

Table 1. Stability bounds for dual circular tunnels.

H/D	ϕ'	S/D	$\gamma D/c'=0$		$\gamma D/c'=1$		$\gamma D/c'=2$		$\gamma D/c'=3$	
			LB	UB	LB	UB	LB	UB	LB	UB
1	5.00	1.25	1.57	1.62	0.37	0.42	-0.83	-0.79	-2.04	-2.00
		1.50	1.73	1.80	0.50	0.56	-0.75	-0.68	-2.00	-1.94
		2.00	2.08	2.17	0.79	0.88	-0.51	-0.43	-1.84	-1.76
		2.50	2.42	2.50	1.10	1.18	-0.25	-0.16	-1.61	-1.53
		3.00	2.74	2.81	1.39	1.47	0.02	0.10	-1.37	-1.29
		3.50	2.91	2.99	1.65	1.72	0.28	0.35	-1.13	-1.06
		4.00	2.91	2.99	1.65	1.72	0.35	0.43	-0.98	-0.91
		4.50	2.91	2.99	1.65	1.72	0.35	0.43	0.98	-0.91
	10.0	1.25	1.80	1.86	0.54	0.59	-0.73	-0.68	-2.00	-1.95
		1.50	2.01	2.10	0.72	0.80	-0.58	-0.50	-1.89	-1.81
		2.00	2.47	2.59	1.14	1.25	-0.20	-0.10	-1.56	-1.45
		2.50	2.94	3.05	1.59	1.69	0.22	0.32	-1.17	-1.06
		3.00	3.40	3.50	2.02	2.13	0.63	0.74	-0.77	-0.67
		3.50	3.60	3.72	2.22	2.33	0.83	0.93	-0.58	-0.49
		4.00	3.60	3.72	2.22	2.33	0.83	0.93	-0.58	-0.49
		4.50	3.60	3.72	2.22	2.33	0.83	0.93	-0.58	-0.49
	15.0	1.25	2.10	2.19	0.76	0.84	-0.59	-0.52	-1.95	-1.88
		1.50	2.37	2.50	1.01	1.13	-0.36	-0.24	-1.73	-1.63
		2.00	3.02	3.17	1.63	1.78	0.24	0.38	-1.17	-1.02
		2.50	3.70	3.85	2.29	2.44	0.88	1.03	-0.54	-0.39
		3.00	4.38	4.54	2.96	3.12	1.52	1.67	-0.04	0.10
		3.50	4.60	4.81	3.07	3.26	1.52	1.67	-0.04	0.10
		4.00	4.60	4.81	3.07	3.26	1.52	1.67	-0.04	0.10
		4.50	4.60	4.81	3.06	3.26	1.52	1.67	-0.04	0.10
	20.0	1.25	2.52	2.66	1.07	1.20	-0.40	-0.29	-1.88	-1.79
		1.50	2.88	3.07	1.43	1.61	-0.03	0.14	-1.51	-1.35
		2.00	3.80	4.04	2.35	2.58	0.89	1.11	-0.57	-0.36
		2.50	4.84	5.09	3.38	3.62	1.91	2.13	0.42	0.64
		3.00	5.94	6.21	4.43	4.71	2.65	2.93	0.85	1.09
		3.50	6.20	6.58	4.43	4.71	2.65	2.93	0.85	1.09
		4.00	6.20	6.58	4.43	4.71	2.65	2.93	0.85	1.09
		4.50	6.20	6.58	4.43	4.71	2.65	2.93	0.85	1.09
3	5.00	1.25	3.65	3.80	0.13	0.27	-3.41	-3.28	-6.98	-6.85
		1.50	3.60	3.76	0.07	0.23	-3.47	-3.32	-7.04	-6.90
		2.00	3.61	3.77	0.08	0.24	-3.47	-3.31	-7.05	-6.89
		2.50	3.71	3.87	0.18	0.34	-3.37	-3.21	-6.96	-6.79
		3.00	3.85	4.01	0.32	0.49	-3.24	-3.06	-6.82	-6.64
		3.50	4.00	4.18	0.48	0.66	-3.08	-2.89	-6.67	-6.46
		4.00	4.16	4.35	0.64	0.84	-2.91	-2.71	-6.50	-6.28
		4.50	4.33	4.53	0.81	1.02	-2.74	-2.52	-6.33	-6.09

	5.00	4.54	4.70	1.02	1.18	-2.53	-2.36	-6.11	-5.92
	5.50	4.70	4.87	1.18	1.36	-2.37	-2.18	-5.95	-5.74
