7.3.2.68 Trailer-Bogie Vertical Load—Empty Intermodal Car

Test Date	December 1986–February 1987
Test Mode	Intermodal Service
Max MPH	65
Average MPH	34.4
Recorded Mileage	3,334
Total Number of Cycles	30,102
Average Cycles/Mile	9.0
Track Class	Various

Table 7.69 Empty ARC-5 Car—intermodal trailer-bogie vertical load (kip)

Maximum Load	Minimum Load	Percent Occurrence
0	-6	0.039864
6	-6	0.026576
6	0	4.248887
12	-6	0.009966
12	0	18.025381
12	6	75.011627
18	-6	0.013288
18	0	0.727526
18	6	1.355392
18	12	0.521560
24	-6	0.003322
24	0	0.016610

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7.3.2.69 Trailer-Bogie Lateral Load—Empty Intermodal Car

Test Date	December 1986–February 1987
Test Mode	Intermodal Service
Max MPH	65
Average MPH	34.4
Recorded Mileage	3,334
Total Number of Cycles	532,213
Average Cycles/Mile	159.6
Track Class	Various

Table 7.70 Empty ARC-5 Car—intermodal trailer-bogie lateral load (kip)

Maximum Load	Minimum Load	Percent Occurrence
10	-4	0.000188
10	-8	0.000188
10	-12	0.000188
10	-28	0.000188
8	6	0.000376
8	0	0.000564
8	-2	0.000752
8	-4	0.001503
8	-6	0.003382
8	-8	0.007140
8	-10	0.001691
8	-26	0.000188
6	4	0.007140
6	2	0.002255
6	0	0.014468
6	-2	0.018414
6	-4	0.163844
6	-6	0.254222
6	-8	0.024802
6	-10	0.001127
4	2	0.037203
4	0	0.114992
4	-2	8.301188
4	-4	4.187609
4	-6	0.288794
4	-8	0.012025
4	-10	0.001503
4	-12	0.000564
4	-14	0.000376
4	-16	0.000188

Maximum Load	Minimum Load	Percent Occurrence
4	-18	0.000564
4	-20	0.000188
2	0	19.410837
2	-2	39.345901
2	-4	1.904876
2	-6	0.093008
2	-8	0.008455
2	-10	0.003194
2	-12	0.001127
2	-14	0.000376
2	-16	0.000939
2	-18	0.000188
2	-20	0.000188
2	-24	0.000188
0	-2	24.589590
0	-4	0.813584
0	-6	0.054489
0	-8	0.010522
0	-10	0.003382
0	-12	0.002255
0	-14	0.000564
-2	-4	0.212509
-2	-6	0.030439
-2	-8	0.005073
-2	-10	0.000752
-4	-6	0.047725
-4	-8	0.010146
-4	-10	0.000752
-6	-8	0.001127

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7.3.2.70 Individual Side-Bearing Load—Loaded 5-Unit Well Car

Test Date	December 2007–May 2008
Test Mode	Unit Train and General Freight Service
Max MPH	65
Average MPH	31
Recorded Mileage	11,123
Total Number of Cycles	229,099
Average Cycles/Mile	20
Track Class	Various

Travel Speed Distribution		
Range (mph)		Percent at Level
0	5	5.0
5	10	7.3
10	15	7.9
15	20	8.6
20	25	10.7
25	30	8.2
30	35	10.9
35	40	10.5
40	45	13.2
45	50	8.0
50	55	6.3
55	60	3.4

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Table 7.71 Loaded 5-unit well car—individual side-bearing load (kip)

Maximum Load	Minimum Load	Percent Occurrence
100	0	0.00044
95	0	0.00044
90	80	0.00044
90	75	0.00044
90	15	0.00044
90	5	0.00044
90	0	0.00044
85	70	0.00044
85	65	0.00044
85	45	0.00044
85	30	0.00044
85	20	0.00044
85	5	0.00044
85	0	0.00087
80	75	0.00044
80	70	0.00087
80	60	0.00044
80	55	0.00044
80	45	0.00044
80	40	0.00044
80	35	0.00044
80	30	0.00044
80	10	0.00044
80	5	0.00044
80	0	0.00131
75	70	0.00044
75	65	0.00087
75	60	0.00044
75	55	0.00044
75	50	0.00044
75	45	0.00044
75	40	0.00044
75	35	0.00087
75	25	0.00044
75	20	0.00044
75	15	0.00044
75	10	0.00044
75	5	0.00044
75	0	0.00262
70	65	0.00175
70	60	0.00480
70	55	0.00524
70	50	0.00349
70	45	0.00306
70	40	0.00393
70	35	0.00349
70	30	0.00436
70	25	0.00393
70	20	0.00393
70	15	0.00436
70	10	0.00655
70	5	0.00611
70	0	0.02139
65	60	0.00436
65	55	0.00829
65	50	0.00655
65	45	0.00567
65	40	0.00698
65	35	0.00480
65	30	0.00611
65	25	0.00567
65	20	0.00524
65	15	0.00829
65	10	0.00655
65	5	0.00742
65	0	0.03143
60	55	0.00742
60	50	0.01179
60	45	0.01266
60	40	0.00960
60	35	0.00960
60	30	0.00786
60	25	0.00873
60	20	0.00873
60	15	0.01091
60	10	0.01135
60	5	0.01222
60	0	0.04190
55	50	0.01615
55	45	0.02706
55	40	0.02401
55	35	0.02139
55	30	0.01790
55	25	0.01833
55	20	0.02008
55	15	0.02488
55	10	0.02881
55	5	0.03055
55	0	0.09079
50	45	0.03710
50	40	0.06678
50	35	0.05238
50	30	0.04278
50	25	0.03885
50	20	0.04278
50	15	0.04321
50	10	0.04801
50	5	0.05413
50	0	0.13837
45	40	0.07682
45	35	0.17067
45	30	0.11087
45	25	0.09297
45	20	0.08861
45	15	0.08424
45	10	0.08730
45	5	0.09908
45	0	0.21126
40	35	0.20166
40	30	0.34876
40	25	0.25709
40	20	0.21956
40	15	0.17940
40	10	0.16805
40	5	0.16499
40	0	0.31820
35	30	0.50546
35	25	0.87997
35	20	0.61153
35	15	0.44173
35	10	0.35269
35	5	0.30205
35	0	0.50415
30	25	1.37539
30	20	2.18159
30	15	1.32432
30	10	0.86687
30	5	0.59581
30	0	0.72982
25	20	3.32520
25	15	4.87649
25	10	2.45309
25	5	1.33130
25	0	1.15801
20	15	7.37454
20	10	8.90750
20	5	3.25885
20	0	1.90398
15	10	11.67879
15	5	10.21174
15	0	3.40595
10	5	11.13798
10	0	7.40684
5	0	6.77611

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7.3.2.71 Center-Plate Load—Loaded 5-unit Well Car

Test Date	December 2007–May 2008
Test Mode	Unit Train and General Freight Service
Max MPH	65
Average MPH	31
Recorded Mileage	8,891
Total Number of Cycles	43,923,924
Average Cycles/Mile	4,940
Track Class	Various

Travel Speed Distribution		
Range (mph)		Percent at Level
0	5	5.0
5	10	7.3
10	15	7.9
15	20	8.6
20	25	10.7
25	30	8.2
30	35	10.9
35	40	10.5
40	45	13.2
45	50	8.0
50	55	6.3
55	60	3.4

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 1 of 11)

Maximum Load	Minimum Load	Percent Occurrence
380	25	0.0000023
375	370	0.0000023
375	80	0.0000023
365	200	0.0000023
365	30	0.0000023
365	20	0.0000023
360	350	0.0000023
360	340	0.0000023
360	110	0.0000023
355	350	0.0000023
355	185	0.0000023
355	55	0.0000023
350	340	0.0000023
350	290	0.0000023
350	215	0.0000023
350	30	0.0000023
345	200	0.0000023
340	330	0.0000023
340	260	0.0000023
340	220	0.0000023
340	180	0.0000023
340	35	0.0000023
340	30	0.0000046
335	295	0.0000023
335	180	0.0000023
335	90	0.0000023
335	70	0.0000023
335	25	0.0000023
330	325	0.0000478
330	320	0.0000569
330	315	0.0000182
330	310	0.0000114
330	300	0.0000023
330	285	0.0000023
330	275	0.0000023
330	190	0.0000023
330	175	0.0000023
330	150	0.0000023
330	105	0.0000023
330	95	0.0000023
330	35	0.0000023
325	320	0.0000433
325	315	0.0000478
325	310	0.0000159
325	305	0.0000068
325	300	0.0000068
325	295	0.0000023
325	275	0.0000023
325	265	0.0000023
325	250	0.0000023
325	210	0.0000023
325	140	0.0000023
325	70	0.0000023
325	60	0.0000023
325	25	0.0000023
325	20	0.0000023
320	315	0.0000319
320	310	0.0000410
320	305	0.0000341
320	300	0.0000091
320	295	0.0000023
320	290	0.0000023
320	280	0.0000023
320	275	0.0000023
320	260	0.0000023
320	250	0.0000023
320	240	0.0000023
320	185	0.0000023
320	175	0.0000023
320	150	0.0000023
320	145	0.0000023
320	100	0.0000023
320	95	0.0000023
320	70	0.0000068
320	45	0.0000023
320	25	0.0000023
315	310	0.0000455
315	305	0.0000615
315	300	0.0000159
315	295	0.0000046
315	290	0.0000068
315	275	0.0000023
315	250	0.0000046
315	240	0.0000023
315	205	0.0000023
315	190	0.0000023
315	145	0.0000023
315	120	0.0000046
315	100	0.0000023
315	85	0.0000023
315	35	0.0000046
315	30	0.0000023
315	25	0.0000023
310	305	0.0000319
310	300	0.0000296
310	295	0.0000137
310	290	0.0000046
310	285	0.0000091
310	280	0.0000023
310	250	0.0000023
310	180	0.0000023
310	105	0.0000023
310	70	0.0000023
310	55	0.0000023
310	50	0.0000023
310	40	0.0000046
310	35	0.0000046
310	25	0.0000023
305	300	0.0000410
305	295	0.0000364
305	290	0.0000250
305	285	0.0000137
305	280	0.0000023
305	275	0.0000023
305	260	0.0000023
305	255	0.0000023
305	245	0.0000023
305	210	0.0000023
305	160	0.0000023
305	125	0.0000023
305	85	0.0000023
305	75	0.0000023
305	70	0.0000023
305	50	0.0000023
305	20	0.0000023
300	295	0.0000433
300	290	0.0000592
300	285	0.0000250
300	280	0.0000068
300	275	0.0000023
300	260	0.0000068
300	210	0.0000023
300	190	0.0000023
300	165	0.0000023
300	155	0.0000023
300	145	0.0000023
300	135	0.0000023
300	85	0.0000023
300	75	0.0000023
300	65	0.0000046
300	60	0.0000023
300	50	0.0000023
300	40	0.0000023
295	290	0.0000455
295	285	0.0000637
295	280	0.0000046
295	270	0.0000023
295	265	0.0000046
295	255	0.0000023
295	230	0.0000023

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 2 of 11)

Maximum Load	Minimum Load	Percent Occurrence
295	200	0.0000023
295	195	0.0000023
295	175	0.0000023
295	160	0.0000023
295	130	0.0000023
295	125	0.0000023
295	120	0.0000023
295	85	0.0000046
295	80	0.0000023
295	75	0.0000023
295	65	0.0000046
295	55	0.0000046
295	45	0.0000046
295	40	0.0000068
295	35	0.0000023
295	30	0.0000023
295	25	0.0000046
290	285	0.0000979
290	280	0.0000706
290	275	0.0000250
290	270	0.0000091
290	265	0.0000091
290	230	0.0000023
290	225	0.0000023
290	195	0.0000023
290	190	0.0000023
290	165	0.0000023
290	155	0.0000023
290	145	0.0000023
290	115	0.0000068
290	110	0.0000023
290	105	0.0000023
290	100	0.0000023
290	95	0.0000023
290	90	0.0000023
290	85	0.0000023
290	80	0.0000023
290	75	0.0000046
290	55	0.0000023
290	40	0.0000023
290	35	0.0000046
290	20	0.0000023
285	280	0.0000751
285	275	0.0000683
285	270	0.0000159
285	265	0.0000023
285	260	0.0000068
285	255	0.0000023
285	230	0.0000046
285	220	0.0000046
285	200	0.0000023
285	180	0.0000023
285	165	0.0000023
285	160	0.0000046
285	120	0.0000023
285	110	0.0000023
285	105	0.0000023
285	100	0.0000046
285	95	0.0000046
285	90	0.0000046
285	85	0.0000068
285	80	0.0000046
285	75	0.0000046
285	70	0.0000046
285	65	0.0000023
285	60	0.0000046
285	55	0.0000023
285	50	0.0000046
285	45	0.0000068
285	40	0.0000068
285	35	0.0000091
285	30	0.0000091
285	25	0.0000068
285	20	0.0000091
280	275	0.0000888
280	270	0.0000660
280	265	0.0000273
280	260	0.0000091
280	255	0.0000091
280	225	0.0000023
280	220	0.0000023
280	180	0.0000023
280	155	0.0000023
280	145	0.0000023
280	115	0.0000046
280	110	0.0000046
280	105	0.0000091
280	100	0.0000046
280	95	0.0000046
280	90	0.0000091
280	85	0.0000023
280	80	0.0000046
280	75	0.0000023
280	70	0.0000046
280	65	0.0000046
280	60	0.0000046
280	55	0.0000091
280	50	0.0000023
280	45	0.0000114
280	40	0.0000114
280	35	0.0000091
280	30	0.0000068
280	25	0.0000046
280	20	0.0000137
275	270	0.0001320
275	265	0.0001161
275	260	0.0000205
275	255	0.0000091
275	250	0.0000046
275	245	0.0000023
275	240	0.0000023
275	230	0.0000023
275	220	0.0000023
275	215	0.0000023
275	180	0.0000023
275	175	0.0000023
275	160	0.0000023
275	140	0.0000023
275	130	0.0000023
275	115	0.0000046
275	110	0.0000023
275	105	0.0000091
275	100	0.0000068
275	95	0.0000023
275	90	0.0000046
275	85	0.0000046
275	80	0.0000046
275	75	0.0000091
275	70	0.0000068
275	65	0.0000091
275	60	0.0000068
275	55	0.0000023
275	50	0.0000137
275	45	0.0000068
275	40	0.0000046
275	35	0.0000137
275	30	0.0000091
275	25	0.0000091
275	20	0.0000091
270	265	0.0001184
270	260	0.0001207
270	255	0.0000250
270	250	0.0000182
270	245	0.0000046
270	240	0.0000068
270	235	0.0000023
270	230	0.0000023
270	210	0.0000023
270	200	0.0000023
270	175	0.0000068

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 3 of 11)

Maximum Load	Minimum Load	Percent Occurrence
270	170	0.0000091
270	165	0.0000023
270	160	0.0000023
270	145	0.0000046
270	135	0.0000046
270	130	0.0000046
270	125	0.0000046
270	120	0.0000046
270	110	0.0000068
270	105	0.0000091
270	100	0.0000159
270	95	0.0000159
270	90	0.0000228
270	85	0.0000046
270	80	0.0000091
270	75	0.0000114
270	70	0.0000091
270	65	0.0000091
270	60	0.0000068
270	55	0.0000023
270	50	0.0000114
270	45	0.0000046
270	40	0.0000068
270	35	0.0000159
270	30	0.0000159
270	25	0.0000068
270	20	0.0000137
265	260	0.0001480
265	255	0.0001480
265	250	0.0000433
265	245	0.0000091
265	240	0.0000046
265	235	0.0000046
265	215	0.0000023
265	185	0.0000023
265	180	0.0000023
265	175	0.0000023
265	170	0.0000023
265	155	0.0000023
265	145	0.0000023
265	140	0.0000114
265	135	0.0000091
265	130	0.0000137
265	125	0.0000137
265	120	0.0000137
265	115	0.0000137
265	110	0.0000046
265	105	0.0000250
265	100	0.0000068
265	95	0.0000159
265	90	0.0000137
265	85	0.0000091
265	80	0.0000068
265	75	0.0000182
265	70	0.0000046
265	65	0.0000159
265	60	0.0000046
265	55	0.0000159
265	50	0.0000068
265	45	0.0000205
265	40	0.0000159
265	35	0.0000205
265	30	0.0000182
265	25	0.0000159
265	20	0.0000182
260	255	0.0001890
260	250	0.0001776
260	245	0.0000637
260	240	0.0000182
260	235	0.0000091
260	225	0.0000023
260	220	0.0000023
260	200	0.0000023
260	195	0.0000023
260	175	0.0000023
260	165	0.0000046
260	160	0.0000023
260	155	0.0000046
260	150	0.0000046
260	145	0.0000046
260	140	0.0000114
260	135	0.0000068
260	130	0.0000091
260	125	0.0000114
260	120	0.0000228
260	115	0.0000205
260	110	0.0000068
260	105	0.0000273
260	100	0.0000228
260	95	0.0000319
260	90	0.0000228
260	85	0.0000091
260	80	0.0000159
260	75	0.0000205
260	70	0.0000250
260	65	0.0000159
260	60	0.0000228
260	55	0.0000068
260	50	0.0000228
260	45	0.0000319
260	40	0.0000228
260	35	0.0000228
260	30	0.0000114
260	25	0.0000182
260	20	0.0000182
255	250	0.0002937
255	245	0.0001799
255	240	0.0000660
255	235	0.0000319
255	230	0.0000091
255	225	0.0000114
255	220	0.0000046
255	210	0.0000023
255	200	0.0000046
255	185	0.0000023
255	175	0.0000068
255	170	0.0000046
255	165	0.0000068
255	160	0.0000091
255	155	0.0000068
255	150	0.0000182
255	145	0.0000296
255	140	0.0000159
255	135	0.0000159
255	130	0.0000273
255	125	0.0000182
255	120	0.0000364
255	115	0.0000410
255	110	0.0000273
255	105	0.0000319
255	100	0.0000228
255	95	0.0000250
255	90	0.0000319
255	85	0.0000319
255	80	0.0000273
255	75	0.0000205
255	70	0.0000228
255	65	0.0000296
255	60	0.0000273
255	55	0.0000159
255	50	0.0000250
255	45	0.0000205
255	40	0.0000137
255	35	0.0000182
255	30	0.0000319
255	25	0.0000319
255	20	0.0000182
250	245	0.0003688
250	240	0.0002982
250	235	0.0000842

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 4 of 11)

Maximum Load	Minimum Load	Percent Occurrence
250	230	0.0000410
250	225	0.0000228
250	220	0.0000023
250	215	0.0000046
250	185	0.0000046
250	180	0.0000114
250	175	0.0000137
250	170	0.0000068
250	165	0.0000046
250	160	0.0000159
250	155	0.0000296
250	150	0.0000433
250	145	0.0000455
250	140	0.0000319
250	135	0.0000319
250	130	0.0000250
250	125	0.0000410
250	120	0.0000364
250	115	0.0000410
250	110	0.0000387
250	105	0.0000455
250	100	0.0000387
250	95	0.0000364
250	90	0.0000387
250	85	0.0000364
250	80	0.0000387
250	75	0.0000410
250	70	0.0000273
250	65	0.0000387
250	60	0.0000341
250	55	0.0000137
250	50	0.0000319
250	45	0.0000387
250	40	0.0000114
250	35	0.0000159
250	30	0.0000433
250	25	0.0000228
250	20	0.0000159
245	240	0.0005282
245	235	0.0004371
245	230	0.0001389
245	225	0.0000387
245	220	0.0000091
245	215	0.0000137
245	210	0.0000023
245	205	0.0000023
245	185	0.0000046
245	180	0.0000364
245	175	0.0000296
245	170	0.0000296
245	165	0.0000455
245	160	0.0000455
245	155	0.0000524
245	150	0.0000524
245	145	0.0000524
245	140	0.0000524
245	135	0.0000501
245	130	0.0000774
245	125	0.0000911
245	120	0.0000615
245	115	0.0000615
245	110	0.0000524
245	105	0.0000524
245	100	0.0000729
245	95	0.0000569
245	90	0.0000478
245	85	0.0000455
245	80	0.0000820
245	75	0.0000524
245	70	0.0000524
245	65	0.0000364
245	60	0.0000569
245	55	0.0000364
245	50	0.0000501
245	45	0.0000455
245	40	0.0000501
245	35	0.0000410
245	30	0.0000319
245	25	0.0000387
245	20	0.0000228
240	235	0.0009061
240	230	0.0007741
240	225	0.0001981
240	220	0.0001047
240	215	0.0000159
240	210	0.0000182
240	205	0.0000114
240	200	0.0000046
240	195	0.0000137
240	190	0.0000137
240	185	0.0000524
240	180	0.0000660
240	175	0.0000797
240	170	0.0000615
240	165	0.0001002
240	160	0.0000911
240	155	0.0001207
240	150	0.0000751
240	145	0.0001070
240	140	0.0001138
240	135	0.0001275
240	130	0.0001138
240	125	0.0001275
240	120	0.0000933
240	115	0.0001343
240	110	0.0000865
240	105	0.0000911
240	100	0.0000751
240	95	0.0001366
240	90	0.0000751
240	85	0.0000911
240	80	0.0000706
240	75	0.0000842
240	70	0.0000637
240	65	0.0000592
240	60	0.0000683
240	55	0.0000546
240	50	0.0000751
240	45	0.0000478
240	40	0.0000592
240	35	0.0000273
240	30	0.0000341
240	25	0.0000341
240	20	0.0000228
235	230	0.0015982
235	225	0.0016255
235	220	0.0004439
235	215	0.0001298
235	210	0.0000865
235	205	0.0000319
235	200	0.0000637
235	195	0.0000683
235	190	0.0001138
235	185	0.0001389
235	180	0.0001480
235	175	0.0001207
235	170	0.0001685
235	165	0.0001662
235	160	0.0001821
235	155	0.0001776
235	150	0.0001821
235	145	0.0001298
235	140	0.0001594
235	135	0.0002140
235	130	0.0001753
235	125	0.0002072
235	120	0.0001503
235	115	0.0001434
235	110	0.0001298
235	105	0.0001525

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 5 of 11)

Maximum Load	Minimum Load	Percent Occurrence
235	100	0.0001457
235	95	0.0001594
235	90	0.0001184
235	85	0.0001298
235	80	0.0001138
235	75	0.0001207
235	70	0.0001024
235	65	0.0000979
235	60	0.0001002
235	55	0.0000524
235	50	0.0000637
235	45	0.0000888
235	40	0.0000637
235	35	0.0000364
235	30	0.0000273
235	25	0.0000182
235	20	0.0000296
230	225	0.0032898
230	220	0.0037702
230	215	0.0010996
230	210	0.0005031
230	205	0.0003734
230	200	0.0002732
230	195	0.0002573
230	190	0.0002254
230	185	0.0002550
230	180	0.0002254
230	175	0.0002072
230	170	0.0002937
230	165	0.0002573
230	160	0.0002641
230	155	0.0002527
230	150	0.0002686
230	145	0.0003256
230	140	0.0003051
230	135	0.0003369
230	130	0.0003073
230	125	0.0002686
230	120	0.0002163
230	115	0.0002095
230	110	0.0002231
230	105	0.0002368
230	100	0.0002778
230	95	0.0002390
230	90	0.0002095
230	85	0.0001890
230	80	0.0002049
230	75	0.0001958
230	70	0.0001707
230	65	0.0001275
230	60	0.0001298
230	55	0.0001207
230	50	0.0000956
230	45	0.0000774
230	40	0.0000797
230	35	0.0000524
230	30	0.0000501
230	25	0.0000341
230	20	0.0000273
225	220	0.0078317
225	215	0.0120231
225	210	0.0057554
225	205	0.0024929
225	200	0.0010495
225	195	0.0008014
225	190	0.0005783
225	185	0.0005031
225	180	0.0004394
225	175	0.0004622
225	170	0.0003870
225	165	0.0004075
225	160	0.0004599
225	155	0.0005122
225	150	0.0004508
225	145	0.0004940
225	140	0.0005692
225	135	0.0004895
225	130	0.0004326
225	125	0.0003483
225	120	0.0003347
225	115	0.0004052
225	110	0.0004121
225	105	0.0004576
225	100	0.0004121
225	95	0.0003051
225	90	0.0002322
225	85	0.0002891
225	80	0.0002504
225	75	0.0001958
225	70	0.0002163
225	65	0.0001844
225	60	0.0001525
225	55	0.0001412
225	50	0.0001002
225	45	0.0000820
225	40	0.0000569
225	35	0.0000615
225	30	0.0000433
225	25	0.0000296
225	20	0.0000205
220	215	0.0351631
220	210	0.0433636
220	205	0.0088130
220	200	0.0037519
220	195	0.0022084
220	190	0.0011292
220	185	0.0008378
220	180	0.0006898
220	175	0.0007103
220	170	0.0007058
220	165	0.0007786
220	160	0.0008037
220	155	0.0007877
220	150	0.0008242
220	145	0.0009198
220	140	0.0007832
220	135	0.0007263
220	130	0.0006124
220	125	0.0005646
220	120	0.0006534
220	115	0.0006807
220	110	0.0006716
220	105	0.0006466
220	100	0.0005350
220	95	0.0004371
220	90	0.0004485
220	85	0.0003961
220	80	0.0004030
220	75	0.0003165
220	70	0.0003324
220	65	0.0002595
220	60	0.0001616
220	55	0.0001343
220	50	0.0001320
220	45	0.0000979
220	40	0.0000478
220	35	0.0000729
220	30	0.0000524
220	25	0.0000501
220	20	0.0000296
215	210	0.0491236
215	205	0.0420136
215	200	0.0119821
215	195	0.0059398
215	190	0.0026614
215	185	0.0016620
215	180	0.0013023
215	175	0.0012704
215	170	0.0012818
215	165	0.0013842

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 6 of 11)

Maximum Load	Minimum Load	Percent Occurrence
215	160	0.0013888
215	155	0.0015550
215	150	0.0014639
215	145	0.0013523
215	140	0.0011793
215	135	0.0010359
215	130	0.0009949
215	125	0.0010837
215	120	0.0011019
215	115	0.0010974
215	110	0.0011588
215	105	0.0009357
215	100	0.0007581
215	95	0.0007103
215	90	0.0006534
215	85	0.0005760
215	80	0.0005054
215	75	0.0004098
215	70	0.0003825
215	65	0.0003005
215	60	0.0002368
215	55	0.0001912
215	50	0.0001662
215	45	0.0001298
215	40	0.0000956
215	35	0.0000797
215	30	0.0000501
215	25	0.0000546
215	20	0.0000455
210	205	0.0647802
210	200	0.0943859
210	195	0.0264685
210	190	0.0085489
210	185	0.0041504
210	180	0.0028891
210	175	0.0022448
210	170	0.0020376
210	165	0.0022197
210	160	0.0024064
210	155	0.0025840
210	150	0.0022197
210	145	0.0019374
210	140	0.0017325
210	135	0.0016210
210	130	0.0015709
210	125	0.0016028
210	120	0.0018737
210	115	0.0016278
210	110	0.0015982
210	105	0.0014070
210	100	0.0011474
210	95	0.0011429
210	90	0.0010291
210	85	0.0008925
210	80	0.0007968
210	75	0.0006238
210	70	0.0005009
210	65	0.0003802
210	60	0.0002960
210	55	0.0002573
210	50	0.0001707
210	45	0.0001343
210	40	0.0001047
210	35	0.0001184
210	30	0.0000683
210	25	0.0000319
210	20	0.0000364
205	200	0.1388514
205	195	0.1240326
205	190	0.0307759
205	185	0.0120823
205	180	0.0065113
205	175	0.0042983
205	170	0.0037246
205	165	0.0037747
205	160	0.0037383
205	155	0.0038134
205	150	0.0031942
205	145	0.0029164
205	140	0.0026500
205	135	0.0024588
205	130	0.0027479
205	125	0.0027434
205	120	0.0026774
205	115	0.0025043
205	110	0.0022311
205	105	0.0019511
205	100	0.0020035
205	95	0.0016870
205	90	0.0015527
205	85	0.0015208
205	80	0.0010632
205	75	0.0008788
205	70	0.0005601
205	65	0.0005122
205	60	0.0003688
205	55	0.0002982
205	50	0.0002026
205	45	0.0001366
205	40	0.0001229
205	35	0.0000842
205	30	0.0000820
205	25	0.0000478
205	20	0.0000524
200	195	0.1542508
200	190	0.1699347
200	185	0.0352359
200	180	0.0168678
200	175	0.0099012
200	170	0.0072170
200	165	0.0067184
200	160	0.0057668
200	155	0.0049586
200	150	0.0048675
200	145	0.0045010
200	140	0.0038999
200	135	0.0040115
200	130	0.0043553
200	125	0.0041891
200	120	0.0041481
200	115	0.0038817
200	110	0.0034947
200	105	0.0032420
200	100	0.0031304
200	95	0.0028868
200	90	0.0026318
200	85	0.0020558
200	80	0.0014457
200	75	0.0011361
200	70	0.0008697
200	65	0.0006716
200	60	0.0004849
200	55	0.0004007
200	50	0.0002664
200	45	0.0001389
200	40	0.0001207
200	35	0.0000637
200	30	0.0000569
200	25	0.0000410
200	20	0.0000410
195	190	0.1517988
195	185	0.1786976
195	180	0.0614426
195	175	0.0259631
195	170	0.0157158
195	165	0.0116474
195	160	0.0090429
195	155	0.0078659
195	150	0.0071829
195	145	0.0066251

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 7 of 11)

Maximum Load	Minimum Load	Percent Occurrence
195	140	0.0067162
195	135	0.0070873
195	130	0.0067184
195	125	0.0063747
195	120	0.0060514
195	115	0.0055300
195	110	0.0053547
195	105	0.0052568
195	100	0.0050337
195	95	0.0041367
195	90	0.0036859
195	85	0.0028003
195	80	0.0021241
195	75	0.0014980
195	70	0.0010882
195	65	0.0008219
195	60	0.0005783
195	55	0.0004257
195	50	0.0002686
195	45	0.0002049
195	40	0.0001548
195	35	0.0001093
195	30	0.0000615
195	25	0.0000546
195	20	0.0000296
190	185	0.2679132
190	180	0.2901927
190	175	0.0819599
190	170	0.0406635
190	165	0.0226574
190	160	0.0165149
190	155	0.0140425
190	150	0.0123714
190	145	0.0115563
190	140	0.0111329
190	135	0.0107982
190	130	0.0103770
190	125	0.0093525
190	120	0.0090702
190	115	0.0084191
190	110	0.0082324
190	105	0.0079456
190	100	0.0071533
190	95	0.0062426
190	90	0.0048948
190	85	0.0037610
190	80	0.0028481
190	75	0.0020057
190	70	0.0014639
190	65	0.0010291
190	60	0.0007672
190	55	0.0005236
190	50	0.0002869
190	45	0.0002322
190	40	0.0001571
190	35	0.0001184
190	30	0.0000660
190	25	0.0000797
190	20	0.0000410
185	180	0.3423351
185	175	0.4313276
185	170	0.1396210
185	165	0.0566912
185	160	0.0353998
185	155	0.0269511
185	150	0.0219448
185	145	0.0198138
185	140	0.0184319
185	135	0.0167631
185	130	0.0152969
185	125	0.0141608
185	120	0.0135985
185	115	0.0130589
185	110	0.0125080
185	105	0.0119047
185	100	0.0106639
185	95	0.0089632
185	90	0.0065249
185	85	0.0049813
185	80	0.0037360
185	75	0.0027957
185	70	0.0018350
185	65	0.0013045
185	60	0.0008173
185	55	0.0005601
185	50	0.0004121
185	45	0.0002778
185	40	0.0001821
185	35	0.0000933
185	30	0.0000820
185	25	0.0000706
185	20	0.0000592
180	175	0.5438357
180	170	0.5962582
180	165	0.1991489
180	160	0.0906226
180	155	0.0568551
180	150	0.0413715
180	145	0.0339291
180	140	0.0275158
180	135	0.0242328
180	130	0.0227234
180	125	0.0215395
180	120	0.0203875
180	115	0.0200824
180	110	0.0188576
180	105	0.0170636
180	100	0.0147619
180	95	0.0112809
180	90	0.0085557
180	85	0.0068345
180	80	0.0049335
180	75	0.0035584
180	70	0.0024679
180	65	0.0016346
180	60	0.0010017
180	55	0.0006420
180	50	0.0004599
180	45	0.0003210
180	40	0.0002322
180	35	0.0001389
180	30	0.0001366
180	25	0.0000729
180	20	0.0000615
175	170	0.7726518
175	165	0.8980436
175	160	0.3104868
175	155	0.1330892
175	150	0.0809627
175	145	0.0590954
175	140	0.0448708
175	135	0.0387898
175	130	0.0349172
175	125	0.0323195
175	120	0.0311061
175	115	0.0293803
175	110	0.0267599
175	105	0.0233221
175	100	0.0185298
175	95	0.0143680
175	90	0.0115040
175	85	0.0087834
175	80	0.0063883
175	75	0.0045624
175	70	0.0028618
175	65	0.0019875
175	60	0.0012135
175	55	0.0007968
175	50	0.0005168
175	45	0.0003574

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 8 of 11)

Maximum Load	Minimum Load	Percent Occurrence
175	40	0.0002436
175	35	0.0001594
175	30	0.0001070
175	25	0.0000706
175	20	0.0000660
170	165	1.1631087
170	160	1.2059373
170	155	0.3932458
170	150	0.1791916
170	145	0.1115702
170	140	0.0805028
170	135	0.0640107
170	130	0.0550862
170	125	0.0494241
170	120	0.0452965
170	115	0.0415400
170	110	0.0370550
170	105	0.0296558
170	100	0.0231468
170	95	0.0184114
170	90	0.0143862
170	85	0.0109735
170	80	0.0076792
170	75	0.0053183
170	70	0.0037929
170	65	0.0023655
170	60	0.0014593
170	55	0.0010291
170	50	0.0006534
170	45	0.0004166
170	40	0.0002504
170	35	0.0002231
170	30	0.0001480
170	25	0.0001116
170	20	0.0000865
165	160	1.4122987
165	155	1.5625562
165	150	0.5398812
165	145	0.2511684
165	140	0.1561177
165	135	0.1144274
165	130	0.0889925
165	125	0.0737343
165	120	0.0631433
165	115	0.0551590
165	110	0.0453739
165	105	0.0358984
165	100	0.0287543
165	95	0.0229260
165	90	0.0173846
165	85	0.0125672
165	80	0.0092250
165	75	0.0062381
165	70	0.0043416
165	65	0.0026250
165	60	0.0017075
165	55	0.0011702
165	50	0.0006989
165	45	0.0005623
165	40	0.0003825
165	35	0.0002550
165	30	0.0001457
165	25	0.0001138
165	20	0.0000637
160	155	1.9204295
160	150	2.1776242
160	145	0.6929344
160	140	0.3251804
160	135	0.2041074
160	130	0.1452511
160	125	0.1086583
160	120	0.0851540
160	115	0.0691719
160	110	0.0555711
160	105	0.0446272
160	100	0.0353270
160	95	0.0269739
160	90	0.0201007
160	85	0.0148325
160	80	0.0101995
160	75	0.0070850
160	70	0.0047241
160	65	0.0033353
160	60	0.0021560
160	55	0.0013888
160	50	0.0008674
160	45	0.0006511
160	40	0.0004781
160	35	0.0002436
160	30	0.0001776
160	25	0.0001070
160	20	0.0000888
155	150	2.3470854
155	145	2.6027206
155	140	0.8678960
155	135	0.3948053
155	130	0.2372079
155	125	0.1614997
155	120	0.1153927
155	115	0.0871575
155	110	0.0683045
155	105	0.0531669
155	100	0.0411484
155	95	0.0304435
155	90	0.0225276
155	85	0.0162759
155	80	0.0113833
155	75	0.0079160
155	70	0.0056302
155	65	0.0036609
155	60	0.0024702
155	55	0.0015459
155	50	0.0011383
155	45	0.0007627
155	40	0.0005168
155	35	0.0002368
155	30	0.0002140
155	25	0.0001207
155	20	0.0000751
150	145	2.8754330
150	140	2.9631278
150	135	0.9692554
150	130	0.4379049
150	125	0.2516647
150	120	0.1647121
150	115	0.1144615
150	110	0.0835422
150	105	0.0602269
150	100	0.0445361
150	95	0.0329433
150	90	0.0247496
150	85	0.0178627
150	80	0.0127357
150	75	0.0089473
150	70	0.0062312
150	65	0.0042779
150	60	0.0028663
150	55	0.0018987
150	50	0.0013819
150	45	0.0008674
150	40	0.0006420
150	35	0.0002960
150	30	0.0002072
150	25	0.0001207
150	20	0.0000933
145	140	3.1104416
145	135	3.2867191
145	130	1.0437592
145	125	0.4477879
145	120	0.2470499

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 9 of 11)

Maximum Load	Minimum Load	Percent Occurrence
145	115	0.1557579
145	110	0.1008926
145	105	0.0671730
145	100	0.0479898
145	95	0.0358711
145	90	0.0266711
145	85	0.0189760
145	80	0.0138102
145	75	0.0099035
145	70	0.0068687
145	65	0.0049039
145	60	0.0032192
145	55	0.0022653
145	50	0.0015641
145	45	0.0010860
145	40	0.0006193
145	35	0.0003597
145	30	0.0002163
145	25	0.0001548
145	20	0.0000637
140	135	3.3832997
140	130	3.2821954
140	125	1.0272352
140	120	0.4194889
140	115	0.2223003
140	110	0.1304027
140	105	0.0806622
140	100	0.0531328
140	95	0.0389059
140	90	0.0282284
140	85	0.0200916
140	80	0.0147255
140	75	0.0104135
140	70	0.0071829
140	65	0.0053274
140	60	0.0037223
140	55	0.0027001
140	50	0.0018987
140	45	0.0011657
140	40	0.0006580
140	35	0.0003893
140	30	0.0002732
140	25	0.0001343
140	20	0.0000956
135	130	3.3316513
135	125	3.1083243
135	120	0.9166941
135	115	0.3609901
135	110	0.1854798
135	105	0.1058535
135	100	0.0639925
135	95	0.0424894
135	90	0.0294168
135	85	0.0220108
135	80	0.0156976
135	75	0.0112376
135	70	0.0080753
135	65	0.0060263
135	60	0.0042255
135	55	0.0029278
135	50	0.0018623
135	45	0.0011452
135	40	0.0007650
135	35	0.0004417
135	30	0.0002390
135	25	0.0001844
135	20	0.0001002
130	125	2.9177789
130	120	2.5564770
130	115	0.7383106
130	110	0.2983067
130	105	0.1493491
130	100	0.0855934
130	95	0.0503325
130	90	0.0335125
130	85	0.0231013
130	80	0.0162827
130	75	0.0121232
130	70	0.0088084
130	65	0.0065067
130	60	0.0044805
130	55	0.0030917
130	50	0.0020467
130	45	0.0014616
130	40	0.0008537
130	35	0.0004872
130	30	0.0003461
130	25	0.0002186
130	20	0.0001207
125	120	2.3186020
125	115	2.1016497
125	110	0.6164886
125	105	0.2460459
125	100	0.1219199
125	95	0.0671502
125	90	0.0400397
125	85	0.0255077
125	80	0.0180972
125	75	0.0132365
125	70	0.0094231
125	65	0.0065500
125	60	0.0045738
125	55	0.0031805
125	50	0.0021924
125	45	0.0013614
125	40	0.0008059
125	35	0.0004827
125	30	0.0003961
125	25	0.0002527
125	20	0.0001389
120	115	1.9544975
120	110	1.8496571
120	105	0.5524119
120	100	0.2036157
120	95	0.0987799
120	90	0.0531965
120	85	0.0308602
120	80	0.0200620
120	75	0.0134756
120	70	0.0096940
120	65	0.0068300
120	60	0.0048470
120	55	0.0032169
120	50	0.0021537
120	45	0.0014548
120	40	0.0009289
120	35	0.0005646
120	30	0.0003233
120	25	0.0002277
120	20	0.0001412
115	110	1.8363728
115	105	1.5693589
115	100	0.4101387
115	95	0.1579868
115	90	0.0753348
115	85	0.0410482
115	80	0.0228691
115	75	0.0143612
115	70	0.0095779
115	65	0.0068937
115	60	0.0047150
115	55	0.0033968
115	50	0.0021264
115	45	0.0015254
115	40	0.0009061
115	35	0.0006352
115	30	0.0004303
115	25	0.0002823
115	20	0.0001639
110	105	1.3249044

