TREE BIOMECHANICS SERIES

Critical Force For Buckling Tree Stems

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Tree strength and stiffness can resist significant forces and not fail. A large proportion of this strength lies with the thickness (diameter) of the stem. Stem buckling occurs when an exerted force begins and continues to bend the stem beyond recovery. Prime among the calculable forces in stem resistance to failure is the relative critical force needed to sustain Euler bucking (as opposed to thin-walled buckling which is not treated here). Euler buckling occurs at a critical force which is proportional to the geometric placement and material strength of woody tissues, and inversely proportional to the square of stem height.

The amount of load which can be applied to cause failure by buckling is dependent upon many complex factors and attributes of tree, soil, and environment. This publication will isolate one simple component of stem strength to help tree specialists appreciate tree biomechanics. This publication does not attempt to provide actual tree stem responses to loads and forces under the dynamic conditions in nature.

Table 1 provides a list of relative critical force values needed for Euler buckling to proceed in a stem at various heights and various diameters. These values can help compare critical force as diameter and height increase. For example, in a 15 inch diameter tree which is 40 feet tall, the relative critical force value is 155. Growing twenty feet in height and two (2) inches in diameter represents a relative critical force of 113, or a 27% loss in the critical force needed for initiating buckling. Note that greater heights and diameters are listed than could be normally expected in order to show strength trends.

Figure 1, 2, and 3 all provide graphical examples of how relative critical forces can vary by height and diameter. General principles for critical force-initiated buckling (stem failure) are: large forces are needed to buckle short, large diameter stems; much smaller forces are needed to buckle tall, small diameter stems; for the same diameter stem, relative bucking force is greatly reduced by doubling height (~25% of force needed for 100 feet tall stem compared with a 50 feet tall stem at 20 inches diameter); bigger and shorter stems are stronger, and thinner and taller stems are weaker.

It is clear across a number of mechanical features, there are proportional limits between height growth and diameter growth. Stem locations which do not meet, or are prevented from meeting, structural sustainability at minimum levels, will be weak areas upon which forces are concentrated.

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Table 1: Relative critical force needed for Euler buckling to proceed in tree stems of a given height (feet) and diameter (inches). Dotted lines are examples from text.

