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Design example: Member subject to bending
Section 5, NZS 3404: 1992

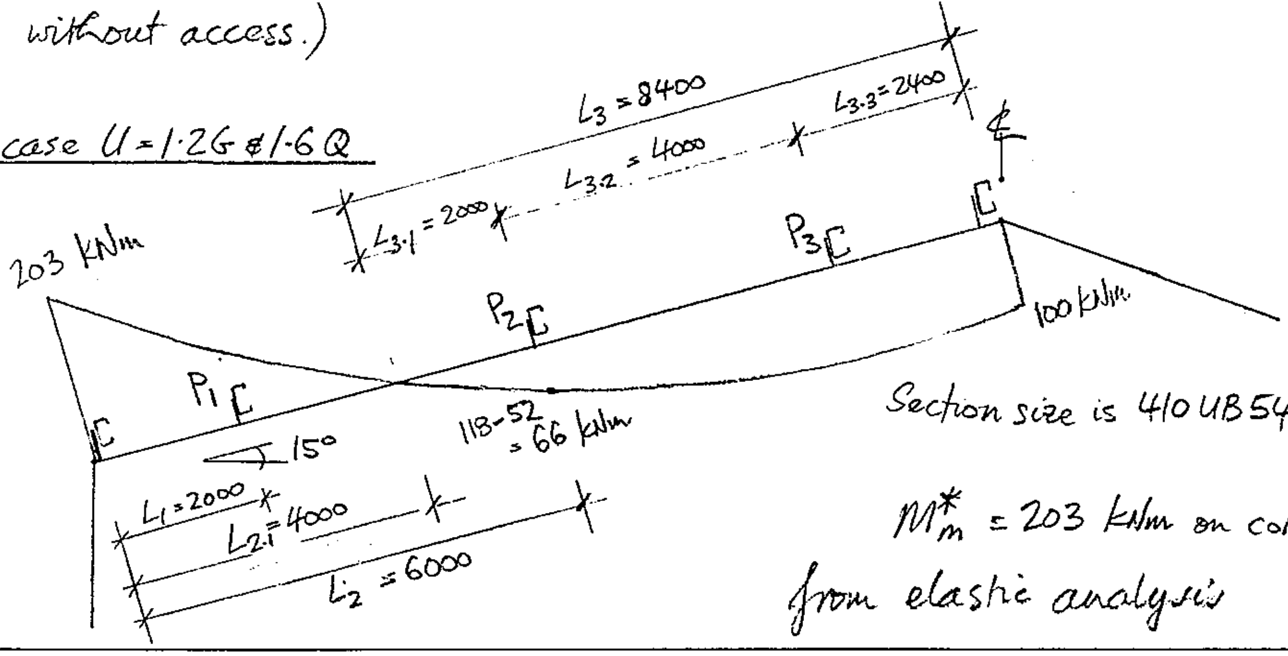
This example illustrates the design of the rafter of a portal frame for bending moment (for the ultimate limit state.

The portal frame is a conventional pinned base portal frame

span = 24 m
frame spacing = 8000 mm crs
roof pitch = 15°

The ultimate limit state load case considered in this example is maximum gravity loading $U = 1.2G + 1.6Q$
Note that in this load combination $Q = 0.25$ kPa, not Q_u (which would be zero for a typical portal frame roof without access.)

Load case $U = 1.2G + 1.6Q$



Section size is 410UB54.

$M_m^* = 203$ kNm on col ℄ from elastic analysis

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- Full / partial restraint is provided at the knee and apex joints i.e. the rafter between knee and apex satisfies Clause 5.3.2.3 (a)

1. Second order effects

Structure analysed using 'first order elastic analysis'
(see Clause 4.4.3

Consider moment amplification factor δ_m in accordance with Clause 4.4.3.3 (d)

For 410UB54, from Clause 4.9.2.3 (a) $\lambda_c = 13.3$

$\Rightarrow \delta_s = 1.03 = \delta_m$

$\therefore$ design bending moment $M^* = \underset{\delta_m}{1.03} \times \underset{M_m^*}{203}$

$= 209$ kNm on column ℄

and $M^* = 200$ kNm at column face.

2. Check section moment capacity Clause 5.2.1

Consider 410UB54 Grade 250

section is compact (refer tables of dimensions and design info.)