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 10 of 11)

Maximum Load	Minimum Load	Percent Occurrence
110	100	1.2184886
110	95	0.3484684
110	90	0.1287909
110	85	0.0571807
110	80	0.0291618
110	75	0.0168428
110	70	0.0108893
110	65	0.0071920
110	60	0.0050747
110	55	0.0033330
110	50	0.0022539
110	45	0.0015846
110	40	0.0010518
110	35	0.0007171
110	30	0.0004781
110	25	0.0002664
110	20	0.0001821
105	100	1.1549128
105	95	1.0883431
105	90	0.2706065
105	85	0.0947912
105	80	0.0440375
105	75	0.0230102
105	70	0.0127903
105	65	0.0079683
105	60	0.0050815
105	55	0.0034924
105	50	0.0024634
105	45	0.0015367
105	40	0.0011201
105	35	0.0006557
105	30	0.0004667
105	25	0.0002914
105	20	0.0002049
100	95	0.9396770
100	90	0.8281432
100	85	0.2100382
100	80	0.0746222
100	75	0.0342774
100	70	0.0167312
100	65	0.0090748
100	60	0.0053661
100	55	0.0034856
100	50	0.0024861
100	45	0.0017166
100	40	0.0010928
100	35	0.0006853
100	30	0.0005168
100	25	0.0003392
100	20	0.0002550
95	90	0.7651275
95	85	0.6944780
95	80	0.1679609
95	75	0.0555779
95	70	0.0239004
95	65	0.0113150
95	60	0.0062699
95	55	0.0039637
95	50	0.0026318
95	45	0.0017416
95	40	0.0011725
95	35	0.0008446
95	30	0.0005897
95	25	0.0004121
95	20	0.0003278
90	85	0.6317423
90	80	0.5155004
90	75	0.1149078
90	70	0.0378040
90	65	0.0166470
90	60	0.0080776
90	55	0.0047423
90	50	0.0030302
90	45	0.0018737
90	40	0.0013410
90	35	0.0010336
90	30	0.0006557
90	25	0.0005100
90	20	0.0004052
85	80	0.4379709
85	75	0.3735254
85	70	0.0870847
85	65	0.0279870
85	60	0.0124351
85	55	0.0061106
85	50	0.0035197
85	45	0.0021537
85	40	0.0014798
85	35	0.0009608
85	30	0.0008128
85	25	0.0005327
85	20	0.0003939
80	75	0.3413151
80	70	0.2943976
80	65	0.0646550
80	60	0.0203397
80	55	0.0089222
80	50	0.0046626
80	45	0.0025840
80	40	0.0017667
80	35	0.0013227
80	30	0.0009471
80	25	0.0006079
80	20	0.0004394
75	70	0.2527279
75	65	0.2115772
75	60	0.0500524
75	55	0.0160459
75	50	0.0066866
75	45	0.0033672
75	40	0.0022493
75	35	0.0014639
75	30	0.0009084
75	25	0.0006967
75	20	0.0005418
70	65	0.2053710
70	60	0.1997340
70	55	0.0452236
70	50	0.0131272
70	45	0.0048493
70	40	0.0024542
70	35	0.0013910
70	30	0.0009334
70	25	0.0008811
70	20	0.0006557
65	60	0.1946024
65	55	0.1734476
65	50	0.0301430
65	45	0.0071783
65	40	0.0032579
65	35	0.0018418
65	30	0.0012749
65	25	0.0010268
65	20	0.0007171
60	55	0.1306327
60	50	0.0961913
60	45	0.0262135
60	40	0.0055255
60	35	0.0025612
60	30	0.0016597
60	25	0.0010700
60	20	0.0007058
55	50	0.1040959
55	45	0.0812040
55	40	0.0242783
55	35	0.0066365
55	30	0.0019534
55	25	0.0011110
55	20	0.0006625
50	45	0.1140859

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Table 7.72 Loaded 5-unit well car—center-plate load (kip) (page 11 of 11)

Maximum Load	Minimum Load	Percent Occurrence
50	40	0.1157524
50	35	0.0184228
50	30	0.0045146
50	25	0.0018555
50	20	0.0008583

Maximum Load	Minimum Load	Percent Occurrence
45	40	0.0907933
45	35	0.0926875
45	30	0.0237137
45	25	0.0035789
45	20	0.0011884

Maximum Load	Minimum Load	Percent Occurrence
40	35	0.1054004
40	30	0.0589428
40	25	0.0119411
40	20	0.0028322

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7.3.2.72 Vertical Bolster Load—Loaded 5-Unit Well Car

Test Date	December 2007–May 2008
Test Mode	Unit Train and General Freight Service
Max MPH	65
Average MPH	31
Recorded Mileage	8,891
Total Number of Cycles	28,186,304
Average Cycles/Mile	3,170
Track Class	Various

Travel Speed Distribution		
Range (mph)		Percent at Level
0	5	5.0
5	10	7.3
10	15	7.9
15	20	8.6
20	25	10.7
25	30	8.2
30	35	10.9
35	40	10.5
40	45	13.2
45	50	8.0
50	55	6.3
55	60	3.4

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 1 of 11)

Maximum Load	Minimum Load	Percent Occurrence
390	20	0.0000035
380	30	0.0000035
380	25	0.0000035
370	365	0.0000035
370	20	0.0000035
365	360	0.0000071
365	45	0.0000035
360	355	0.0000035
360	350	0.0000071
360	345	0.0000035
360	290	0.0000035
355	350	0.0000035
355	340	0.0000035
355	55	0.0000035
355	45	0.0000035
350	345	0.0000035
350	220	0.0000035
350	200	0.0000035
350	185	0.0000035
345	340	0.0000071
345	335	0.0000035
345	330	0.0000035
345	325	0.0000035
345	315	0.0000035
340	335	0.0000035
340	330	0.0000142
340	35	0.0000035
335	330	0.0000142
335	325	0.0000142
335	280	0.0000035
335	30	0.0000035
330	325	0.0000106
330	320	0.0000177
330	310	0.0000035
330	250	0.0000035
330	205	0.0000035
330	115	0.0000035
330	75	0.0000035
330	30	0.0000035
330	15	0.0000035
325	320	0.0000106
325	315	0.0000035
325	310	0.0000035
325	275	0.0000035
325	65	0.0000035
325	60	0.0000035
320	315	0.0000177
320	310	0.0000071
320	275	0.0000035
320	95	0.0000035
320	85	0.0000071
320	80	0.0000071
320	55	0.0000035
320	40	0.0000035
320	20	0.0000035
315	310	0.0000177
315	305	0.0000071
315	300	0.0000035
315	235	0.0000035
315	120	0.0000035
315	95	0.0000035
315	55	0.0000035
315	15	0.0000071
310	305	0.0000461
310	300	0.0000390
310	295	0.0000106
310	200	0.0000035
310	185	0.0000035
310	135	0.0000035
310	110	0.0000035
310	100	0.0000071
310	90	0.0000035
310	80	0.0000035
310	70	0.0000035
310	50	0.0000035
310	45	0.0000071
310	35	0.0000035
310	25	0.0000035
305	300	0.0000745
305	295	0.0000284
305	290	0.0000035
305	285	0.0000035
305	280	0.0000035
305	195	0.0000035
305	125	0.0000035
305	110	0.0000106
305	100	0.0000106
305	95	0.0000035
305	80	0.0000035
305	70	0.0000071
305	65	0.0000035
305	60	0.0000106
305	50	0.0000071
305	45	0.0000035
305	40	0.0000035
305	35	0.0000035
305	30	0.0000035
305	20	0.0000071
305	15	0.0000071
300	295	0.0000319
300	290	0.0000426
300	285	0.0000071
300	240	0.0000035
300	205	0.0000035
300	130	0.0000035
300	120	0.0000035
300	115	0.0000035
300	110	0.0000035
300	105	0.0000035
300	95	0.0000071
300	75	0.0000035
300	65	0.0000071
300	60	0.0000106
300	45	0.0000071
300	40	0.0000071
300	25	0.0000035
300	20	0.0000106
300	15	0.0000177
300	10	0.0000035
295	290	0.0000568
295	285	0.0000497
295	280	0.0000142
295	270	0.0000035
295	215	0.0000071
295	200	0.0000035
295	190	0.0000035
295	165	0.0000035
295	155	0.0000071
295	115	0.0000071
295	105	0.0000106
295	100	0.0000035
295	95	0.0000071
295	90	0.0000106
295	85	0.0000071
295	80	0.0000142
295	75	0.0000035
295	70	0.0000071
295	65	0.0000106
295	60	0.0000071
295	55	0.0000071
295	50	0.0000071
295	45	0.0000035
295	40	0.0000106
295	25	0.0000071
295	20	0.0000035
295	15	0.0000035
295	10	0.0000213
295	5	0.0000035
290	285	0.0000781
290	280	0.0000532

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 2 of 11)

Maximum Load	Minimum Load	Percent Occurrence
290	275	0.0000035
290	270	0.0000071
290	265	0.0000035
290	225	0.0000035
290	160	0.0000035
290	130	0.0000035
290	115	0.0000035
290	110	0.0000035
290	105	0.0000035
290	100	0.0000142
290	95	0.0000106
290	85	0.0000035
290	80	0.0000035
290	75	0.0000035
290	70	0.0000035
290	65	0.0000071
290	60	0.0000177
290	55	0.0000035
290	50	0.0000071
290	45	0.0000071
290	40	0.0000071
290	35	0.0000071
290	30	0.0000106
290	25	0.0000035
290	15	0.0000071
290	10	0.0000035
285	280	0.0000851
285	275	0.0000674
285	270	0.0000248
285	265	0.0000106
285	230	0.0000035
285	185	0.0000035
285	180	0.0000071
285	155	0.0000035
285	135	0.0000071
285	120	0.0000142
285	115	0.0000213
285	110	0.0000106
285	105	0.0000106
285	100	0.0000071
285	95	0.0000035
285	90	0.0000142
285	85	0.0000142
285	80	0.0000142
285	75	0.0000071
285	70	0.0000071
285	65	0.0000071
285	60	0.0000106
285	55	0.0000071
285	50	0.0000071
285	40	0.0000142
285	35	0.0000213
285	30	0.0000177
285	25	0.0000071
285	20	0.0000035
285	15	0.0000106
285	10	0.0000035
285	5	0.0000035
280	275	0.0001313
280	270	0.0000958
280	265	0.0000035
280	260	0.0000071
280	255	0.0000106
280	235	0.0000071
280	230	0.0000035
280	205	0.0000035
280	190	0.0000035
280	185	0.0000035
280	180	0.0000035
280	140	0.0000142
280	130	0.0000106
280	125	0.0000071
280	120	0.0000319
280	115	0.0000248
280	110	0.0000142
280	105	0.0000071
280	100	0.0000284
280	95	0.0000142
280	90	0.0000071
280	85	0.0000213
280	80	0.0000071
280	75	0.0000177
280	70	0.0000071
280	65	0.0000106
280	60	0.0000071
280	55	0.0000142
280	50	0.0000106
280	45	0.0000177
280	40	0.0000106
280	30	0.0000213
280	25	0.0000106
280	20	0.0000035
280	10	0.0000142
280	0	0.0000035
275	270	0.0001455
275	265	0.0000603
275	260	0.0000284
275	255	0.0000177
275	250	0.0000035
275	200	0.0000035
275	180	0.0000035
275	145	0.0000106
275	140	0.0000071
275	135	0.0000142
275	130	0.0000213
275	125	0.0000213
275	120	0.0000213
275	115	0.0000319
275	110	0.0000284
275	105	0.0000142
275	100	0.0000071
275	95	0.0000177
275	90	0.0000177
275	85	0.0000106
275	80	0.0000106
275	75	0.0000177
275	65	0.0000071
275	60	0.0000142
275	55	0.0000142
275	50	0.0000142
275	45	0.0000106
275	40	0.0000106
275	35	0.0000142
275	30	0.0000106
275	25	0.0000035
275	20	0.0000071
275	15	0.0000142
275	10	0.0000071
275	5	0.0000071
275	0	0.0000035
270	265	0.0001916
270	260	0.0001774
270	255	0.0000497
270	250	0.0000177
270	245	0.0000035
270	230	0.0000071
270	225	0.0000035
270	195	0.0000071
270	155	0.0000106
270	150	0.0000035
270	145	0.0000142
270	140	0.0000035
270	135	0.0000248
270	130	0.0000248
270	125	0.0000461
270	120	0.0000461
270	115	0.0000390
270	110	0.0000390
270	105	0.0000106
270	100	0.0000426

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 3 of 11)

Maximum Load	Minimum Load	Percent Occurrence
270	95	0.0000319
270	90	0.0000319
270	85	0.0000177
270	80	0.0000142
270	75	0.0000248
270	70	0.0000071
270	65	0.0000071
270	60	0.0000071
270	55	0.0000177
270	50	0.0000319
270	45	0.0000071
270	40	0.0000071
270	35	0.0000213
270	30	0.0000213
270	25	0.0000177
270	20	0.0000177
270	15	0.0000071
270	10	0.0000035
270	5	0.0000035
265	260	0.0002625
265	255	0.0002342
265	250	0.0000248
265	245	0.0000035
265	240	0.0000035
265	190	0.0000035
265	185	0.0000035
265	165	0.0000035
265	160	0.0000035
265	155	0.0000071
265	150	0.0000106
265	145	0.0000177
265	140	0.0000319
265	135	0.0000497
265	130	0.0000461
265	125	0.0000674
265	120	0.0000426
265	115	0.0000426
265	110	0.0000284
265	105	0.0000461
265	100	0.0000319
265	95	0.0000284
265	90	0.0000248
265	85	0.0000177
265	80	0.0000213
265	75	0.0000213
265	70	0.0000177
265	65	0.0000248
265	60	0.0000177
265	55	0.0000213
265	50	0.0000142
265	45	0.0000284
265	40	0.0000390
265	35	0.0000142
265	30	0.0000142
265	25	0.0000106
265	20	0.0000106
265	15	0.0000142
265	10	0.0000035
265	5	0.0000035
260	255	0.0004045
260	250	0.0003654
260	245	0.0000674
260	240	0.0000106
260	235	0.0000248
260	230	0.0000071
260	215	0.0000035
260	205	0.0000035
260	180	0.0000035
260	170	0.0000035
260	165	0.0000035
260	160	0.0000035
260	155	0.0000177
260	150	0.0000319
260	145	0.0000284
260	140	0.0000568
260	135	0.0000674
260	130	0.0000745
260	125	0.0000639
260	120	0.0000603
260	115	0.0000816
260	110	0.0000461
260	105	0.0000568
260	100	0.0000461
260	95	0.0000355
260	90	0.0000142
260	85	0.0000390
260	80	0.0000355
260	75	0.0000390
260	70	0.0000213
260	65	0.0000319
260	60	0.0000355
260	55	0.0000248
260	50	0.0000319
260	45	0.0000213
260	40	0.0000319
260	35	0.0000355
260	30	0.0000177
260	25	0.0000035
260	20	0.0000071
260	15	0.0000035
260	10	0.0000142
255	250	0.0005499
255	245	0.0004967
255	240	0.0001100
255	235	0.0000355
255	230	0.0000106
255	225	0.0000035
255	200	0.0000071
255	195	0.0000035
255	180	0.0000035
255	175	0.0000071
255	170	0.0000106
255	165	0.0000071
255	160	0.0000355
255	155	0.0000532
255	150	0.0000426
255	145	0.0001135
255	140	0.0001348
255	135	0.0001171
255	130	0.0001135
255	125	0.0001490
255	120	0.0001242
255	115	0.0000851
255	110	0.0000745
255	105	0.0000993
255	100	0.0000781
255	95	0.0000639
255	90	0.0000461
255	85	0.0000284
255	80	0.0000745
255	75	0.0000568
255	70	0.0000390
255	65	0.0000532
255	60	0.0000426
255	55	0.0000532
255	50	0.0000177
255	45	0.0000319
255	40	0.0000355
255	35	0.0000284
255	30	0.0000106
255	25	0.0000142
255	20	0.0000213
255	15	0.0000071
250	245	0.0010573
250	240	0.0008515
250	235	0.0001313
250	230	0.0000497
250	225	0.0000213
250	210	0.0000035
250	205	0.0000071

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 4 of 11)

Maximum Load	Minimum Load	Percent Occurrence
250	190	0.0000035
250	185	0.0000035
250	180	0.0000071
250	175	0.0000071
250	170	0.0000106
250	165	0.0000106
250	160	0.0000426
250	155	0.0001135
250	150	0.0001455
250	145	0.0001987
250	140	0.0002093
250	135	0.0001667
250	130	0.0002164
250	125	0.0001774
250	120	0.0002235
250	115	0.0001809
250	110	0.0001242
250	105	0.0000745
250	100	0.0000958
250	95	0.0000958
250	90	0.0000603
250	85	0.0000532
250	80	0.0000851
250	75	0.0000851
250	70	0.0000568
250	65	0.0000816
250	60	0.0000355
250	55	0.0000426
250	50	0.0000426
250	45	0.0000355
250	40	0.0000248
250	35	0.0000319
250	30	0.0000213
250	25	0.0000213
250	20	0.0000213
250	15	0.0000071
250	10	0.0000035
250	5	0.0000035
250	0	0.0000035
245	240	0.0015930
245	235	0.0014759
245	230	0.0002235
245	225	0.0000851
245	220	0.0000284
245	215	0.0000071
245	210	0.0000071
245	200	0.0000035
245	185	0.0000106
245	180	0.0000071
245	175	0.0000035
245	170	0.0000284
245	165	0.0000710
245	160	0.0001348
245	155	0.0002696
245	150	0.0002945
245	145	0.0002980
245	140	0.0003654
245	135	0.0003832
245	130	0.0004080
245	125	0.0003193
245	120	0.0003087
245	115	0.0002058
245	110	0.0001916
245	105	0.0001951
245	100	0.0001490
245	95	0.0001029
245	90	0.0000993
245	85	0.0001206
245	80	0.0001029
245	75	0.0001064
245	70	0.0000958
245	65	0.0001029
245	60	0.0000816
245	55	0.0000603
245	50	0.0000674
245	45	0.0000284
245	40	0.0000355
245	35	0.0000426
245	30	0.0000035
245	25	0.0000071
245	20	0.0000284
245	15	0.0000177
245	10	0.0000071
245	0	0.0000035
240	235	0.0029411
240	230	0.0023416
240	225	0.0004222
240	220	0.0001029
240	215	0.0000390
240	210	0.0000071
240	205	0.0000035
240	200	0.0000035
240	195	0.0000071
240	190	0.0000106
240	180	0.0000142
240	175	0.0000284
240	170	0.0000851
240	165	0.0002164
240	160	0.0004648
240	155	0.0005002
240	150	0.0005073
240	145	0.0005996
240	140	0.0005925
240	135	0.0005712
240	130	0.0006138
240	125	0.0005286
240	120	0.0004257
240	115	0.0003548
240	110	0.0003051
240	105	0.0002058
240	100	0.0001880
240	95	0.0001809
240	90	0.0002483
240	85	0.0002200
240	80	0.0001880
240	75	0.0001738
240	70	0.0001206
240	65	0.0001135
240	60	0.0000781
240	55	0.0000993
240	50	0.0000639
240	45	0.0000426
240	40	0.0000142
240	35	0.0000284
240	30	0.0000284
240	25	0.0000142
240	20	0.0000142
240	15	0.0000035
240	5	0.0000035
240	0	0.0000035
235	230	0.0055736
235	225	0.0042645
235	220	0.0006634
235	215	0.0001916
235	210	0.0000639
235	205	0.0000355
235	200	0.0000142
235	195	0.0000142
235	190	0.0000106
235	180	0.0000355
235	175	0.0001206
235	170	0.0003796
235	165	0.0007663
235	160	0.0009295
235	155	0.0009721
235	150	0.0009473
235	145	0.0009473
235	140	0.0009153
235	135	0.0008905
235	130	0.0008941

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 5 of 11)

Maximum Load	Minimum Load	Percent Occurrence
235	125	0.0009260
235	120	0.0006812
235	115	0.0005641
235	110	0.0003867
235	105	0.0003016
235	100	0.0002483
235	95	0.0002164
235	90	0.0002413
235	85	0.0002625
235	80	0.0002271
235	75	0.0002022
235	70	0.0001987
235	65	0.0001419
235	60	0.0001455
235	55	0.0000781
235	50	0.0000319
235	45	0.0000568
235	40	0.0000390
235	35	0.0000248
235	30	0.0000142
235	25	0.0000142
235	20	0.0000035
235	15	0.0000035
235	10	0.0000071
235	5	0.0000035
230	225	0.0095401
230	220	0.0084119
230	215	0.0013730
230	210	0.0003903
230	205	0.0001313
230	200	0.0000461
230	195	0.0000213
230	190	0.0000213
230	185	0.0000355
230	180	0.0001277
230	175	0.0004683
230	170	0.0012027
230	165	0.0016285
230	160	0.0017491
230	155	0.0016817
230	150	0.0017881
230	145	0.0014972
230	140	0.0014475
230	135	0.0015327
230	130	0.0014369
230	125	0.0013446
230	120	0.0010182
230	115	0.0006493
230	110	0.0005818
230	105	0.0005073
230	100	0.0004399
230	95	0.0004151
230	90	0.0004506
230	85	0.0004435
230	80	0.0003548
230	75	0.0002625
230	70	0.0002696
230	65	0.0001845
230	60	0.0001100
230	55	0.0000922
230	50	0.0000781
230	45	0.0000497
230	40	0.0000355
230	35	0.0000213
230	30	0.0000106
230	25	0.0000142
230	20	0.0000035
230	10	0.0000035
230	5	0.0000071
230	0	0.0000035
225	220	0.0166322
225	215	0.0155572
225	210	0.0027779
225	205	0.0007450
225	200	0.0002129
225	195	0.0001277
225	190	0.0001597
225	185	0.0002413
225	180	0.0005535
225	175	0.0013198
225	170	0.0022742
225	165	0.0025154
225	160	0.0027602
225	155	0.0026609
225	150	0.0025296
225	145	0.0022280
225	140	0.0021926
225	135	0.0023877
225	130	0.0022742
225	125	0.0019513
225	120	0.0013411
225	115	0.0009757
225	110	0.0008905
225	105	0.0006776
225	100	0.0006847
225	95	0.0006280
225	90	0.0006599
225	85	0.0005677
225	80	0.0005251
225	75	0.0003548
225	70	0.0002767
225	65	0.0002093
225	60	0.0001100
225	55	0.0000532
225	50	0.0000568
225	45	0.0000355
225	40	0.0000177
225	35	0.0000319
225	30	0.0000213
225	25	0.0000071
225	20	0.0000035
225	15	0.0000071
220	215	0.0287764
220	210	0.0271799
220	205	0.0057404
220	200	0.0016178
220	195	0.0008834
220	190	0.0007167
220	185	0.0007841
220	180	0.0014688
220	175	0.0028312
220	170	0.0038316
220	165	0.0038246
220	160	0.0040481
220	155	0.0038778
220	150	0.0037642
220	145	0.0035585
220	140	0.0036862
220	135	0.0035939
220	130	0.0032746
220	125	0.0024303
220	120	0.0017739
220	115	0.0015043
220	110	0.0013091
220	105	0.0011105
220	100	0.0011353
220	95	0.0010963
220	90	0.0010182
220	85	0.0009118
220	80	0.0006244
220	75	0.0004541
220	70	0.0002980
220	65	0.0001916
220	60	0.0001809
220	55	0.0000603
220	50	0.0000497
220	45	0.0000390
220	40	0.0000426
220	35	0.0000319
220	30	0.0000035

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 6 of 11)

Maximum Load	Minimum Load	Percent Occurrence
220	25	0.0000035
220	20	0.0000071
220	15	0.0000071
220	10	0.0000035
220	5	0.0000035
215	210	0.0498717
215	205	0.0514221
215	200	0.0138472
215	195	0.0056339
215	190	0.0023238
215	185	0.0022103
215	180	0.0036933
215	175	0.0055169
215	170	0.0056623
215	165	0.0055665
215	160	0.0060065
215	155	0.0056481
215	150	0.0056517
215	145	0.0058752
215	140	0.0055914
215	135	0.0051656
215	130	0.0038884
215	125	0.0029624
215	120	0.0025331
215	115	0.0021110
215	110	0.0021571
215	105	0.0019194
215	100	0.0017987
215	95	0.0017562
215	90	0.0014972
215	85	0.0011992
215	80	0.0009224
215	75	0.0005002
215	70	0.0003477
215	65	0.0001703
215	60	0.0001526
215	55	0.0000816
215	50	0.0000958
215	45	0.0000177
215	40	0.0000390
215	35	0.0000177
215	30	0.0000177
215	20	0.0000177
215	10	0.0000035
210	205	0.0951207
210	200	0.1116500
210	195	0.0335979
210	190	0.0130986
210	185	0.0083835
210	180	0.0096359
210	175	0.0097884
210	170	0.0090115
210	165	0.0087312
210	160	0.0085148
210	155	0.0083871
210	150	0.0085999
210	145	0.0085715
210	140	0.0076952
210	135	0.0061342
210	130	0.0045802
210	125	0.0040268
210	120	0.0036081
210	115	0.0033456
210	110	0.0031682
210	105	0.0032108
210	100	0.0027283
210	95	0.0026041
210	90	0.0021358
210	85	0.0015539
210	80	0.0011034
210	75	0.0005606
210	70	0.0003867
210	65	0.0002200
210	60	0.0001455
210	55	0.0000887
210	50	0.0000745
210	45	0.0000319
210	40	0.0000177
210	35	0.0000213
210	30	0.0000177
210	25	0.0000177
210	20	0.0000035
210	15	0.0000035
210	10	0.0000071
205	200	0.2090874
205	195	0.2556525
205	190	0.0918886
205	185	0.0472002
205	180	0.0263922
205	175	0.0169054
205	170	0.0141806
205	165	0.0130134
205	160	0.0129070
205	155	0.0129921
205	150	0.0130241
205	145	0.0116440
205	140	0.0094053
205	135	0.0077094
205	130	0.0063293
205	125	0.0058752
205	120	0.0055843
205	115	0.0051514
205	110	0.0050521
205	105	0.0046441
205	100	0.0045412
205	95	0.0038494
205	90	0.0030263
205	85	0.0020400
205	80	0.0011850
205	75	0.0007025
205	70	0.0003761
205	65	0.0002093
205	60	0.0000993
205	55	0.0000993
205	50	0.0000532
205	45	0.0000355
205	40	0.0000213
205	35	0.0000177
205	30	0.0000177
205	20	0.0000071
200	195	0.4837988
200	190	0.7356055
200	185	0.2509055
200	180	0.0773319
200	175	0.0350241
200	170	0.0237917
200	165	0.0208931
200	160	0.0201552
200	155	0.0190873
200	150	0.0177249
200	145	0.0151740
200	140	0.0123713
200	135	0.0100616
200	130	0.0094408
200	125	0.0090824
200	120	0.0087276
200	115	0.0077839
200	110	0.0080394
200	105	0.0074824
200	100	0.0064393
200	95	0.0053182
200	90	0.0038423
200	85	0.0022706
200	80	0.0014830
200	75	0.0008302
200	70	0.0004186
200	65	0.0002625
200	60	0.0001242
200	55	0.0000851
200	50	0.0000710

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 7 of 11)

Maximum Load	Minimum Load	Percent Occurrence
200	45	0.0000248
200	40	0.0000532
200	35	0.0000213
200	30	0.0000142
200	20	0.0000106
200	15	0.0000071
195	190	1.1617734
195	185	1.2094597
195	180	0.3277478
195	175	0.0918105
195	170	0.0473067
195	165	0.0344671
195	160	0.0302558
195	155	0.0266512
195	150	0.0239655
195	145	0.0207157
195	140	0.0175724
195	135	0.0152947
195	130	0.0147199
195	125	0.0140742
195	120	0.0129354
195	115	0.0130099
195	110	0.0120697
195	105	0.0104945
195	100	0.0087596
195	95	0.0064535
195	90	0.0042326
195	85	0.0026147
195	80	0.0014901
195	75	0.0008657
195	70	0.0004257
195	65	0.0002164
195	60	0.0001384
195	55	0.0000922
195	50	0.0000603
195	45	0.0000390
195	40	0.0000390
195	35	0.0000248
195	30	0.0000106
195	25	0.0000035
195	15	0.0000142
190	185	1.5179464
190	180	1.2510437
190	175	0.3376072
190	170	0.1176493
190	165	0.0648435
190	160	0.0480198
190	155	0.0392673
190	150	0.0335411
190	145	0.0292518
190	140	0.0260836
190	135	0.0249909
190	130	0.0241678
190	125	0.0225996
190	120	0.0210776
190	115	0.0192611
190	110	0.0172424
190	105	0.0140352
190	100	0.0113317
190	95	0.0081174
190	90	0.0047080
190	85	0.0029979
190	80	0.0016107
190	75	0.0007238
190	70	0.0004045
190	65	0.0002306
190	60	0.0001526
190	55	0.0000993
190	50	0.0000568
190	45	0.0000426
190	40	0.0000284
190	35	0.0000390
190	30	0.0000284
190	25	0.0000035
190	15	0.0000071
190	10	0.0000071
185	180	1.5302467
185	175	1.4993523
185	170	0.3911368
185	165	0.1607589
185	160	0.0922044
185	155	0.0652054
185	150	0.0518124
185	145	0.0459372
185	140	0.0441101
185	135	0.0419920
185	130	0.0386784
185	125	0.0355350
185	120	0.0320262
185	115	0.0278540
185	110	0.0230999
185	105	0.0180726
185	100	0.0128005
185	95	0.0080819
185	90	0.0050876
185	85	0.0028383
185	80	0.0014901
185	75	0.0007983
185	70	0.0004896
185	65	0.0002590
185	60	0.0001490
185	55	0.0001100
185	50	0.0000568
185	45	0.0000497
185	40	0.0000248
185	35	0.0000355
185	30	0.0000142
185	25	0.0000035
185	20	0.0000071
185	15	0.0000035
180	175	1.7343103
180	170	1.9331693
180	165	0.5941822
180	160	0.2345217
180	155	0.1337955
180	150	0.0965824
180	145	0.0819476
180	140	0.0732377
180	135	0.0658227
180	130	0.0603236
180	125	0.0532635
180	120	0.0449970
180	115	0.0365958
180	110	0.0276198
180	105	0.0199991
180	100	0.0131518
180	95	0.0079684
180	90	0.0049563
180	85	0.0026644
180	80	0.0014901
180	75	0.0007983
180	70	0.0004080
180	65	0.0002377
180	60	0.0001490
180	55	0.0000993
180	50	0.0000710
180	45	0.0000355
180	40	0.0000497
180	35	0.0000390
180	30	0.0000284
180	25	0.0000035
180	20	0.0000035
180	15	0.0000035
175	170	2.6008624
175	165	2.9431563
175	160	0.7897027
175	155	0.3235649
175	150	0.1908374
175	145	0.1421293
175	140	0.1194516

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 8 of 11)

Maximum Load	Minimum Load	Percent Occurrence
175	135	0.1015103
175	130	0.0875709
175	125	0.0725955
175	120	0.0550764
175	115	0.0409703
175	110	0.0293228
175	105	0.0191973
175	100	0.0123038
175	95	0.0077981
175	90	0.0043567
175	85	0.0025190
175	80	0.0013943
175	75	0.0006847
175	70	0.0005038
175	65	0.0002909
175	60	0.0001632
175	55	0.0000851
175	50	0.0000710
175	45	0.0000710
175	40	0.0000390
175	35	0.0000426
175	30	0.0000355
175	25	0.0000071
175	20	0.0000071
170	165	3.3884292
170	160	3.6440569
170	155	1.1069099
170	150	0.4183947
170	145	0.2541731
170	140	0.1872505
170	135	0.1457729
170	130	0.1113484
170	125	0.0827459
170	120	0.0585426
170	115	0.0397888
170	110	0.0273573
170	105	0.0176149
170	100	0.0114169
170	95	0.0065528
170	90	0.0040055
170	85	0.0024125
170	80	0.0013233
170	75	0.0008302
170	70	0.0005570
170	65	0.0002909
170	60	0.0002022
170	55	0.0001135
170	50	0.0000887
170	45	0.0000426
170	40	0.0000603
170	35	0.0000142
170	30	0.0000177
170	25	0.0000106
170	15	0.0000071
165	160	4.4218354
165	155	4.3819756
165	150	1.3068439
165	145	0.4934240
165	140	0.2757509
165	135	0.1911460
165	130	0.1306024
165	125	0.0865562
165	120	0.0548103
165	115	0.0360955
165	110	0.0237420
165	105	0.0157027
165	100	0.0100545
165	95	0.0063754
165	90	0.0038246
165	85	0.0022990
165	80	0.0012240
165	75	0.0008266
165	70	0.0004293
165	65	0.0002909
165	60	0.0001845
165	55	0.0000922
165	50	0.0000710
165	45	0.0000958
165	40	0.0000568
165	35	0.0000248
165	30	0.0000426
165	25	0.0000106
165	15	0.0000071
165	10	0.0000035
160	155	5.0274167
160	150	4.7420689
160	145	1.3203717
160	140	0.4913166
160	135	0.2515903
160	130	0.1536243
160	125	0.0881173
160	120	0.0504607
160	115	0.0314266
160	110	0.0210315
160	105	0.0138791
160	100	0.0090044
160	95	0.0058575
160	90	0.0036365
160	85	0.0020648
160	80	0.0012453
160	75	0.0006563
160	70	0.0004790
160	65	0.0002838
160	60	0.0002093
160	55	0.0000922
160	50	0.0001171
160	45	0.0000922
160	40	0.0000390
160	35	0.0000319
160	30	0.0000355
160	25	0.0000071
160	20	0.0000035
160	15	0.0000106
160	5	0.0000035
155	150	4.9198290
155	145	4.7238579
155	140	1.1247696
155	135	0.3849848
155	130	0.1881658
155	125	0.1018083
155	120	0.0534267
155	115	0.0297698
155	110	0.0187219
155	105	0.0124670
155	100	0.0085361
155	95	0.0049634
155	90	0.0031221
155	85	0.0018733
155	80	0.0010076
155	75	0.0006315
155	70	0.0003796
155	65	0.0002235
155	60	0.0001809
155	55	0.0001384
155	50	0.0000674
155	45	0.0000887
155	40	0.0000390
155	35	0.0000568
155	30	0.0000284
155	25	0.0000177
155	15	0.0000071
155	10	0.0000035
150	145	3.9926872
150	140	3.1956157
150	135	0.8092724
150	130	0.2807676
150	125	0.1310566
150	120	0.0654609
150	115	0.0321433
150	110	0.0178917

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 9 of 11)

Maximum Load	Minimum Load	Percent Occurrence
150	105	0.0114488
150	100	0.0072979
150	95	0.0042396
150	90	0.0025509
150	85	0.0015646
150	80	0.0009331
150	75	0.0006280
150	70	0.0003654
150	65	0.0002342
150	60	0.0002200
150	55	0.0001632
150	50	0.0001242
150	45	0.0000816
150	40	0.0000426
150	35	0.0000461
150	30	0.0000284
150	25	0.0000071
150	20	0.0000035
150	15	0.0000035
150	10	0.0000071
145	140	2.8087364
145	135	2.3728509
145	130	0.5798845
145	125	0.1905429
145	120	0.0866875
145	115	0.0399343
145	110	0.0188035
145	105	0.0100261
145	100	0.0058929
145	95	0.0034130
145	90	0.0022387
145	85	0.0012382
145	80	0.0008799
145	75	0.0005286
145	70	0.0003477
145	65	0.0002767
145	60	0.0002306
145	55	0.0001206
145	50	0.0001348
145	45	0.0000851
145	40	0.0000568
145	35	0.0000284
145	30	0.0000319
145	25	0.0000071
145	20	0.0000106
145	15	0.0000035
145	10	0.0000071
140	135	2.0146131
140	130	1.5320632
140	125	0.3758882
140	120	0.1264799
140	115	0.0535437
140	110	0.0233021
140	105	0.0101574
140	100	0.0049421
140	95	0.0027105
140	90	0.0017420
140	85	0.0012488
140	80	0.0006670
140	75	0.0005286
140	70	0.0004151
140	65	0.0003903
140	60	0.0002661
140	55	0.0001703
140	50	0.0000781
140	45	0.0000922
140	40	0.0001064
140	35	0.0000639
140	30	0.0000355
140	25	0.0000035
140	20	0.0000106
140	10	0.0000071
135	130	1.2711670
135	125	1.0980191
135	120	0.2784012
135	115	0.0835654
135	110	0.0321291
135	105	0.0131908
135	100	0.0053040
135	95	0.0026573
135	90	0.0016143
135	85	0.0009437
135	80	0.0008550
135	75	0.0005996
135	70	0.0004364
135	65	0.0004257
135	60	0.0002838
135	55	0.0002164
135	50	0.0001632
135	45	0.0000993
135	40	0.0001064
135	35	0.0000532
135	30	0.0000603
135	25	0.0000071
135	20	0.0000035
135	15	0.0000177
135	10	0.0000071
130	125	1.0300179
130	120	0.7931440
130	115	0.1738397
130	110	0.0541256
130	105	0.0201197
130	100	0.0077201
130	95	0.0034095
130	90	0.0018236
130	85	0.0011850
130	80	0.0007947
130	75	0.0007415
130	70	0.0004825
130	65	0.0003690
130	60	0.0002803
130	55	0.0002306
130	50	0.0001774
130	45	0.0001455
130	40	0.0001171
130	35	0.0000532
130	30	0.0000461
130	25	0.0000071
130	10	0.0000071
125	120	0.6704213
125	115	0.5672790
125	110	0.1141512
125	105	0.0324519
125	100	0.0130986
125	95	0.0048924
125	90	0.0024161
125	85	0.0014475
125	80	0.0008621
125	75	0.0007060
125	70	0.0006244
125	65	0.0004009
125	60	0.0002980
125	55	0.0002342
125	50	0.0002235
125	45	0.0001277
125	40	0.0001100
125	35	0.0000745
125	30	0.0000639
125	25	0.0000071
125	20	0.0000035
125	15	0.0000071
125	10	0.0000071
125	5	0.0000035
120	115	0.4326250
120	110	0.2891794
120	105	0.0662485
120	100	0.0216807
120	95	0.0086141
120	90	0.0034378
120	85	0.0015504