	6.00	4.89	5.01	1.37	1.49	-2.17	-2.05	-5.75	-5.62
	6.50	5.05	5.18	1.53	1.66	-2.02	-1.89	-5.66	-5.51
	7.00	5.21	5.34	1.68	1.82	-1.93	-1.77	-5.66	-5.51
	7.50	5.36	5.50	1.77	1.93	-1.93	-1.77	-5.66	-5.51
	8.00	5.42	5.60	1.77	1.93	-1.93	-1.77	-5.66	-5.51
	8.50	5.42	5.60	1.77	1.93	-1.93	-1.77	-5.66	-5.51
10.00	1.25	4.76	5.01	0.78	1.02	-3.27	-3.04	—	—
	1.50	4.69	4.93	0.73	0.98	-3.29	-3.05	—	—
	2.00	4.64	4.90	0.76	1.02	-3.17	-2.91	—	—
	2.50	4.77	5.03	0.95	1.21	-2.91	-2.64	—	—
	3.00	4.97	5.25	1.20	1.48	-2.61	-2.32	—	—
	3.50	5.21	5.52	1.47	1.78	-2.30	-1.98	—	—
	4.00	5.47	5.80	1.75	2.09	-2.00	-1.65	—	-5.41
	4.50	5.73	6.11	2.03	2.41	-1.72	-1.32	-5.52	-5.08
	5.00	6.09	6.38	2.40	2.69	-1.34	-1.03	-5.20	-4.96
	5.50	6.37	6.69	2.68	3.01	-1.08	-0.73	-5.20	-4.96
	6.00	6.69	6.92	3.01	3.23	-0.83	-0.58	-5.20	-4.96
	6.50	6.97	7.22	3.28	3.52	-0.83	-0.58	-5.20	-4.96
	7.00	7.24	7.51	3.41	3.70	-0.83	-0.58	-5.20	-4.96
	7.50	7.51	7.80	3.41	3.70	-0.83	-0.58	-5.20	-4.96
8.00	7.51	7.80	3.41	3.70	-0.83	-0.58	-5.20	-4.96	
8.50	7.51	7.80	3.41	3.70	-0.83	-0.58	-5.20	-4.96	
15.00	1.25	6.54	6.98	1.86	2.29	-3.07	-2.68	—	—
	1.50	6.41	6.88	1.82	2.28	-2.99	-2.56	—	—
	2.00	6.28	6.75	1.90	2.36	-2.63	-2.16	—	—
	2.50	6.43	6.91	2.20	2.68	-2.10	-1.61	—	—
	3.00	6.73	7.26	2.62	3.15	-1.55	-1.01	—	—
	3.50	7.12	7.72	3.08	3.68	-1.02	-0.40	—	—
	4.00	7.55	8.23	3.56	4.24	-0.52	0.20	—	—
	4.50	8.00	8.78	4.04	4.82	-0.06	0.77	—	-3.72
	5.00	8.69	9.29	4.74	5.35	0.64	1.28	—	-3.71
	5.50	9.19	9.87	5.24	5.93	1.07	1.82	—	-3.71
	6.00	9.81	10.30	5.86	6.34	1.29	1.86	—	-3.71
	6.50	10.33	10.87	6.36	6.89	1.29	1.86	—	-3.71
	7.00	10.85	11.44	6.42	7.06	1.29	1.86	—	-3.71
	7.50	11.35	11.98	6.42	7.11	1.26	2.01	—	-3.71
8.00	11.35	11.98	6.42	7.11	1.26	2.01	—	-3.71	
8.50	11.35	11.98	6.42	7.11	1.26	2.01	—	-3.71	
20.00	1.25	9.62	10.51	3.82	4.70	-2.59	-1.79	—	—
	1.50	9.39	10.36	3.82	4.76	-2.25	-1.38	—	—
	2.00	9.15	10.10	4.01	4.93	-1.43	-0.49	—	—
	2.50	9.24	10.26	4.43	5.43	-0.51	0.49	—	—
	3.00	9.71	10.86	5.11	6.26	0.42	1.57	—	—
	3.50	10.39	11.72	5.91	7.25	1.63	2.68	—	-2.04
	4.00	11.17	12.74	6.76	8.35	2.59	3.80	-2.26	-0.98

		4.50	12.02	13.85	7.65	9.50	3.50	4.93	-1.70	-0.02
		5.00	13.47	14.93	9.14	10.60	4.44	5.97	-1.41	0.41
		5.50	14.47	16.18	10.13	11.85	5.28	7.11	-1.41	0.41
		6.00	15.78	17.02	11.42	12.63	6.06	7.45	-1.41	0.41