Stem Diamt. (in.)	Height (feet)													
	20ft	30	40	50	60	70	80	90	100	110	120	130	140	150
4 in.	3	1	0	0	0	0	0	0	0	0	0	0	0	0
5	7	3	1	1	0	0	0	0	0	0	0	0	0	0
6	15	7	3	2	1	1	0	0	0	0	0	0	0	0
7	29	13	7	4	3	2	1	1	1	0	0	0	0	0
8	50	22	12	8	5	4	3	2	2	1	1	1	1	0
9	80	35	20	12	8	6	5	3	3	2	2	1	1	1
10	122	54	30	19	13	10	7	6	4	4	3	2	2	2
11	179	79	44	28	19	14	11	8	7	5	4	4	3	3
12	254	113	63	40	28	20	15	12	10	8	7	6	5	4
13	350	155	87	56	38	28	21	17	14	11	9	8	7	6
14	471	209	117	75	52	38	29	23	18	15	13	11	9	8
15	621	276	**155**	99	69	50	38	30	24	20	17	14	12	11
16	804	357	201	128	89	65	50	39	32	26	22	19	16	14
17	1,024	455	256	163	**113**	83	64	50	40	33	28	24	20	18
18	1,288	572	322	206	143	105	80	63	51	42	35	30	26	22
19	1,599	710	399	255	177	130	99	78	63	52	44	37	32	28
20	1,963	872	490	314	218	160	122	96	78	64	54	46	40	34
21	2,386	1,060	596	381	265	194	149	117	95	78	66	56	48	42
22	2,874	1,277	718	459	319	234	179	141	114	95	79	68	58	51
23	3,434	1,526	858	549	381	280	214	169	137	113	95	81	70	61
24	4,071	1,809	1,017	651	452	332	254	201	162	134	113	96	83	72
25	4,793	2,130	1,198	766	532	391	299	236	191	158	133	113	97	85
26	5,607	2,492	1,401	897	623	457	350	276	224	185	155	132	114	99
27	6,521	2,898	1,630	1,043	724	532	407	322	260	215	181	154	133	115
28	7,542	3,352	1,885	1,206	838	615	471	372	301	249	209	178	153	134
29	8,679	3,857	2,169	1,388	964	708	542	428	347	286	241	205	177	154
30	9,940	4,417	2,485	1,590	1,104	811	621	490	397	328	276	235	202	176
31	11,333	5,037	2,833	1,813	1,259	925	708	559	453	374	314	268	231	201
32	12,867	5,719	3,216	2,058	1,429	1,050	804	635	514	425	357	304	262	228
33	14,553	6,468	3,638	2,328	1,617	1,188	909	718	582	481	404	344	297	258
34	16,399	7,288	4,099	2,623	1,822	1,338	1,024	809	655	542	455	388	334	291
35	18,415	8,184	4,603	2,946	2,046	1,503	1,150	909	736	608	511	435	375	327
36	20,611	9,160	5,152	3,297	2,290	1,682	1,288	1,017	824	681	572	487	420	366
37	22,999	10,221	5,749	3,679	2,555	1,877	1,437	1,135	919	760	638	544	469	408
38	25,588	11,372	6,397	4,094	2,843	2,088	1,599	1,263	1,023	845	710	605	522	454
39	28,390	12,617	7,097	4,542	3,154	2,317	1,774	1,401	1,135	938	788	671	579	504
40	31,415	13,962	7,853	5,026	3,490	2,564	1,963	1,551	1,256	1,038	872	743	641	558
45	50,322	22,365	12,580	8,051	5,591	4,107	3,145	2,485	2,012	1,663	1,397	1,191	1,026	894
50	76,698	34,088	19,174	12,271	8,522	6,261	4,793	3,787	3,067	2,535	2,130	1,815	1,565	1,363
55	112,294	49,908	28,073	17,967	12,477	9,166	7,018	5,545	4,491	3,119	2,657	2,291	1,996	3,712
60	159,042	70,685	39,760	25,446	17,671	12,983	9,940	7,853	6,361	4,417	3,764	3,245	2,827	5,257
65	219,059	97,359	54,764	35,049	24,339	17,882	13,691	10,817	8,762	6,084	5,184	4,470	3,894	7,241
70	294,646	130,954	73,661	47,143	32,738	24,052	18,415	14,550	11,785	9,740	8,184	6,973	6,013	5,238
75	388,288	172,572	97,072	62,126	43,143	31,697	24,268	19,174	15,531	12,835	10,785	9,190	7,924	6,902
80	502,654	223,401	125,663	80,424	55,850	41,033	31,415	24,822	20,106	16,616	13,962	11,897	10,258	8,936
85	640,597	284,710	160,149	102,495	71,177	52,293	40,037	31,634	25,623	21,176	17,794	15,162	13,073	11,388
90	805,155	357,846	201,288	128,824	89,461	65,726	50,322	39,760	32,206	26,616	22,365	19,056	16,431	14,313

Relative Critical Force for Buckling = ((((3.14159) x (stem diameter)^4) / 64) / (stem height)^2)) x 100

(not to scale)

