Evaluation of the Effect of Wood Quality on W-beam Guardrail Performance

Final Report

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9. Abstract

Due to the failure of an independent testing laboratory to accurately grade wood guardrail posts, the Nebraska Department of Roads has installed a large number of posts of unknown quality. This study was undertaken to determine the quality of these posts and to determine their effect on the performance of guardrail installations in the State. Results of the grading, static and dynamic testing, and simulation study has shown that the posts installed, while not meeting the salient Nebraska specifications, meet or exceed the nationally accepted criteria.

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INTRODUCTION

The purpose of this research study, was to evaluate the mixed grade guardrail posts installed by NDOR over the past 6 years in order to establish the integrity of these installations. Due to the failure of an independent testing laboratory to accurately grade wood guardrail posts, the Nebraska Department of Roads has installed a large number of posts that are below the DS-65 classification specified by the State. This specification provides a high factor of safety and is more stringent than required by Federal guidelines.

Strong-post W-beam guardrails represent the most commonly used longitudinal traffic barrier across the nation. These barriers have traditionally been designed to contain and redirect full-size automobiles impacting under high-speed and high-angle situations. This barrier's wide use can be credited to its low cost and relatively low lateral deflection during severe impacts. The most widely used strong post barriers incorporate 6 in. X 8 in. wood posts and blockouts in wide variety of wood grades and species. Douglas Fir and Southern Yellow Pine are the two most common types of wood used in W-beam guardrails. An 8 MPa allowable stress rating is recommended for both of these woods by the *AASHTO/ARTBA/AGC A Guide to Standardized Highway Hardware.*

To determine the condition of guardrail systems in the State, a three phase study was initiated to:

1) Determine the actual quality of the posts installed over the past six years (determined to cover the time frame of the inaccurate independent inspection).

2) Determine the performance of the installed posts.

3) Determine how the performance of the installed posts will relate to the performance of guardrail systems.

DEFINITION OF IN-PLACE CONDITION

The key to defining the current situation in the field was to develop a better picture of the quality of posts supplied to the State through the past 6 years. A major component of the study focused on selection and grading of posts. Selection of a sample population of posts was initiated with a review of construction records from various Districts over the past six years. Because of the potential variation of supply in different years, posts from 1989, 1992, and 1994 were identified for sample selection. Because of the limited selection of 1989 construction projects, two additional samples from 1990 were also selected to assure adequate representation from various Districts. The number of years selected was limited to assure significant sample sizes to allow statistical comparison. The faculty and engineering staff involved with the project, took the selected records and surveyed the identified installations. Samples were selected from each of the years 1989, 1992, and 1994 from each of the Districts. To account for the potential for environmental degradation that may have been caused by excess subgrade moisture, about one-half the samples were selected from low areas and one-half from areas substantially above the groundwater table. This sample provided the ability to quantify grade and performance with respect to age, location, and moisture conditions. Posts selected for the study were numbered and documented in the field. For a given year, district, and elevation lots of approximately 30 posts were selected. In total 605 posts were selected.

Under our direction, the Districts pulled and replaced these posts and transported them to our testing facility at the Lincoln airport. Posts were pulled using the bolt hole at the top to minimize damage, and the lots from each site were palletized and marked. After arrival at the field site, the posts were washed and organized by sample number.

GRADING

To assess the actual grades of the posts in the sample, an independent grader from the Southern Pine Inspection Bureau was contracted to inspect the posts. The grading of lumber is based on the effects of various defects on the anticipated structural performance. To this end, the grading system is sensitive to wane (missing wood) on the ends. While this is a practical consideration for lumber to be used in construction, missing wood on the ends of guardrail post has little effect on performance. For this reason, we requested that the grader perform two inspections on each post. The first, a complete survey which should reflect the grading the State had contracted for prior to initial installation and the second, a grading without consideration of wane on the ends of the post, which would more accurately reflect the actual performance of the posts in guardrail applications. The results of these gradings are shown in Figure 1.

From this evaluation, it was immediately clear that over 75% of the posts in the sample did not meet the State specifications. In terms of performance criteria, defined from the grading without considering wane, about 90% of the posts are grade 1 or better, with the bulk of the remainder being grade 2 and 2D. The posts classified as grade 3 and E were generally attributable to damage due to installation or removal. Evaluation of grading with respect to installation and location showed that there was no statistically significant differences.

All references to grading made in the remainder of this document refer to the grading performed without considering wane on the ends of the posts. This criteria was determined to much more accurately reflect the actual performance of the posts in static and dynamic testing.

