{PFIX}	P_{TAPER}, KN	R_{PFIX}
Top Web Depth, mm -->		**300**		**350**		**400**		**450**		**500**	
4.0	2506	2506	**1.00**	2747	**1.10**	2986	**1.19**	3224	**1.29**	3461	**1.38**
5.0	1612	1612	**1.00**	1767	**1.10**	1921	**1.19**	2074	**1.29**	2227	**1.38**
6.0	1123	1123	**1.00**	1231	**1.10**	1338	**1.19**	1444	**1.29**	1551	**1.38**
7.0	826	826	**1.00**	906	**1.10**	985	**1.19**	1063	**1.29**	1141	**1.38**
8.0	633	633	**1.00**	694	**1.10**	755	**1.19**	815	**1.29**	875	**1.38**
9.0	501	501	**1.00**	549	**1.10**	597	**1.19**	645	**1.29**	692	**1.38**
HEIGHT	**BASE**	**550**		**600**		**650**		**700**		**750**	
4.0	2506	3698	**1.48**	3936	**1.57**	4175	**1.67**	4415	**1.76**	4657	**1.86**
5.0	1612	2379	**1.48**	2532	**1.57**	2686	**1.67**	2840	**1.76**	2996	**1.86**
6.0	1123	1657	**1.48**	1763	**1.57**	1870	**1.67**	1978	**1.76**	2086	**1.86**
7.0	826	1219	**1.48**	1298	**1.57**	1376	**1.67**	1456	**1.76**	1535	**1.86**
8.0	633	935	**1.48**	995	**1.57**	1055	**1.67**	1116	**1.76**	1177	**1.86**
9.0	501	740	**1.48**	787	**1.57**	835	**1.67**	883	**1.76**	931	**1.86**

Buckling Load Factor is INDEPENDENT of Height Of Column.

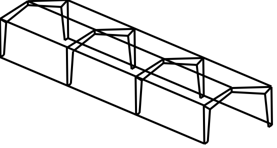
BUCKLING LOAD FACTOR METHOD

Mathematical Relation Between R_{ppin} & R_{pfix}



From similarity of equations of calculation of Buckling Loads, Equation of interrelation is

$$R_{pfix} = 0.9847 R_{ppin}^{0.5876}$$



BUCKLING LOAD OF WEB TAPERED COLUMNS

OBSERVATIONS & CONCLUSIONS

- Buckling load factor for web-tapered member varies in accordance to ratio of moment of inertia at top and bottom.

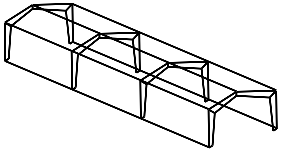
- For columns with both ends pinned and fixed base, buckling load factor can be calculated using separate polynomial equations for R_i upto 10 and for R_i above 10 upto 30. Else single polynomial can be used for R_i upto 30 with reasonable accuracy.

- Effective length factor method also presents a tool to calculate buckling load and effective length of tapered column.

- Buckling load factor, R_p, is independent of height of column.

- Buckling load factor of tapered column with fixed base and free top can be calculated from that of similar column with pinned end condition and vice versa.

- For columns with both ends pinned, buckling load analysis using SAP2000 shows that for all members with slender flange, such as of size 180x06 mm, buckling load remains constant for ratio of top web depth to base web depth, above 3 or d/t ratio of web above 150, indicating collapse.



PATH AHEAD

- Similar exercise for Web-Tapered Columns in Portal Frames
- These equations can be directly used in as tools for dedicated software development for PEB designs.

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THANK YOU !!!