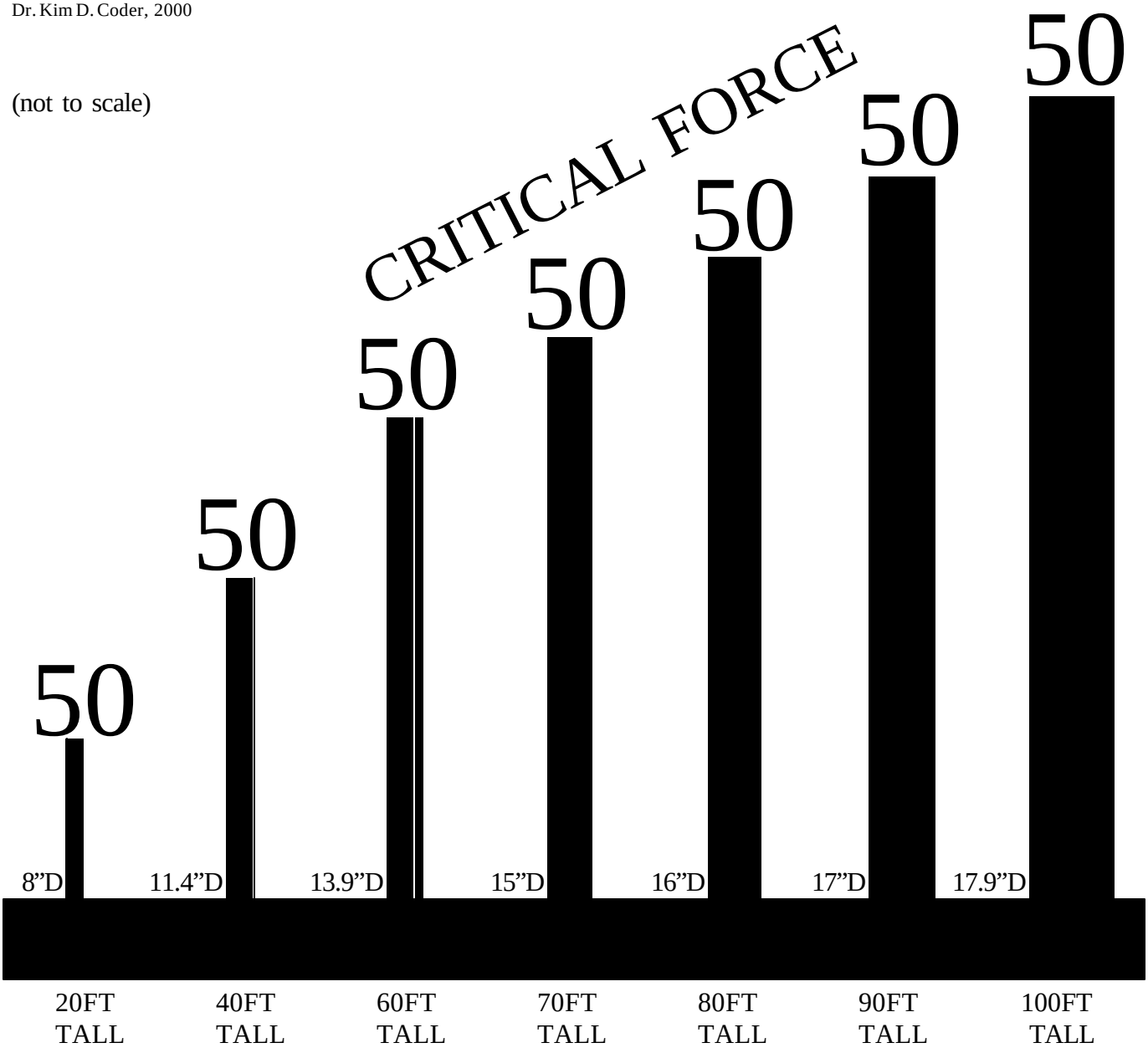

Figure 1: Stem heights and diameters which have equivalent relative critical forces required to propagate Euler buckling.