$\therefore Z_e = S_x$

$\Rightarrow \phi M_{sx} = \underset{\phi}{0.9} \times 1050 \times 10^{-6} m^3 \times 260 MPa$

$= 245$ kNm

$M^* = 200 < \phi M_{sx} = 245 \Rightarrow$ OK

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3. Evaluate restraint conditions

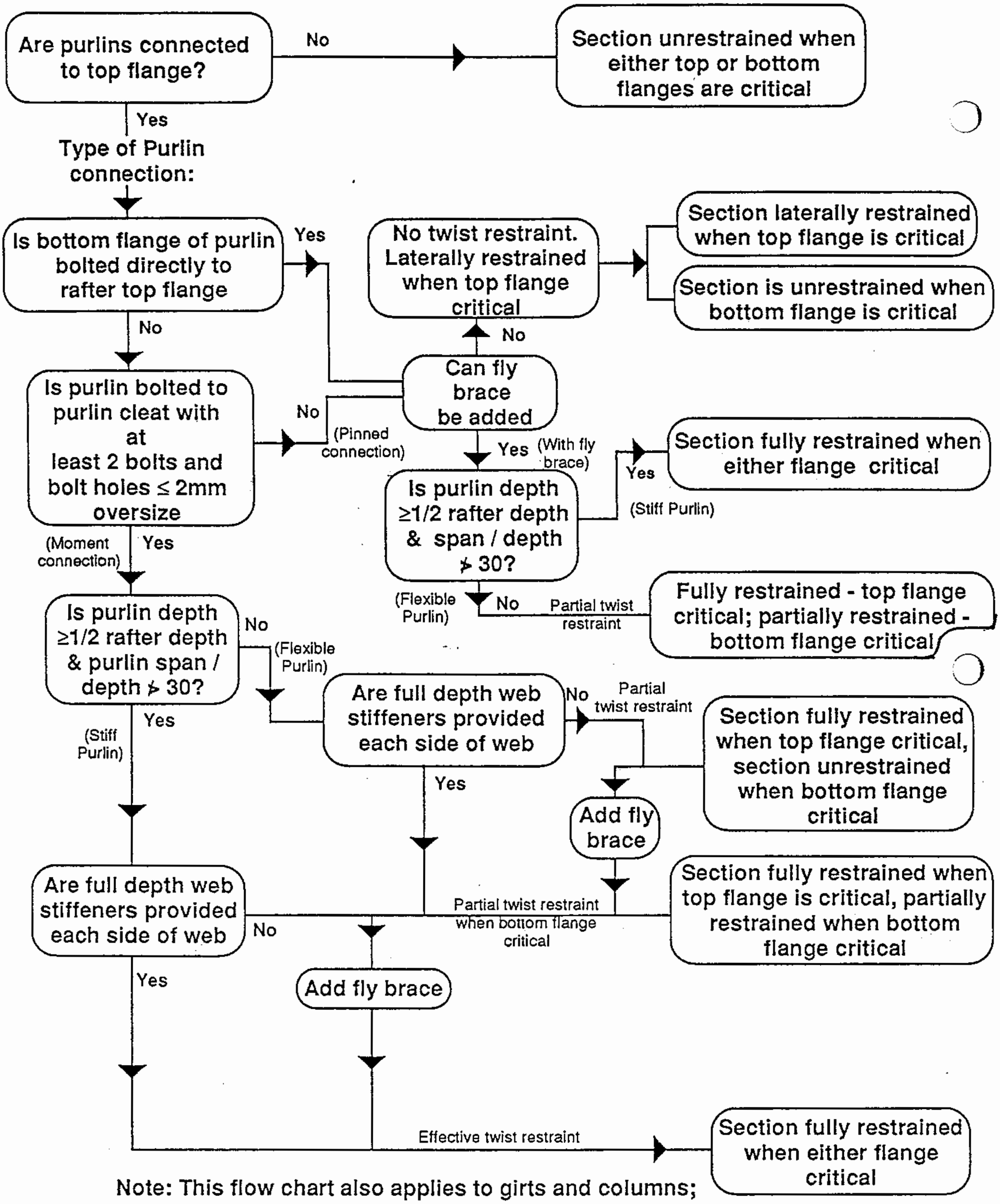
The effectiveness of purlins etc in providing lateral and twist restraint to the rafter is evaluated in accordance with Clause 5·4. (The attached flow chart may also be useful here, particularly for load cases producing nett wind uplift for which the bottom flange is the critical flange.)