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 10 of 11)

Maximum Load	Minimum Load	Percent Occurrence
120	80	0.0010892
120	75	0.0007273
120	70	0.0005570
120	65	0.0003016
120	60	0.0002767
120	55	0.0002483
120	50	0.0001738
120	45	0.0001526
120	40	0.0001667
120	35	0.0000674
120	30	0.0000745
120	25	0.0000142
120	20	0.0000071
120	15	0.0000106
120	10	0.0000035
115	110	0.2460308
115	105	0.1952473
115	100	0.0453554
115	95	0.0152343
115	90	0.0057120
115	85	0.0025615
115	80	0.0012843
115	75	0.0007521
115	70	0.0006422
115	65	0.0004612
115	60	0.0002980
115	55	0.0002590
115	50	0.0001845
115	45	0.0002164
115	40	0.0001100
115	35	0.0000958
115	30	0.0000710
115	25	0.0000035
115	20	0.0000035
115	10	0.0000106
110	105	0.1703203
110	100	0.1490263
110	95	0.0338143
110	90	0.0103313
110	85	0.0041793
110	80	0.0019513
110	75	0.0010005
110	70	0.0007415
110	65	0.0004612
110	60	0.0003761
110	55	0.0002058
110	50	0.0002200
110	45	0.0001809
110	40	0.0001455
110	35	0.0001526
110	30	0.0001100
110	25	0.0000071
110	20	0.0000071
110	15	0.0000035
105	100	0.1283283
105	95	0.0978844
105	90	0.0242032
105	85	0.0090860
105	80	0.0033953
105	75	0.0015433
105	70	0.0008160
105	65	0.0004825
105	60	0.0004293
105	55	0.0003725
105	50	0.0003016
105	45	0.0001987
105	40	0.0002448
105	35	0.0001313
105	30	0.0000922
105	15	0.0000071
105	10	0.0000071
105	5	0.0000035
100	95	0.0942053
100	90	0.0936341
100	85	0.0180194
100	80	0.0062655
100	75	0.0028737
100	70	0.0014014
100	65	0.0007557
100	60	0.0005215
100	55	0.0004186
100	50	0.0003229
100	45	0.0002448
100	40	0.0002164
100	35	0.0001419
100	30	0.0001951
100	25	0.0000035
100	20	0.0000106
100	15	0.0000177
100	10	0.0000071
100	5	0.0000035
95	90	0.0665962
95	85	0.0532883
95	80	0.0132192
95	75	0.0047080
95	70	0.0021606
95	65	0.0012595
95	60	0.0007734
95	55	0.0004790
95	50	0.0004009
95	45	0.0002732
95	40	0.0002696
95	35	0.0002200
95	30	0.0001916
95	25	0.0000035
95	15	0.0000035
90	85	0.0485094
90	80	0.0408319
90	75	0.0126622
90	70	0.0055275
90	65	0.0019868
90	60	0.0010395
90	55	0.0007131
90	50	0.0004257
90	45	0.0004009
90	40	0.0002342
90	35	0.0002058
90	30	0.0001987
90	25	0.0000071
90	20	0.0000142
90	15	0.0000035
90	10	0.0000106
85	80	0.0493679
85	75	0.0660746
85	70	0.0135314
85	65	0.0052401
85	60	0.0018023
85	55	0.0010360
85	50	0.0006244
85	45	0.0004186
85	40	0.0003016
85	35	0.0002377
85	30	0.0002342
85	25	0.0000177
85	20	0.0000071
85	15	0.0000071
85	10	0.0000177
80	75	0.0528732
80	70	0.0643185
80	65	0.0111260
80	60	0.0033988
80	55	0.0015539
80	50	0.0008834
80	45	0.0004861
80	40	0.0003725
80	35	0.0002483
80	30	0.0002164
80	25	0.0000106
80	20	0.0000035
75	70	0.0408496

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Table 7.73 Loaded 5-unit well car—vertical bolster load (kip) (page 11 of 11)

Maximum Load	Minimum Load	Percent Occurrence
75	65	0.0233198
75	60	0.0064109
75	55	0.0027460
75	50	0.0012169
75	45	0.0007770
75	40	0.0004790
75	35	0.0003087
75	30	0.0003158
75	25	0.0000035
75	20	0.0000071
75	15	0.0000106
70	65	0.0184026
70	60	0.0170828
70	55	0.0053537
70	50	0.0024196
70	45	0.0011459
70	40	0.0006386
70	35	0.0005109
70	30	0.0003548
70	25	0.0000213
70	20	0.0000071
70	15	0.0000071
70	10	0.0000035
65	60	0.0141274
65	55	0.0139962
65	50	0.0046760
65	45	0.0022209
65	40	0.0010076
65	35	0.0005712
65	30	0.0004967
65	25	0.0000106
65	20	0.0000106
60	55	0.0121868
60	50	0.0124351
60	45	0.0042964
60	40	0.0020081
60	35	0.0011708
60	30	0.0006776
60	25	0.0000035
60	20	0.0000035
60	10	0.0000035
55	50	0.0113779
55	45	0.0116901
55	40	0.0043567
55	35	0.0021180
55	30	0.0011992
55	25	0.0000248
55	15	0.0000035
50	45	0.0102922
50	40	0.0113424
50	35	0.0042822
50	30	0.0018271
50	25	0.0000284
50	20	0.0000142
50	15	0.0000071
50	10	0.0000071
45	40	0.0095401
45	35	0.0101290
45	30	0.0038387
45	25	0.0000851
45	20	0.0000213
45	15	0.0000106
45	10	0.0000035
40	35	0.0091321
40	30	0.0094656
40	25	0.0001490
40	20	0.0000568
40	15	0.0000248

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7.3.2.73 Longitudinal Coupler Force—loaded 5-Unit Well Car

Test Date	November 2013–December 2014
Test Mode	Unit Intermodal Train and General Freight Service
Max MPH	N/A
Average MPH	N/A
Recorded Mileage	8,171
Total Number of Cycles	776,757
Average Cycles/Mile	95.06
Track Class	Various

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Table 7.74 Loaded 5-unit well car—longitudinal coupler force (kip) (page 1 of 4)

Maximum Load	Minimum Load	Percent Occurrence
180	120	0.0009012
180	-140	0.0003862
180	-180	0.0003862
160	140	0.0251044
160	120	0.0154488
160	100	0.0025748
160	-100	0.0011587
140	120	0.0415831
140	100	0.0227870
140	60	0.0014161
140	0	0.0007724
140	-80	0.0006437
140	-120	0.0002575
120	100	0.1922094
120	80	0.0852261
120	60	0.0066945
120	40	0.0033473
120	20	0.0033473
120	-60	0.0012874
120	-80	0.0007724
100	80	0.2345650
100	60	0.0569033
100	40	0.0042484
100	20	0.0036047
100	0	0.0014161
100	-20	0.0015449
100	-40	0.0010299
100	-100	0.0014161
80	60	0.1940118
80	40	0.0615379
80	20	0.0198260
80	0	0.0060508
80	-20	0.0047634
80	-60	0.0033473
60	40	0.4149303
60	20	0.1165101
60	0	0.0112004
40	20	0.3160577
40	0	0.0593493
40	-20	0.0087543
40	-40	0.0043772
20	0	0.0623103
20	-20	0.0711934
20	-40	0.0166075
20	-80	0.0015449
0	-20	0.1274530
0	-40	0.0477627
0	-120	0.0021886
-20	-40	0.0966840
-20	-60	0.0366910
-20	-80	0.0029610
-20	-120	0.0003862
-40	-60	0.0683611
-40	-80	0.0324426
-40	-100	0.0020598
-60	-80	0.1154801
-60	-100	0.0315414
-60	-180	0.0001287
-80	-100	0.0746694
-80	-120	0.0164788
-80	-140	0.0011587
-80	-180	0.0001287
-100	-120	0.0258768
-100	-140	0.0041197
-120	-140	0.0054071
260	240	0.0011587
260	-140	0.0002575
260	-180	0.0002575
240	220	0.0009012
240	200	0.0005150
240	180	0.0005150
240	40	0.0003862
240	-60	0.0001287
240	-120	0.0001287
220	200	0.0047634
220	180	0.0045059
220	160	0.0011587
220	140	0.0005150
220	80	0.0002575
220	-100	0.0002575
200	180	0.0175087
200	160	0.0078532
200	140	0.0007724
200	100	0.0006437
180	160	0.0173800
180	140	0.0045059
180	40	0.0005150
180	20	0.0007724
180	-60	0.0001287
180	-80	0.0002575
160	20	0.0005150
160	-140	0.0003862
140	40	0.0024461
140	-100	0.0003862
100	-60	0.0014161
40	-100	0.0006437
40	-160	0.0001287
20	-100	0.0002575
20	-120	0.0002575
0	-60	0.0077244
0	-80	0.0024461
0	-100	0.0009012
-20	-100	0.0016736
-20	-140	0.0005150
-60	-120	0.0021886
-120	-160	0.0014161
-140	-160	0.0078532
300	-180	0.0001287
260	200	0.0002575
260	-100	0.0002575
240	140	0.0006437
240	100	0.0002575
240	80	0.0001287
240	-80	0.0002575
200	80	0.0002575
200	-20	0.0001287
180	100	0.0007724
160	80	0.0005150
160	40	0.0006437
160	-20	0.0001287
140	80	0.0034760
140	20	0.0011587
80	-40	0.0032185
80	-80	0.0011587
80	-140	0.0002575
60	-60	0.0010299
60	-80	0.0006437
60	-120	0.0006437
40	-60	0.0009012
20	-60	0.0036047
20	-160	0.0002575
0	-160	0.0001287
-40	-120	0.0003862
120	-100	0.0009012
120	-120	0.0006437
80	-100	0.0009012
60	-20	0.0052784
60	-40	0.0052784
60	-100	0.0002575
40	-80	0.0001287
220	-140	0.0005150
160	60	0.0010299
140	-40	0.0003862
140	-140	0.0005150
120	0	0.0005150
100	-80	0.0009012
100	-120	0.0005150
0	-140	0.0002575
160	-120	0.0003862
280	-140	0.0002575

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Table 7.74 Loaded 5-unit well car—longitudinal coupler force (kip) (page 2 of 4)

Maximum Load	Minimum Load	Percent Occurrence
-40	-140	0.0003862
120	-180	0.0001287
160	-320	0.0002575
140	-60	0.0009012
-200	-240	0.0001287
-260	-280	0.0002575
20	-220	0.0001287
-100	-160	0.0002575
60	-180	0.0001287
180	-200	0.0001287
140	-180	0.0002575
140	-200	0.0002575
120	-20	0.0009012
120	-140	0.0001287
-140	-180	0.0010299
200	-180	0.0001287
160	0	0.0009012
120	-40	0.0005150
120	-160	0.0001287
-20	-160	0.0002575
-160	-180	0.0005150
420	-180	0.0001287
400	180	0.0002575
380	280	0.0001287
340	180	0.0003862
320	240	0.0001287
320	200	0.0002575
300	280	0.0002575
300	240	0.0002575
300	180	0.0001287
300	140	0.0001287
280	260	0.0003862
280	240	0.0002575
280	160	0.0001287
260	60	0.0002575
260	-160	0.0001287
240	60	0.0002575
160	-80	0.0002575
140	-20	0.0002575
-100	-180	0.0001287
-120	-180	0.0001287
240	-160	0.0002575
220	60	0.0001287
200	-100	0.0002575
200	-160	0.0002575
180	60	0.0001287
180	0	0.0002575
180	-20	0.0001287
180	160	0.0469902
180	-180	0.0002575
160	140	0.0762143
160	120	0.0448017
160	100	0.0061795
160	80	0.0019311
160	40	0.0006437
160	20	0.0005150
160	-120	0.0006437
160	-140	0.0002575
160	-160	0.0003862
160	-180	0.0005150
140	120	0.1644015
140	100	0.2195024
140	80	0.0522686
140	60	0.0256193
140	40	0.0056646
140	20	0.0023173
140	0	0.0016736
140	-20	0.0006437
140	-80	0.0010299
140	-120	0.0015449
120	100	0.6382949
120	80	0.7849302
120	60	0.1736708
120	40	0.0625678
120	20	0.0148051
120	0	0.0056646
120	-60	0.0012874
120	-140	0.0005150
100	80	1.2029502
100	60	1.4582424
100	40	0.1575782
100	20	0.0308977
100	0	0.0097843
100	-20	0.0023173
100	-40	0.0028323
100	-120	0.0028323
100	-160	0.0024461
80	60	1.5016279
80	40	0.7203025
80	20	0.1108455
80	0	0.0366910
80	-20	0.0272930
80	-40	0.0173800
80	-60	0.0234308
60	40	3.6398771
60	20	2.1647697
60	0	0.4258732
60	-20	0.1897633
40	20	7.3548098
40	0	5.5220616
40	-20	1.3867915
40	-140	0.0052784
20	0	30.6878470
20	-20	3.5448667
20	-40	0.3033124
20	-80	0.1168963
0	-20	11.0242972
0	-40	5.3995007
0	-120	0.0169937
0	-140	0.0064370
0	-160	0.0021886
-20	-40	7.2417757
-20	-60	1.1322717
-20	-100	0.0186674
-40	-60	2.3585240
-40	-80	0.5271919
-40	-100	0.0159638
-40	-140	0.0015449
-60	-80	1.6570176
-60	-100	0.3425782
-60	-120	0.0110717
-60	-140	0.0050209
-80	-100	0.8064298
-80	-120	0.1420007
-80	-140	0.0218859
-100	-120	0.4370736
-100	-140	0.1225609
-100	-160	0.0132603
-120	-140	0.5013151
-120	-160	0.0682324
-140	-160	0.1541022
140	-140	0.0009012
140	-160	0.0006437
140	-240	0.0003862
120	-40	0.0007724
120	-120	0.0014161
120	-160	0.0006437
100	-80	0.0077244
100	-100	0.0048921
80	-100	0.0037335
80	-120	0.0041197
80	-140	0.0033473
60	-40	0.0570320
60	-80	0.0068232
60	-120	0.0056646
60	-140	0.0036047
60	-160	0.0014161
40	-40	0.0593493
40	-60	0.0203410
40	-100	0.0169937

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Table 7.74 Loaded 5-unit well car—longitudinal coupler force (kip) (page 3 of 4)

Maximum Load	Minimum Load	Percent Occurrence
40	-120	0.0114579
20	-120	0.0154488
0	-60	0.7003477
0	-80	0.1102018
0	-100	0.0324426
0	-200	0.0003862
-20	-80	0.0643702
-20	-120	0.0093980
-20	-140	0.0016736
-40	-120	0.0052784
-160	-180	0.0292241
-180	-200	0.0272930
-200	-240	0.0415831
140	-100	0.0012874
120	-80	0.0018024
120	-100	0.0020598
80	-80	0.0132603
60	-60	0.0306402
40	-80	0.0160925
20	-60	0.2416457
20	-100	0.0391371
20	-140	0.0064370
-20	-220	0.0001287
-220	-240	0.0427418
300	-300	0.0001287
240	60	0.0002575
220	140	0.0005150
160	-80	0.0006437
140	-40	0.0007724
120	-20	0.0016736
100	-60	0.0041197
100	-140	0.0020598
100	-280	0.0001287
80	-200	0.0001287
60	-100	0.0050209
60	-180	0.0005150
40	-160	0.0021886
40	-180	0.0010299
40	-200	0.0003862
20	-180	0.0007724
-140	-180	0.0199548
-160	-200	0.0187961
-160	-240	0.0007724
-180	-220	0.0216284
-180	-240	0.0066945
-200	-220	0.0226583
-200	-260	0.0132603
-200	-300	0.0003862
-220	-260	0.0150626
-220	-280	0.0009012
-240	-260	0.0325713
-240	-280	0.0231733
-240	-300	0.0006437
-260	-280	0.0493076
140	-180	0.0002575
140	-200	0.0002575
320	-140	0.0001287
320	-180	0.0001287
220	160	0.0014161
200	60	0.0001287
80	-180	0.0007724
280	240	0.0001287
280	-240	0.0001287
260	220	0.0001287
160	-20	0.0007724
120	-180	0.0003862
120	-200	0.0001287
120	-220	0.0003862
100	-180	0.0016736
100	-200	0.0005150
100	-220	0.0001287
80	-160	0.0011587
80	-220	0.0001287
60	-200	0.0005150
20	-160	0.0012874
20	-200	0.0006437
0	-180	0.0003862
-20	-160	0.0003862
200	-80	0.0001287
160	0	0.0009012
180	-140	0.0005150
220	200	0.0081106
220	-120	0.0001287
220	-60	0.0001287
200	20	0.0002575
200	-40	0.0001287
180	-40	0.0001287
360	-100	0.0001287
240	-240	0.0001287
200	-120	0.0003862
200	-180	0.0002575
160	-60	0.0001287
160	-220	0.0001287
140	-220	0.0001287
340	-480	0.0001287
320	300	0.0001287
300	0	0.0001287
280	200	0.0001287
140	-60	0.0007724
-20	-180	0.0005150
-80	-280	0.0001287
-100	-180	0.0014161
-120	-180	0.0033473
-140	-200	0.0016736
-200	-460	0.0001287
220	-200	0.0001287
200	180	0.0347599
200	160	0.0224008
200	-100	0.0001287
180	140	0.0343737
180	100	0.0002575
180	20	0.0002575
180	-100	0.0001287
160	60	0.0003862
160	-40	0.0001287
-60	-160	0.0010299
200	-220	0.0002575
180	-160	0.0002575
-40	-200	0.0001287
-80	-180	0.0006437
-80	-200	0.0001287
260	200	0.0002575
260	180	0.0001287
260	140	0.0001287
260	-320	0.0001287
240	220	0.0066945
240	200	0.0072095
240	180	0.0006437
240	160	0.0002575
240	140	0.0001287
240	120	0.0001287
240	-160	0.0001287
220	180	0.0033473
220	60	0.0001287
220	40	0.0001287
220	-80	0.0001287
200	140	0.0016736
200	120	0.0010299
200	100	0.0002575
200	80	0.0001287
200	40	0.0002575
200	-60	0.0001287
180	120	0.0020598
180	80	0.0002575
180	60	0.0001287
180	40	0.0001287
180	0	0.0001287
180	-20	0.0002575
160	-100	0.0003862
-20	-300	0.0001287

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Table 7.74 Loaded 5-unit well car—longitudinal coupler force (kip) (page 4 of 4)

Maximum Load	Minimum Load	Percent Occurrence
-40	-160	0.0002575
-40	-180	0.0003862
-60	-180	0.0001287
-60	-200	0.0001287
-80	-160	0.0055358
-120	-200	0.0001287
-120	-220	0.0001287

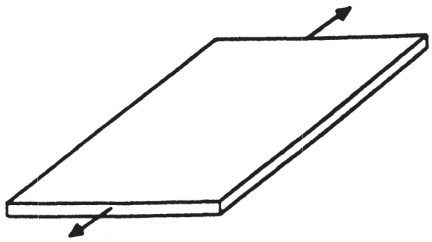
Maximum Load	Minimum Load	Percent Occurrence
-120	-260	0.0001287
-140	-220	0.0002575
-140	-240	0.0001287
-140	-300	0.0001287
-160	-220	0.0047634
-160	-260	0.0002575
-180	-260	0.0012874

Maximum Load	Minimum Load	Percent Occurrence
-200	-280	0.0015449
-260	-300	0.0005150
200	-160	0.0001287
180	-120	0.0003862
180	-80	0.0001287
200	-140	0.0001287

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7.4 Material Properties—Fatigue Properties of Members and Details

7.4.1 Detail Summary for Material Fatigue Properties—Steels



Plain Material
Fig. 7.4.1.1 Plate, as rolled (axial load)
Fig. 7.4.1.2 Machine flame-cut edges (axial load)

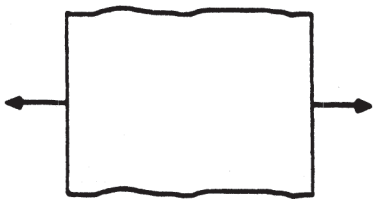
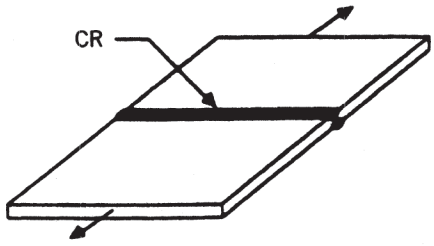
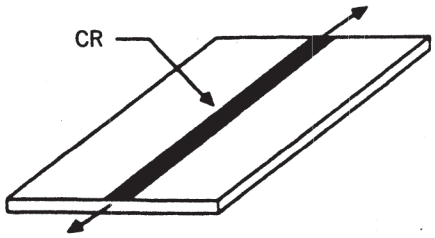


Plate
Fig. 7.4.1.3 Flame-cut edges (axial load)



Butt Joints—transverse (axial load)
Fig. 7.4.1.4 Weld reinforcement intact
Fig. 7.4.1.5 Weld reinforcement removed



Butt joints—Longitudinal (axial load)
Fig. 7.4.1.6 Weld reinforcement intact
Fig. 7.4.1.7 Weld reinforcement removed

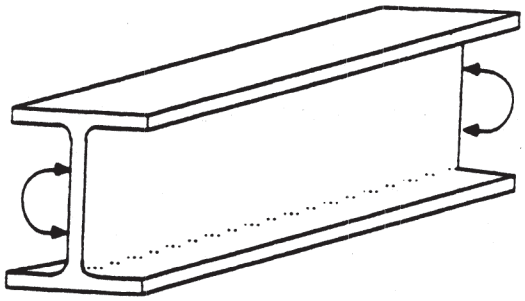


Fig. 7.4.1.8 Beam—rolled (flexural loading)

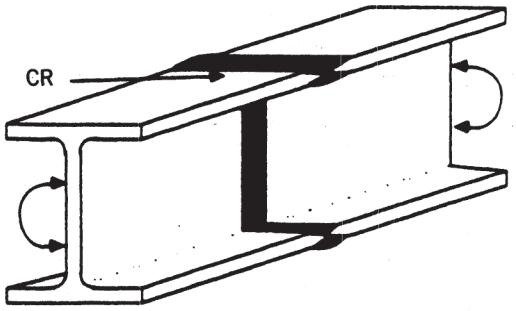


Fig. 7.4.1.9 Beam—rolled or fabricated—in-line or staggered splices (flexural loading)

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7.4.1 Detail Summary for Material Fatigue Properties—Steels (page 2 of 6)

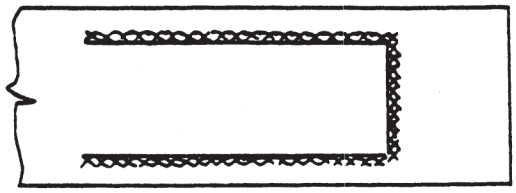
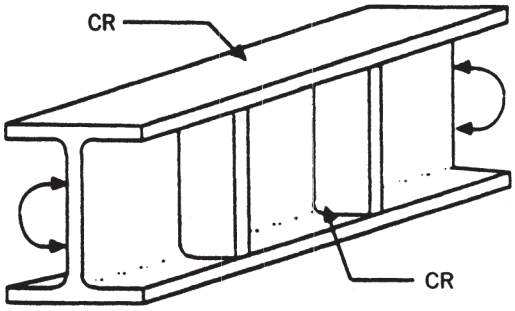


Fig. 7.4.1.10 Continuous welded I-beam with square end cover plates (flexural loading)



Beam—rolled or fabricated, with fillet-welded stiffeners (flexural loading)
Fig. 7.4.1.13 and
Fig. 7.4.1.14

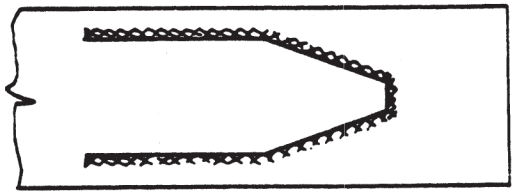


Fig. 7.4.1.11 Continuous welded I-beam with tapered end cover plates (flexural loading)

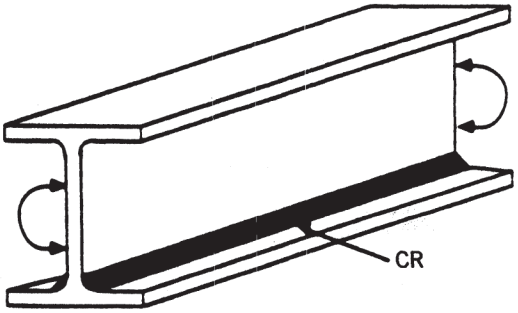


Fig. 7.4.1.15 Fabricated I-beam (flexural loading)

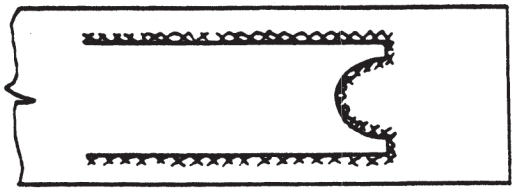


Fig. 7.4.1.12 Continuous welded I-beam with inscribed semicircle end cover plates (flexural loading)

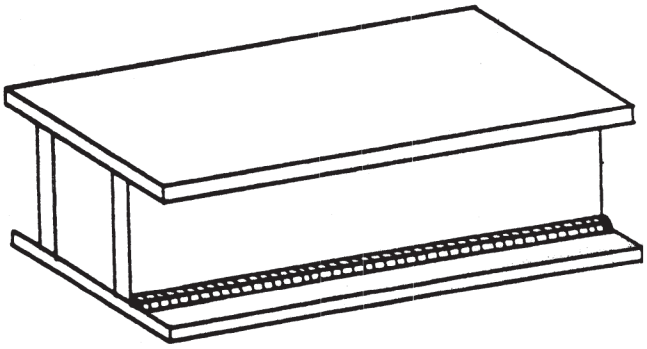


Fig. 7.4.1.16 Continuous welded box beam (flexural loading)

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7.4.1 Detail Summary for Material Fatigue Properties—Steels (page 3 of 6)

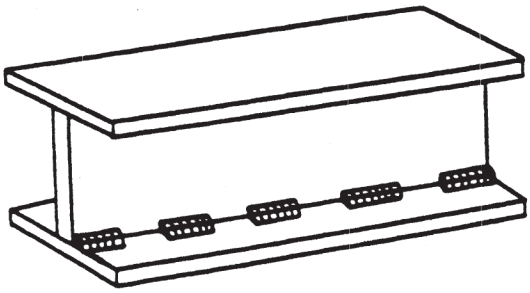


Fig. 7.4.1.17 Intermittent welded box beam or I-beam (flexural loading)

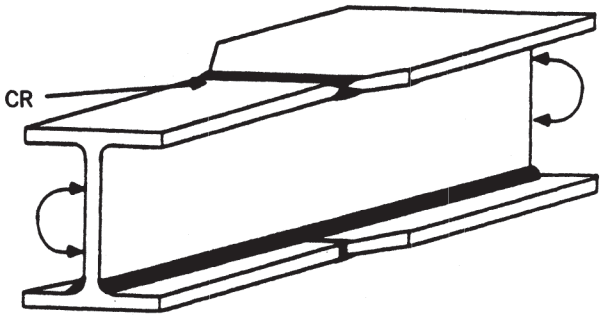


Fig. 7.4.1.21 Beam—fabricated, flange width transition with full penetration splice (flexural loading)

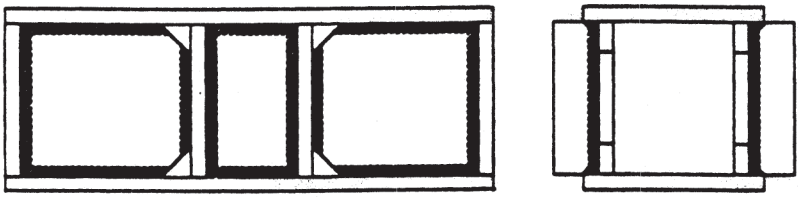
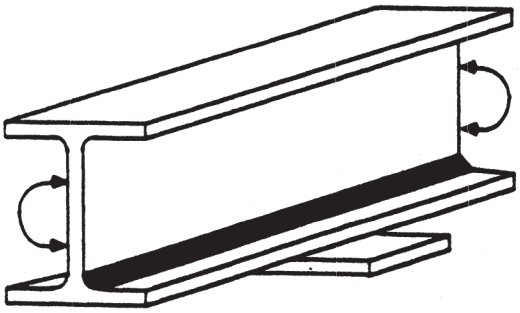


Fig. 7.4.1.18Continuous welded box beam with intermittent webs (flexural loading)



Beam—rolled or fabricated, lateral plate attachment to flange (flexural loading)
Fig. 7.4.1.19 and
Fig. 7.4.1.20

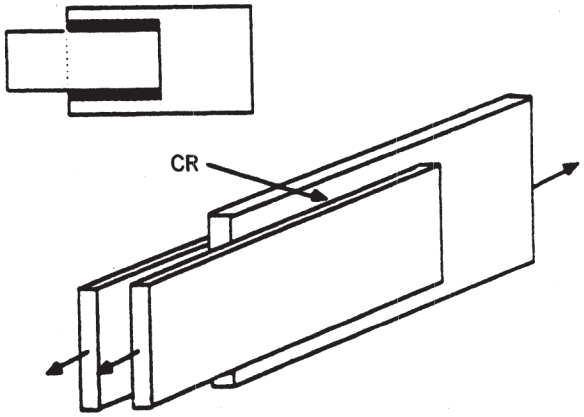


Fig. 7.4.1.22 Lap-welded joint—weld stress critical (axial load)

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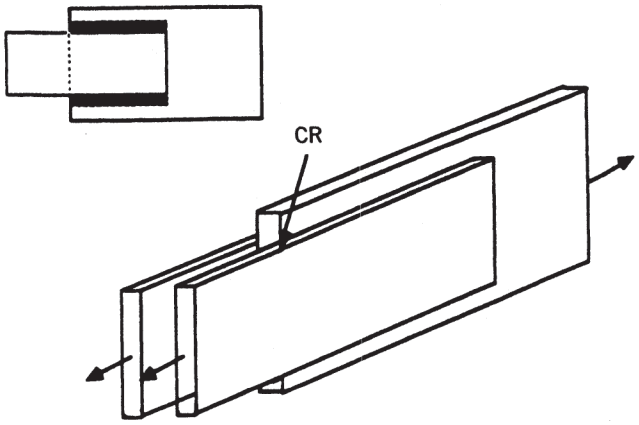


Fig. 7.4.1.23 Lap-welded joint—plate stress critical (axial load)

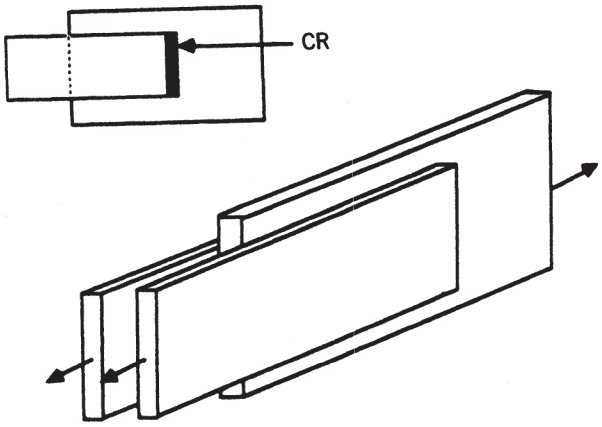
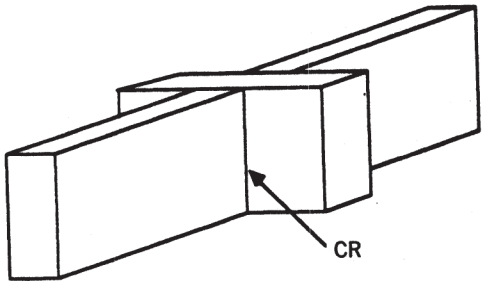


Fig. 7.4.1.24 Lap-welded joint—with transverse weld only (axial load)



Tee joint (axial load)

Fig. 7.4.1.25 Full penetration groove welds—plate stress critical

Fig. 7.4.1.26 Partial penetration groove welds—plate stress critical

Fig. 7.4.1.27 Partial penetration groove welds—weld stress critical

Fig. 7.4.1.28 Continuous fillet welds—weld stress critical

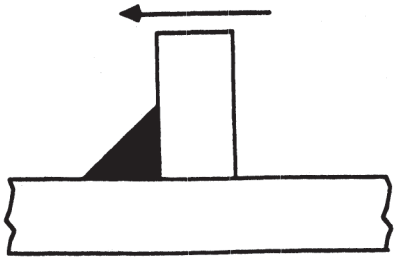


Fig. 7.4.1.29 Single fillet-welded tee joint (bending—opening of root: maximum to zero)

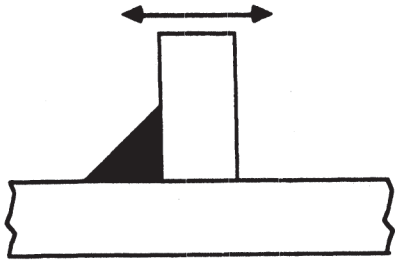


Fig. 7.4.1.30 Single fillet-welded tee joint (reversed bending)

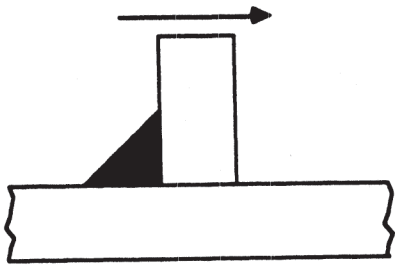


Fig. 7.4.1.31 Single fillet-welded tee joint (bending—closing of root: maximum to zero)

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7.4.1 Detail Summary for Material Fatigue Properties—Steels (page 5 of 6)

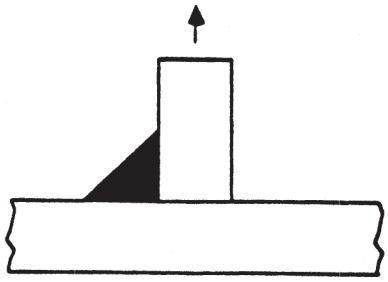


Fig. 7.4.1.32 Single fillet-welded tee joint (axial load)

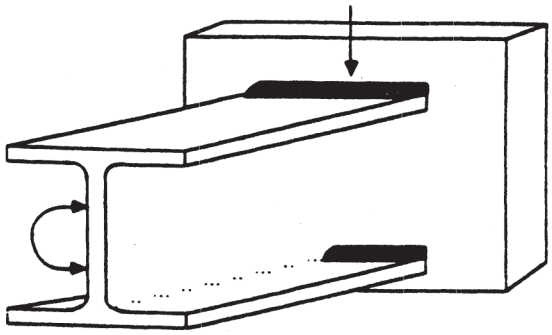


Fig. 7.4.1.36 I-beam—with horizontal fillet welds to vertical plate (flexural loading)

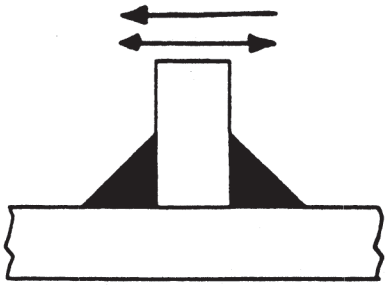


Fig. 7.4.1.33 Double fillet-welded tee joint (bending)

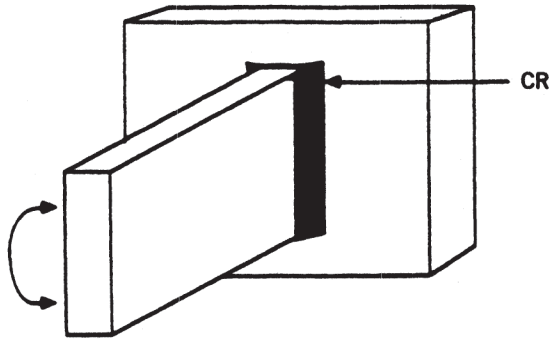
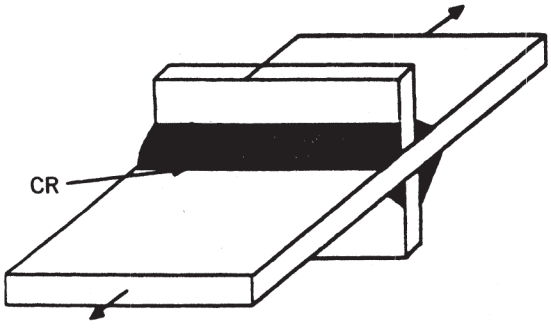


Fig. 7.4.1.37 Vertical plate—with vertical fillet welds (flexural loading)



Plate—with transverse fillet-welded rib
Fig. 7.4.1.34 One side (axial load)
Fig. 7.4.1.35 Both sides (axial load)

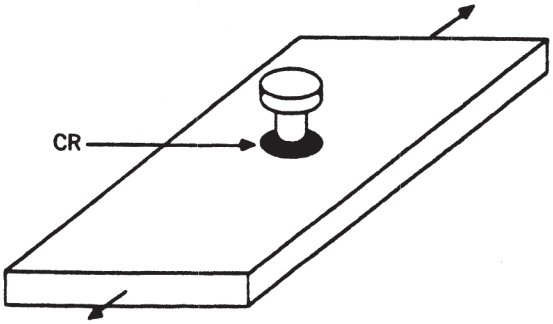
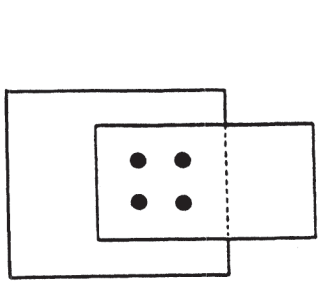


Fig. 7.4.1.38 Plate—with stud welded to surface (axial load)

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7.4.1 Detail Summary for Material Fatigue Properties—Steels (page 6 of 6)