(not to scale)

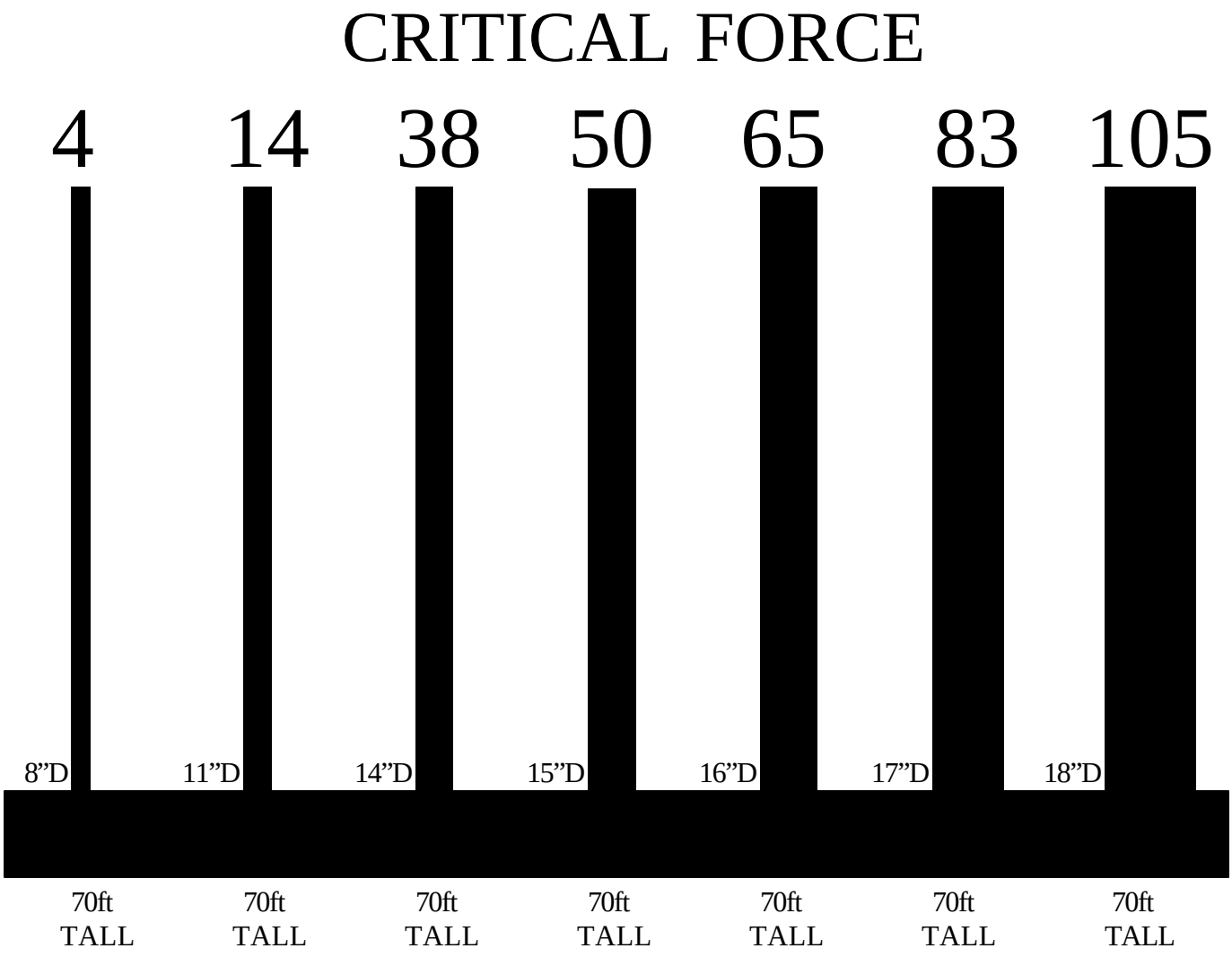

Figure 2: For each stem, with heights all equal to 70 feet and with increasing diameters, the relative critical forces required to propagate Euler buckling are listed.