3.1 Assuming the roof plane is effectively laterally restrained (either by bracing or as a stressed skin diaphragm) then the purlins provide lateral restraint to the rafter when the top flange is critical (i.e. at positions P_2, P_3 for load case $U = 1{\cdot}2G + 1{\cdot}6Q$)

For the rafter segment adjacent to the apex, the critical flange is the top (compression) flange - see Clause 5·5·2
∴ rafter cross section is laterally restrained at purlins P_2, P_3.

If the purlin connection is a moment connection (see Clause C5·4·2·1) then the rafter is fully restrained at P_2, P_3 without the need for flybraces.
(Assume this is the case for this design example.)

Section 5 -Effectiveness of Purlins as Lateral Restraints To Rafters



Note: This flow chart also applies to girts and columns; in this case substitute outer flange for top flange and inner flange for bottom flange.

Use the restraint classification details given in Appendix A5 of DG Vol. 1 (R4-80) for more direct design guidance than is given by this flowchart.

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4. Subdivide the rafter into segments

Consider 3 segments of lengths $L_2 = 6000$

$L_{3.2} = 4000$

$L_{3.3} = 2400$

5. Check member moment capacity for each segment. Clause 5.6

5.1 Segment L_2

- from Table 5.6.1, for $\beta_m = \frac{+66}{203} = 0.33 \Rightarrow \alpha_m = 2.1$
- actual length = 6000 mm
- at each end of this segment, torsional end restraint arrangement = F (fully restrained) at knee
  = F (" ") at purlin P_2
- ∴ from table 5.6.3(1) $k_t = 1.0$
- system transferring load is laterally restrained (see part 3.1 above) ∴ from table 5.6.3(2) $k_l = 1.0$
- let $k_r = 1.0$ from table 5.6.3(3)
- effective length $L_e = k_t . k_l . k_r . L$
  $= 6000$ mm
- from Equations 5.6.1.1(2) and 5.6.1.1(3) for $L_e = 6.0$m
  $\Rightarrow \alpha_s = 0.413$ for 410UB54
- $\phi M_b = \alpha_m \alpha_s \phi M_{sx} \leq \phi M_{sx}$
  $= 2.1 \times 0.41 \times 245$ kNm
  $= 213$ kNm

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$M^* = 200\,kNm < \phi M_b = 213\,kNm \Rightarrow OK$

5.2 <u>Segment</u> $L_{3.2}$

- $\beta_m \doteq -\frac{66}{107} = -0.61 \Rightarrow \alpha_m = 1.22$ (Table 5.6.1)
- actual length = 4000 mm
- torsional end restraints = FF $\Rightarrow k_t = 1.0$ Table 5.6.3(1)
- $k_l = k_r = 1.0$ as for segment L_2 Tables 5.6.3(2) and (3)

$\therefore$ effective length $L_e = 4000$ mm

- for $L_e = 4.0m \Rightarrow \alpha_s = 0.617$ Eqns 5.6.1.1 (2) and (3)

$\Rightarrow \phi M_b = 1.22 \times 0.617 \times 245\,kNm \leq 245\,kNm$

$= 184\,kNm$

for this segment, $M^* \approx 110\,kNm < \phi M_b = 184 \Rightarrow OK$

5.3 <u>Segment</u> $L_{3.3}$

actual length = 2400

for this segment $M^* \approx 110\,kNm < \phi M_b$ by inspection

$\Rightarrow$ OK

Hence 410 UB 54 Grade 250 rafter OK
(for this load case)

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Alternatively, the AISC Design Capacity Tables may be used:

Section moment capacity

Table 3.2-5 (p 3-55) for 410 UB54 Grade 250 $\phi M_{sx} = 245$ kNm

$M^* = 200 < \phi M_{sx}$ ⇒ OK

Member moment capacity

Table 3.3-5 (p 3-72)