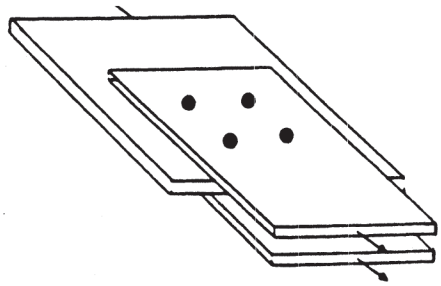


Fig. 7.4.1.39 Slot- and plug-welded joint—plate stress critical (axial load)
Fig. 7.4.1.40 Slot- and plug-welded joint— weld shear stress (axial load)

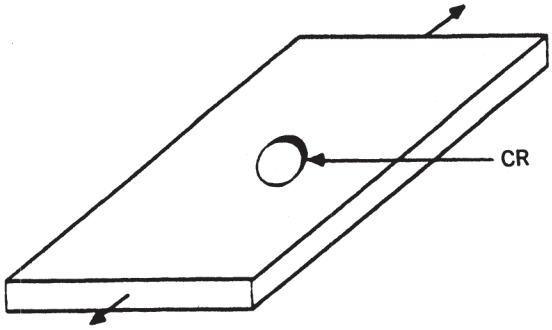
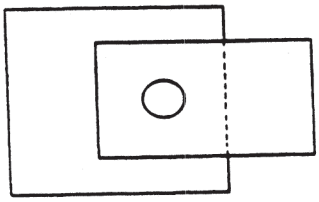


Fig. 7.4.1.41 Plate—with hole at centerline (axial load)



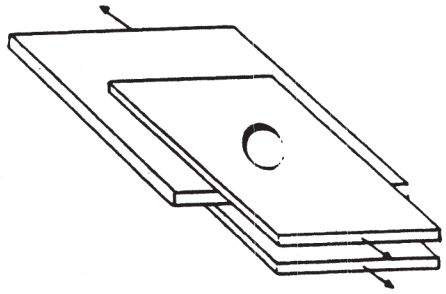


Fig. 7.4.1.42 Riveted or non-friction bolted joint (axial load)
Fig. 7.4.1.43 Bolted friction joint (axial load)

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Flg. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Y Intercept of MGD (ksi) at 2×10^6 (b)	MGD Slope (m)	S-N Slope (k)
7.4.1.1	Plate, as rolled (axial load)		36	27	0.84	0.10
			50	31	0.86	0.10
			100	32	0.77	0.16
7.4.1.2	Plate—Machine flame-cut edges (axial load)		36	(21)	(1.0)	(0.12)
			50	25	(1.0)	0.12
			100	25	(1.0)	0.20
7.4.1.3	Plate—Flame-cut edges (axial load)		36	19.3	1.0	0.16
			50	21.5	1.0	0.21

( ) = estimated value

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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.4	Butt Joints—transverse (axial load), full penetration, Weld reinforcement intact		36	16	0.11
			50	20	0.09
			100	20	0.17
7.4.1.5	Butt Joints—transverse (axial load), full penetration, Weld reinforcement removed		36	20	0.12
			50	24	0.08
			100	31	0.07
7.4.1.6	Butt joints—Longitudinal (axial load), full penetration, Weld reinforcement intact		36	19	0.11
			50	20	0.15
			100	22	0.16

( ) = estimated value

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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Y Intercept of MGD (ksi) 2×10^6 (b)	MGD Slope (m)	S-N Slope (k)	Stress Range (ksi) at 2×10^6 cycles (S_e)
7.4.1.7	Butt joints—Longitudinal (axial load), full penetration, Weld reinforcement removed		36			0.15	19
			50			0.10	25
			100			(0.15)	31
7.4.1.8	Beam—rolled (flexural loading)		36	24	(0.9)	0.15	
			50	26	(0.9)	0.16	
			100	28	0.9	0.16	
7.4.1.9	Beam—rolled or fabricated—in-line or staggered splices (flexural loading)		36			0.14	15
			50			0.23	15
			100			0.23	15

( ) = estimated value

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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.10	Continuous welded I-beam with square end cover plates (flexural loading)		50	6.3	0.31
7.4.1.11	Continuous welded I-beam with tapered end cover plates (flexural loading)		50	6.5	0.30
7.4.1.12	Continuous welded I-beam with inscribed semicircle end cover plates (flexural loading)		50	7.3	0.33

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Flg. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.13	Beam—rolled or fabricated, with fillet-welded stiffeners (flexural loading); bending stress at extreme fiber of beam		36	14	0.21
			50	14	0.24
			100	14	0.28
7.4.1.14	Beam—rolled or fabricated, with fillet-welded stiffeners (flexural loading); principle tensile stress at end of weld to web		36	13	0.21
			50	13	0.24
			100	13	0.28
7.4.1.15	Fabricated I-beam (flexural loading)		36	17	0.13
			50	17	0.15
			100	17	0.23

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Table 7.75 Fatigue properties of members and details—steels
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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.16	Continuous welded box beam (flexural loading)		50	17.1	0.29
7.4.1.17	Intermittent welded box beam or I-beam (flexural loading)		50	11.3	0.31
7.4.1.18	Continuous welded box beam with intermittent webs (flexural loading)		36	7.8	0.28
			50	7.6	0.32

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Flg. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.19	Beam—rolled or fabricated, lateral plate attachment to flange (flexural loading); maximum plate attachment length of 2 in.		36	(9.7)	(0.30)
			50	9.7	(0.30)
			100	(9.7)	(0.30)
7.4.1.20	Beam—rolled or fabricated, lateral plate attachment to flange (flexural loading); maximum plate attachment length of 4 in.		36	(8.9)	(0.30)
			50	8.9	(0.30)
			100	(8.9)	(0.30)
7.4.1.21	Beam—fabricated, flange width transition with full penetration splice (flexural loading)		36	17	0.28
			50	17	0.22
			100	17	0.25

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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.22	Lap-welded joint—weld stress critical (axial load)		36	13	0.14
			50	13	0.14
			100	(13)	(0.14)
7.4.1.23	Lap-welded joint—plate stress critical (axial load)		36	6.7	0.25
			50	6.7	0.25
			100	(6.7)	(0.25)
7.4.1.24	Lap-welded joint—with transverse weld only (axial load)		36	11	0.18
			50	11	0.18
			100	(11)	(0.18)

( ) = estimated value

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Flg. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.25	Tee joint (axial load)—Full penetration groove welds— plate stress critical		36	14	0.13
			50	15	0.13
			100	15	(0.13)
7.4.1.26	Tee joint (axial load)—Partial penetration groove welds— plate stress critical		36	9.7	0.21
			50	(9.7)	(0.21)
			100	(9.7)	(0.21)
7.4.1.27	Tee joint (axial load)—Partial penetration groove welds— weld stress critical		36	8.3	0.17
			50	(8.3)	(0.17)
			100	(8.3)	(0.17)

( ) = estimated value

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Table 7.75 Fatigue properties of members and details—steels
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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.28	Tee joint (axial load)—Continuous fillet welds—weld stress critical; weld throat shear stress		36	12	0.21
			50	12	0.18
			100	(12)	(0.18)
7.4.1.29	Single fillet-welded tee joint (bending—opening of root: maximum to zero)		50	6.2	0.24
7.4.1.30	Single fillet-welded tee joint (reversed bending)		50	13.4	0.19

( ) = estimated value

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Flg. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.31	Single fillet-welded tee joint (bending—closing of root: maximum to zero)		50	14.8	0.21
7.4.1.32	Single fillet-welded tee joint (axial load)		50	2.0	0.25
7.4.1.33	Double fillet-welded tee joint (bending)		50	23.8	0.19

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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.34	Plate—with transverse fillet-welded rib; One side (axial load)		36	16	0.15
			50	16	0.17
			100	16	0.21
7.4.1.35	Plate—with transverse fillet-welded rib; Both sides (axial load)		36	14	0.15
			50	14	0.18
			100	14	0.23
7.4.1.36	I-beam—with horizontal fillet welds to vertical plate (flexural loading) (includes one overhead fillet weld)		36	8.5	0.10
			50	(8.5)	(0.10)
			100	(8.5)	(0.10)

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Flg. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Stress Range (ksi) at 2×10^6 cycles (S_e)	S-N Slope (k)
7.4.1.37	Vertical plate—with vertical fillet welds (flexural loading); weld throat stress		36	20	0.12
			50	(20)	(0.12)
			100	(20)	(0.12)
7.4.1.38	Plate—with stud welded to surface (axial load); weld throat stress		36	11	0.28
			50	(11)	(0.28)
			100	(11)	(0.28)

( ) = estimated value

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Fig. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Y Intercept of MGD (ksi) 2×10^6 (b)	MGD Slope (m)	S-N Slope (k)	Stress Range (ksi) at 2×10^6 cycles (S_e)
7.4.1.39	Slot- and plug-welded joint—plate stress critical (axial load)		36			0.25	6.7
			50			(0.25)	(6.7)
			100			(0.25)	(6.7)
7.4.1.40	Slot- and plug-welded joint—weld shear stress (axial load)		36			0.17	8.7
			50			(0.17)	(8.7)
			100			(0.17)	(8.7)
7.4.1.41	Plate—with hole at centerline (axial load); net section stress		36	20	(1.0)	0.06	
			50	20	(1.0)	0.08	
			100	26	(1.0)	0.15	

( ) = estimated value

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Flg. No.	Description of Member	Member Details	Nom. Yield Stress (ksi)	Y Intercept of MGD (ksi) 2×10^6 (b)	MGD Slope (m)	S-N Slope (k)
7.4.1.42	Riveted or non-friction bolted joint (axial load); net section stress		36	17	(1.0)	0.10
			50	17	(1.0)	0.10
			100	17	(1.0)	0.10
7.4.1.43	Bolted friction joint (axial load); net section stress		36	22	(1.0)	0.08
			50	25	(1.0)	0.17
			100	25	(1.0)	0.29

( ) = estimated value

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7.4.2 Detail Summary for Material Fatigue Properties—Aluminum

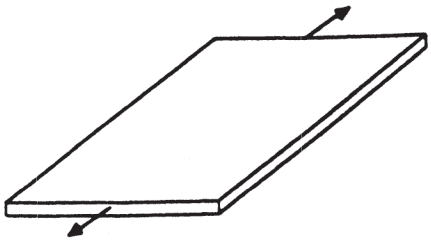
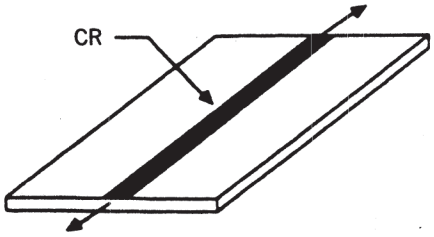
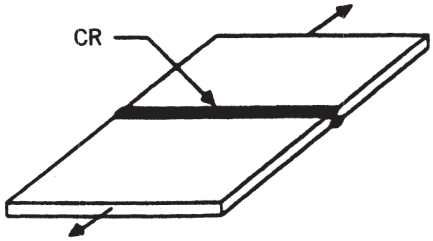


Fig. 7.4.2.1 Sheet or plate (axial load)
Fig. 7.4.2.2 Extrusions (axial load)



Butt joints—longitudinal (axial load)
Fig. 7.4.2.7 Weld reinforcement intact
Fig. 7.4.2.8 Weld reinforcement removed



Butt joints—transverse (axial load)
Fig. 7.4.2.3 Weld reinforcement intact
Fig. 7.4.2.4 Weld reinforcement removed

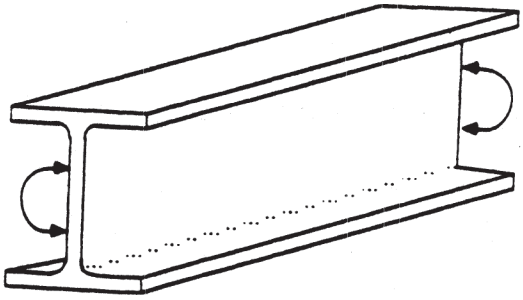
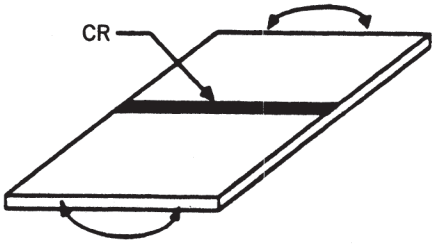


Fig. 7.4.2.9 Beam—extruded (flexural loading)



Butt joints—transverse (flexural loading)
Fig. 7.4.2.5 Weld reinforcement intact
Fig. 7.4.2.6 Weld reinforcement removed

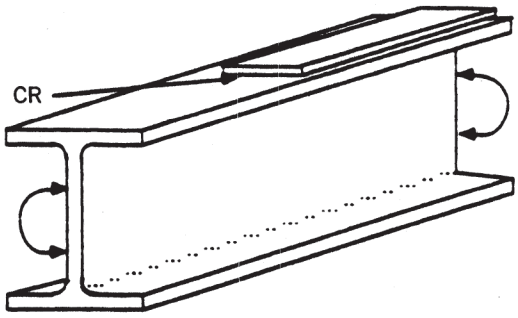


Fig. 7.4.2.10 Beam—extruded or fabricated, with partial length cover plate (flexural loading)

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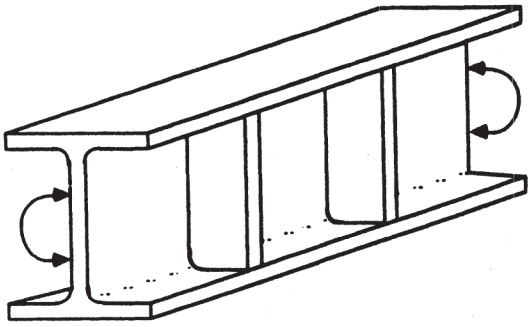


Fig. 7.4.2.11 Beam—extruded or fabricated, with fillet-welded stiffeners (flexural loading)

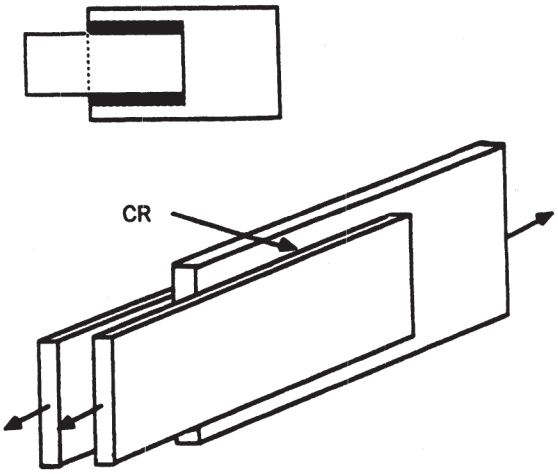


Fig. 7.4.2.15 Lap-welded joint—weld stress critical (axial load)

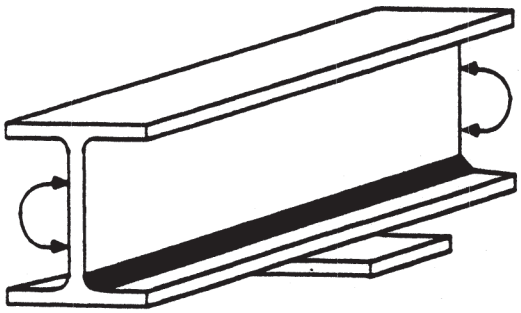
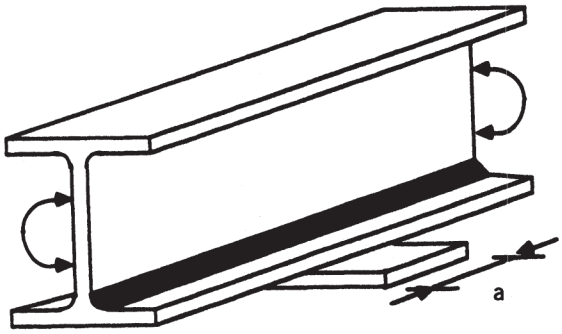


Fig. 7.4.2.12 Beam—fabricated (flexural loading)



Beam—extruded or fabricated, with lateral plate attachment to flange (flexural loading)
Fig. 7.4.2.13 a < 2 in.
Fig. 7.4.2.14 a ≤ 4 in.

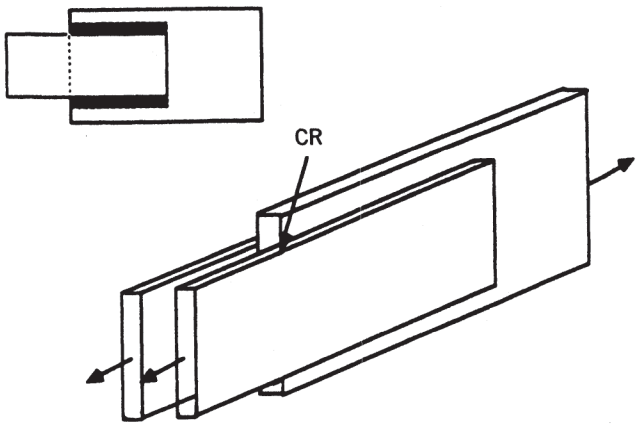


Fig. 7.4.2.16 Lap-welded joint—plate stress critical (axial load)

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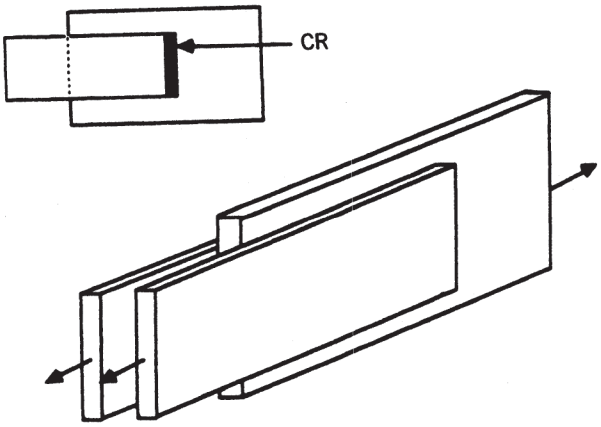


Fig. 7.4.2.17 Lap-welded joint—with transverse weld only (axial load)

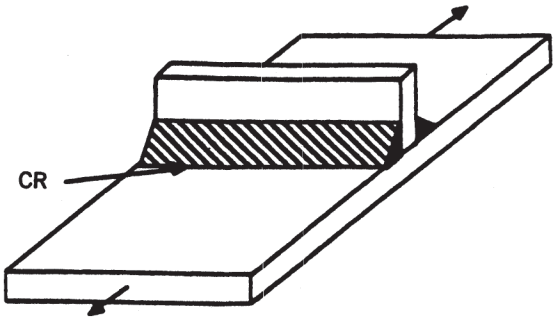
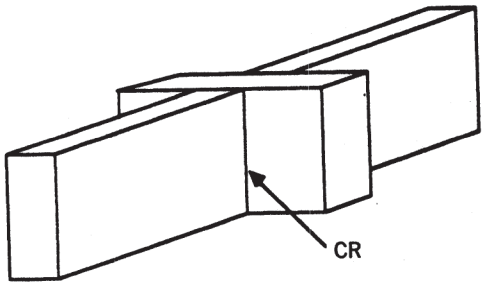
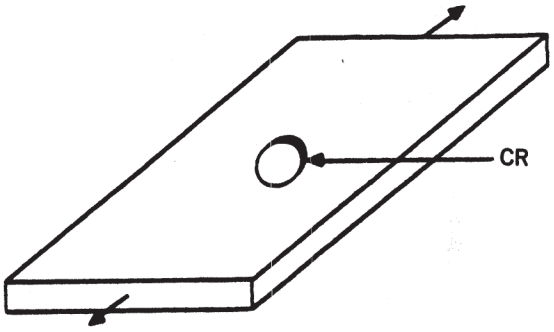


Fig. 7.4.2.25 Plate—with transverse fillet-welded rib—one side (axial load)





Tee joints (axial load)

Fig. 7.4.2.18 Full penetration groove weld—plate stress critical

Fig. 7.4.2.19 Partial penetration groove weld—plate stress critical

Fig. 7.4.2.20 Partial penetration groove weld—weld stress critical

Fig. 7.4.2.21 Fillet-welded—weld stress critical

Fig. 7.4.2.22 Fillet-welded—plate stress critical

Fig. 7.4.2.26 Plate—with holes (axial load)

Tee joints (flexural loading)

Fig. 7.4.2.23 Full penetration groove welds—plate stress critical

Fig. 7.4.2.24 Partial penetration groove welds—plate stress critical

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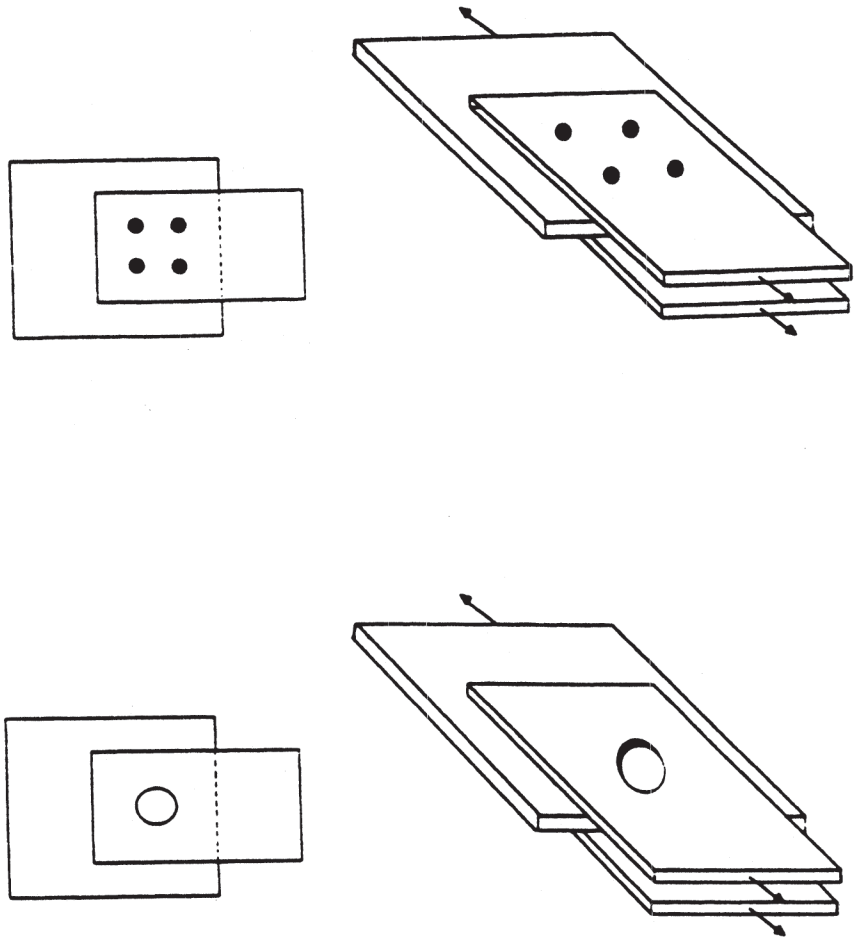


Fig. 7.4.2.27 Riveted or nonfriction bolted joint—net section stress (axial load)

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Fig. No.	Description of Member	Member Details	MGD Intercept (b)[a/]	MGD Slope (m)	S-N Slope (k)	Stress Range (ksi) at 10×10^6 cycles (S_e)
7.4.2.1	Sheet or plate (axial load)		7.3	0.80	0.16	
7.4.2.2	Extrusions (axial load)		7.3	0.80	0.16	
7.4.2.3	Butt joints—transverse (axial load); full penetration; Weld reinforcement intact				0.24	3.7

a/ y-intercept at 10×10^6 cycles

Table 7.76 Fatigue properties of members and details—aluminumC-II–404
(If no value is shown, variable does not apply for this detail.)
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Flg. No.	Description of Member	Member Details	Stress Range (ksi) at 10×10^6 cycles (S_e)	S-N Slope (k)
7.4.2.4	Butt Joints—transverse (axial load), full penetration, Weld reinforcement removed		4.6	0.21
7.4.2.5	Butt joints—transverse (flexural loading); full penetration; Weld reinforcement intact		3.7	0.24
7.4.2.6	Butt joints—transverse (flexural loading); Weld reinforcement removed		4.6	0.21

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Table 7.76 Fatigue properties of members and details—aluminumC-II–404
(If no value is shown, variable does not apply for this detail.)
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Fig. No.	Description of Member	Member Details	MGD Intercept (b)[a/]	MGD Slope (m)	S-N Slope (k)	Stress Range (ksi) at 10×10^6 cycles (S_e)
7.4.2.7	Butt joints—longitudinal (axial load); full penetration; Weld reinforcement intact				0.24	5.1
7.4.2.8	Butt joints—longitudinal (axial load); full penetration; Weld reinforcement removed				0.21	6.0
7.4.2.9	Beam—extruded (flexural loading)		7.3	.080	0.16	

[a/] y-intercept at 10×10^6 cycles

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Table 7.76 Fatigue properties of members and details—aluminumC-II–404
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Flg. No.	Description of Member	Member Details	Stress Range (ksi) at 10×10^6 cycles (S_e)	S-N Slope (k)
7.4.2.10	Beam—extruded or fabricated, with partial length cover plate or attachment more than 4 in. long (flexural loading)		1.6	0.29
7.4.2.11	Beam, extruded or fabricated, with fillet welded stiffeners, bending stress at extreme fiber of beam (flexural loading)		3.1	0.24
7.4.2.11	Beam—extruded or fabricated, with fillet- welded stiffeners (flexural loading); principle tensile stress at end of weld to web		2.7	0.24

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Table 7.76 Fatigue properties of members and details—aluminumC-II–404
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Fig. No.	Description of Member	Member Details	Stress Range (ksi) at 10×10^6 cycles (S_e)	S-N Slope (k)
7.4.2.12	Beam—fabricated (flexural loading)		4.3	0.16
7.4.2.13	Beam—extruded or fabricated, with lateral plate attachment to flange (flexural loading) where a < 2 in. long		2.5	0.29
7.4.2.14	Beam—extruded or fabricated, with lateral plate attachment to flange (flexural loading) where a £ 4 in. long		(2.3)	0.25

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Table 7.76 Fatigue properties of members and details—aluminumC-II–404
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Flg. No.	Description of Member	Member Details	Stress Range (ksi) at 10×10^6 cycles (S_e)	S-N Slope (k)
7.4.2.15	Lap-welded joint—weld stress critical (axial load); longitudinal or longitudinal with transverse fillet weld		2.3	0.25
7.4.2.16	Lap-welded joint—plate stress critical (axial load); longitudinal or longitudinal with transverse fillet weld		1.6	0.29
7.4.2.17	Lap-welded joint—with transverse weld only (axial load); plate stress at toe of weld		2.4	0.24

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Table 7.76 Fatigue properties of members and details—aluminumC-II–404
(If no value is shown, variable does not apply for this detail.)
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Fig. No.	Description of Member	Member Details	Stress Range (ksi) at 10×10^6 cycles (S_e)	S-N Slope (k)
7.4.2.18	Tee joint—Full penetration groove weld— plate stress critical (axial load)		2.4	0.24
7.4.2.19	Tee joint—Partial penetration groove weld— plate stress critical (axial load)		(1.0)	0.29
7.4.2.20	Tee joint—Partial penetration groove weld— weld stress critical (axial load)		(1.6)	0.29

( ) = estimated value

Table 7.76 Fatigue properties of members and details—aluminumC-II–404
(If no value is shown, variable does not apply for this detail.)
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Flg. No.	Description of Member	Member Details	Stress Range (ksi) at 10×10^6 cycles (S_e)	S-N Slope (k)
7.4.2.21	Tee joint—Fillet-welded—weld stress critical (axial load)		3.0	0.25
7.4.2.22	Tee joint—Fillet-welded—plate stress critical (axial load)		2.4	0.24
7.4.2.23	Tee joint—Full penetration groove welds— plate stress critical (flexural load)		2.3	0.27

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Table 7.76 Fatigue properties of members and details—aluminumC-II–404
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Fig. No.	Description of Member	Member Details	MGD Intercept (b)[a/]	MGD Slope (m)	S-N Slope (k)	Stress Range (ksi) at 10×10^6 cycles (S_e)
7.4.2.24	Tee joint—Partial penetration groove welds— plate stress critical (flexural load)				0.27	2.0
7.4.2.25	Plate—with transverse fillet-welded rib—one side (axial load)				0.26	(2.3)
7.4.2.26	Plate—with holes (axial load)		4.6	(1.0)	0.21	

( ) = estimated value

[a/] y-intercept at 10×10^6 cycles

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Table 7.76 Fatigue properties of members and details—aluminumC-II–404
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Fig. No.	Description of Member	Member Details	MGD Intercept (b)[a/]	MGD Slope (m)	S-N Slope (k)
7.4.2.27	Riveted or nonfriction bolted joint—net section stress (axial load)		4.3	(.90)	0.21

( ) = estimated value

[a/] y-intercept at 10×10^6 cycles

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7.5 Strain Life Method for Fatigue Analysis

7.5.1 The strain life method is an alternative fatigue analysis method and is not mandatory. It is used extensively by the automotive and aircraft industries, and it is particularly useful for low-cycle fatigue applications for critical freight car components. The method is also applicable to high-cycle fatigue analysis. The strain life method allows for the presence of plastic strains and results in more accurate life estimates for ductile metals. This method is particularly useful for features in which there may be localized areas of plastic stress, but the plastic strains are constrained by surrounding material or alternative load paths that remain elastic.

7.5.2 The strain life method is described in detail in AAR Report R-762, "Strain Life Method for Fatigue Analysis of Freight Cars and Components," by D. Socie and V. Sharma.

7.6 Fatigue Test Requirements for Updating Freight Car REPOS

In the late 1970s and early 1980s, a test methodology was developed and implemented by the AAR. The resulting output was a REPOS data set (test data required for railcar fatigue analysis) and this Chapter 7, "Fatigue Design of New Freight Cars," in Specification M-1001. Load spectra for the following cars were published:

- **High side 263K coal gondola in unit train service**
  - Empty and loaded side-bearing loads
  - Empty and loaded center-plate loads
  - Empty and loaded total vertical bolster loads
  - Empty and loaded longitudinal coupler loads
- **263K open top hopper.**
  - Empty and loaded side-bearing loads
  - Empty and loaded center-plate loads
  - Empty and loaded total vertical bolster loads
  - Empty and loaded coupler loads
  - Severe loaded coupler loads
  - Empty and loaded car body twist moment
- **263K stub sill tank car:**
  - Empty and loaded side-bearing loads
  - Empty and loaded center-plate loads
  - Empty and loaded total vertical bolster loads
  - Empty and loaded longitudinal coupler loads
  - Empty and loaded vertical coupler loads
- **70-ton boxcar:**
  - Loaded side-bearing loads
  - Loaded center-plate loads
  - Loaded total bolster loads
- **5-unit articulated TOFC spine car for 65K trailers (ARC-5 Car)**
  - Empty & Loaded end bolster side-bearing loads
  - Empty & Loaded end bolster center-plate loads
  - Empty & Loaded end bolster total bolster loads
  - Loaded "articulated bolster" side-bearing loads
  - Loaded "articulated bolster" center-plate loads
  - Loaded "articulated bolster" total vertical loads
  - Empty & Loaded articulated connector vertical, lateral and longitudinal loads
  - Empty & Loaded vertical and lateral trailer-hitch loads
  - Empty & Loaded vertical and lateral trailer bogie loads

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As the rail industry has continued to evolve, the need for continually updated data has become apparent for the following reasons:

- change in car design/car types
- change in analysis techniques and tools
- change in the railroad environment

This section of Chapter 7 describes the test requirements for obtaining updated fatigue load spectra. The AAR Equipment Engineering Committee and subordinate task force groups (when currently operating) must approve each application to test for new load spectra. Test proponents may vary some of the test specification requirements listed below in the actual conduct of the testing, but for the resulting data to be utilized as load spectra in paragraph 7.3 of this AAR specification, the proponent's test plan must be approved by the Freight Car Fatigue Task Force (FCFTF).

7.6.1 Test Car Selection and Loading

Only loaded testing is to be conducted. Experience has shown that empty car operation has a minimal effect on fatigue life. The Freight Car Fatigue Task Force performed an initial prioritization of the car types to be tested, as listed below. Actual cars selected for testing will be approved by the AAR Equipment Engineering Committee and the subordinate Industry Task Force. Cars will be obtained for testing through donation agreements.

The test car will be fully loaded, unless otherwise designated by the Task Force, to accommodate special situations where certain cars typically operate in conditions other than fully loaded.

FCFTF II—Car types to be tested—priority ranking
S-286 stub sill tank car
S-286 high side coal gondola. Severe and regular unit train service. (Rotary dump, steel under frame with aluminum body.) The forces from this car type would also serve for open top hopper cars.
5-unit 40 ft double stack car (70/125-ton split wedge stabilizers)
3-unit 53 ft double stack car (70/125-ton split wedge stabilizers)
S-286 grain covered hopper car (through center sill with about 5,100 ft^3)
S-286 boxcar (60 ft Plate F paper car with EOCC)
S-286 73 ft center beam car
Single unit 53 ft double stack car (70-ton split wedge stabilizers)
89 ft 70-ton flat car with autorack
S-283 89 ft flat car
S-286 60 ft steel gondola car
S-286 62 ft bulkhead flat car
53 ft spine car

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7.6.2 Test Instrumentation Preparations

The transducers to be installed on the test car are shown in paragraph 7.6.2.3. Strain gauges will be mounted on one bolster to measure dynamic center plate and side-bearing loads applied to the car. Instrumentation will be applied in as stealthy a manner as possible to keep the instrumentation as inconspicuous as possible. All computers and instrumentation will be in compliance with *MSRP*, Section C-I, Standard S-2045 "Remote Monitoring Equipment."

7.6.2.1 Car Body Load Spectra Measurements

An example of a typical gauge installation is shown in Fig. 7.3. A finite element analysis of each bolster design shall be completed to determine the optimum locations for the gauges on that design. Gauges should be located in areas that exhibit high sensitivity for the intended load measurement but relativity low sensitivity for the other acting loads. The gauges also should be located in areas with relatively uniform stress distribution.

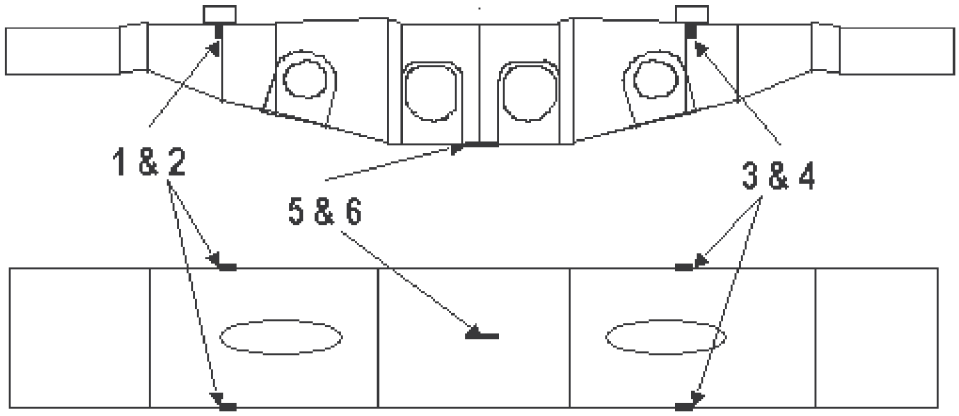


Fig. 7.3 Example strain gauge locations—bolsters

For the example shown in Fig. 7.3, the strain gauges at locations 1 and 2 on the bolster would be single element gauges wired into a half-bridge circuit to measure side bearing forces on one end of the bolster. The gauges at bolster locations 3 and 4 would be connected in a similar manner to measure side bearing forces on the opposite end of the bolster. Two gauges at location 5 on the bolster would be wired into a half-bridge configuration to measure center bowl load.

There will be redundant strain gauges mounted at all bolster locations noted. These gauges would serve as backup units in the event that problems occur with the primary units. A calibrated, instrumented coupler will be mounted on one end of the car to provide longitudinal coupler force data. The coupler uses strain gauges to measure axial forces in compression and tension. This coupler also has a redundant circuit that can be used to measure force if the primary circuit should become inoperative. Car velocity and position (longitudinal and latitude) data will be supplied by an on-board global positioning system (GPS). In addition to car position, this system shall be able to provide vehicle speed data with a resolution of at least 0.5 miles per hour for speeds over 2 mph.

7.6.2.2 Additional Measurements

Six channels of critical location dynamic strain shall also be recorded. Locations for placement of these gauges should be determined for each car design based on field experience or stress analysis by the car manufacturer.

If capacity allows additional recording channel capacity, it is beneficial to the understanding of the load environment to record vertical and lateral load into one side frame as well as the spring deflection occurring within that same side frame. Both vertical and lateral side frame load environment would each be measured using voltage output from strain gauges. For each load component, four strain gauges shall be mounted to the casting and wired into a full bridge circuit. Placement of the vertical gauges will be designed for maximum voltage output from vertical load while being relatively insensitive to lateral force. Placement of the lateral gauges would follow a similar philosophy. An example of a typical gauge installation is shown in Fig. 7.4. As with the bolster, a finite element analysis of each design should be completed to determine the optimum locations for the gauges on that design. Spring displacement would be measured by string potentiometers, ultrasonic gap measurement devices, or similar equipment capable of similar time-versus-displacement response.