PERFORMANCE

While grading is related to the anticipated performance of the wood posts, actual measurements are required for accurate assessment of the impact on the performance of guardrail systems. A series of static and dynamic tests were undertaken to quantify the performance of the different grades of wood. Initially, a larger series of static tests was planned, but during the course of the work it was determined that the cost savings of static testing over dynamic testing was not great, so the bulk of the testing program was focused on dynamic testing. In total 24 static and 86 dynamic tests were performed.

Static tests were performed with the posts cantilevered from a rigid frame, and load applied at a constant rate. Load and deformation were recorded continuously during the test.

Dynamic tests were performed using an approximately 21 mph impact velocity with a 2080 lb bogey. Posts were placed in a steel tube embedded in concrete, with neoprene padding on the front and back faces of the post/steel interface. Impact forces and deformations were determined with an on-board accelerometer.

Posts for dynamic testing were randomly selected, with the exception of a test set of grade 1 posts, from the 605 post sample. As shown in Figure 2, 16 posts from the grades 65, 1D, 2D, and 2 were tested. To study the effects of knots in the tension region of the post more carefully, the testing of grade 1 posts was subdivided with 7 posts selected at random for testing, and then from the remaining posts 9 were selected that had the worst case defects, which are believed to be knots in the tension face. All of the posts for static testing were randomly selected. For comparison with relevant national standards, a series of grade 1 Douglas Fir posts were included in the dynamic testing portion of the study. After selection each post was weighed and measured, moisture contents were taken throughout the length, and significant knots

and defects were cataloged.

Dynamic testing of the posts, summarized in Figure 2, showed that the DS-65 posts were significantly stronger than the other posts tested. With the limited sample size and high variability of the dynamic strengths measured, there is no statistically significant difference in any of the remaining grades of posts tested. It is anticipated that if the number of tests were increased significantly that a statistically significant difference could be shown between the dense posts (grades 1D and 2D) and the nondense posts (grades 1 and 2).

Static tests, summarized in Figure 2, of grades DS-65, 1D, and 1 posts yielded a significantly smaller difference in the peak forces obtained compared to dynamic testing. The dynamic magnification factor varied from 2.1 for the DS-65 posts to 1.2 for the 1D posts.

From the performance testing, it can be concluded that there is no significant difference in the strength or energy absorption between grade 1 Southern Yellow Pine and Douglas Fir posts, the nationally recognized standard, and any of the lower grade posts currently installed in the State. Results also indicate that the DS-65 grading has a significant strength advantage over the lower grades.

MODELING OF IN-PLACE SYSTEMS

Concurrent to the performance testing effort, computer simulation of various guardrail systems was undertaken. The simulation effort was used to evaluate the performance of a functionally worst case scenario. The system was modeled with a relatively strong soil that offers high resistance to post rotation. Four weak posts in series leading to a strong post was determined to be the worst case orientation. Utilizing dynamic results from this study showed that in comparison with a system employing DS-65 posts, deflections of the weak post system increased approximately

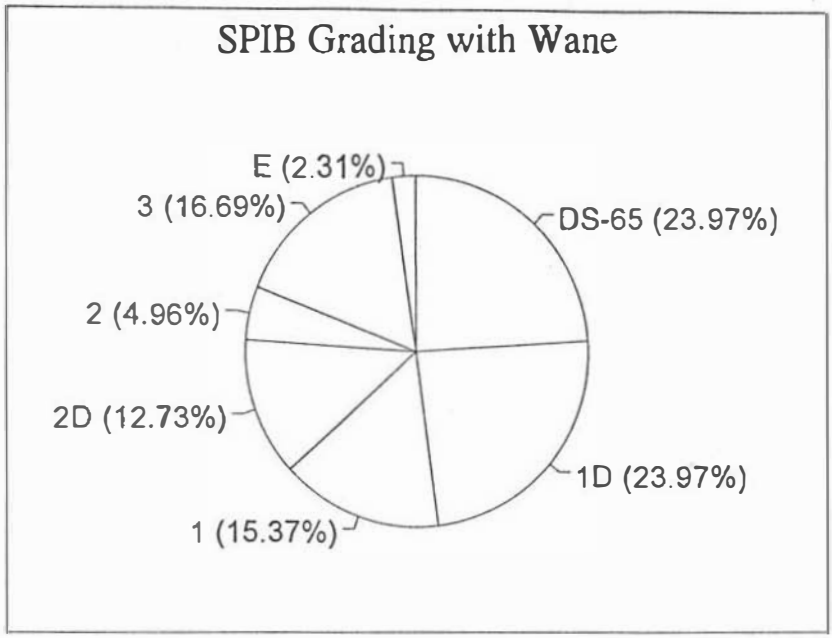
30%. The system with the weak posts was shown to perform safely, despite this increased deflection.