- Segment L_2 : for $L_e = 6.0$ m, $\alpha_m = 2.1$

  $\Rightarrow \phi M_b = 2.1 \times 101 = 212$ kNm

  $M^* = 200 < \phi M_b$ ⇒ OK

- Segment $L_{3.2}$: for $L_e = 4.0$ m, $\alpha_m = 1.22$

  $\Rightarrow \phi M_b = 1.22 \times 151 = 184$ kNm

  $M^* \doteq 110 < \phi M_b$ ⇒ OK

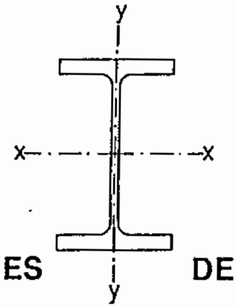


Table 3.2-5

DESIGN SECTION MOMENT AND SHEAR CAPACITIES FOR MEMBERS SUBJECT TO BENDING

UNIVERSAL BEAMS — GRADE 250

Designation	Bending About x-axis				About y-axis
	ϕM_{sx}	$\phi M'_{sx}$	FLR	ϕV_v	ϕM_{sy}
	kNm	kNm	m	kN	kNm
760UB244	2010	2010	1.74	2030	261
220	1810	1810	1.73	1820	233
197	1610	1610	1.71	1620	206
173	1390	1390	1.67	1470	173
147	1160	1160	1.62	1310	139
690UB140	1030	1030	1.62	1150	138
125	899	899	1.57	1120	117
610UB125	827	827	1.49	1030	116
113	740	740	1.46	953	102
101	648	648	1.42	893	86.4
530UB 92.4	532	532	1.35	761	77.2
82.0	463	463	1.31	708	64.9
460UB 82.1	412	412	1.27	640	66.0
74.6	373	373	1.26	584	59.2
67.1	331	331	1.24	540	51.6
410UB 59.7	269	269	1.19	445	45.5
53.7	245	245	1.13	429	40.2
360UB 56.7	227	227	1.18	400	43.5
50.7	209	187	1.14	364	39.6
44.7	181	162	1.11	339	33.3
310UB 46.2	169	149	1.15	290	38.0
40.4	146	129	1.13	260	32.4
250UB 37.3	114	97.7	1.02	230	27.4
31.4	92.6	80.4	0.986	215	21.6
200UB 29.8	73.3	61.9	0.935	183	20.1
25.4	60.8	51.7	0.910	167	16.3
180UB 22.2	45.7	45.7	0.612	151	9.52
18.1	36.8	36.8	0.605	123	7.61
150UB 18.0	31.6	31.6	0.503	130	6.29
14.0	23.9	23.9	0.490	105	4.64

NOTES: FLR — Segment Length for Full Lateral Restraint for Sections without Holes in Tension Flange

$\phi M'_{sx}$ — For Section with Two Holes on Tension Flange

Table 3.2-6

DESIGN SECTION MOMENT AND SHEAR CAPACITIES FOR MEMBERS SUBJECT TO BENDING

UNIVERSAL BEAMS — GRADE 350

Designation	Bending About x-axis				About y-axis
	ϕM_{sx}	$\phi M'_{sx}$	FLR	ϕV_v	ϕM_{sy}
	kNm	kNm	m	kN	kNm
760UB244	2740	2540	1.50	2760	355
220	2460	2280	1.48	2480	317
197	2190	2030	1.47	2210	280
173	1900	1760	1.43	2000	236
147	1580	1480	1.39	1790	189
690UB140	1400	1310	1.39	1560	187
125	1220	1150	1.35	1550	159
610UB125	1130	1040	1.28	1420	158
113	1010	933	1.26	1320	138
101	882	820	1.22	1240	117
530UB 92.4	724	666	1.16	1050	105
82.0	629	581	1.13	981	88.2
460UB 82.1	561	509	1.09	886	89.8
74.6	507	460	1.08	808	80.5
67.1	450	410	1.06	748	70.2
410UB 59.7	365	328	1.02	616	61.9
53.7	337	304	0.964	594	55.2
360UB 56.7	309	275	1.01	554	59.1
50.7	290	259	0.968	504	54.9
44.7	246	218	0.944	469	45.1
310UB 46.2	234	206	0.976	402	52.6
40.4	201	177	0.962	360	44.5
250UB 37.3	157	135	0.867	319	37.9
31.4	127	109	0.838	298	29.4
200UB 29.8	101	85.7	0.795	253	27.9
25.4	83.2	70.0	0.774	231	22.2
180UB 22.2	63.3	63.3	0.520	209	13.2
18.1	50.9	50.9	0.514	170	10.5
150UB 18.0	43.7	43.7	0.428	181	8.71
14.0	33.0	33.0	0.416	146	6.42