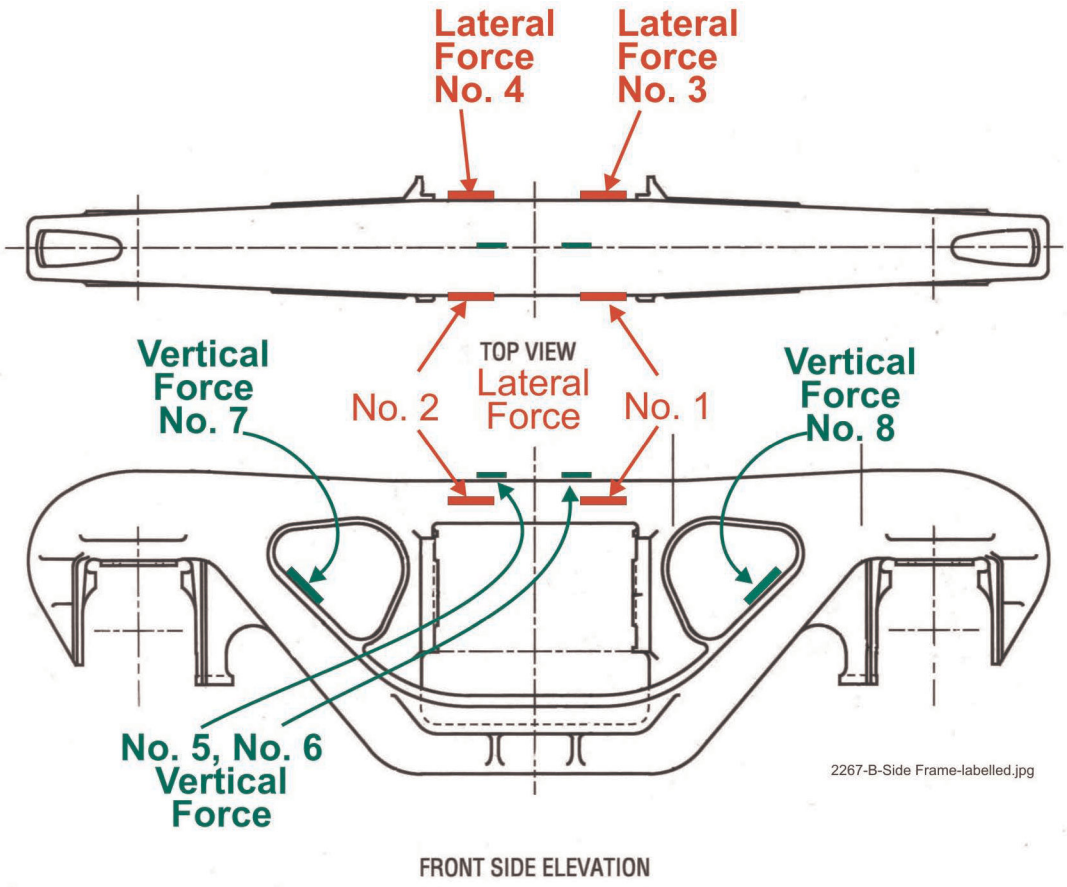


Fig. 7.4 Example strain gauge locations—side frame

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7.6.2.3 Transducer List

Measurement	Install and Calibrate	Record	Transducer Type, Comment	Data Type, Analysis
Car Fatigue Load Spectra Measurements				
Center Plate Vert Load—One End Only	2	1	Strain gauge, calibrated in load frame,	Time History, Rainflow Post Processing
Side-Bearing Load Bridge—One End Only	4	2	Strain gauge, calibrated in load frame	Time History, Rainflow Post Processing
Longitudinal Coupler Load—One End Only	2	1	Instrumented Coupler (strain gauge), calibrated in load frame, 20kip Bins	Time History, Rainflow Post Processing
System Measurements				
Power	n/a	1	System	Time History
GPS Train Speed	1		GPS, may not count against channel count	Time History
GPS Train Location	1		GPS, may not count against channel count	Time History
Car Body Structural Measurements				
Car Body Strain Locations (Key locations, twist, etc.)	6	6	Strain gauge, locations based on car type (history, analysis)	Time History, Rainflow Post Processing
Bolster and Side Frame Load Spectra				
Bolster Load Vector Long Location—One End Only	1	1	Strain gauge, calibrated in load frame	Time History, Rainflow Post Processing
SF Load Vertical Load Magnitude—One End Only	1	1	Strain gauge, calibrated in load frame	Time History, Rainflow Post Processing
SF Load Lateral Load Magnitude—One End Only	1	1	Strain gauge, calibrated in load frame	Time History, Rainflow Post Processing

7.6.2.4 Data Acquisition System

A relatively small, self-contained system capable of recording at least 16 channels of data shall be used. Rate at which data is sampled should be at least 256 samples per second with the data low-pass filtered at a minimum of 30 Hz. Data storage size should be large enough so that during a test, all 16 channels can be sampled at 256 Hz. The test should be conducted for approximately 10,000 miles.

All data will be recorded and stored continuously at a speed of 5 mph or above. When travel speed is below 5 mph, data can be recorded in a "burst" mode. The burst mode should contain at least 4 seconds of the event beginning at least 1/2 second before the trigger. The trigger is recommended to be a longitudinal coupler force and/or acceleration. The burst mode should capture all the channels following a triggered event. Power for the system must be self-contained and fulfill the system's needs during the testing period.

7.6.2.5 Calibration of Transducers

The instrumented couplers shall be calibrated against certified load cells by the manufacturer prior to the test. Output from the instrumented coupler will be in units of thousands of pounds (kips). The calibration of the bolster gauges, 1 through 6, will be accomplished by applying static forces (through calibrated load cells) in the following sequence:

1. Apply load to center bowl only (at bowl center and at bowl edges independently).
2. Apply load to one side bearing location only.
3. Apply load to opposite side bearing location only.
4. Apply load to each bowl edge and the corresponding side bearing simultaneously.

The loads will be applied slowly from zero to at least 50,000 lb. Such a sequence will be repeated at least three times at each location. From the resulting linear equations relating gauge output in volts with applied force, relationships will be established that can be used to calculate center bowl and side bearing forces using the output from strain gauges 1 through 6. These relationships or algorithms relating strain gauge output in volts to applied forces will be reviewed by representatives of the Fatigue Task Force.

In a similar manner, the output from the strain gauges mounted on the side frame can be calibrated to allow measurement of the vertical and lateral forces applied to the side frame. First, a slowly applied vertical load of 2,000 to 100,000 lb will be applied to the casting through the spring nest support area. Response will be recorded from both vertical and lateral gauge circuits. This loading sequence will be repeated two more times. Forces will then be applied to the casting at the locations normally reacting the loads from the bolster. The forces will be applied slowly from 1,000 lb to 25,000 lb pushing outboard on the casting and then back through zero load to 25,000 lb pushing inboard. This sequence will also be repeated at least twice while recording the output from both vertical and lateral circuits. Again the equations relating gauge output in volts with applied force will be used to establish relationships that can calculate vertical and lateral forces applied to the side frame as a function of only output from the two applied strain gauge circuits.

7.6.2.6 System Check-Out in Controlled Environment

After the calibration tasks have been completed and the test car/instrumentation package fully assembled, it will first undergo a static load evaluation. The car body with rated payload on board will be raised off of the instrumented truck and then lowered back onto the truck as data from the bolster and side frame strain gauges is recorded continuously on the acquisition system that will be used for the over-the-road test. This static test sequence will be repeated at least one additional time.

After the static load test, the loaded test car will be placed in a consist with at least four other cars and tested on the rails in a controlled environment. This will provide an opportunity to demonstrate that all systems and transducers are working properly before the car leaves for the over-the-road trip. The test car will be placed in the next-to-last position farthest from the locomotive. The test car should first traverse sections of track containing known, calibrated perturbations. These perturbations should include “twist and roll” and “pitch and bounce sections.” Test speeds used for each section should include those that produce the maximum car response. Such tests provide a way to demonstrate that the bolster and side frame transducers are recording the expected responses during the types of maneuvers that are known to produce those car body responses.

The test car and its consist will also be subjected to an extended test over standard curved and tangent track. This test will be two to three days in length, and test speed will range from zero to 50 mph. The purpose of this test is to ensure that the coupler force circuits are working properly and that the data acquisition system, batteries, charging system, and system health reporting sequences can all function properly for an extended period.

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7.6.3 Test Route Selection

The test route for each car type will be determined by the task force and approved by the Equipment Engineering Committee. Routes selected will be the most appropriate service and train makeup for the car type. Time of year also will be a consideration.

7.6.4 Train Makeup

The test conductor will work to ensure that the car is located in the middle third of the train consists, as much as is reasonably possible.

7.6.5 Test Operations and Reporting

As each car type and route will have some specific issues, the test conductor will outline a plan for the following. The AAR Equipment Engineering Committee and the Freight Car Fatigue Task Force will review and approve the plan for each car type.

7.6.5.1 Test Logs

When possible, a train list indicating the number of cars in the train, the location of the test car within the train, and the number and location of the locomotives will be obtained daily from the railroad transporting the test car.

7.6.5.2 Test Data Downloads and Archiving

The following steps will be followed. Variations of testing techniques or specific values used will be reviewed by the FCFTF if the resulting data is to be included in the specification's fatigue spectra.

- Car location will be monitored using information broadcast by on-board global position system (GPS)
- Basic system health and GPS data will be monitored every 6 hours via a wireless connection (allowing for signal availability). The following data will be inspected:
  - battery voltage
  - GPS location and speed
  - values for each data channel (maximum, minimum, mean, and standard deviation)
- All data channels will be recorded continuously while car velocity is above 5 mph. At a velocity of less than 5 mph, data can be collected continuously or in burst mode. In burst mode, thresholds will be set so that data will be recorded when either of the following occurs:
  - vertical coupler force exceeds about 10,000 lb; or
  - longitudinal coupler force exceeds approximately 20,000 lb

  The burst mode should contain at least 4 seconds of the event beginning at least 1/2 second before the trigger.
- Total test duration should cover approximately 10,000 miles. Data can be downloaded periodically, but efforts should be made to minimize testing interference.
- Time domain longitudinal coupler force will be Rainflow-cycle-counted to produce a single range-mean histogram file.
- Time domain strain data will be converted to force data using the previously determined conversion factors and will be Rainflow-cycle-counted to produce range-mean histograms of bolster center bowl and side bearing force. Side frame vertical and lateral force spectra can be processed in a similar manner.
- In addition to GPS location, car speed and accumulated mileage data will be available within each data file.
- All data from the on-board system shall be archived in permanent storage.

7.6.5.3 Progress Reporting

Weekly updates to the Freight Car Fatigue Task Force shall be done via phone or e-mail.

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7.6.6 Chapter 7 Updating and Data Formatting

Upon review and approval by the Freight Car Fatigue Task Force, the load spectra data will be added to paragraph 7.3 “Environmental Load Spectra” of this standard, either as an augmentation of existing data or as a replacement of existing data.

7.7 Finite Element Analysis of Freight Car Structures—Recommended Practice

The Freight Car Fatigue Task Force was constituted by the Association of American Railroads in order to improve fatigue life prediction accuracy in freight car structures. There are numerous ways to model any given structural feature and small changes in modeling can affect the calculated stresses significantly. These changes in calculated stress can cause large changes in calculated fatigue life. It was therefore determined that a Finite Element Analysis Recommended Practice should be developed in order to promote the following:

- Consistency between manufacturers
- Consistency over time for each manufacturer
- Accurate fatigue life calculations
- Efficient model development
- Incorporation of “lessons learned”

7.7.1 Scope

This recommended practice applies to all railroad freight cars built to Association of American Railroad standards, but does not apply to tank cars, passenger cars, or components.

This recommended practice applies to a formal analysis of a car for the purpose of assessing its structural integrity and/or fatigue life for submission to the AAR for approval. It is realized that, during the design process, simpler and less detailed analysis is often performed to support design decisions.

This recommended practice does not cover the effects of vibration on a freight car structure.

7.7.1.1 Non-Mandatory

This recommended practice is intended to give guidance. All freight car designs are different and no standard can cover every eventuality. Also, some car structural designs are complex and it is not always possible to achieve the best practices in their analysis. Accordingly, this recommended practice is not mandatory but should be followed as closely as is practical in any given situation.

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7.7.2 Modeling and Meshing

7.7.2.1 Extent of Analysis

It is important to model those details that are likely to be susceptible to fatigue failure. In general, this includes the following:

- Free edges with geometrical stress concentrations
- Joints (welded, bolted, or of any other type)
- Areas of the structure where brackets or other items are attached
- Areas of abrupt section change

7.7.2.2 Element Type Selection

7.7.2.2.1 Beam Elements

In general, beam elements do not provide sufficiently fine resolution of stresses when representing plate-type structures and should not be used in areas where fatigue stresses are to be calculated.

7.7.2.2.2 Plate and Shell Elements

The majority of freight car structures should be modeled using plate or shell elements. They adequately represent thin-plate materials where through-thickness properties are not critical to the design. Where such properties are critical, solid elements should be used. Plate thicknesses of 5/8 in. or greater—where significant through-thickness stresses can occur—can suffer inter-laminar separation, and accurate through-thickness stresses are needed. In these cases, solid elements should be used. Cross-weld situations as shown in Fig. 7.5 can result in high local through-thickness stresses, and either solid elements should be used or great care must be taken in interpreting the results.

Shell elements of Type H should be a minimum of four node quadrilateral with six degrees of freedom at each node. Membrane and bending stresses must be adequately represented by the element. This type of element does not perform well when allowed to degenerate into its triangular form, and this should be avoided in regions where fatigue stresses are to be calculated. The shape of quadrilateral elements should be as close to a square as possible. Excessive length-to-width ratio (above 10:1) and angularity (internal angle at corner greater than 155°, deviation from parallel for opposite edges greater than 70° included angle) should not be used. Length-to-width ratios greater than three should be avoided as far as possible in regions where fatigue stresses are to be calculated. Elements of higher order may be used as needed in areas of high-stress gradient.

Elements of Type P can increase the degree of the polynomial defining their shape in order to improve their accuracy in regions of high-stress gradient. This often is accomplished automatically within the FE code. It is the analyst's responsibility to demonstrate that adequate accuracy has been achieved when this type of element is used.

When modeling curved surfaces and cut-outs, each element should not extend over an arc of more than 23° (see Fig. 7.6).

Plate elements do not provide any stiffness at the nodes about an axis normal to the element surface, and this must be born in mind when developing an element mesh. (See paragraph 7.7.2.6, "Mesh Density and Element Shape.")

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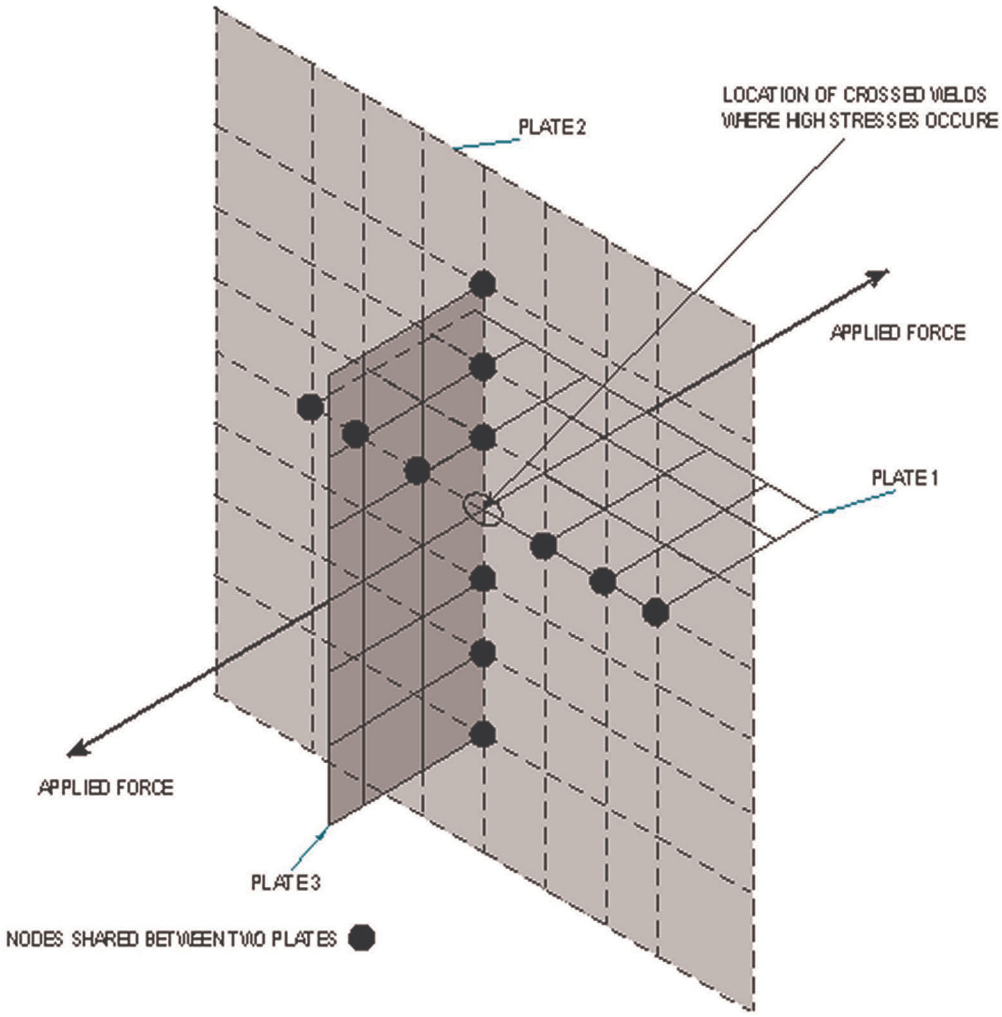


Fig. 7.5 Cross-welds producing high stress

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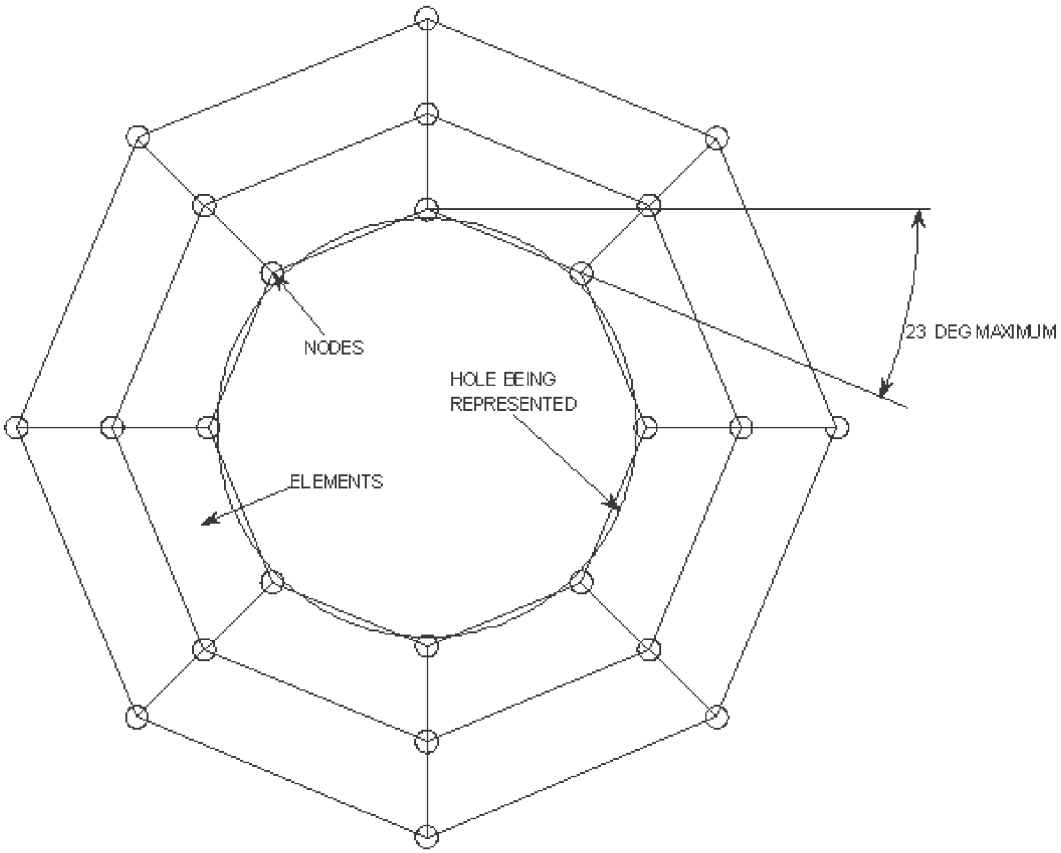


Fig. 7.6 Idealization of a hole

7.7.2.2.3 Solid Elements

Solid elements should be used under any of following conditions:

- when the component being modeled is a solid (such as a casting) as opposed to a plate member;
- when through-thickness properties are important in a plate structure; or
- when the geometry of the structure cannot be well represented using plate elements.

Solid elements also can be used to provide higher accuracy in the region of a weld by modeling the weld itself. The stresses developed in the weld will then include the stress concentration due to the weld geometry, and these stresses should not be compared with allowable stresses in Chapter 7 of this specification. This type of element does not perform well when allowed to degenerate into its pyramidal form with triangular sides, and this should be avoided in regions where fatigue stresses are to be calculated. Ten-node tetrahedral elements offer reasonable results. The shape limitations applied to plate elements also should be applied to solid elements. Some solid elements do not support rotational degrees of freedom at their nodes, and this must be born in mind when developing an element mesh.

7.7.2.3 Element Type Transitions

When it is necessary to transition between solid elements and plate elements, it must be remembered that although plate elements can represent bending moments and rotational displacements at nodes, solid elements often cannot. Attaching a plate element to a solid will therefore result in a hinge, and no moment will be transmitted between the elements. This can be overcome by continuing the plate element mesh so as to lap over two rows of nodes in the solid element mesh. This will transmit moment through the couple developed between the two rows. This method does, however, add area to the structure, and this must be born in mind when interpreting the results. Transitions between element types should not take place in areas where fatigue stresses are to be calculated.

7.7.2.4 Mid-Plane Offsets

In situations were the moment induced by the mid-plane offset of two overlapping plates is significant, this offset should be accounted for in the model. (See paragraph 7.7.2.5.1 “Modeling of Weld Joints” below).

7.7.2.5 Joint-Detail Modeling Methodologies

7.7.2.5.1 Modeling of Weld Joints

AAR 4.1.1 is a typical lap joint with a fillet weld all round (see Fig. 7.7). This joint can be modeled in a variety of ways, and the modeling method will greatly affect the resulting stress levels. This joint will be used as an example.

The simplest model would butt the two plates together in-plane and increase the thickness of the larger plate in the region of the overlap (see Fig. 7.8). Plate elements themselves have no thickness and represent the plate thickness mathematically. This approach essentially ignores the weld joint all together and will produce very optimistic results. It should not be used.

A better model results from extending the smaller plate so that it overlaps the larger plate (but still in-plane) and merging the nodes at the edge of the smaller plate (see Fig. 7.9). This addresses the weld specifically and is thus a satisfactory representation for many conditions. It does not, however, take into account the moment induced by the offset of the mid-planes of the two plates. To do this, we need to separate the plate elements comprising the larger and smaller plates and connect the matching nodes around the edge of the smaller plate. This can be accomplished using plate elements representing about the same thickness as the weld throat (see Fig. 7.10. In addition to including the offset moment, this method also incorporates some representation of the flexibility in the weld. Use of this method is advisable when the load is being shared between several weld joints. It also is possible to use short beam elements or rigid links to connect the two plates. In this case, moments will be developed at the ends of these links that do not occur in the structure.

Plate elements cannot provide any information about stresses through the thickness of the plates. If this is required, solid elements must be used. Here, the weld must be represented explicitly as solid elements. Simply merging the nodes around the periphery of the smaller plate will not produce accurate results, because the nodes cannot transmit moment.

The level of detail of solid element models must be considered carefully. Because stress concentrations in the weld will result in high stresses, the more a model is refined, the higher the stresses will be—almost without limit if linear material properties are assumed. To avoid this problem, the plastic behavior of the material can be included in the model, but stresses thus calculated are not used when calculating fatigue life by the AAR stress-life method. (See paragraph 7.7.2.6, “Mesh Density and Element Shape.”)

In the above representations, the two plates can pass through one another since the formulation of the elements does not comprehend contact between elements. This is normally a conservative assumption because it reduces the stiffness and support of the joint. Contact elements can be used to better represent this situation if required. It then becomes important to ensure that the manufacturing process used can actually ensure intimate contact between the plates.

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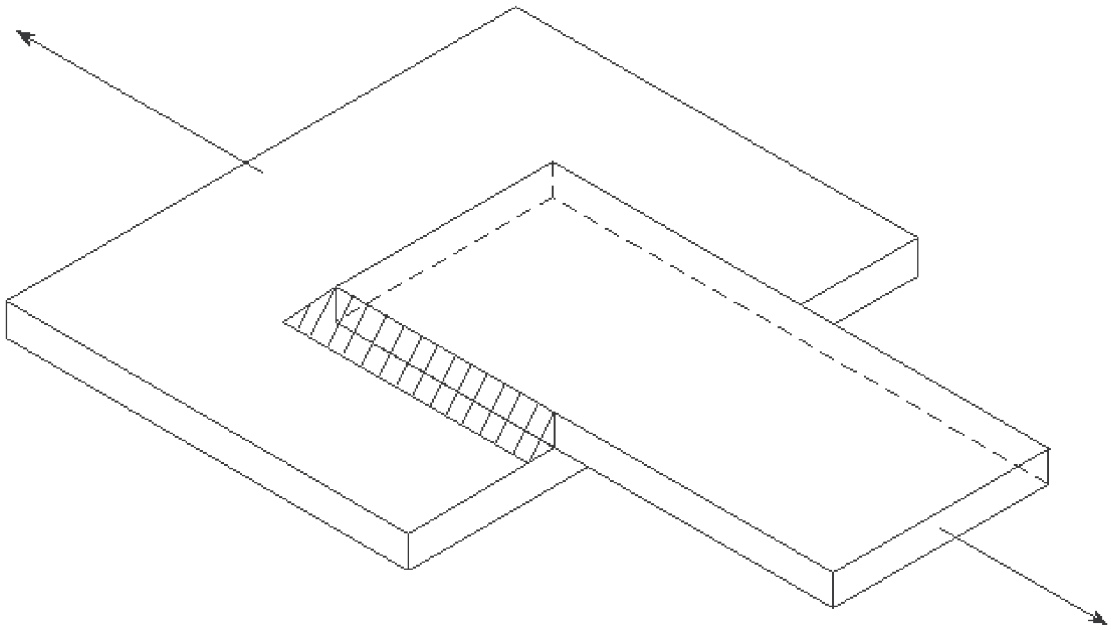


Fig. 7.7 Example weld joint

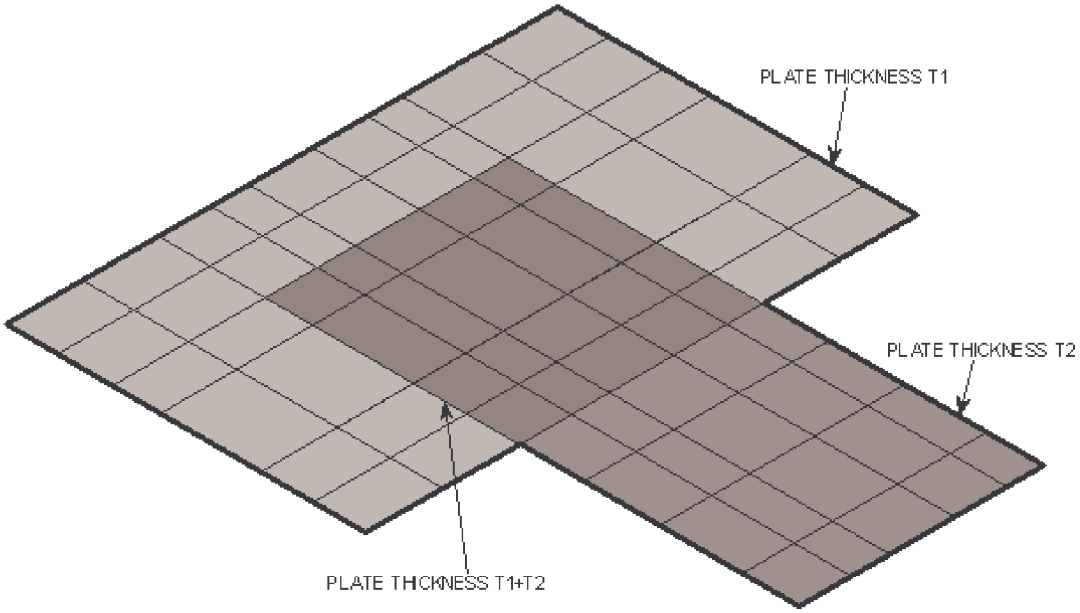


Fig. 7.8 Modeling by increasing thickness (not allowed)

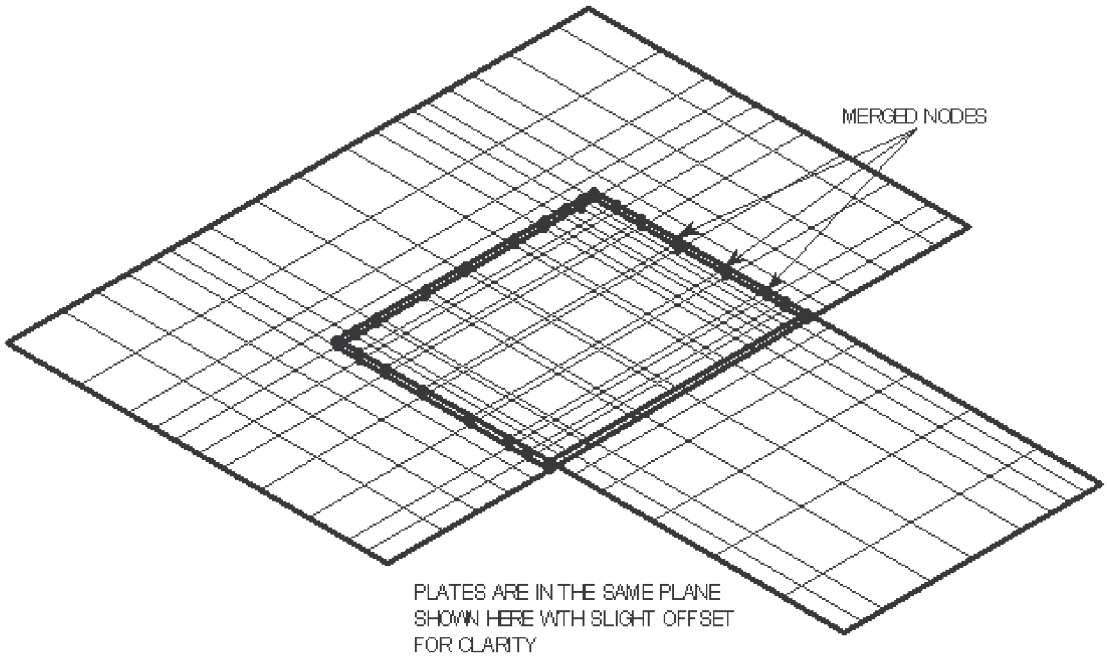


Fig. 7.9 Modeling by overlapping plates in plane

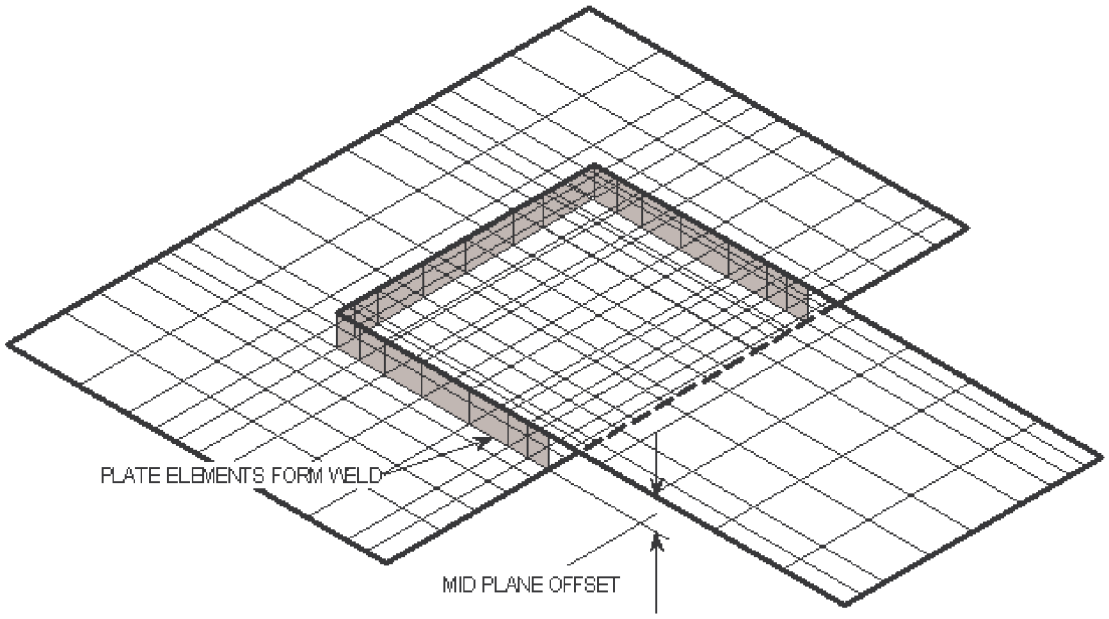


Fig. 7.10 Modeling with mid-plane offset

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7.7.2.5.2 Bolted Joints

Here, there are a number of possible modeling methods—none of which is ideal. Merging nodes at the bolt locations will allow bolt forces to be extracted. These then need to be compared with allowable bolt loads to complete the analysis. If stresses in the plates are important, merging single nodes is not satisfactory. The bolt load is transmitted through a single point, and unrealistically high local stresses will result. Also, the bolt hole cannot be represented. A refinement of this method is to represent the bolt hole in the plates and to place a ring of elements around the hole covering the area of contact of the bolt head or washer (see Fig. 7.11). These elements are then merged, and a more realistic stress distribution calculated. Even this method will, however, overestimate stresses because in a friction joint, load is transmitted in friction between the plates over a wide, but unpredictable area.

Short beam elements can be used to represent the bolts, but this will introduce an offset moment that our simplified model will not be able to react to without developing high local bending stresses. Also, this type of analysis does not represent the friction transfer of load. For this reason, local stresses should not be used for fatigue analysis. Instead, the forces transmitted through the bolt should be compared with standard bolt strength data.

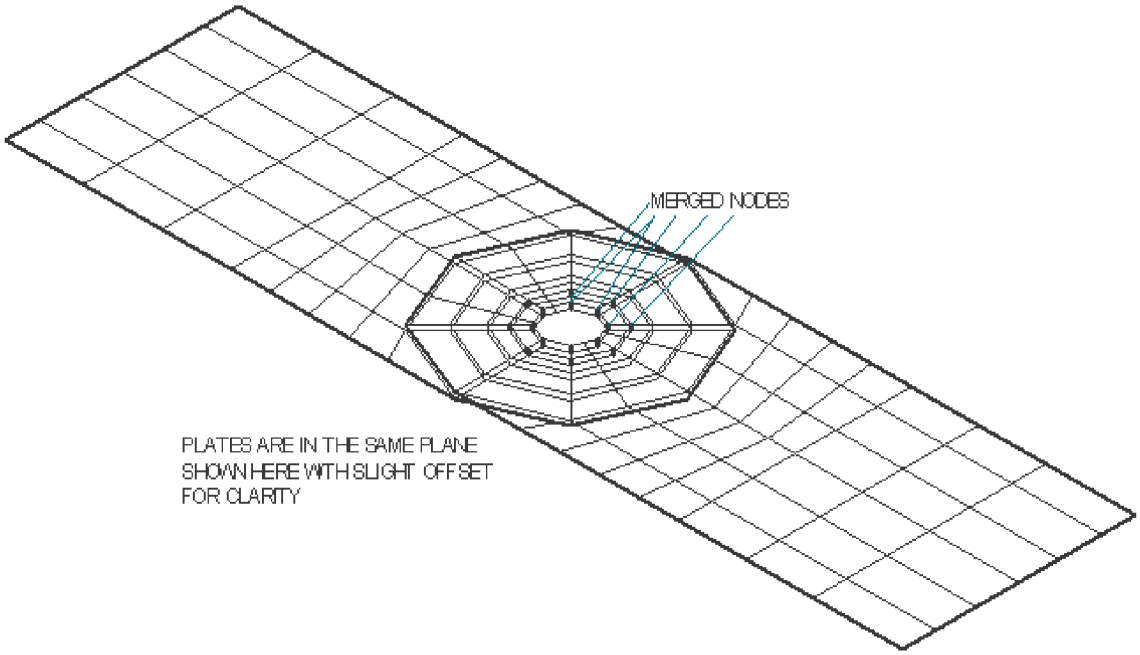


Fig. 7.11 Modeling of bolt joint

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7.7.2.6 Mesh Density and Element Shape

In general, elements should be as near square or cubic as possible. This is not achievable everywhere in the structure because of its complex geometry. It is, however, important in areas of high stress and where fatigue life is to be calculated. Meshes should follow and reflect the contour that they represent (see Fig. 7.12). Thus, when modeling a hole in a plate, the elements around the hole should form a concentric circular pattern expanding out from the circumference of the hole, and the elements should be approximately square for best results.

Areas of lower stress or of less interest from a fatigue standpoint—that is, areas away from joints or geometric changes in the structure—can be modeled in less detail. In these areas, it often is necessary to use elongated, out-of-square elements or even triangular elements to transition from one detailed area to another. In areas of low stress, it is permissible to use larger elements of less optimal shape.

In areas where fatigue is critical and stress concentrations are present (such as weld terminations, etc.), it is necessary to size elements appropriately. Many weld terminations, when modeled using simple plate elements, produce extremely abrupt changes in geometry. These changes can result in mathematical singularities in which the stress concentration factor can be unrealistically large. As the mesh density is increased and the element size reduced, the stresses will increase, almost without limit. This is not physically possible, and such stress levels are not appropriate for calculating fatigue life.

The “Stress Life” method set out in Chapter 7 of this specification requires the use of a “free-field” stress that does not include the effect of stress concentrations.

The stress close to a weld or any discontinuity can be thought of as a free-field stress with stress concentrations applied to it. The free-field stress is equivalent to the nominal stress applied to the small laboratory test samples used to develop the fatigue allowables for the Stress-Life method. The joint geometry itself creates a stress concentration in the region of the joint—the geometric stress concentration (GSC). There is also a further stress concentration at the toe of the weld caused by the weld geometry (WSC). Both of these stress concentrations are accounted for by the test specimen and must not to be included in the stress used when calculating fatigue lives using the AAR Stress-Life method.

It is, however, necessary to include other GSCs that may affect the stress at the weld. In a complex structure, these might include other weld joints, the geometry of the structure, or other details such as holes, etc. It is therefore difficult to define a “free-field” stress. To ensure that other GSCs are included, it is necessary to take the stress value close to the weld but without including its own GSC or WSC. Hobbacher recommends determining the stress at a distance of 0.4t and 1.0t from the toe of the weld and extrapolating linearly to the weld toe (The International Institute of Welding. 1996. *Fatigue Design of Welded Joints and Components—Recommendations of IIW Joint Working Group XIII-XV*. A. Hobbacher, Cambridge: Abington Publishing). This excludes the WSC but includes the joint’s own GSC and the GSCs from other structural details. This is somewhat conservative, but does guarantee that other GSCs are included. A fair—and less conservative—assessment of the free-field stress can be made by taking the stress at one or two thicknesses from the weld toe (see Fig. 7.13). Assuming a fillet weld of typical dimensions, this implies taking the stress at about 2.2t to 3.2t from the centerline of the attached plate (or the location of the FE plate element). Further, British Standard recommends 4.0t (*Code of Practice for Fatigue Design and Assessment of Steel Structures,* BS7608:1993). It is therefore recommended that the stress about four times the material thickness away from the joint be used in stress-life fatigue calculations. This can be established by using elements of this size and taking the stress at the first node from the joint or by using an element stress from a larger element, providing the shape function of the element is capable of describing the stress gradient adequately.