		6.50	16.88	18.27	12.48	13.84	6.06	7.45	-1.41	0.41
		7.00	18.00	19.54	12.68	14.27	6.06	7.45	-1.41	0.41
		7.50	18.87	20.53	12.68	14.27	6.06	7.45	-1.41	0.41
		8.00	18.87	20.53	12.68	14.27	6.06	7.45	-1.41	0.41
		8.50	18.87	20.53	12.68	14.27	6.06	7.45	-1.41	0.41
5	5.00	1.25	5.14	5.36	-0.76	-0.54	-6.71	-6.49	—	—
		1.50	5.07	5.31	-0.83	-0.59	-6.78	-6.54	—	—
		2.00	4.97	5.19	-0.90	-0.67	-6.85	-6.60	—	—
		2.50	4.93	5.13	-0.91	-0.70	-6.82	-6.59	—	—
		3.00	4.93	5.14	-0.88	-0.66	-6.74	-6.51	—	—
		3.50	4.98	5.19	-0.80	-0.58	-6.63	-6.40	—	—
		4.00	5.05	5.28	-0.70	-0.47	-6.50	-6.26	—	—
		4.50	5.14	5.38	-0.59	-0.35	-6.36	-6.11	—	—
		5.00	5.27	5.47	-0.44	-0.24	-6.19	-5.98	—	—
		5.50	5.38	5.59	-0.32	-0.11	-6.05	-5.84	—	—
		6.00	5.50	5.71	-0.19	0.02	-5.91	-5.69	—	-11.44
		6.50	5.62	5.84	-0.06	0.16	-5.77	-5.55	—	-11.29
		7.00	5.73	5.96	0.06	0.29	-5.65	-5.41	-11.40	-11.16
		7.50	5.85	6.09	0.18	0.43	-5.52	-5.28	-11.33	-11.05
		8.00	5.99	6.18	0.33	0.52	-5.38	-5.19	-11.33	-11.05
		8.50	6.10	6.30	0.44	0.64	-5.27	-5.07	-11.33	-11.05
		9.00	6.21	6.42	0.56	0.77	-5.17	-4.96	-11.33	-11.05
		9.50	6.32	6.54	0.67	0.88	-5.14	-4.90	-11.33	-11.05
	10.00	6.43	6.66	0.78	1.00	-5.14	-4.90	-11.33	-11.05	
	10.50	6.54	6.77	0.88	1.11	-5.14	-4.90	-11.33	-11.05	
	11.00	6.65	6.89	0.91	1.16	-5.14	-4.90	-11.33	-11.05	
	11.50	6.75	7.00	0.91	1.16	-5.14	-4.90	-11.33	-11.05	
	12.00	6.85	7.11	0.91	1.16	-5.14	-4.90	-11.33	-11.05	
	12.50	6.88	7.14	0.91	1.16	-5.14	-4.90	-11.33	-11.05	
	10.00	1.25	7.14	7.54	0.25	0.66	—	—	—	—
		1.50	7.03	7.45	0.18	0.62	—	—	—	—
		2.00	6.87	7.29	0.14	0.57	—	—	—	—
		2.50	6.79	7.16	0.19	0.58	—	—	—	—
3.00		6.75	7.13	0.29	0.67	—	—	—	—	
3.50		6.81	7.20	0.45	0.85	—	-5.61	—	—	
4.00		6.92	7.34	0.64	1.07	—	-5.27	—	—	
4.50		7.06	7.51	0.86	1.32	-5.42	-4.95	—	—	
5.00		7.28	7.67	1.13	1.52	-5.09	-4.70	—	—	
5.50		7.47	7.88	1.37	1.78	-4.83	-4.42	—	—	
6.00	7.68	8.11	1.60	2.03	-4.59	-4.16	—	—		
6.50	7.88	8.34	1.83	2.28	-4.37	-3.91	—	—		
7.00	8.09	8.58	2.05	2.53	-4.17	-3.69	—	—		
7.50	8.30	8.82	2.27	2.78	-4.00	-3.48	—	—		

		8.00	8.56	8.98	2.53	2.95	-3.95	-3.45	—	—
		8.50	8.78	9.22	2.75	3.18	-3.95	-3.45	—	—
		9.00	8.99	9.45	2.95	3.41	-3.95	-3.45	—	—
		9.50	9.20	9.68	3.15	3.63	-3.95	-3.45	—	—
		10.00	9.40	9.91	3.29	3.80	-3.95	-3.45	—	—
		10.50	9.61	10.14	3.29	3.80	-3.95	-3.45	—	—