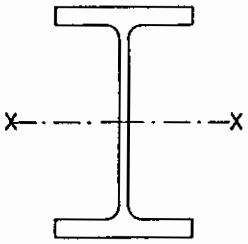
NOTES: FLR — Segment Length for Full Lateral Restraint for Sections without Holes in Tension Flange

$\phi M'_{sx}$ — For Section with Two Holes on Tension Flange

Table 3.3-5

DESIGN MOMENT CAPACITIES FOR MEMBERS WITHOUT FULL LATERAL RESTRAINT SUBJECT TO BENDING about x-axis

UNIVERSAL BEAMS — GRADE 250



Designation	Design Moment Capacities ϕM_b (kNm) for Effective Length in metres												
	2	3	4	5	6	7	8	9	10	11	12	14	16
760UB244	1960	1820	1660	1500	1350	1210	1090	988	899	823	757	652	571
220	1760	1630	1480	1330	1190	1060	945	849	768	699	640	546	475
197	1570	1450	1310	1170	1030	913	809	721	647	586	533	451	390
173	1350	1240	1120	987	864	754	661	583	519	465	421	352	301
147	1120	1030	916	800	691	595	515	449	394	350	314	259	219
690UB140	989	904	806	705	613	531	463	407	361	323	292	243	208
125	863	786	695	603	518	445	384	334	294	261	234	194	164
610UB125	787	710	625	542	468	406	355	313	280	252	229	193	166
113	701	630	551	473	405	348	301	264	234	209	189	158	136
101	612	547	474	403	340	289	248	215	189	168	151	125	107
530UB 92.4	497	440	378	320	272	232	201	176	156	140	127	106	91.6
82.0	429	377	320	268	224	189	162	140	123	110	99.0	82.4	70.6
460UB 82.1	380	332	284	241	206	177	155	137	123	111	101	85.9	74.6
74.6	342	298	253	212	179	153	133	117	104	93.4	84.8	71.7	62.0
67.1	302	262	220	182	152	128	110	96.1	85.0	76.1	68.8	57.7	49.7
410UB 59.7	243	208	174	145	121	103	89.1	78.2	69.6	62.6	56.9	48.1	41.6
53.7	219	185	151	123	101	84.8	72.4	63.0	55.6	49.7	44.9	37.7	32.5
360UB 56.7	205	176	149	125	106	91.8	80.3	71.2	63.9	57.9	52.9	45.1	39.3
50.7	187	158	131	108	90.7	77.1	66.7	58.7	52.3	47.1	42.8	36.3	31.5
44.7	160	134	110	89.1	73.3	61.5	52.7	45.9	40.6	36.4	32.9	27.7	23.9
310UB 46.2	151	129	108	91.0	77.4	66.8	58.5	52.0	46.7	42.3	38.7	33.1	28.8
40.4	130	110	90.6	74.9	62.7	53.4	46.3	40.7	36.3	32.8	29.8	25.3	22.0
250UB 37.3	98.1	82.3	68.4	57.5	49.1	42.6	37.5	33.5	30.2	27.5	25.2	21.6	18.9
31.4	78.8	64.6	52.3	42.8	35.7	30.4	26.5	23.4	20.9	18.9	17.3	14.7	12.8
200UB 29.8	61.9	51.5	43.0	36.3	31.2	27.3	24.2	21.7	19.6	17.9	16.5	14.2	12.5
25.4	50.5	41.1	33.4	27.6	23.3	20.1	17.6	15.6	14.1	12.8	11.7	10.0	8.78
180UB 22.2	33.3	26.5	21.7	18.2	15.7	13.7	12.1	10.9	9.87	9.02	8.30	7.15	6.28
18.1	25.7	19.7	15.6	12.8	10.9	9.39	8.26	7.37	6.66	6.06	5.57	4.78	4.19
150UB 18.0	21.6	17.0	13.9	11.7	10.0	8.74	7.74	6.95	6.29	5.75	5.29	4.56	4.00
14.0	15.0	11.2	8.86	7.26	6.13	5.30	4.67	4.16	3.76	3.42	3.14	2.70	2.37