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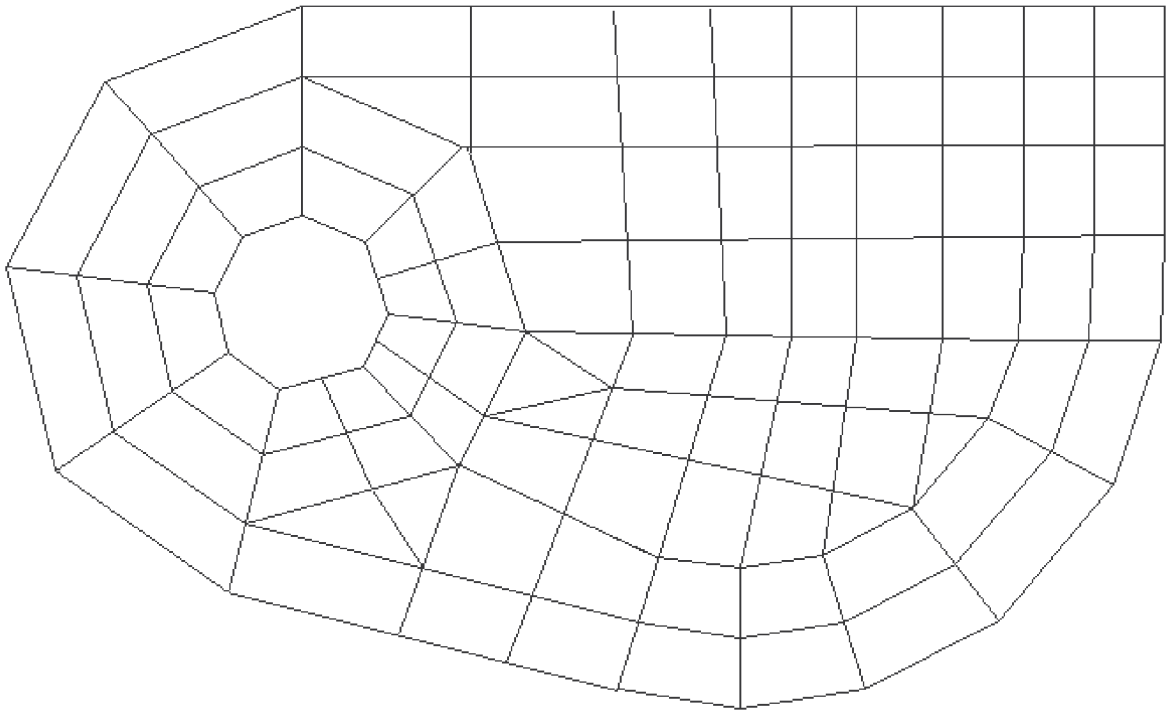


Fig. 7.12 Mesh should follow contour of part

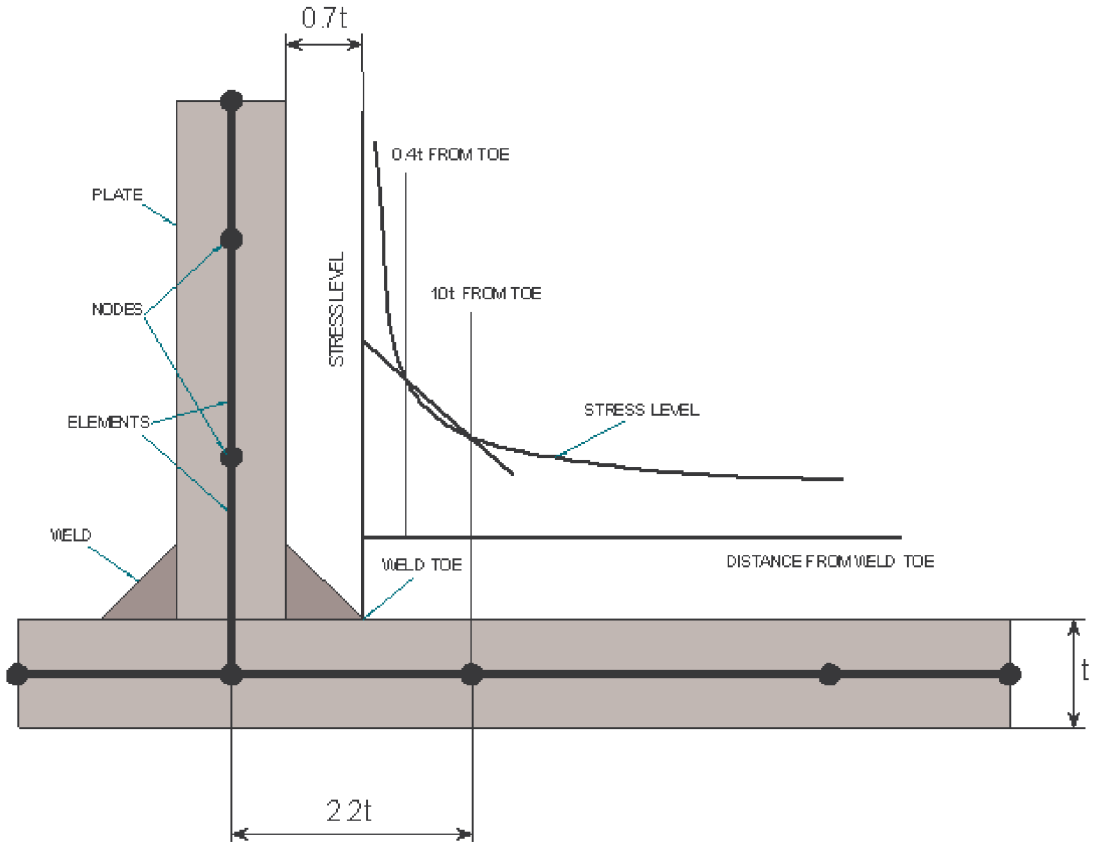


Fig. 7.13 Joint geometry and weld stress concentrations

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7.7.3 Boundary Conditions

7.7.3.1 Kinematic Support

The boundary conditions must not constrain the structure more than would the car's actual support. To achieve this, the boundary conditions should be kinematic. They should provide constraints that make the model stable and prevent rigid body motion without constraining the model in any other way. This generally implies single node constraints at support locations. The distribution of load across an area at support locations should generally be achieved by applying those loads explicitly and not by restraining an area of nodes by using boundary conditions. This requires an accurate free-body analysis to determine the loads to be applied.

7.7.3.2 Center Plate Support

A freight car is supported on its truck center plates, and these are, in turn, supported by the primary suspension. There is no pitch restraint introduced by this arrangement, and so no moment restraint in this plane should be introduced by the boundary conditions.

The load distribution on the center plate should be applied explicitly. For vertical load cases, the load can be applied as a uniform pressure over the area of the center plate between the reliefs. For load cases involving lateral load, a triangular load distribution or a line load along the edge of the relief may be appropriate. In general, the loads applied to the model should be in equilibrium so that the forces developed at the constraints are approximately zero.

The trucks provide no longitudinal restraint to the car body, and the boundary conditions at the center plate should not do so either. On a simple whole car model, it is necessary to apply a longitudinal constraint even when there is no longitudinal load or when all longitudinal loads are balanced. As long as this is only applied to a single node (not a single node at each center plate), the reaction force will be approximately zero. This constraint could be applied anywhere on the model. When a symmetrical half model is used—either lateral or longitudinal—the symmetrical boundary conditions automatically impose a longitudinal or lateral constraint. So, in this case, no further longitudinal or lateral constraint should be applied at any other part of the model.

7.7.3.3 Side Bearing Support

The side bearings should be assumed to provide vertical support only. Loads can be applied as an even pressure or line load over the area to the side bearing.

7.7.3.4 Buff and Draft Lugs

Loads should be applied to these components explicitly and not by the use of boundary conditions. The load can be applied as an even pressure over the lug face or using a more exact area of contact between the lug face and the draft gear.

As load is applied to the lug faces, the lugs tend to rotate and the load shifts toward the draft sill webs. This effect can be included providing the distribution used is justified in each case.

7.7.3.5 Use of Symmetry and Anti-Symmetry

Symmetric and anti-symmetric boundary conditions can be used providing knematic support is achieved. Static analysis of buff/draft, vertical ,and lateral loads can employ half or quarter models as desired. Impact analysis can employ only longitudinal symmetry, and modal analysis cannot employ any form of symmetry.

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7.7.4 Checking the Model

FE modeling of a freight car is a complex task and mistakes can easily be made. Careful checking of the model is therefore very important.

7.7.4.1 Equilibrium

Each load case should be applied and the reactions studied. If the loads were calculated to be in equilibrium as described above, the reactions should be zero. This should be established.

If symmetry has been used, then check the loads at these boundaries. If a load has been applied perpendicular to the boundary, then the resultant load on the boundary should equal this. If no load has been applied, the result should be zero.

7.7.4.2 Comparison with Classical Analysis

Perform a simple classical analysis of the structure in sufficient detail to establish the overall distribution of loads. Slice the structure with planes perpendicular to the length of the car (a centerline plane of symmetry can be used for one of these) and other key locations. Determine the distribution of load and compare the results of the two analyses. They will not report the same values, but the differences should be explainable in terms of the simplifying assumptions made in the classical analysis. Differences that cannot be explained should be cause for concern.

7.7.4.3 Joint Details

Check each joint detail to ensure that the correct nodes are merged and no others. Also review any decisions not to include the mid-plane offset of the plates in the light of the stress levels reported for the joint.

7.7.4.4 Deflected Shape

Plot the deflected shape of the model at an exaggerated scale and compare the deflections with those calculated in the classical analysis. The shapes should correspond in general. There should also be no gaps, separations, hinges, or abrupt changes in shape that would indicate improper connection of elements in the model.

7.7.5 Load Application

It is often convenient to apply loads at a point rather than distributing them over an area. When this is done, the stresses under the load are usually unrealistically high. This is acceptable if the stresses in this region are not of interest. However, it is not possible to infer anything about the fatigue life of the structure in this area. In general, it is preferred to apply the loadings in a realistic manner so that realistic stresses are calculated and the fatigue life in the region of load application can be assessed.

7.7.6 Solving Methodologies

The small displacement, linear static solving methodology should generally be used for fatigue analysis. Large displacement analysis should be used when plates tend to bulge out under pressure loads and a small displacement analysis predicts excessive displacements. The AAR stress-life methodology assumes the use of free-field stresses that are within the elastic limits of the material. If higher stresses are predicted, this fatigue methodology is not applicable. It should not be necessary, therefore, to use material non-linearity in an FE analysis intended to provide stresses for this method of fatigue analysis.

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7.7.7 Results Interpretation

The interpretation of FE results is not at all straightforward. Care must be exercised when drawing conclusions from the analysis. It is not possible to set forth hard and fast rules, but the following are some general guidelines.

7.7.7.1 Mid-Plane versus Surface Stresses

Plate elements include bending in their formulation. As a result, the stress level varies through the plate in a linear manner, with the mid-plane stress being the average of the two surface stresses. This means that, except for pure tension or compression, at least one of the surface stresses must be numerically larger than the mid-plane stress. In many design codes, the mid-plane stress is used and a factor is included in the analysis to take account of bending. This is not the case for the *MSRP*. When performing a static stress analysis, it is permissible to use only mid-plane stresses if the local structure is clearly restrained from yielding in bending.

Weld joints are frequently on the surface of a plate, and the stress on that surface should be used when calculating the fatigue life of the joint.

The laboratory samples on which the stress allowables are based are frequently unsymmetrical and therefore develop some bending. This level of bending is included in the allowable stress level for that joint detail and need not be included in our analysis. The level of bending stress for each joint detail is not, however, known. If it is desired to take advantage of this effect, an FE model of the joint detail should be used to establish the level of bending stress already included. This stress can then be subtracted from the stress reported by the car body FE model prior to calculating the fatigue life.

7.7.7.2 Through-Thickness Considerations

Plate elements cannot represent through-thickness stresses in any way. If a cruciform type of joint is modeled with plate elements, the plates are all connected at single nodes, and stresses pass directly between the plates. This can be critical when the intersection between the weld lines is short and stress concentrations result. This type of joint should be modeled using solid elements if accurate stresses are needed through the plate thickness, but these stresses should not be compared with AAR allowables in this Chapter 7 of Specification M-1001.

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7.7.7.3 Nodal Averaging

The calculation of stresses at a node can take into account the stresses in adjacent elements and average these. In situations where the stress in an adjacent element is low due to it not being in the direct load path, this can result in an artificially low level of stress being reported. This is particularly true when stresses are present in a plate and a second plate is welded perpendicularly to it, when this second plate does not take part in the stress field and carries minimal stress (see Fig. 7.14). It is generally better not to use nodal averaging unless it can be shown that the stress at the node is truly shared between all of the elements adjacent to it. The type of weld joint may be important here, with a full penetration joint offering more opportunity for the stresses to average themselves between the plates than would, for instance, a single-sided fillet.

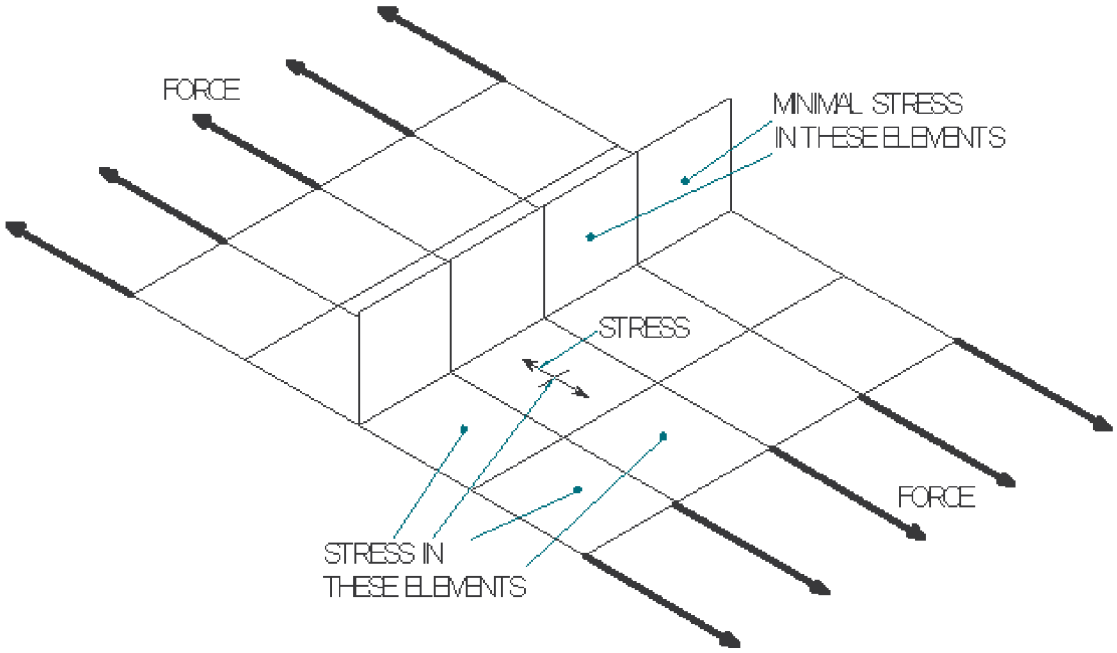


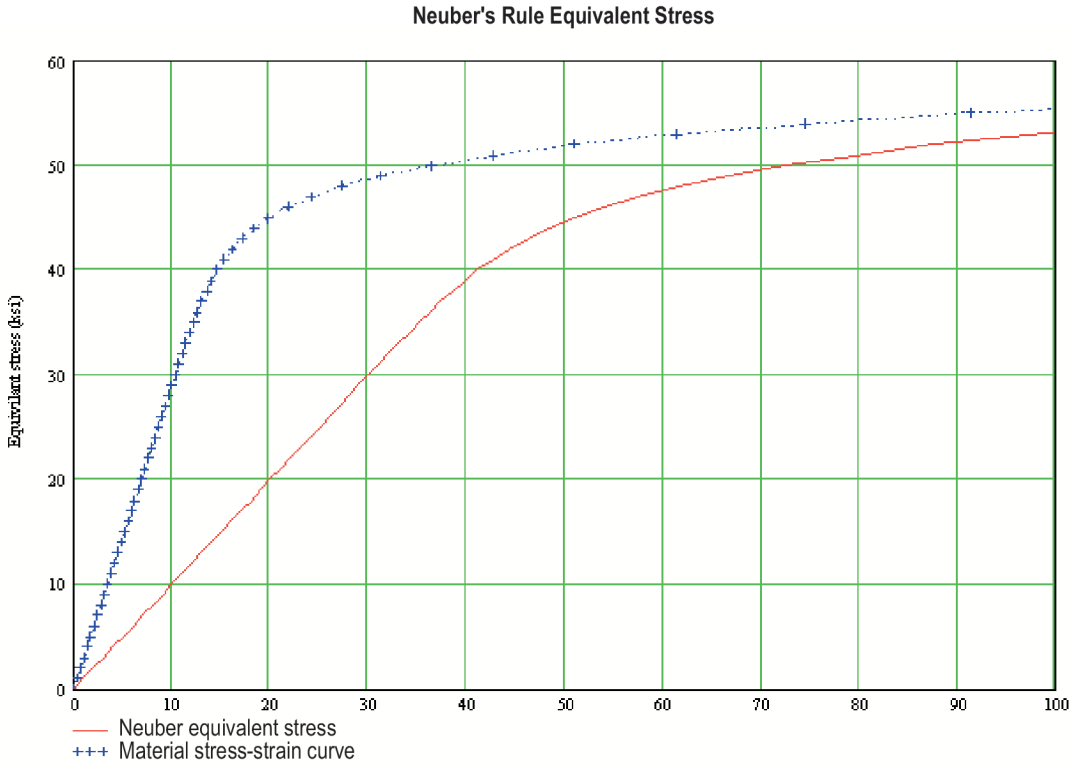
Fig. 7.14 Nodal averaging can reduce reported stresses

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7.7.7.4 Stress Concentrations Due to Modeling

Since an FE analysis must include sharp intersections where one element joins another, very high stresses may be reported at these points. They represent high-stress concentrations that are not found in the real structure. In addition, the basic, linear FE does not include the effects of material yielding that can occur in real structures in these regions. It is not realistic to report these stresses because they are the result of the limitations of the analysis and not the underling structure. It is possible to include material plasticity in the analysis, but this leads to a more complex analysis process and is often not needed. Instead, it is possible to make an estimate of the actual stress using Neuber's Rule ("Theory of Stress Concentration for Shear-Strained Prismatical Bodies with Arbitrary Nonlinear Stress-Strain Law," H. Neuber, *Journal of Applied Mechanics*, Transactions of the ASME, December, 1961). This states that the product of the stress and strain in a highly localized region that is completely surrounded by unyielded material remains constant even after yielding has taken place in the isolated region.

This results in the calibration curve shown in Fig. 7.15, in which the apparent stress can be translated into an actual stress that can be compared with the yield of the material. The MH equivalent stress should be used for this calculation. It is only applicable if the yielded area is completely surrounded by unyielded material or a free edge. In addition, the yield area must be small in relation to the area transmitting the load-ideally less than 0.1%.



Horizontal axis = Horizontal axis represents stress (ksi) for Neuber equivalent line and also represents strain (10 units on scale represents 1000 micro-strain) for stress-strain curve of material

Fig. 7.15 Neuber's rule equivalent stress—50 ksi yield material

7.7.7.5 Stress Sampling Locations for Fatigue

When using the "stress life" fatigue method as outlined by the AAR, fatigue stresses should be taken at a node approximately four material thicknesses from the intersection of adjoining plate elements. This stress shall be considered as the free-field stress for the joint details shown. The maximum principal stress shall be used in the calculation, and its direction shall be considered when selecting the joint detail to be used. In general, the surface stress shall be used except where modeling of the joint detail has shown that it can be reduced.

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7.7.8 Life Prediction

The AAR provides a stress-life analysis method, but allows other methods to be used. Three methods listed below are in common use:

7.7.8.1 Simple, Allowable Stress Comparison

Here, an allowable stress is calculated for each weld type, and the FE-calculated free-field stress is compared with this value. A standardized loading case—such as static vertical with live and dead load—is used for the comparison.

7.7.8.2 Stresses for Stress-Life Analysis

This is the method described in this Chapter 7 of Specification M-1001 and requires the use of the FE-calculated free-field stress as described above.

7.7.8.3 Stresses for Strain-Life Analysis

Strain-life analysis can be applied in several different ways. The free-field stress can be used along with standardized stress concentration factors for weld joints. Alternatively, the joints can be modeled in detail using solid elements and the stress concentrations included directly from the FE results. This method is not supported by AAR Specification M-1001.

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CHAPTER 8
DESIGN AND TEST REQUIREMENTS FOR TRAILER/CONTAINER TRANSPORT CARS

8.1 General

8.1.1 Cars covered by this specification are to be of an intermodal service type designed to carry trailers and/or containers and governed by the design and load requirements applicable to such cars as outlined in Chapter 4.

8.1.2 Cars must meet all other applicable design, stress, and service worthiness requirements of M-1001, except as modified by these requirements.

8.2 Tests

8.2.1 A car of the configuration proposed for interchange service shall be utilized in all tests. Deviation from such configuration is permitted only with the explicit concurrence of the Equipment Engineering Committee.

8.2.2 A car consisting of the maximum number of units proposed for revenue service must be utilized in all tests, unless a number of units is specified below for individual tests.

8.2.3 Dynamic Squeeze

Reference paragraph 11.3.4.2.

8.2.4 Impact Tests

8.2.4.1 The candidate car is to be loaded as outlined below and impacted into a string of three standing, fully loaded cars of at least 70-ton capacity, (preferably 100-ton). The impact string shall be equipped with M-901E draft gear on the struck end and have the hand brake fully set on the last car (opposite end).

8.2.4.2 Free slack between cars is to be removed; draft gears are not to be compressed. No restraint other than a handbrake on the last car is to be used.

8.2.4.3 Impacts are to be conducted at maximum 2-mph speed increments, until speed of 10 mph is reached. Coupler force is to be measured in accordance with paragraph 11.3.1.1.

8.2.4.4 Impact series is to be as follows:

8.2.4.4.1 Trailer Service

8.2.4.4.1.1 All units of the car are to be loaded with 65,000 lb gross weight trailers secured to the test cars by an approved kingpin restraining device (hitch) and impacted into the string of standing cars at speeds up to and including 10 mph in both directions (A-end of car facing the standing string and B-end of car facing the standing string).

8.2.4.4.1.2 Horizontal reaction force on any trailer kingpin may not exceed 240,000 lb at any impact speed up to and including 10 mph.

8.2.4.4.1.3 Coupler force may not exceed 1,250,000 lb at any speed up to and including 10 mph. No wheel lift or car body suspension disengagement is permitted at any test speed.

8.2.4.4.1.4 Trailers for this test are to be loaded in accordance with the AAR *Manual of Standards and Recommended Practices (MSRP)*, Section I, Specification M-928, having a center of gravity of no less than 83 in. and tandem suspension position at a distance of 110 in. to 115 in. from the rear of the trailer to the centerline of the rear axle.

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8.2.4.4.2 Container Service

8.2.4.4.2.1 All units of the car are to be loaded with 40-ft M-930-approved intermodal containers weighing 67,000 lb gross, secured to the car by an approved container restraint device and impacted into the string of standing cars at speeds up to and including 8 mph in both directions (A-end of car facing the standing string and B-end of car facing the standing string). One directional impact may suffice if the car and the container restraint system are symmetrical for both directions.

8.2.4.4.2.2 Longitudinal force acting on any container shall not exceed two times the container's maximum gross weight at any speed up to and including 8 mph, and the coupler force shall not exceed 1,250,000 lb at any speed up to and including 10 mph.

8.2.4.4.2.3 Containers used in this test shall be loaded in accordance with the *MSRP*, Section I, Specification M-952, having a center of gravity no less than 57 in.

8.2.4.4.2.4 When double-stacking of containers is employed, the combined center of gravity of the containers is to be 114 in. above the bottom support surface.

8.2.4.4.3 Combination Car

A car designed for combination trailer and container carrying service shall be tested for trailer and container service separately and for a combination loading resulting in the most adverse coupler, longitudinal kingpin, or container restraint forces.

8.2.4.4.4 Partially Loaded Car

8.2.4.4.4.1 A car consisting of two or more units must undergo impact testing as outlined above with the leading unit of the test car being empty for a two-unit car, or with the two units being empty for a three or more unit car.

8.2.4.4.4.2 The car shall be impacted into the standing string with the empty unit(s) leading. No car body suspension disengagement or wheel lift is permitted. Kingpin, container restraint, and coupler forces are not to exceed values given for fully loaded car tests.

8.3 Floor Restraint

8.3.1 Cars designed for the transport of containers and not equipped with flooring or a through center sill that would bolster the container floor if it failed must be equipped with supplemental floor support structure meeting the following requirements:

8.3.2 Longitudinal members, two of which must be located so as to ensure a minimum 3-in. overlap of the container side running the full length of the container, must be provided.

8.3.3 A number of members spanning the width of the car shall be provided so as to ensure that no container floor area greater than 30 ft^2 is open to the ground.

8.3.4 Structurally, the supplemental floor structure shall be capable of supporting a 2 ft × 8 ft pallet uniformly loaded to 15,000 lb, placed crosswise on the car at any location without failure or deflection greater than 3 in. downward.

8.4 Brakes

8.4.1 Cars are to be equipped with an air-actuated system using approved AAR components and conforming to the *MSRP*, Section E-I, Standard S-401.

8.4.2 The handbrake must be effective on not less than one half of the axles and must be connected to the B-end of the truck or suspension system.

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8.5 Components and Structural Configuration

8.5.1 Major car system components (draft, truck, brakes, trailer tie down, etc.) used in the test car configuration must not be changed in the production version of the car without the concurrence of the Equipment Engineering Committee.

8.5.2 Major structural components (center sill, suspension supports, truck centers, car length, car height, etc.) used in the test car configuration must not be changed in the production version of the car without the concurrence of the Equipment Engineering Committee.

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CHAPTER 9
DESIGN AND TEST REQUIREMENTS FOR RAIL-COMPATIBLE VEHICLES

9.1 Scope

This chapter defines procedures and requirements for approval of equipment intended for use in specialized controlled interchange service under the heading of rail-compatible vehicles (RCV). For this type equipment, requirements of this chapter supersede approval procedures outlined in Chapter 1, paragraph 1.3.

9.2 General

Following are the minimum provisions for rail-compatible vehicles to be operated by agreement in interchange with like vehicles or similar vehicles approved under this specification, or operated as a portion of a train of conventional equipment. The specification is applicable to rail-compatible vehicles designed and constructed as multimodal vehicles when operated on rail and in controlled interchange service. The specification is mandatory and is applicable to each unit or combination of units.

9.3 Definitions

Rail-Compatible Vehicle	For purpose of this specification, a rail-compatible vehicle is defined as a structural cargo entity designed for operation in other modes of transport (highway, water, or air) equipped with a rail-compatible suspension system, permitting it to be operated on rails and being capable of coupling to a conventional railroad locomotive or car either directly or through an appropriate adapter.
Controlled Interchange Equipment	Controlled Interchange Equipment is defined as freight-carrying rail equipment that, due to its configuration or use, does not meet one or more requirements contained in Chapters 1 through 11 of this specification. Operating restrictions for controlled interchange equipment will be listed in UMLER and the Official Railway Equipment Register (ORER). Acceptance of this equipment in interchange is not mandatory.
Unit of Equipment (Car)	For this chapter, a unit (or car) is defined as a unit of equipment having a single reporting mark and car number, regardless of the number of intermediate units that may be included.

9.4 Application Procedures

Application for all units intended for operations as rail-compatible vehicles under this specification must be submitted in accordance with the AAR *Manual of Standards and Recommended Practices (MSRP)*, Administrative Standards, Standard S-060 and in accordance with the provisions of this chapter. Application for RCV approval proceeds in three phases: prototype design, conditional approval, and approval. As a result of the Committee's favorable review of the application and any available test and inspection results, prototype design approval, conditional approval, or approval will be granted and the applicant will be so notified.

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9.4.1 Submission—Prototype Design

9.4.1.1 Prior to introduction of cars into the prototype design phase, the proponent of the design will advise the Equipment Engineering Committee (eec@aar.com) of the intent to request approval of the design under the provisions of this chapter. The proposal shall be submitted electronically using standard formats and packages readily available.

9.4.1.1.1 Drawings shall be submitted electronically, using AutoCAD® or compatible format. The information outlined in paragraphs 9.4.1.2 through 9.4.1.4 is to be submitted concurrently with the letter of intent. This information will be treated as confidential proprietary data; however, if the proponent has concerns, it is recommended that the proponent provide protection for the design by patent application.

9.4.1.1.2 Should the proponent not be able to make an electronic proposal or should proponent wish to provide supporting documents, the proposal, along with copies of supporting documents, shall be submitted in accordance with Standard S-060, latest revision.

9.4.1.2 A new car rating form for the proposed design as prescribed in Chapter 1, paragraph 1.3.8, must be completed. Section II of the rating form must clearly indicate and document the specific reasons why the proposed design cannot comply with M-1001 requirements and must detail all recommended operating restrictions for the cars.

9.4.1.3 The following information must be provided:

- General arrangement drawings for the complete unit or units, including adapter units
- Truck and suspension arrangement drawing
- Stress analysis and stress summary, to include information as to assumptions, loads, etc.
- A complete clearance diagram
- Brake arrangement, to include AAR Form 600 and braking force diagrams
- Bill of Material
- Copy of letter requesting FRA (or other as applicable) review and reply when received
- Arrangement and details of the coupling system
- Floor arrangement, including details of support structure and rating
- Applicable patents or patents for which applied
- Test plan proposal
- Detailed statement of restrictions for operation of equipment

9.4.1.4 As a minimum requirement, results of all applicable static and dynamic tests specified in Specification M-1001 must be submitted. If analysis indicates that the published acceptance values for any test are not attainable, testing shall be performed to revised values deemed practical by the proponent, implications of such deviations shall be fully explained, and appropriate operating restrictions shall be specified. If, in the opinion of the proponent, any test requirement of Specification M-1001 is not applicable to the equipment being considered, the reason for not performing such test or tests must be fully explained in the proponent's submission, and a description of specific operating restrictions or other compensating safeguards must be provided.

9.4.1.5 A review of all information submitted shall be conducted by the Prototype Design Review Group exclusively consisting of Equipment Engineering Committee representatives of those railroads that will be operating the RCVs and responsible AAR staff or designates. This confidential review group will function to ensure that the requirements of this chapter have been met. In the case where there is less than unanimous conclusion on conformance with the intent of this chapter, the equipment will not be interchanged between parties involved until differences are resolved. Following this technical review, the proponent shall be advised of any comments and/or recommendations.

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9.4.1.6 As a result of the Committee's favorable review of the application and any available test and inspection results, approval will be granted for operation in the prototype design phase. Interchange between roads during the prototype design phase shall be operated only by agreement between the carriers involved. The applicant will be so notified.

9.4.1.7 Operating restrictions specified by the proponent or Equipment Engineering Committee must be entered in UMLER and the ORER prior to cars being placed in service under the prototype design phase.

9.4.1.8 A maximum of 200 units may be placed in agreement service under the prototype design phase.

9.4.1.9 The manufacturer is required to initiate a service inspection process and provide a report to the Committee semiannually to include not less than five car sets for documentation, due within 30 days of the January 1 and July 1 reporting dates.

9.4.1.10 The prototype phase is not a requirement for existing equipment manufactured under the former *MSRP,* Section C-I, Recommended Practice RP-257 (now archived), but is available to manufacturers as a method of introducing a new design into the rail fleet.

9.4.2 Submission—Conditional Approval

9.4.2.1 The manufacturer must notify eec@aar.com in writing of its desire to obtain conditional approval. This notification can be triggered by reaching the number of units specified for sale under the prototype design phase or when at least 10 units have been in service 2 years and have accumulated 25,000 miles each or when at least 10 units have accumulated 30,000 miles each. Upon notification, the Equipment Engineering Committee will initiate the conditional approval review process.

9.4.2.2 In addition to the notification, proponent is to make a complete electronic submission for approval to eec@aar.com (or if unable to do so, refer to *MSRP* Standard S-060) for review by the Equipment Engineering Committee. The submission must include all data previously provided under prototype design application, supplemented by additional requirements outlined in Chapter 1, paragraph 1.2. A report of service experience with the units, including estimated mileage and operational problems encountered must be provided.

9.4.2.3 If, after review of the submission, the Equipment Engineering Committee determines that additional testing is required, the proponent will be so advised and a test procedure and schedule will be requested. The test plan must be provided sufficiently in advance of tests (minimum of 10 working days) to permit review of the proposal and assignment of personnel to witness the tests as AAR observers.

9.4.2.4 Upon action of the Equipment Engineering Committee following a complete review of all data, including the results of supplemental testing performed under paragraph 9.4.2.3, the units may be conditionally approved as rail-compatible vehicles. This approval will include the units operated in prototype design phase unless major modifications have been made.

9.4.2.5 Conditional approval shall consist of authority to manufacture and sell up to 2000 units. It will be the manufacturer's responsibility to maintain a file, including car numbers, name of owner, and date introduced into service for each model number. This information shall be supplied semiannually to the Equipment Engineering Committee along with a report of service experience.

9.4.2.6 Manufacturer shall provide an illustrative drawing showing the plan view along with top and end views and including AAR clearance line, Plate C, for inclusion in the *MSRP*. The drawing shall be in 8 1/2 × 11 in. format composed in AutoCAD or equivalent software application, suitable for editing as required to accommodate AAR publication needs.

9.4.2.7 The manufacturer is required to initiate a service inspection process and provide a report to the Committee semiannually, to include not less than five units/sets for documentation, due

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within 30 days of the January 1 and July 1 reporting dates. The intent is to randomly sample the units in service, not to specifically inspect the same units each time; however, if sample access is limited, repeated inspections are not precluded, assuming they are indicative of the units in service.

9.4.3 Submission—Approval

9.4.3.1 The manufacturer must notify eec@aar.com in writing of its desire to obtain approval. This notification can be triggered by reaching the number of units specified for sale under conditional approval phase or when at least 10 units have been in service for not less than 2 years and at least 300 units have been in service at least 1 year and accumulated 30,000 miles each. In addition, not less than 30 of the latter shall have been inspected and determined to be operating without service problems. Upon notification, the Equipment Engineering Committee will initiate the approval review process.

9.4.3.2 Application for upgrade from conditional approval to approval status shall include the latest service application file, copies of inspection reports by unit number,, and photos indicating the condition of the equipment. Service reports shall have been properly filed and shall be up to date. All requested information should have been supplied, tests accomplished and documented, and unfavorable occurrences explained.

9.4.3.3 Upon receipt of request, the Equipment Engineering Committee shall begin the final review process. Proponent will be advised of Committee handling.

9.5 Regulatory Approval and Jurisdiction

9.5.1 Units built that will operate on rail in the United States are subject to FRA review of brakes and safety appliances in accordance with Part 221 and comment prior to release of unit for service. Units will require public disclosure of results of FRA review, restrictions, or waivers as applicable. Units built that will operate on rail in Canada are subject to review by Transport Canada. Units built that will operate on rail in Mexico are subject to review by the appropriate Mexican regulatory organization.

9.5.2 This specification does not substitute for compliance with applicable controlling specifications when operated in non-rail mode. Unit intended for intermodal operation shall be able to meet provisions of applicable U.S. Federal Highway Administration or other appropriate regulatory organizations having jurisdiction for that mode of operation.

9.5.3 Public disclosure of any and all restrictions, conditions of operation, or limitations imposed by regulatory entities, designers, manufacturers, owners, or individual operating roads shall be made available to the AAR, the Equipment Engineering Committee, and operating railroads prior to operation of equipment.

9.6 Unit Mechanical Requirements

9.6.1 Coupling

9.6.1.1 Unit must couple to existing locomotives and cars equipped with AAR standard couplers without modification. Other means, such as adapter cars, transition units, or other systems to enhance compatibility between unlike equipment, are acceptable alternatives. The transition units shall comply with the most stringent of the operational criteria shown below as related to vertical and horizontal curvature, draft and buff forces, and safety to the operator.

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9.6.1.2 Coupling techniques other than standard railway systems are acceptable for connecting units within a multi-unit assemblage provided it is demonstrated that the connected units comply with existing rail curvature requirements. Proponent shall provide information on non-standard coupling system including vertical curvature, horizontal curvature, draft, buff, or any other operating restrictions. Proponent shall address coupling to locomotive and coupling between units.

9.6.2 Brakes

9.6.2.1 The propagation of brake signal and application of retardation forces shall be compatible with the operation and performance requirements of existing freight systems. Net braking forces must be in accordance with *MSRP* Standard S-401, latest revision. Brake shoes, if used, must meet requirements of *MSRP*, Section E-I, Specification M-926, latest revision. Hoses used shall be routed and restrained to protect from transient damage, such as abrasion, during all modes of operation, including train assembly and yard handling.

9.6.2.2 Manufacturer shall specify brake piston travel, how measured, and how adjusted, including dimensions acceptable for release from terminal and for continuation in train. These instructions shall be prominently displayed on each unit near the area where piston travel would be measured. If system does not involve piston travel as normally seen in freight service (e.g., rotary piston), information to verify functionality shall be displayed and FRA shall be advised.

9.6.2.3 Provision shall be made to accommodate application of an "End of Train" device on each unit that could be the end unit.

9.6.2.4 Designs utilizing electronic brake control shall have systems designed and applied in accordance with latest AAR specifications as applicable.

9.6.2.5 Design shall provide protection for train line, air pipes, and other brake transmission conduits from fasteners used in the floor for load blocking or securement.

9.6.3 Parking brake force must be in accordance with *MSRP* Standard S-401 for hand brake and shall be totally achieved through application of retardation force of rail wheels.

9.6.4 Hot bearing detector compatibility must be demonstrated or the vehicle must be equipped with an on-board system to ensure detection. Detector window should be adjusted as appropriate to accommodate the design speed of operation, taking into account the time required by detectors to read a bearing.

9.6.5 Buff and Draft Capability

9.6.5.1 Buff and draft capability shall be no less than 400,000 lb or 1.6 times the maximum in-train forces of the proposed operation, whichever is greater. The development of the maximum in-train forces, if less than those specified in M-1001 as standard for interchange, must be justified by engineering analysis. The buff and draft capability must be verified by testing.

9.6.5.2 Proponent may offer a design or system for specialized or restricted operation that does not meet the 400,000 lb minimum for this specification. These designs will require engineering analysis and testing as described in paragraph 9.6.5. However, in addition, they shall have appropriate restrictive marking and be suitably identified in UMLER. The Equipment Engineering Committee may specify additional analysis or tests. The proponent shall clearly identify areas of noncompliance with this specification when approaching the AAR for review of the design.

9.6.6 Proponent shall provide a fail-safe system to prevent highway wheels or equivalent from inadvertent release into the rail clearance envelope. Analysis of the support system to justify acceptability is required.

9.6.7 Proponent must meet AAR clearance diagrams and provide AAR with a clearance diagram depicting the most severe clearance condition.