		11.00	9.81	10.36	3.29	3.80	-3.95	-3.45	—	—
		11.50	10.01	10.59	3.29	3.80	-3.95	-3.45	—	—
		12.00	10.20	10.76	3.29	3.80	-3.95	-3.45	—	—
		12.50	10.20	10.76	3.29	3.80	-3.95	-3.45		
	15.00	1.25	10.74	11.33	2.24	2.76	—	—	—	—
		1.50	10.56	11.20	2.21	2.71	—	—	—	—
		2.00	10.26	10.99	2.25	2.83	—	—	—	—
		2.50	10.07	10.80	2.37	3.02	—	—	—	—
		3.00	9.96	10.68	2.55	3.20	—	—	—	—
		3.50	10.00	10.78	2.83	3.57	—	—	—	—
		4.00	10.18	11.05	3.19	4.00	—	-3.28	—	—
		4.50	10.45	11.37	3.60	4.42	-3.46	-2.66	—	—
		5.00	10.78	11.78	4.02	4.91	-2.96	-2.10	—	—
		5.50	11.18	12.17	4.48	5.45	-2.50	-1.53	—	—
		6.00	11.52	12.65	4.90	5.94	-2.09	-1.07	—	—
		6.50	11.95	13.12	5.37	6.47	-1.69	-0.60	—	—
		7.00	12.40	13.59	5.77	7.00	-1.37	-0.20	—	—
		7.50	12.80	14.09	6.23	7.50	-1.04	0.20	—	—
		8.00	13.21	14.63	6.62	7.97	-1.06	0.50	—	—
		8.50	13.69	15.16	7.06	8.48	-1.06	0.50	—	—
		9.00	14.12	15.66	7.48	9.06	-1.06	0.50	—	—
	9.50	14.53	16.14	7.91	9.46	-1.06	0.50	—	—	
	10.00	15.04	16.66	8.16	9.85	-1.06	0.50	—	—	
	10.50	15.46	17.18	8.16	9.85	-1.06	0.50	—	—	
	11.00	15.89	17.79	8.16	9.85	-1.06	0.50	—	—	
	11.50	16.26	18.29	8.16	9.85	-1.06	0.50	—	—	
	12.00	16.60	18.44	8.16	9.85	-1.06	0.50	—	—	
	12.50	16.60	18.44	8.16	9.85	-1.06	0.50	—	—	
	20.00	1.25	17.84	19.46	6.60	7.97	—	—	—	—
		1.50	17.44	19.26	6.55	8.03	—	—	—	—
		2.00	16.86	19.01	6.77	8.54	—	—	—	—
		2.50	16.48	18.87	7.02	8.94	—	-1.76	—	—
		3.00	16.28	18.67	7.32	9.52	-2.30	-0.34	—	—
		3.50	16.24	18.68	7.78	9.95	-0.98	0.88	—	—
		4.00	16.52	19.06	8.37	10.84	-0.10	2.11	—	—
		4.50	16.97	19.86	9.13	11.88	0.85	3.22	—	—
		5.00	17.58	20.83	9.99	13.06	1.77	4.63	—	—
		5.50	18.37	21.62	10.91	14.04	2.71	5.43	—	—
	6.00	19.18	22.74	11.76	15.18	3.54	6.63	—	—	
	6.50	20.16	23.83	12.69	16.14	4.37	7.53	—	—	
	7.00	21.14	24.97	13.67	17.41	5.18	8.66	—	—	

	7.50	22.06	26.22	14.62	18.67	5.92	9.72	—	—
	8.00	23.11	27.58	15.59	19.86	6.65	10.81	—	—
	8.50	24.13	28.98	16.63	20.99	7.38	11.81	—	—
	9.00	25.11	30.35	17.62	22.46	7.39	12.68	—	—
	9.50	26.26	31.51	18.64	24.01	7.39	12.68	—	—
	10.00	27.37	33.23	19.65	24.93	7.39	12.68	—	—
	10.50	28.30	34.28	20.02	26.01	7.39	12.68	—	—
	11.00	29.44	35.87	20.02	26.01	7.39	12.68	—	—
	11.50	30.41	37.59	20.02	26.01	7.39	12.68	—	—
	12.00	30.41	37.59	20.02	26.01	7.39	12.68	—	—
	12.50	30.41	37.59	20.02	26.01	7.39	12.68	—	—