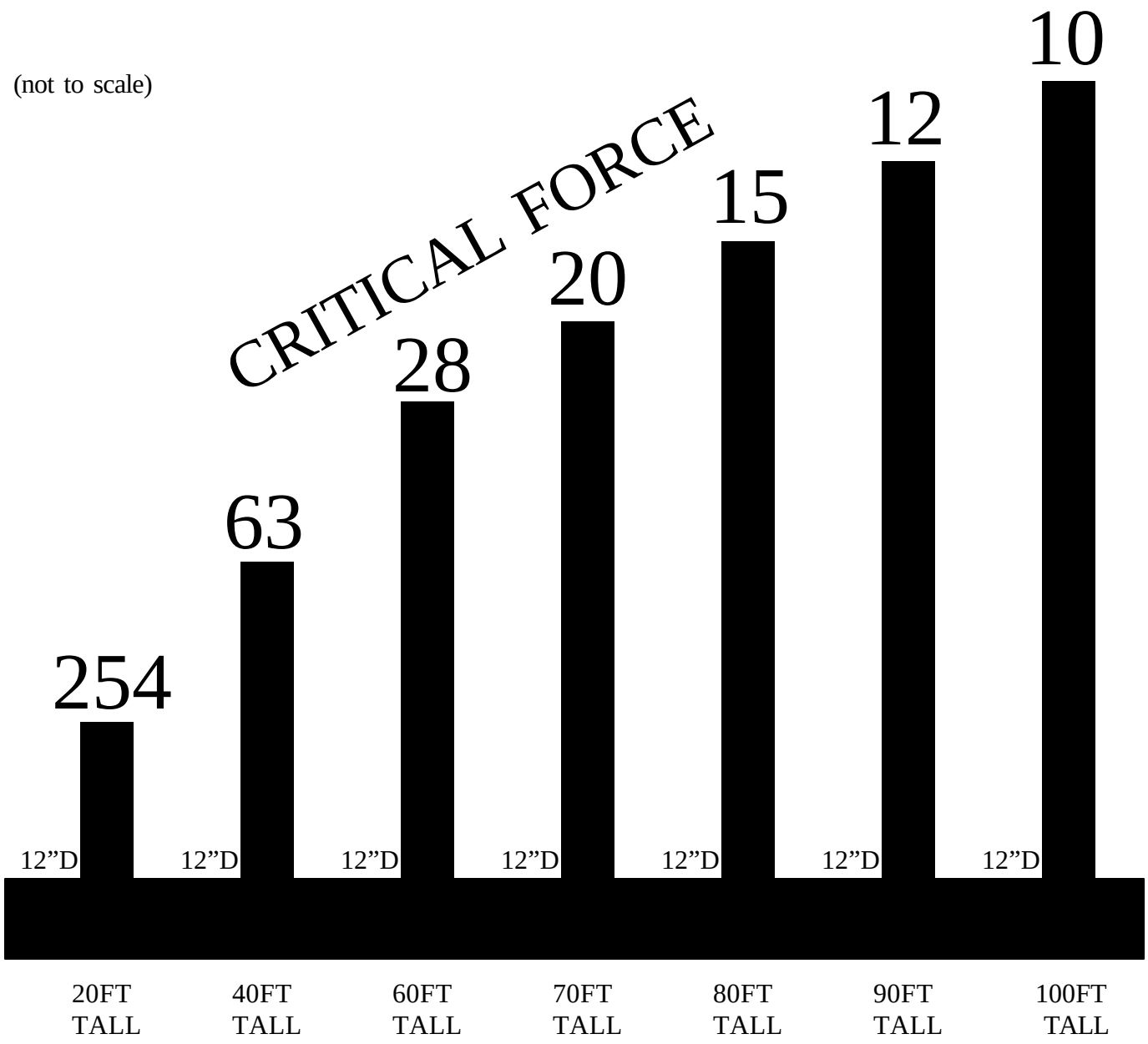

Figure 3: For each stem, with increasing heights and with diameters all equal to 12 inches, the relative critical forces required to propagate Euler buckling are listed.