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9.6.8 Units designed for operation under this specification shall be designed and tested for operation in at least one direction, at speeds of not less than 70 mph with lateral and vertical accelerations not to exceed the provisions of the operating specifications found in equipment qualified under *MSRP,* Section N, Recommended Practice RP-803, (i.e., 0.13 G RMS lateral, 0.5 G vertical) with low pass filter at 10 Hz). Noncompliant designs shall be identified and reviewed on an individual basis for specialized service. In addition, the condition at the maximum compressive spring travel shall not exceed 95% of the spring travel from the empty car height of the outer load coils to solid spring height, or the suspension must not bottom with one broken outer coil per nest.

9.6.9 If designed to carry any portion of the vehicle weight, the structural connector between vehicles shall be designed to sustain vertical forces of 2.0 times the static reaction of a fully loaded vehicle and must meet vertical and horizontal curvature requirements of Specification M-1001 where applicable.

9.6.10 Design of an adapter unit or system to permit coupling or uncoupling of the vehicle to a locomotive or car (if used) shall permit performance of this function without special tools or equipment, (i.e., in a manner similar to coupling two conventional cars). Adapter unit shall meet all structural and operational requirements of the units, including the requirements for testing as outlined in this specification.

9.6.11 Design shall include provision to jack and replace rail wheels on line-of-road or in shop. Units must be designed with support points from which the loaded unit can be jacked or lifted free of the truck at that end of the unit. If special handling techniques or equipment are required, the proponent shall ensure that the operating roads have access to the information and equipment.

9.6.12 Fasteners used in design of equipment shall be compatible with materials used in construction. Provisions shall be made to minimize galvanic corrosion through use of sealants, appropriate isolation material, and appropriate choice of fastener material.

9.6.13 Welding, when used, shall be done in accordance with AWS D 15.1. Joints not prequalified shall be qualified by personnel having the appropriate credentials to perform that function. Welders qualified for the position in which they are working shall do all welding required for construction.

9.6.14 AAR standard wheels are to be used. Should special wheels be specified, they must have specific approval of the WABL Committee.

9.7 Operational Requirements

Proponent shall meet the following operational requirements:

9.7.1 Provide the following:

- Verification that equipment can allow reverse movement of unit or group of units at maximum speed specified by manufacturer
- Verification that the air brake system can be bypassed on a malfunctioning unit
- Verification that a defective unit can be removed from a block of units or train on line of road.
- Maintenance or repair material that is non-standard or not AAR approved, to include as applicable on-board tools or parts, information, and training.

9.7.2 Register the equipment in UMLER with restrictions as appropriate for Chapter 9 operation, using the information contained in Chapter 12.

9.7.3 Provide in advance of operations appropriate maintenance and operating instructions in a format that is readily accessible throughout the systems operating the equipment. Methods to accomplish this should include providing such information on a Web site, and packages of material should be included with the train's crew information.

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9.7.4 Provide audio-visual training (e.g., video tapes or CDs) in advance of operating equipment to assist operating roads with their training programs.

9.7.5 Demonstrate that the RCV can successfully pass static and dynamic requirements outlined in Chapter 11, with the following modifications:

9.7.5.1 Coupler vertical load is defined as the vertical load applied at the designed support points at each end of the unit required to lift the loaded unit free of the trucks.

9.7.5.2 Curve stability load to be 125,000 lb on a 10° curve as outlined in Chapter 2, paragraph 2.1.6. Test consist shall incorporate at least one transitional unit at each end with at least one intermediate (non-transition) unit between. Proponents using less than 125,000 lb must provide a train length restriction required to prevent wheel lift.

9.7.5.3 When no impact or dynamic squeeze requirements are defined, testing is not required unless the provision is made in the design to accommodate switching or coupling with motive power detached. If operations of this type are contemplated, the Committee shall be notified and appropriate requirements will be developed for that design on an individual basis.

9.7.6 Provide operating limitations and recommended restrictions to the operating railroads and be included in UMLER as appropriate.

9.7.7 Proponents of designs that utilize containers must provide a system to control the contents of the container in the event of a floor failure and to limit container floor deflection similar to requirements for rail cars used in handling container-on-flatcar (COFC) shipments.

9.8 Construction Requirements

9.8.1 Equipment built, rebuilt, or having major modification to qualify for any level of approval under this specification shall be manufactured in a shop approved under *MSRP*, Section C-I, Standard S-2034.

9.8.2 Major components or appurtenances having AAR specifications controlling manufacture or application of the component shall be manufactured in compliance with applicable specifications and in shops approved under specifications as applicable. Examples of applicable components include, but are not limited to, wheels, axles, roller bearings, truck castings, and air brake components.

9.8.3 Fabricated truck components shall be identified and submitted to the Equipment Engineering Committee for approval. Welding when used shall be done in accordance with AWS D 15.1. Joints not prequalified shall be qualified by personnel having the appropriate credentials to perform the function. Welders qualified for the position in which they are working shall do construction welding. Structural weld joints shall be tested by nondestructive means, such as ultrasonic testing, x-ray, or other appropriate and equivalent technique.

Fabricated and/or new and untried truck components shall be subjected to appropriate fatigue analysis and testing.

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9.9 Specialities and Appurtenances

9.9.1 The following specialized items are considered appropriate for an RCV that will operate as a trailer when not in rail service:

- Floor and floor support designed for 18,000 lb minimum fork truck load per Truck Trailer Manufacturers Association (TTMA) RP-37, extending the full length of the trailer
- Four hinges per door for rear doors
- Dual cam locks
- Flat sand shoes not less than 8 in. × 8 in., located on 5 ft 5 in. centers
- Diagonal braces to strengthen elevation tubes and resist buckling when assembling and disassembling trains
- Securement feature for highway air hoses when on rail, and rail hoses when on highway
- Door hold-open feature
- Reduced post spacing at nose and nose-end of sides to accommodate loads from rail environment
- Provision to protect train line from nails used in floor

9.9.2 The following specialized items are considered appropriate for an RCV that will operate as a container when not in rail service:

- Floor and floor support designed for 18,000 lb minimum fork truckload per TTMA RP-37, extending the full length of the container
- Four hinges per door for rear doors
- Dual cam locks

9.10 Marking

9.10.1 Automatic Equipment Identification (AEI) application is required on each side of each unit, container, and truck (rail bogie) as appropriate and as specified in the latest revision contained in the *MSRP*.

9.10.2 Reporting mark and number of the component (truck, container, or trailer) owner or lessor shall be displayed as large as possible c but not less than 2 in. in height.

9.10.3 Periodic maintenance and component identification required by AAR or other regulatory body shall be displayed appropriately.

9.10.4 Restriction marking or marking to indicate noncompliance with the requirements of this specification shall be displayed appropriately.

9.10.5 Restrictions on advertising shall conform to those applicable to freight cars.

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CHAPTER 10
SINGLE-AXLE SUSPENSION SYSTEM PARAMETERS AND DESIGN GUIDELINES <RETIRED>

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CHAPTER 11
SERVICE-WORTHINESS TESTS AND ANALYSES FOR NEW FREIGHT CARS

11.1 Purpose and Scope

11.1.1 This chapter presents guidelines for testing and analysis to ascertain the interchange-service worthiness of freight cars. The regimes of vehicle performance to be examined are divided into structural, static, impact, and dynamic requirements. The dynamic requirements cover the following vehicle performance regimes to be examined: hunting, car body twist and roll, pitch and bounce, yaw and sway, curving and spiral negotiation, and longitudinal train action.

11.1.2 Braking performance, structural fatigue life, car handling, and other design considerations were outlined in the preceding chapters.

11.1.3 This specification documents the methods for analysis and measurement of a rail car's performance. Other rational methods may be proposed at the time of submission for design approval. Their use and applicability must be agreed to by the Equipment Engineering Committee.

11.2 General Requirements

11.2.1 Application for approval of new and untried types of cars, along with supporting data specified in paragraph 1.2.3, shall be submitted to eec@aar.com prior to initiation of official AAR testing. A proposed testing schedule and testing procedures will be submitted sufficiently in advance of tests to permit review and approval of the proposal and assignment of personnel to witness tests as AAR observers. Tests will conform to the following requirements, and all costs are to be borne by the applicant, including observers.

11.2.2 The proposed car that is configured for interchange service must be utilized for all tests. Any deviations from the purposed configuration must acquire the permission of the Equipment Engineering Committee.

11.2.3 Cars designed for bulk loading shall have a minimum of 85% of the total volume filled.

11.2.4 Cars designed for general service, other than bulk loading, shall be loaded so that the combined center of gravity of the car and loading is as close as practicable to the center of gravity computed in accordance with the requirements of Chapter 2, except that general service flatcars may be loaded by any practicable method. The loads shall be rigidly braced where necessary and shall be uniformly distributed throughout the test car or as specified by the Equipment Engineering Committee.

11.2.5 The test car must be equipped with any AAR-approved draft gear or any AAR-approved cushioning device for which the car was designed.

11.3 Static and Impact Tests

11.3.1 Instrumentation

11.3.1.1 The coupler force shall be measured by means of a transducer complying with the AAR *Manual of Standards and Recommended Practices (MSRP)*, Section B, Specification M-901F, or other approved means. Instrumentation used for recording of other data shall be of a generally acceptable type, properly calibrated, and certified as to accuracy.

11.3.1.2 Speed at impact shall be recorded.

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11.3.2 Inspection

11.3.2.1 A visual inspection of the test car shall be made after each static test and after each impact. Following the impact tests, the car shall be unloaded and inspected.

11.3.2.2 Any permanent damage to any major structural part of the car, found before or after all tests are completed, will be sufficient cause for disapproval of the design. Damage will be considered permanent when the car requires shopping for repairs.

11.3.3 Static Tests

11.3.3.1 Compressive End Load

11.3.3.1.1 A horizontal compressive static load of 1,000,000 lb shall be applied at the centerline of draft to the draft system of car/unit structure interface areas and sustained for a minimum of 60 seconds. The car/unit structure tested shall simulate an axially loaded beam having rotation-free translation-fixed end restraints (see Fig. 11.1).

11.3.3.1.2 No other restraints, except those provided by the suspension system in its normal running condition, are permissible. Multi-unit car must have each structurally different unit subjected to such test, and two empty units joined together by their connector also shall undergo this test to verify the connector's compressive adequacy and its anti-jackknifing properties.

11.3.3.1.3 The test is to be performed with the car subjected to the most adverse stress or stability conditions (empty and/or loaded).

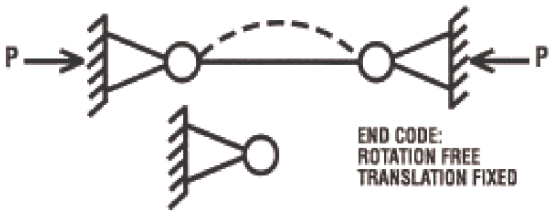


Fig. 11.1 Draft system end conditions

11.3.3.2 Coupler Vertical Loads

For all cars, a load of 50,000 lb shall be applied in both directions to the coupler head as near to the pulling face as practicable and held for 60 seconds.

11.3.3.3 Curve Stability

11.3.3.3.1 The test consist is to undergo a squeeze and draft load of 200,000 lb without car body-suspension separation or wheel lift. Load application shall simulate a static load condition and shall be of minimum 20 seconds sustained duration.

11.3.3.3.2 Cars consisting of more than two units shall be tested with a minimum of three units in the test consist. The number of units used shall generate maximum load in the critical L/V location of the car.

11.3.3.3.3 For the purpose of this test, wheel lift is defined as a separation of wheel and rail exceeding $\frac{1}{8}$ in. when measured 2 $\frac{5}{8}$ in. from the rim face at the inside of curve for buff and outside for draft.

11.3.3.3.4 Empty car shall be subjected to squeeze and draft load on a curve of not less than 10°. The curve is to have $\frac{1}{2}$-in. maximum superelevation. The test car is to be coupled to a base car as defined in paragraph 2.1.6.1 or a like car, whichever is most severe, and a long car having 90-ft over strikers, 66-ft truck centers, 60-in. couplers, and conventional draft gear.

11.3.3.3.5 The test consist shall have means for measuring and recording coupler forces.

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11.3.3.4 Jacking

Vertical load capable of lifting a fully loaded car/unit shall be applied at designated jacking locations sufficient to lift the unit and permit removal of the truck or suspension arrangement nearest to the load application points. No permanent deformation of car/unit structure shall be produced by this test.

11.3.3.5 Twist Load

Loaded car/unit shall be jacked by 3 in. from underneath the wheels on one side of one truck at one end of the car. No permanent deformation of the car/unit structure shall be produced by this test.

11.3.4 Impact Tests

These requirements apply to all cars except those exempted by other specification requirements.

During impact tests, the test car will be the striking car and shall be loaded to AAR maximum gross rail load for the number and size of axles used under the car (see paragraph 2.1.5.17). Exceptions to this procedure will be considered by the Equipment Engineering Committee when justified by the applicant.

11.3.4.1 Single Car Impact

11.3.4.1.1 The loaded candidate car is to be impacted into a string of three standing, fully loaded cars of at least 70-ton capacity (preferably 100-ton). The impact string shall be equipped with M-901E draft gear on the struck end and have the hand brake fully set on the last car (opposite end).

11.3.4.1.2 Free slack between cars is to be removed; however, draft gears are not to be compressed. No restraint other than the hand brake on the last car is to be used.

11.3.4.1.3 A series of impacts shall be made on tangent track by the striking car. Successive impacts shall be made at increments of 2 mph starting at 6 mph or less until the design coupler force of the car as specified in paragraph 4.1.10 or a speed of 14 mph has been reached, whichever occurs first. The coupler force shall not exceed 1,250,000 lb during any impact with a speed of 6 mph or less.

11.3.4.1.4 A car consisting of two or more units must also undergo impact testing as outlined above with the leading unit of the test car being empty for a two-unit car, or with the first two units being empty for a three- (or more) unit car.

11.3.4.2 Dynamic Squeeze

Optional —This test is performed at the discretion of the Equipment Engineering Committee.

11.3.4.2.1 This test is performed to determine the response of the candidate car to compressive forces while negotiating tangent track, curves, and crossovers. The candidate car is successful if it maintains wheel-to-rail contact throughout the test sequences.Test operation shall consist of sufficient locomotive power to subject the candidate car to compressive loads of 100, 200, and 300 kips at speeds above 5 mph when coupled against a consist sufficient to resist the load. The candidate car shall traverse from tangent through a 30-mph crossover, and from a tangent into a minimum 5-degree curve.

11.4 Retarder and “Hot Box” Detection

Cars with other than conventional three-piece trucks must be operated while fully-loaded over a hump and through a retarder. The retarder shall be operated to determine the capability to brake the test cars. Such cars must also demonstrate their compatibility with hot box detection systems per the *MSRP,* Section D, Standard S-3007, latest revision or be equipped with on-board hot box detection systems.

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11.5 Trackworthiness Assessment

11.5.1 Methodology

11.5.1.1 The trackworthiness assessment is intended to establish the dynamic performance of a vehicle as operated in free interchange revenue service. This assessment includes consideration of performance on smooth tangents and curves and consideration of operation on tracks that could excite rigid body modes. A successful vehicle will demonstrate the ability to control dynamic response to track inputs specially engineered to induce these modes.

11.5.1.2 Regimes identified are representative of the performance of the car in service. Tests are defined for each regime. The results of the tests are an indication of the car's trackworthiness.

11.5.1.3 Track configurations used for vehicle testing specified herein are intended to excite specific adverse vehicle dynamic behaviors (e.g., resonant harmonic responses), not to replicate any known in-service track geometry standards or conditions. Exception limits given for dynamic behavior are intended as benchmarks of behavior for new freight cars. These limits are considered conservative and do not represent limits of safe performance.

11.5.1.4 Validated computer models that estimate vehicle performance in each regime should be made available at the request of the Equipment Engineering Committee (EEC). The results of the model analysis shall be included for the consideration of the EEC. The characteristic properties of the car body and its suspension, required for the analysis, shall have evidence of their validity. Characterization tests, such as those defined in Appendix A, are required to verify the values used in the analyses.

11.5.1.5 The tests shall be completed by the AAR observers. The results identified shall be submitted as required data for the consideration of the Equipment Engineering Committee.

11.5.1.6 Any unfavorable vehicle dynamic behaviors or derailments that occur at any time during official testing shall be reported to the Equipment Engineering Committee.

11.5.2 Trackworthiness Criteria

11.5.2.1 The criteria applied to the analyses and tests are chosen from a consideration of the processes by which cars deviate from normal and required guidance. They are also subject to the requirement of being easily measurable in tests. Typical of these are lateral and vertical forces, the lateral over vertical force (L/V) ratios, dynamic displacements, and accelerations of the masses. These criteria are based on considerations of the processes of wheel climb, rail and track shift, wheel lift, coupler and component separation, and structural integrity.

11.5.2.2 Testing criteria apply to all listed and interim speeds at or below the maximum speed of the test regime. The AAR observer is fully authorized to conduct testing at an undocumented speed if deemed necessary and must report the results to the EEC.

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11.5.2.3 The values chosen for the criteria selected have been used in tests on cars currently in service. Those included in the body of this chapter are shown in Table 11.1. Values worse than these are regarded as having undesirable behavior. Values better than these are regarded as acceptable car performance.

Table 11.1 Criteria for assessing the requirements for field service

Regime	Paragraph	Criterion	Limiting Value
Hunting (empty and loaded)	11.7.2	maximum lateral acceleration (g)	1.5[a/]
		standard deviation of lateral acceleration (G)	0.13
Constant curving (empty and loaded)	11.7.3	95th percentile maximum wheel L/V	0.8
		95th percentile maximum axle sum L/V	1.5
Spiral (empty and loaded)	11.7.4	minimum vertical load (%)	10[b/]
		maximum wheel L/V	1.0[c/]
		maximum axle sum L/V	1.5[c/]
Twist, roll (empty and loaded)	11.8.2	maximum roll (deg)[a/]	6
		maximum axle sum L/V	1.5[c/]
		minimum vertical load (%)	10[b/]
		dynamic augment acceleration (G)	1.0
		loaded spring capacity maximum (%)	95
Pitch, bounce (loaded) (empty at EEC discretion)	11.8.3	minimum vertical load (%)	10[b/]
		dynamic augment acceleration (G)	1.0
		loaded spring capacity maximum (%)	95
Yaw, sway (loaded)	11.8.4	maximum L/V truck side	0.6[d/]
		maximum axle sum L/V	1.5[c/]
Dynamic curving (empty and loaded)	11.8.5	maximum wheel L/V	1.0[c/]
		maximum axle sum L/V	1.5[c/]
		maximum roll (deg)[a/]	6
		minimum vertical load (%)	10[c/]

[a/] Peak-to-peak.

[b/] Not to fall below indicated value for a period greater than 50 milliseconds and for a distance greater than 3 ft per instance as illustrated in Fig. 11.2.

[c/] Not to exceed indicated value for a period greater than 50 milliseconds and for a distance greater than 3 ft per instance as illustrated in Fig. 11.2.

[d/] Not to exceed indicated value for a duration equivalent to 6 ft of track per instance.

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Fig. 11.2 Time and distance to climb limits

11.5.2.4 Data Sampling Requirements

All trackworthiness data shall be acquired with a minimum digital sampling rate of 200 samples per second using a four-pole Bessel filter or equivalent filter with a cutoff of 15 Hz.

11.5.2.5 Track Geometry Standards

The criteria of wheel and axle sum L/V are sensitive to track geometry, wheel and rail profiles, and the coefficient of friction between wheel and rail during the tests. In order to provide a repeatable set of test conditions, the test track sections must be maintained to the tolerances outlined in Table 11.2.

Table 11.2 Track geometry tolerances

Test Zone	Tolerances
Twist and roll	± 1/8 in. cross level
	± 1/4 in. gauge
Pitch and bounce	± 1/8 in. amplitude
	± 1/8 in. cross level
	± 1/4 in. gauge
Yaw and sway	± 1/8 in. alignment
	± 1/8 in. gauge
	± 1/8 in. cross level
Hunting	+ 1/2 in. gauge
	– 3/16 in. gauge
Curving (for 7.5°, 10°, and 12° WRM curves)	± 1/4 in. gauge
	± 1/4 in. superelevation
	± 1/4 in. vertical profile
Dynamic curving	± 1/8 in. gauge
	± 1/8 in. cross level
	± 1/8 superelevation
Limiting spiral	± 1/4 in. gauge
	± 1/4 in. alignment
	± 1/8 in. cross level

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11.6 Glossary of Terms (page 1 of 2)

Radial misalignment of axles in a truck or car	The difference in yaw angle between the axles in their loaded but otherwise unforced condition. It causes a preference to curving in a given direction.
Lateral misalignment	The difference in lateral position between axles. It causes both axles to be yawed in the same direction on straight track.
Inter-axle shear stiffness	Equivalent to the lozenge or tramming stiffness in 3-piece trucks, it is the stiffness between axles in a truck or car found by shearing the axles in opposite directions along their axes and measuring the lateral deflection between them.
Inter-axle bending stiffness	The stiffness in yaw between axles in a truck or car.
Bounce	The simple vertical oscillation of the body on its suspensions in which the car body remains horizontal.
Pitch of the body	The rotation about its transverse axis through the mass center.
Body yaw	The rotation of the body about a vertical axis through the mass center.
Body roll	The rotation about a longitudinal axis through the mass center.
Upper and lower center roll	The coupled lateral motion and roll of the body center of mass. They combine to give an instantaneous center of rotation above or below the center of mass. When below the center of mass, the motion is called lower center roll. When above, the motion is called upper center roll.
Sway	The coupled body mode in roll and yaw; it occurs where the loading is not symmetrical.
Unbalance	Used in this chapter to mean the additional height in inches, which if added to the outer rail in a curve, at the designated car speed, would provide a single resultant force, due to the combined effects of weight and centrifugal force on the car, having a direction perpendicular to the plane of the track. Thus, the unbalance (U) is defined as: $$\text{Unbalance } U = \frac{V^2 D}{1480} - H$$ where D = degree of the curve V = vehicle speed (mph) H = height of the outer rail over the inner rail in the curve (in.)

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11.6 Glossary of Terms (page 2 of 2)

Lateral forces to vertical forces (L/V)	Three ratios of lateral (L) to vertical (V) forces are used as criteria in the assessment of car performance: 1. The individual wheel L/V (or wheel L/V). This is defined as the ratio of the lateral force to the vertical force between the wheel and rail on any individual wheel. It is used to assess the proximity of the wheel to climbing the rail. 2. The instantaneous sum of the absolute wheel L/Vs on an axle (or axle sum L/V). This is defined as the sum of the absolute values of the individual wheel L/Vs on the same axle, as given in the following algebraic equation. They must be measured at the same time. $$\text{Axle sum } \frac{L}{V} = \left[\frac{L}{V}(\text{left wheel})\right] + \left[\frac{L}{V}(\text{right wheel})\right]$$ It is used to assess the proximity of the wheel to climbing the rail and is more appropriate where the angle of attack of the flanging wheel to the rail does not result in full slippage at the area of contact. 3. The truck side L/V (or L/V truck side). This is defined as the total sum of the lateral forces between the wheels and rails on one side of a truck divided by the total sum of the vertical forces on the same wheels of the truck, as given in the following algebraic equation. $$\text{Truck side } \frac{L}{V} = \frac{\Sigma L \text{ (truck side)}}{\Sigma V \text{ (truck side)}}$$ The equation is used to indicate the proximity to moving the rail laterally, i.e., rail rollover.

11.7 Single Car on Unperturbed Track

11.7.1 Unperturbed Track—General

11.7.1.1 The regimes described in this section are intended to establish vehicle dynamic performance on premium track. Subsections describe methods to determine high speed performance on tangent track and curving performance on selected curvatures. These regimes qualify a car's performance in operating conditions similar to those found in normal service, while removing the effects of dynamic variations due to adjacent cars or large perturbations caused by poor track.

11.7.1.2 All test procedures and rail conditions shall be dry during the conduct of applicable Chapter 11 tests, the following will be adhered to:

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11.7.1.3 Following the prescribed track conditioning run, the coefficient of rail friction shall be measured in contact zones of the rail head and gauge face of each rail. Two tribometer readings shall be taken, the first reading starting at the first third point of the designated total length of each test track section. The first tribometer reading shall be the value registered by the instrument after rolling it at least 15 ft along the rail. The second reading shall be started at least 50 ft from the end of the first reading. The two values for each top of rail and gauge face will be averaged and the averages for each rail shall be a minimum of 0.4 or greater to conduct the test.

11.7.1.4 Friction readings shall be taken before starting a series of tests for the applicable regime and a record of the tribometer readings shall be made part of the official Chapter 11 report to the Equipment Engineering Committee. If the readings show a discrepancy, a visual inspection of the rails shall be made for the presence of spills, grease, or other contaminants. Repeat readings shall be made if the visual inspection shows no signs of lubrication. Otherwise, all attempts shall be made to eliminate the presence of any materials contributing to coefficients of friction below 0.4. Proper measurement techniques as per the tribometer operations manual shall be followed.

11.7.2 Lateral Stability on Tangent Track (Hunting)

This requirement tests hunting control. Hunting is the transfer of energy from forward motion into sustained lateral oscillations of the axle between the wheel flanges.

11.7.2.1 Modeling Procedure and Conditions (Hunting)

11.7.2.1.1 An analysis shall be made of the critical speed at which continuous full-flange contact is predicted to commence using a validated mathematical model. The criteria for success (modeling and test) are listed in Table 11.1.

11.7.2.1.2 The analytic requirement is that no hunting (sustained lateral axle displacements of ±0.2 in.) be predicted given the following conditions:

- Empty and loaded car
- Maximum speed of 70 mph
- A coefficient of friction of 0.5
- AAR 2A wide flange wheel profiles on new AREMA 136-lb rail
- Standard gauge
- On tangent track, 1° and 2° curves.

11.7.2.2 Test Procedure and Conditions (Hunting)

Hunting tests shall be conducted under the following conditions:

- Testing in both the empty and loaded conditions
- End of consist following a stable buffer car (can be the instrumentation car)
- Maximum speed of 70 mph
- Track with FRA class 6 or better designation
- Rail profile is AREMA 136 lb or equivalent
- 56 5/16 in. < Track Gauge < 57 in.
- Wheels shall all have AAR 2A wide flange wheel profiles with maximum flange wear of 9/32 in
- Minimum coefficient of friction of 0.4
- If hunting is predicted from the modeling analysis or observed during testing, then hunting tests in shallow curves may be requested by the observer.

11.7.2.3 Instrumentation and Test Conduct (Hunting)

11.7.2.3.1 Each truck location on the end unit or car shall be equipped with a lateral accelerometer on the deck above the center of the truck.

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11.7.2.3.2 Sustained truck hunting shall be measured using the lateral acceleration of the car body in 2000-ft windows sliding every 10 ft over a tangent track section that is a minimum of 4000 ft long. Lower levels of acceleration may be necessary to prevent in-transit damage to lading.

11.7.2.3.3 The use of an instrumented wheel set may be required by the Equipment Engineering Committee if, in the Committee's judgment, a derailment potential caused by adverse wheel set motions is possible and these motions are not detectable by the car body acceleration data. If instrumented wheel sets are used, they shall be applied to the leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks. The standard AAR 2A wide flange wheel profiles profile is acceptable when instrumented wheelsets are necessary. Instrumented wheelset criterion is that the sum of the absolute values of the L/V ratios shall not exceed 1.5 on any axle.

11.7.2.3.4 Time histories of the worst-case results that exceed criteria shall be submitted with the report.

11.7.3 Operation in Constant Curves

This requirement is designed to ensure the satisfactory negotiation of track curves. The analyses and tests are required to show that the resulting forces between the wheel and rail are safe from any tendency to derail and to confirm other predictions of the car behavior relating to the guidance of the car and absence of interferences.

11.7.3.1 Modeling Procedure and Conditions (Curving)

11.7.3.1.1 An analysis shall be made of the wheel forces, axle lateral displacements, and yaw angles using a validated mathematical model. The model shall include a fundamental representation of the rolling contact forces using the geometry of the profiles of the wheel and rail and car parameters from the measurements described in Appendix A.

11.7.3.1.2 The criteria for success (modeling and test) are listed in Table 11.1.

11.7.3.1.3 The analysis will be conducted given the following conditions:

- Use a single car
- Model empty and loaded
- For curves of 15° or lower
- Unbalance range of –3 in. to +3 in.
- Coefficient of friction is 0.5
- AAR 2A wide flange wheel profiles
- New AREMA 136-lb rail

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11.7.3.2 Test Procedure and Conditions (Curving)

Curving tests will be performed under the following conditions:

- Unbalance speeds of –3, 0, and 3 in.
- Testing in both loaded and empty conditions
- Use of a leading and trailing buffer car (one of which can be the instrumentation car)
- Test in both directions (turning consist)
- Minimum coefficient of friction is 0.4
- AAR 2A wide flange wheel profiles with maximum flange wear of 9/32 in.
- Rail must not have more than 0.5 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Minimum curvature is 7° with a balance speed of 20 to 30 mph
- Class 5 track or better
- Curve length must be a minimum of 500 ft

11.7.3.3 Instrumentation and Test Conduct (Curving)

11.7.3.3.1 The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheel sets. The lateral and vertical forces and their ratio, L/V, shall be measured for the length of the body of the curve. Force components and ratios having frequencies above 15 Hz are to be filtered out.

11.7.3.3.2 A time history of the worst-case results that exceed criteria must be submitted in the report.

11.7.4 Spiral Negotiation

This requirement is designed to ensure the satisfactory negotiation of spirals leading into and away from curves. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency to derail, especially under reduced wheel loading, and to confirm other predictions of the car behavior.

11.7.4.1 Modeling Procedure and Conditions (Spiral Negotiation)

11.7.4.1.1 An analysis shall be carried out of the lateral and vertical wheel forces on a single car, with the car loaded asymmetrically, consistent with AAR loading rules, to give maximum wheel unloading.

11.7.4.1.2 Criteria for success (modeling and test) are listed in Table 11.1.

11.7.4.1.3 Modeling analysis shall be conducted under the following conditions:

- Unbalance conditions of –3 to +3 in.
- Coefficient of friction is 0.5
- AAR 2A wide flange wheel profiles
- New AREMA 136-lb rail
- Spiral geometry has superelevation rate of 3 in. in 62 ft and a minimum length of 89 ft

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11.7.4.2 Test Procedure and Conditions (Spiral Negotiation)

This test may be carried out concurrently with the previous test, paragraph 11.7.3.2. Curving tests will be performed under the following conditions:

- Unbalance speeds of –3, 0, and 3 in.
- Testing in both loaded and empty conditions
- Use of a leading and trailing buffer car (one of which can be the instrumentation car)
- Test in both directions (turning consist)
- Minimum coefficient of friction is 0.4
- AAR 2A wide flange wheel profiles with maximum flange wear of 9/32 in.
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Minimum curvature is 7° with a balance speed of 20 to 30 mph
- Class 5 track or better
- Spiral geometry shall have a super elevation rate of 3 in. in 62 ft and a minimum length of 89 ft

11.7.4.3 Instrumentation and Conduct (Spiral Negotiation)

11.7.4.3.1 The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheel sets.

11.7.4.3.2 The lateral and vertical forces and their ratio, L/V, shall be measured continuously through qualified spirals in both directions, and their maxima and minima computed. Measured force components and ratios having frequencies above 15 Hz are to be filtered out.

11.7.4.3.3 Time histories of the worst-case results that exceed criteria shall be submitted with the report.

11.8 Single Car on Perturbed Track

11.8.1 Perturbed Track—General

The analyses and tests described in this section are intended to provide a severe, but realistic, basis for the evaluation of trackworthiness performance under less than ideal conditions. Each subsection describes a method to excite a vehicle dynamic mode historically associated with poor performance through the introduction of specially perturbed track geometry. A successful vehicle design will demonstrate the ability to control dynamic response to these inputs resulting in an adequate margin of safety from any tendency to derail or cause any structural damage. The situations described in this section are intended to exercise the vehicle in important dynamic performance modes; they are not intended to represent a worst-case scenario or to replicate any specific revenue track condition. This investigation excludes consideration of dynamic response due to coupling with adjacent cars.

11.8.2 Response to Varying Cross-Level Excitation (Twist and Roll)

This requirement is designed to ensure the satisfactory negotiation of oscillatory cross-level excitation of cars, such as occurs on staggered jointed rail, which may lead to large car roll and twist amplitudes. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency to derail.

11.8.2.1 Modeling Procedure and Conditions (Twist and Roll)

11.8.2.1.1 Criteria for success (modeling and test) are given in Table 11.1.

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11.8.2.1.2 An analysis shall be carried out in the roll and twist modes given the following conditions:

- Empty and loaded car
- AAR 2A wide flange wheel profiles
- New AREMA 136-lb rail
- Maximum speed of 70 mph
- Coefficient of friction of 0.5
- Estimate upper and lower center roll modes
- Tangent track
- Ten staggered perturbations of 39-ft wavelength and 0.75-in. cross-level (see Fig. 11.3)

11.8.2.2 Test Procedure and Conditions (Twist and Roll)

Twist and roll tests shall be conducted given the following conditions:

- Test car has a stable buffer car at each end (one can be the instrumentation car)
- AAR 2A wide flange wheel profiles with maximum flange wear of 9/32 in.
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Starting test speed is well below predicted resonance and increases (but is not limited to) in 2 mph increments until resonance is passed. It is acceptable to approach a resonant condition from a higher speed.
- Minimum coefficient of friction is 0.4
- Tangent track
- Ten staggered perturbations of 39-ft wavelength and 0.75-in. cross-level (see Fig. 11.3)
- Otherwise class 5 or better track

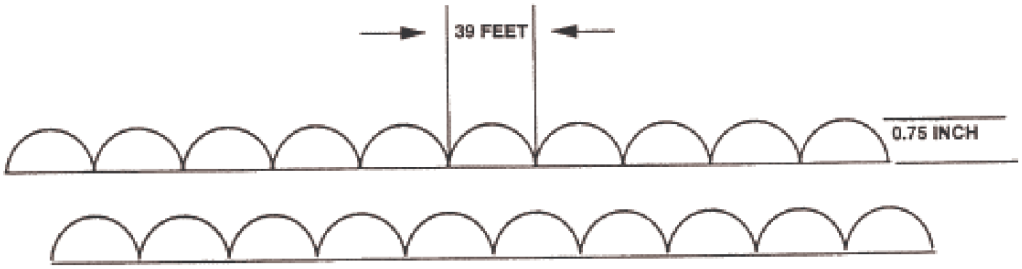


Fig. 11.3 Cross-level variation for twist and roll

11.8.2.3 Instrumentation and Conduct (Twist and Roll)

11.8.2.3.1 The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheel sets. The car body roll angle shall also be measured at a minimum of each end of an end unit.

11.8.2.3.2 The wheel forces and the roll angles at each end for each instrumented unit shall be measured continuously through the test zone. Measured force components and ratios having frequencies above 15 Hz are to be filtered out.

11.8.2.3.3 Time histories of the worst-case results that exceed criteria shall be submitted with the report.

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11.8.3 Response to Surface Variation (Pitch and Bounce)

This requirement is designed to ensure the satisfactory negotiation of the car over track that provides an oscillatory excitation in pitch and bounce. Such excitation is a result of negotiating track constructed with parallel joints and/or track structure where changes in the vertical track stiffness may lead to sudden changes in the loaded track profile beyond those measured during inspection. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car to derail.

11.8.3.1 Modeling Procedure and Conditions (Pitch and Bounce)

11.8.3.1.1 Criteria for success (modeling and test) are given in Table 11.1.

11.8.3.1.2 An analysis shall be carried out in the pitch and bounce modes given the following conditions:

- Loaded car
- Empty at the discretion of the EEC
- AAR 2A wide flange wheel profiles
- New AREMA 136-lb rail
- Maximum speed of 70 mph
- Coefficient of friction of 0.5
- Tangent track
- Ten parallel perturbations of 39-ft wavelength and maximum 0.75-in. vertical amplitude (see Fig. 11.4)

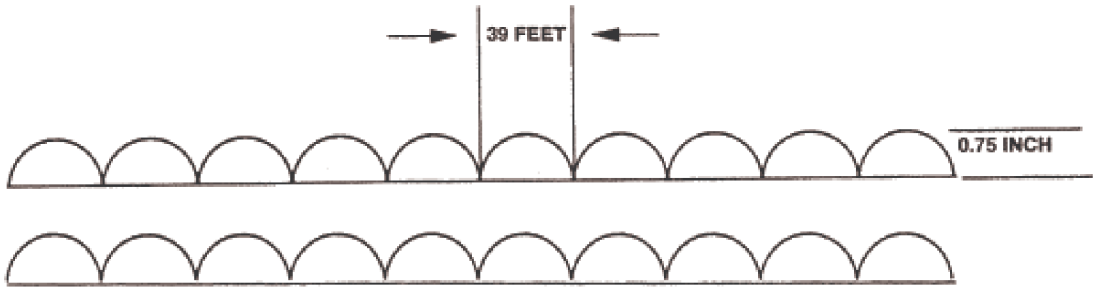


Fig. 11.4 Track surface variation for pitch and bounce

11.8.3.2 Test Procedure and Conditions (Pitch and Bounce)

Pitch and bounce tests shall be conducted given the following conditions:

- Loaded car
- Empty car at the discretion of the EEC
- Test car has a stable buffer car at each end with a minimum 45-ft truck center (one can be the instrumentation car)
- AAR 2A wide flange wheel profiles with maximum flange wear of 9/32 in.
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Starting test speed is well below predicted resonance and increases (but is not limited to) in 5 mph increments until resonance. an unsafe condition, or 70 mph is reached. It is acceptable to approach a resonant condition from a higher speed.
- Tangent track
- Ten parallel perturbations of 39-ft wavelength and maximum 0.75-in. vertical amplitude (see Fig. 11.4)
- Otherwise class 5 or better track

11.8.3.3 Instrumentation and Conduct (Pitch and Bounce)

11.8.3.3.1 The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheel sets. The vertical wheel forces shall be measured continuously through the test zone. Measured force components having frequencies above 15 Hz are to be filtered out.

11.8.3.3.2 Time histories of the worst-case results that exceed criteria shall be submitted with the report.

11.8.4 Response to Alignment Variation on Tangent Track (Yaw and Sway)

This requirement is designed to ensure the satisfactory negotiation of the car over track with misalignments that provide excitation in yaw and sway. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car to derail or to move the track or rail.

11.8.4.1 Modeling Procedure and Conditions (Yaw and Sway)

11.8.4.1.1 Criteria for success (modeling and test) are given in Table 11.1.

11.8.4.1.2 The model should estimate the speed associated with the resonant modes. An analysis shall be carried out in the yaw and sway modes given the following conditions:

- Loaded car
- AAR 2A wide flange wheel profiles
- New AREMA 136-lb rail
- Maximum speed of 70 mph
- Coefficient of friction of 0.5
- Tangent track
- Constant wide gauge of 57.5 in.
- Five parallel perturbations of 39-ft wavelength and maximum 1.25-in. lateral amplitude (see Fig. 11.5)

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11.8.4.2 Test Procedure and Conditions (Yaw and Sway)

Yaw and sway tests shall be conducted given the following conditions:

- Loaded condition only
- Test car has a leading stable buffer with a minimum truck center of 45 ft (can be the instrumentation car)
- Minimum coefficient of friction is 0.4
- AAR 2A wide flange wheel profiles with maximum flange wear of 9/32 in.
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Starting test speed is well below predicted resonance and increases (but is not limited to) in 5 mph increments until resonance, an unsafe condition, or 70 mph is reached.
- Tangent track
- Constant wide gauge of 57.5 in.
- Five parallel perturbations of 39-ft wavelength and maximum 1.25-in. lateral amplitude (see Fig. 11.5)
- Track otherwise is class 5 or better

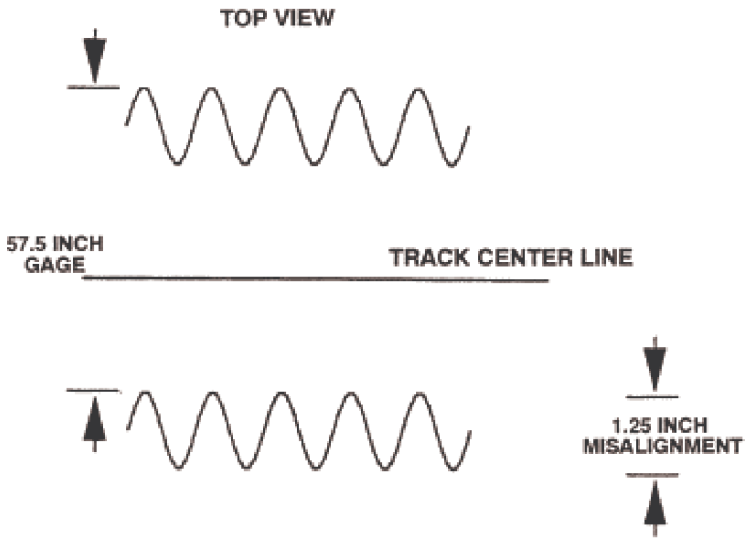


Fig. 11.5 Track alignment variation for yaw and sway

11.8.4.3 Instrumentation and Conduct (Yaw and Sway)

11.8.4.3.1 All axles on the truck estimated to provide the worst total truck side L/V, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheel sets. The wheel forces shall be measured continuously through the test zone. Measured force components and ratios having frequencies above 15 Hz are to be filtered out.

11.8.4.3.2 Time histories of the worst-case results that exceed criteria shall be submitted with the report.

11.8.5 Alignment, Gauge, and Cross-Level Variation in Curves (Dynamic Curving)

This requirement is designed to ensure the satisfactory negotiation of the car over jointed track with a combination of misalignments at the outer rail joints and cross-level due to low joints on staggered rails at low speed. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car forces to cause the wheel to climb the rail or to move the track or rail.

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11.8.5.1 Modeling Procedure and Conditions (Dynamic Curving)

11.8.5.1.1 Criteria for success (modeling and test) are given in Table 11.1.

11.8.5.1.2 The model should estimate the speed associated with the resonant modes. Modeling analysis of dynamic curving is conducted given the following conditions:

- Loaded and empty car
- AAR 2A wide flange wheel profiles
- New AREMA 136-lb rail
- Maximum speed of 70 mph
- Coefficient of friction of 0.5

11.8.5.1.3 Predictions shall be made for a curve between 10° and 15° with a balance speed of between 15 and 25 mph. Cross-level and gauge/alignment variations shall be as shown in Figs. 11.5 and 11.6. The maximum amplitude of the car body roll angle, the maximum instantaneous sum of the absolute values of the wheel L/V ratios on any axle, and the minimum vertical wheel load shall be predicted.

11.8.5.2 Test Procedure and Conditions (Dynamic Curving)

11.8.5.2.1 Dynamic curve tests shall be conducted given the following conditions:

- Loaded and empty
- Test car between two stable buffers (one can be the instrumentation car)
- Minimum coefficient of friction is 0.4
- AAR 2A wide flange wheel profiles with maximum flange wear of 9/32 in.
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Curvature is between 10° and 15° with a balance speed between 15 and 25.
- Starting test speed is –3 in. under-balance with (but not limited to) 2 mph increments and a maximum of +3 in. over-balance. The resonance point may be approached from a higher speed.
- Five staggered perturbations of 39-ft wavelength and 0.5-in. cross-level (see Fig. 11.6)
- Five alignment cusps having the maximum gauge of 57.5 in. coincident with low points of the outside rail and the 56.5 in. gauge points associated with the inner rail low points (see Fig. 11.6). There are no alignment variations on the low rail.

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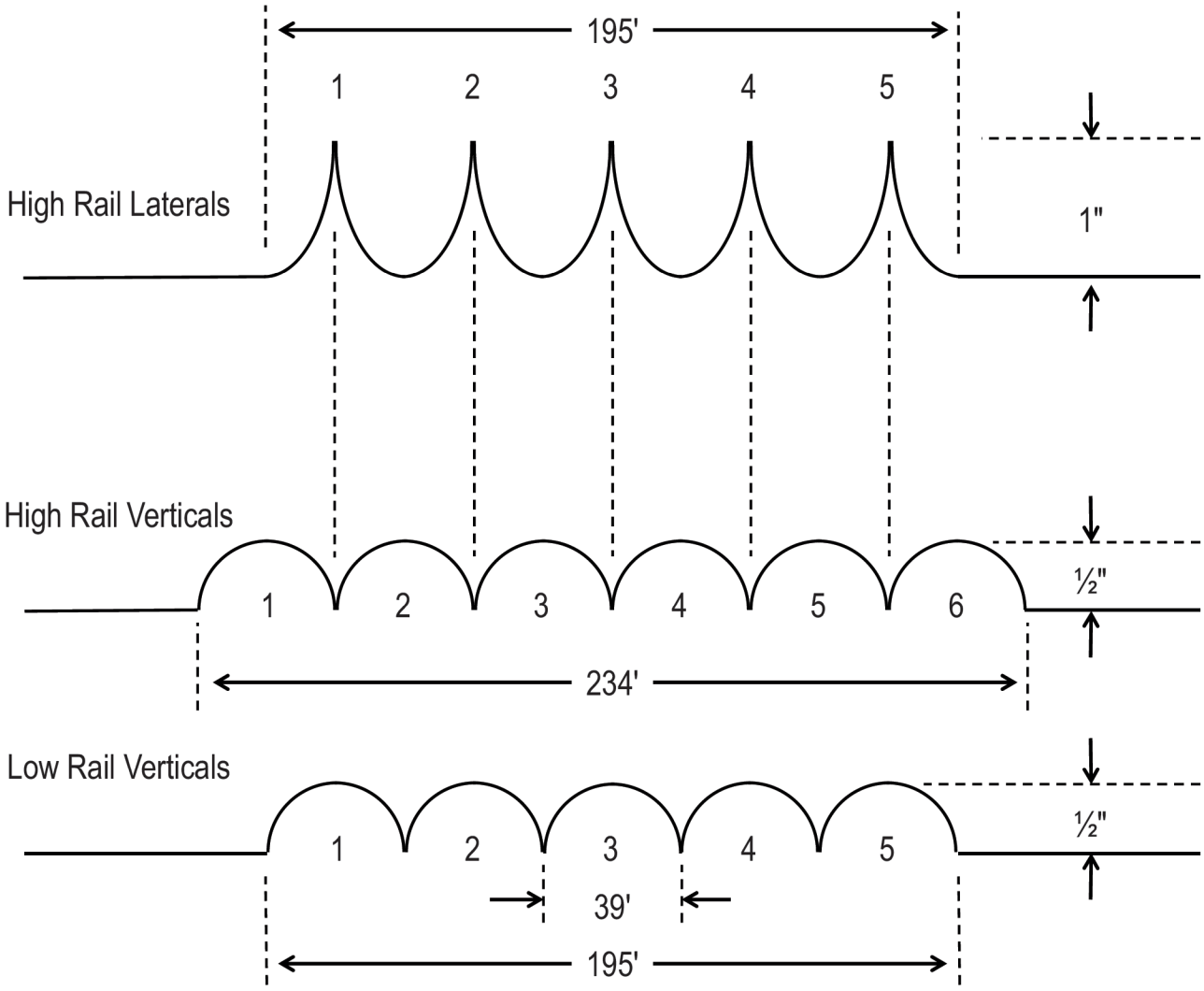


Fig. 11.6 Cross-level, gauge, and alignment variations for dynamic curving

11.8.5.2.2 It is recommended that a guard rail be used to prevent unpredicted derailment; however, it must not be in contact with the wheel during normal test running.

11.8.5.3 Instrumentation and Conduct (Dynamic Curving)

11.8.5.3.1 The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheel sets. The car body roll angle shall also be measured at one end of the lead unit. The lateral and vertical wheel forces and the roll angle shall be measured continuously through the test zone. Measured force components and ratios having frequencies above 15 Hz are to be filtered out.

11.8.5.3.2 Time histories of the worst-case results that exceed criteria shall be submitted with the report.

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CHAPTER 12
CONTROLLED INTERCHANGE EQUIPMENT

12.1 General

12.1.1 This chapter became effective April 30, 1990.

12.1.2 This chapter defines procedures and requirements for approval of equipment intended for use in controlled interchange service. For this type of equipment, requirements of this chapter supersede approval procedures outlined in paragraph 1.3 of Chapter 1.

12.2 Definition

Controlled interchange equipment is defined as freight-carrying rail equipment that, due to its configuration or use, does not meet one or more requirements contained in Chapters 1 through 11 of this specification. Operating restrictions for controlled interchange equipment will be listed in *UMLER* and the *Official Railway Equipment Register* (*ORER*). Acceptance of this equipment in interchange is not mandatory.

12.3 Application Procedures

Application for all cars intended for operation as controlled interchange equipment must be submitted in accordance with the provisions of this chapter. Application for controlled interchange approval proceeds in two phases—prototype design and controlled interchange. The proponent has the option of by-passing the prototype design phase and requesting approval under the provisions of paragraph 12.4.

12.4 Prototype Design

12.4.1 Cars intended for interchange between two or more carriers during the prototype design phase may be operated only by agreement between the carriers involved.

12.4.2 Prior to introduction of cars into the prototype design phase, the proponent of the design will advise the AAR Equipment Engineering Committee (eec@aar.com) of the intent to request approval of the design under the provisions of this chapter. The information outlined in paragraphs 12.4.3 to 12.4.5 is to be submitted with the letter of intent. This information will be treated as confidential proprietary data.

12.4.3 A new car rating form for the proposed design as prescribed in paragraph 1.3.8 of Chapter 1 must be completed. Section II of the rating form must clearly indicate and document the specific reasons why the proposed design cannot comply with M-1001 requirements and must detail all recommended operating restrictions for the cars.

12.4.4 The following must be provided:

- General arrangement drawings for the complete car
- Stress analysis
- A complete clearance diagram
- Brake arrangement to include AAR Form 600 and braking force diagram

12.4.5 As a minimum requirement, results of all applicable static and dynamic tests specified in M-1001 must be submitted. If analysis indicates that the published acceptance values for any test are not attainable, testing shall be performed to revised values deemed practical by the proponent, implications of such deviations fully explained, and appropriate operating restrictions specified. If, in the opinion of the proponent, any test requirement of M-1001 is not applicable to the equipment being considered, the reason for not performing such test or tests must be fully explained in the proponent's submittal, and a description of specific operating restrictions or other compensating safeguards must be provided.

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12.4.6 A review of all information submitted will be conducted by the Prototype Design Review Group exclusively consisting of members of the Equipment Engineering Committee representing those railroads who will be operating the car(s) and responsible AAR staff. This confidential review group will function to ensure that the requirements of this chapter have been complied with. In cases where there is less than a unanimous conclusion on conformance with the intent of this chapter, the equipment will not be interchanged between parties involved until differences are resolved. Following this technical review, the proponent will be advised of any comments and/or recommendations.

12.4.7 A maximum of 100 cars, not to exceed 1,200 axles, may be placed in agreement service under the prototype design phase of controlled interchange. For purposes of this chapter, a car is defined as a unit of equipment having a single reporting mark and car number, regardless of the number of intermediate units that may be included.

12.4.8 Operating restrictions specified by the proponent must be entered in *UMLER* and the *ORER* prior to cars being placed in service under the prototype design phase.

12.4.9 Cars in the prototype design phase must be marked "NON-INTERCHANGE CAR—SEE EQUIPMENT REGISTER" in letters not less than 1 ½ in. high, to the right of the reporting marks and car numbers, in a contrasting color.

12.5 Controlled Interchange

When the number of cars operating under the prototype design phase of controlled interchange reaches the limit stipulated in paragraph 12.4.7, a complete submission for approval must be made in accordance with the requirements of AAR *Manual of Standards and Recommended Practices (MSRP)* Standard S-060. The submission must include all data previously provided under paragraph 12.4, supplemented by additional requirements outlined in paragraph 1.2 of Chapter 1. A report of service experienced with the cars, including estimated mileage and all operational problems encountered, must be provided.

12.5.1 If, after review of the submission, the Equipment Engineering Committee determines that additional testing is required, the proponent will be so advised and a test procedure and schedule will be requested. The test plan must be provided sufficiently in advance of tests (minimum of 10 working days) to permit review of the proposal and assignment of personnel to witness the tests as AAR observers.

12.5.2 Upon action of the Equipment Engineering Committee following a complete review of all data, including the results of supplemental testing performed under paragraph 12.5.1, the cars may be approved as controlled interchange equipment. This approval will include the cars operated in the prototype design phase unless major modifications have been made.

12.5.3 Operating restrictions applicable to the cars as determined under paragraph 12.4.8 must be entered and maintained in *UMLER* and the *ORER* for all cars approved for controlled interchange unless modified by the Equipment Engineering Committee during the review process.

12.6 Marking

Cars in controlled interchange must be marked "CONTROLLED INTERCHANGE CAR—SEE EQUIPMENT REGISTER" in letters not less than 1 ½ in. high, to the right of the reporting marks and car number, in a contrasting color.

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APPENDIX A
PERFORMANCE SPECIFICATION FOR YAW-DAMPING DEVICES

1.0 GENERAL

1.1 This specification was adopted in 1987.

1.2 The purpose of this specification is to provide an evaluation guideline for wheel set or truck yaw-damping devices.

1.3 The yaw-damping characteristics normally are matched to a specific car-suspension system and therefore are not transferable to other suspension systems or to other car structures equipped with similar suspension systems.

1.4 The damper design shall provide for satisfactory functional and mechanical performance of at least 300,000 miles of maintenance-free service in the normal railroad environment.

1.5 Request for approval of the device must include a set of detail and assembly drawings incorporating performance criteria, material specifications, and complete dimensional and tolerance data depicting the device.

2.0 PERFORMANCE CRITERIA

2.1 The yaw damper of a design to be used in production must pass paragraph 11.5 performance tests on a car for which it is designed, as outlined in Chapter 11 of this specification and must provide the required damping levels in both its "new" and "worn" condition.

2.2 The yaw damper shall provide for "free" curving of the wheel set through all curves up to and inclusive of 4°. "Free" curving for purpose of this test is defined as the average measured reading during the test being no less than 90% of the axle-to-car body rotation angle when compared with readings obtained from the same car negotiating the same curve without the damper installed, (minimum three runs through curve in either direction should be performed at speeds of 10 mph and 30 mph on dry rail).

2.3 At the completion of the test, the device will be removed and held for future comparison purposes. This device will be designated as test unit "witness," and will be retained for reference purposes.

3.0 FIELD TEST REQUIREMENTS

3.1 Upon successful completion of the tests outlined in paragraphs 2.1 and 2.2, which have been witnessed by authorized AAR representatives, five carsets of the design for field testing purpose can then be authorized for approval. A lesser quantity can be authorized for prototype testing.

3.2 Conditional Approval

To obtain conditional approval, five sets of the device that have been placed in the field test must have completed at least 50,000 miles of service each and fulfilled the following requirements:

3.2.1 The devices shall be inspected at the end of the test trial by an authorized AAR representative for absence of mechanical distress and for proper functioning.

3.2.2 A retest shall be conducted in accordance with the lateral stability requirements in paragraph 2.1.

3.2.3 Two devices chosen by an AAR representative will be removed from cars. Tests may be performed at the vendor's or other approved test facility and must be witnessed by AAR representatives. The AAR must be given at least 10 days' notice prior to the start of testing.

3.2.4 The following tests shall be performed on both the original witness device and a device removed from field service:

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3.2.4.1 A constant force of 5000 lb shall be applied against the piston stops at each end of the stroke. The load shall be applied and then maintained for a period of not less than 30 seconds. The structure of the damper shall not exhibit any permanent deformation or leakage of oil as a result of this test.

3.2.4.2 Both the witness and the test device will undergo an extension and compression test. The resistance forces measured at velocities of .06 ft/second, .3 ft/second, and 1 ft/second shall not vary more than 10% from the comparable force obtained from the same test performed with the witness device. Devices using acceleration sensing as movement arresting mode shall be tested at predetermined acceleration levels for comparison purposes, and results shall not vary more than 10% from those of the witness device. Alternatively, for mechanical friction devices, the field test unit shall undergo a ± ½-in. displacement induced by a 1-Hz sinusoidal velocity input. The device will be cycled about the nominal installed length. The double amplitude of the result force shall not vary more than 10% from that of the witness device.

3.2.4.3 After completion of the above-referenced tests, the devices shall be examined for performance and wear deterioration. Both items must be judged to be within the life expectancy of 300,000 miles of maintenance-free service.

3.2.5 Successful completion of the field test and lab test will qualify the device to receive conditional approval for service.

3.2.6 Any external, internal, design, material, or performance changes of an approved damper must be reported to the AAR Equipment Engineering Committee for review and concurrence before incorporation of such in production. Willful disregard of this provision will cause revocation of the approval.

3.2.7 The "witness" device will be used for comparative evaluation and verification purposes of any future performance verifications of design improvements, etc.

3.2.8 Semiannual service reports are to be provided by the manufacturer until at least 10% of the authorized devices—no less than 400—have obtained a service life of 300,000 miles and have been inspected by an authorized AAR representative. Two such devices will be removed from a car sent to the lab for inspection and test as outlined in paragraph 3.2.4 using, however, the *worn* witness device data for comparison purposes.

3.2.9 Upon completion of the above stated service experience and satisfactory completion of test requirements outlined in paragraph 3.2.8, the device will be considered fully approved.

4.0 DATA PLATE

Each device must be equipped with a data plate with the following information: (lb-sec per ft)

AAR Specification M-1001
Design Damping Rate (lb-sec per ft)
Damping Range (Velocity) (ft per sec)
Limiting Force (maximum output force in lb)

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APPENDIX B
VEHICLE CHARACTERIZATION

1.0 GENERAL

The characteristic properties of the car body and its suspension, required for analysis of its trackworthiness, must be supported by test results providing evidence of their validity. Forces and motions between suspension components and the body modal frequencies of the car, as assembled, can vary significantly from the values calculated or specified in the design and may be important to the safe performance of the vehicle.

1.1 Test Car

1.1.1 It is important that characterizations be carried out on the particular car in the same condition that the car is to be track tested so that accurate predictions of its performance can be made. For cars with more than one type of suspension, at least one of each type should be tested.

1.1.2 The tests apply to all new car suspensions, including trucks retrofitted with devices such as inter-axle connections, side frame cross-bracing, and additional suspension elements, that have not been tested previously.

1.1.3 Tests for horizontal characteristics of the suspension of trucks with at least two axles may be carried out with the truck separated from the body. In this case, static vertical loads must be applied to simulate the weight of the body or bodies, and the rotational and lateral characteristics between the truck and body must be measured separately.

1.1.4 Where connections exist between the truck and body that may affect the truck characteristics, such as with a truck steered through links to the body, and for all cars with single-axle trucks, the suspension characteristics must be tested while connected to the body.

1.1.5 Where the truck is at the junction of two articulated bodies, both must be simulated or used in the suspension characterization tests specified.

1.2 Test Loads

Modal tests and tests for the horizontal and vertical suspension characteristics are required with vertical loads equivalent to the car in the loaded condition required for the analyses in which the results will be used. Tests to measure the alignment of the axles to each other and to other elements in the system will be included.

1.3 General Procedure

1.3.1 In tests for the suspension characteristics, the recommended procedure is to load the suspension and to measure the load and displacement, or velocity, across the particular suspension element in the required direction. These measurements should be recorded up to the required maximum and down to the required minimum identified.

1.3.2 The loads may be applied, either through automatic cycling at an appropriate frequency or through manual increase and decrease of load, through at least two complete cycles. If manual loading is used, delays and intermediate load reversals between measurements should be avoided. For the determination of stiffness and frictional energy dissipation, the frequency of cycling must be between 0.2 and 0.5 Hz.

1.3.3 Graphs of load versus displacement or velocity are desirable for the determination of the required stiffness or damping.

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2.0 TESTS WITH THE WHEELS RESTRAINED

2.1 General

2.1.1 In the tests described in this section, the wheels are rigidly attached to the rails or supporting structure and the frame is moved relative to them.

2.1.2 The methods described are not suitable for trucks having steering links, which couple the lateral or roll motion of the body or truck frame to the yaw motion of the axles. In such a case, provision must be made for unrestrained longitudinal movement of the wheels, discussed in paragraph 3.0. The steering links may be disconnected to measure the characteristics of suspension elements in the unsteered condition.

2.1.3 All tests require that the actuators and restraining links, other than those at the wheels, have the equivalent of ball joints at both ends to allow for motion perpendicular to their axis.

2.2 Vertical Suspension Stiffness

2.2.1 For this test, equal measured vertical loads are applied across the spring groups in the range from 0 to 1.5 times the static load, if possible, and at least to the static load of the fully loaded car. Vertical actuators are attached to each side of the body or the structure simulating it. The load may also be applied by adding dead load or a combination of both the dead and actuator loads.

2.2.2 Vertical deflections are required across all significant spring elements under load. It is important to report any differences in the measurements taken between each axle and frame or side frame.

2.3 Total Roll Stiffness

2.3.1 A roll test is required if the roll characteristic between the body and axle includes movement at or forces due to elements other than the vertical suspension, such as clearances at side bearings, or anti-roll bars.

2.3.2 For the roll test, two vertical actuators are required as in the vertical test, but with the loads in the actuators in opposite directions. The range of roll moments, in inch-pounds, applied to the truck should be between ±30 times its static load, in pounds, or until the wheels lift. The roll angle across all suspension elements may be measured directly or deduced from displacements.

2.4 Total Lateral Stiffness

2.4.1 The lateral stiffness characteristic may be found by attaching an actuator to apply loads laterally to the body or bodies, which should be positioned as if on tangent track. If the lateral motion of the truck frame is coupled to its yaw through a steering mechanism, it should be disconnected to prevent the yaw resistance of the frame from affecting the measurement of lateral stiffness.

2.4.2 The minimum and maximum lateral loads applied per truck should be ±20% of the static load carried. Measurements are required of the lateral displacements across all suspension elements.

2.5 Inter-Axle Twist and Equalization

This test is carried out with only one axle fixed to the track. One wheel of the other axle in the car or truck is jacked up to a height of 3 in., and the vertical load and displacement are measured. The stiffness between the axles in twist is the ratio of the load to the displacement multiplied by the square of the gauge. It is a measure of the truck equalization.

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3.0 TESTS WITH UNRESTRAINED WHEELS

3.1 General

3.1.1 These tests involve movements in the suspension system and axles relative to other elements of the system or to other axles, without restraint between the wheel and rail, but with the normal static vertical load.

3.1.2 The shear resistance between the rail and the wheel must be eliminated by the provision of a device having very low resistance, such as an air bearing, under each axle.

3.2 Axle Alignment

3.2.1 Both radial and lateral misalignments may be deduced from measurements of the yaw angle of each axle from a common datum. The radial misalignment between axles is half the difference in their yaw angles, taken in the same sense, and the lateral misalignment is their mean yaw angle.

3.2.2 In the case of trucks that have significant clearance between the axle and frame, it may be necessary to establish the axle in the center of the clearance for the purpose of identifying the mean axle misalignments.

3.3 Longitudinal Stiffness

3.3.1 A longitudinal load must be applied to the axle, equivalent to a single load at its center, and cycled between tension and compression up to half the static load on the axle.

3.3.2 The load may be applied directly between axles, or between the test axle and ground through an appropriate structure, with the body or truck frame restrained. The load may also be applied directly between the axle and frame, or in the case of a car with single axle trucks, between the axle and the body.

3.3.3 The longitudinal deflection across each spring element must be measured and the results plotted.

3.3.4 Where the load is applied directly between the axles of a truck or car, this measurement may be combined with the inter-axle shear test in paragraph 3.4, or the inter-axle bending stiffness test in paragraph 3.5.

3.4 Axle Lateral and Inter-Axle Shear Stiffness

3.4.1 The inter-axle shear stiffness may be found by shearing the axles, or moving them in opposite directions along their axes, and measuring the shear or lateral deflection between them. The shear force on each axle must be at least one tenth of the static vertical axle load.

3.4.2 This test may be combined with the inter-axle longitudinal test of paragraph 3.3, where the required load can be achieved.

3.4.3 In the case of direct inter-axle loading, the locations of the applied force and restraint are such that they are equal and opposite, diagonally across the truck or car.

3.4.4 The actuator and restraint each provide two components of force on the axle to which they are attached. One component lies along the direction of the track and provides tension and compression, as in paragraph 3.3, for the longitudinal stiffness. The other component lies along the axle and applies the required shear force between axles. This component may be applied separately with a suitable arrangement of actuators and restraints.

3.4.5 Measurements are made of the lateral misalignment of the axles during the load cycle. The shear stiffness is the ratio of shear force to the lateral misalignment.

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3.4.6 For single axle trucks, a test similar to that described above may be used to determine the lateral stiffness, with force applied laterally between ground and the axle with the body restrained, or with the truck frame restrained in the case of trucks having more than one axle. For trucks that also provide steering through coupling axle lateral motion to its yaw angle, this test may be preferred over the lateral test of paragraph 2.4 for finding the lateral stiffness, because the axles are free to yaw.

3.5 Axle Yaw and Inter-Axle Bending Stiffness

3.5.1 The inter-axle bending stiffness may be found by yawing the axles in the opposite directions and measuring the yaw angle between them. The yaw moment applied, in inch-pounds, must be at least equal to the axle load in pounds.

3.5.2 This test may be combined with the inter-axle longitudinal test of paragraph 3.3. If combined, the test is carried out by applying an effective force on the axle a known distance laterally from the truck centerline.

3.5.3 In the case of direct inter-axle loading, the restraint must be applied to the axle, at the other end of the car or truck, on the same side as the applied force. The applied and restraining forces each provide a longitudinal force and a yaw moment on the axle to which they are attached. The force provides the tension and compression as in paragraph 3.3 for the longitudinal stiffness, and the moment is applied between the truck axles in yaw. This moment may be applied independently of the longitudinal force.

3.5.4 Measurements are made of the resulting radial misalignment of the axles during the load cycle. The bending stiffness is the ratio of applied bending moment to the radial misalignment.

3.5.5 A similar test of the axle yaw stiffness may be arranged with forces applied in yaw between a single axle and ground, with the body restrained, or with the truck frame restrained in the case of trucks having more than one axle.

3.6 Yaw Moment Between the Suspension and Body

3.6.1 The required yaw stiffness and breakout torque between the car body and truck must be measured by applying a yaw moment using actuators in equal and opposite directions at diagonally opposite corners of the truck to rotate the truck in yaw. The car body must be restrained.

3.6.2 The applied yaw moment must be increased until gross rotation is observed, representing the breakout torque, or to the limit recommended for the yaw of the secondary suspension.

3.6.3 The angle in yaw between the car body and truck bolster or frame must be measured.

4.0 RIGID AND FLEXIBLE BODY MODAL CHARACTERISTICS

4.1 General

Tests are required to identify the rigid and flexible body modal frequencies and damping. The rigid body modal frequencies may be compared to predictions using estimated or measured body masses and inertias, and the suspension parameters measured according to the requirements of paragraphs 2.0 and 3.0. Tests and estimates should be made with the car in the empty and fully loaded state.

4.2 Test Car Body

4.2.1 For cars consisting of more than one coupled unit, tests for body modes are required on one of each of the unit bodies having a different structural design. Dead loads may be added to give the required additional loading to any shared suspensions.

4.2.2 Where coupling exists between the modes of adjacent bodies, such as in roll or torsion, the condition may be examined in a dynamic analysis, validated for the case of tests without coupling.

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4.2.3 The frequency and modal damping are only required for the flexible body modes that are predicted to have a natural frequency below 12 Hz.

4.3 General Procedure

4.3.1 Transient or continuous excitation may be applied, using one or more actuators or dropping the car in a manner to suit the required mode of excitation.

4.3.2 The modal frequency and damping are required for an amplitude typical of the car running on Class 2 track.

4.3.3 In the case of the rigid body modes, the actuators must be located at the rail level or the level of the truck frame with the body free to oscillate on its suspension. In the case of the flexible body modes, the excitation may be applied directly to the body.

4.3.4 The frequency in hertz may be determined from the wavelength in the transient test, or from the peak response, or from the 90° phase shift between the response and excitation where continuous excitation is used.

4.3.5 The percentage modal damping may be determined using the logarithmic decrement in transient tests or the bandwidth of the response from a range of frequencies.

4.4 Rigid Body Modes

4.4.1 The rigid body modes for the car are

- Body bounce
- Body pitch
- Body yaw and sway
- Lower center roll
- Upper center roll

4.4.2 In the case where the normal load on the body is not centered between the suspensions, the body bounce mode may be coupled to the body pitch. The required measurement of bounce and pitch may be achieved by two vertical measurements at the ends of the car. Their weighted sum provides bounce and their weighted difference pitch. The weighting is dependent on their position relative to the center of mass.

4.4.3 Yaw and sway are deduced from lateral measurements made at each end of the body, a known distance from its mass center, similar to the determination of pitch.

4.4.4 Measurement of the upper and lower center roll modes are determined from lateral displacements taken at two heights or by a single lateral displacement and a roll angle measurement.

4.5 Flexible Body Modes

4.5.1 The flexible body modes for the car are

- Torsion
- Vertical bending
- Lateral bending

4.5.2 Determination of the frequency and damping in the torsion mode require excitation and measurement of roll at one end of the car.

4.5.3 The excitation for the torsion mode is similar to that for roll but resonance occurs at a higher frequency. The response between the ends of the car is out of phase for the first fundamental mode.

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4.5.4 Vertical or lateral bending modes are measured as a response to the vertical or lateral excitation at one end or both ends of the car. The first bending mode has a maximum amplitude at or near the car center. The second bending mode has a node or a point of minimum response at the center.

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APPENDIX C
SPECIFICATION FOR INSTRUMENTED WHEEL SETS

1.0 INTRODUCTION

Instrumented wheel sets (IWS) to be used in acceptance testing of new and untried cars under Chapter 11 of this specification must meet the requirements of this appendix. Load measuring wheel sets are a critical transducer for a wide range of the Chapter 11 vehicle dynamics tests. Calibrated wheel sets will be required to accurately measure lateral and vertical wheel/rail forces, as well as wheel lateral-to-vertical force (L/V) ratios. IWS to be used for AAR Specification M-976, Truck Performance for Rail Cars, traction ratio testing must also accurately measure longitudinal wheel/rail forces. A verification of wheel set accuracy is performed through a three-step process consisting of calibration, analysis, and field procedures.

2.0 INSTRUMENTED WHEEL SET SPECIFICATIONS

To be accepted for Chapter 11 testing, a load measuring wheel set design must meet the following Specifications for accuracy and dynamic range (note these are not calibration requirements):

2.1 Vertical wheel load measurements must be within ±5% or 250 lb (whichever is greater) of the actual vertical load. This accuracy is to be maintained for loads ranging from 0% to 200% of the nominal AAR design static vertical wheel load. The minimum signal resolution is to be no greater than 0.5% of the nominal AAR design static vertical wheel load.

2.2 Maximum difference between lateral wheel load measurements and actual lateral load shall be no greater than 5% of the actual lateral load, 1% of the actual vertical load, or 100 lb (whichever is greatest).This accuracy is to be maintained for loads ranging from 0% to 100% of the nominal AAR design static vertical wheel load in the flanging direction and 0% to 50% of the nominal AAR design static vertical wheel load in the non-flanging direction. The minimum signal resolution is to be no greater than 0.5% of the nominal AAR design static vertical wheel load.

2.3 Additional Requirement for IWS to be used for AAR M-976 Traction Ratio Tests

2.3.1 Maximum difference between longitudinal wheel load measurements and actual longitudinal load shall be no greater than 5% of the actual longitudinal load, 0.5% of the actual vertical axle load, or 100 lb (whichever is greatest). This accuracy is to be maintained for loads ranging from 0% to 50% of the nominal AAR design static vertical wheel load in both longitudinal directions. The minimum signal resolution is to be no greater than 0.5% of the nominal AAR design static vertical wheel load.

2.4 Maintain the above-stated accuracy requirements, at all times, for the following:

2.4.1 All potential load cases, including longitudinal loads of up to 50% of the nominal AAR design static vertical wheel load, lateral loads of up to 100% of the nominal AAR design static vertical wheel load, and vertical loads of up to 200% of the nominal AAR design static vertical wheel load.

2.4.2 All potential wheel/rail contact conditions, including full flange contact, outside tread contact, two-point contact, and flange contact at high wheel set angles of attack.

2.4.3 An operating speed (for dynamic wheel set output) of from 5 mph to 80 mph.

2.4.4 Input signals ranging from 0 Hz to 15 Hz.

2.4.5 A recommended operating ambient air temperature range of 0 F° to 110 F°. Any restrictions in the operating temperature range are to be noted.

2.5 Wheel set reprofiling or recalibration requirements due to profile wear must be documented. The wheel sets are to be equipped with the current standard interchange AAR profile. The machining grooves shall be worn smooth on the tread. Details of construction that deviate from AAR interchange standards must be noted.

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3.0 VERIFICATION

Wheel set accuracy is to be substantiated through calibration, analysis, and testing. A minimum number of required wheel set tests to calibrate and verify wheel set output are described. Since dynamic calibration of load measuring wheel sets can be difficult, further verification of wheel set accuracy relies on required static and dynamic analyses. A limited set of simple experimental procedures are then prescribed to confirm proper wheel set function under field conditions.

3.1 Calibration

3.1.1 Tests to determine the wheel set calibration factors are required of all instrumented wheel sets. Documentation in support of the calibration tests is to include a complete description of the calibration stand and the calibration procedure. Load cell accuracy and certification information should be included. Calibration for vertical and lateral loads shall include testing at sufficient intervals to document accuracy and repeatability for all rotational positions around the wheel over the range of operating speeds.

3.1.2 The calibration report is to include a description of the calibration process. The calibration report must also include tables and/or graphs comparing the applied forces and the measured forces, with sufficient numbers of (at least three) points to document linearity over the operating ranges for the various forces. The calibration tests are as follows:

3.1.2.1 Using an appropriate loading scheme, vertical loads ranging from 0% to at least 100% of the nominal AAR design static vertical wheel load are to be applied. Calibration for vertical loads shall include testing for a minimum of three contact point lateral positions to document accuracy over the range of expected wheel/rail contact positions across the wheel tread.

Note: For calibration purposes, the static wheel set weight may be substituted for the zero load case.

3.1.2.2 Using an appropriate loading scheme, lateral wheel loads are to be applied ranging from 0% to at least 30% of the nominal AAR design static vertical wheel load.

3.1.2.3 (Only required for IWS to be used for AAR M-976 Traction Ratio Tests) Using an appropriate loading scheme, longitudinal loads are to be applied. The loading method and any supplemental analytical calculations shall be described in cases where direct applications of longitudinal forces to the wheels are not used, or where a dynamic calibration process is used. Linearity and operating range are to be documented.

3.2 Analysis

3.2.1 The following analyses are required to verify theoretical wheel set accuracy for load combinations that cannot satisfactorily be applied using a conventional loading frame and to establish uncertainty or error bands to be used when reporting results. Any variations in wheel set output or accuracy due to rotational position are to be documented. Any variations in wheel set output or accuracy due to direction of lateral (flanging or non-flanging) or longitudinal (forward or backward) forces are to be documented.

3.2.2 Static finite element analysis, calibration data, and/or data from a dynamic calibration fixture (such as a roller rig) may be used to verify theoretical wheel set accuracy for the following:

- L/V (lateral-to-vertical ratio) from –0.5 to 1.0
- T/V (longitudinal-to-vertical ratio) from –0.5 to 0.5
- tread contact positions from –1.5 in. (toward flange) to +2 in. (toward rim) from tape line.

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3.2.3 An error estimate, from known force input to computed force output, is to be made for each wheel set design, for the load cases described above. The maximum error associated with each component in the data acquisition system (wheelset sensors, processor, signal conditioning, digitizer, etc.) must be determined and documented. The systemic error is then to be computed and reported using the following equation:

$$\xi = \sqrt{\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2 \ldots}$$

where ε_1 = Processor error
ε_2 = Signal conditioning error
ε_3 = Digitizer error
etc.

3.3 Test Procedures

The following experimental analyses are required:

3.3.1 A zero speed jacking test to verify the wheel set zero followed by a slow roll (up to 30 mph) along tangent track to verify that wheel vertical load signals are within ±5% of the calibrated scale axle load for constant speed operation on level tangent track. Wheel set signals will be evaluated on the basis of mean values for a randomly chosen output segment having a minimum duration of 10 seconds.

3.3.2 A test on tangent track to verify that wheel vertical load signals are within ±5% of the calibrated scale axle load for constant speed operation at 80 mph or the maximum stable speed of the test car, whichever is lower. Wheel set signals will be evaluated on the basis of mean values for a randomly chosen output segment having a minimum duration of 10 seconds.

3.3.3 A steady state curving test to confirm that total truck (or car) vertical loads are within ±5% of the theoretical value. The test shall also confirm that differences between the net truck lateral loads and the theoretical values are within ±5% of the nominal static vertical wheel load. Tests shall be conducted on a sharp curve (7° curvature or above with constant curvature and super elevation). Test speeds shall be constant and correspond to +3, 0, and -3 inch cant deficiency. Wheel set signals will be evaluated on the basis of mean values for a randomly chosen output segment having a minimum duration of 10 seconds or a minimum distance of 500 feet.

4.0 RECORDS

4.1 The theoretical analyses described are necessary only once for each wheel set design. The calibration and field procedures must be performed for each wheel set produced to an accepted specification.

4.2 An instrumented wheel set that has met these requirements will be so certified by the designated AAR representative.

4.3 The designated AAR observer for AAR qualification testing will verify that the instrumented wheel sets to be used are acceptable for testing. A copy of the calibration report must be provided to the observer prior to certification testing. The report must include the calibration date and documentation of recalibration requirements and status.

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