CONCLUSIONS

This study was undertaken to evaluate the effects of posts that have been installed in Nebraska over the last six years. After random sampling of a significant number of posts and subsequent grading, performance testing, and computer simulation, it is our conclusion that the guardrail systems installed in the State meet or exceed the nationally accepted criteria.

Appendix A

Static and Dynamic Test Results



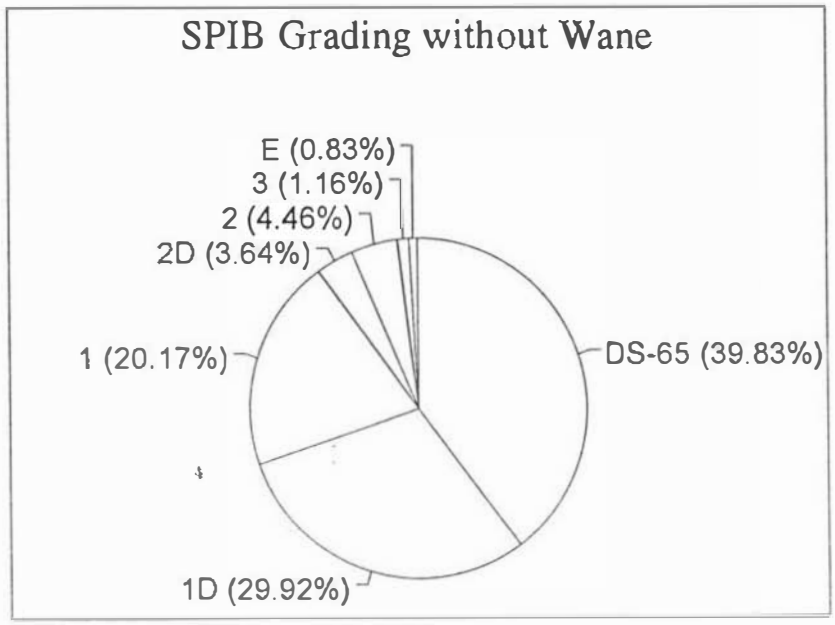


Figure 1:SPIB grading of the 605 post sample.

Bogey Post Testing Summary October 1995

Speeds: 20 - 22 MPH

Number of Posts	Grade	Peak Force				Rupture		
		Force (kips)	Time (ms)	Defl (in)	Energy (kip-in)	Time (ms)	Defl (in)	Energy (kip-in)
16	65	31.7	12.4	4.6	46.8	16.4	5.7	70.1
16	1D	14.6	10.5	3.9	25.2	14.8	5.4	39.0
9	1 - Worst	12.1	11.6	4.3	21.1	15.5	5.6	31.1
7	1 - Random	13.3	11.2	4.3	26.9	15.1	5.6	38.5
16	2D	16.1	10.7	4.1	27.1	14.9	5.4	41.1
16	2	12.7	10.7	4.0	22.6	15.3	5.6	35.2
7	Doug-Fir	13.1	11.4	4.3	26.0	15.3	5.5	37.2

Static Post Testing Summary October 1995

Number of Posts	Grade	Peak Force			Fracture		
		Force (kips)	Defl (in.)	Energy (kip-in.)	Force (kips)	Defl (in.)	Energy (kip-in.)
10	65	15.12	2.70	26.88	3.73	8.08	63.59
7	1	8.97	2.11	12.26	1.87	8.96	29.50
7	1D	12.30	1.94	17.41	1.07	9.24	39.10

Figure 2:Summary of the dynamic and static performance of posts based on post grading not considering wane.

TABLE A-1. BOGIE VEHICLE TESTS OF DS-65 POSTS

Post Number	Grade SPIB	Grade No Wane	Peak Force Force (kips)	Peak Force Time (ms)	Peak Force Defl (in)	Peak Force Energy (kip-in)	Rupture Time (ms)	Rupture Defl (in)	Rupture Energy (kip-in)	Impact Velocity (MPH)
1127	65	65	58.8	14	4.8	85.6	18	5.7	123.4	21.4
106	65	65	38.8	13	4.7	57.3	17	5.7	83.4	21.4
1059	65	65	18.8	12	4.5	30.8	16	5.8	47.8	21.6
330	65	65	29.2	13	4.8	45.0	17	5.9	65.6	21.8
1308	65	65	27.5	13	4.9	44.3	17	6.1	66.4	22.3
2	65	65	27.4	13	4.8	40.7	17	6.0	63.0	21.8
119	65	65	24.6	13	4.7	37.0	17	5.9	56.7	21.4
429	65	65	24.3	12	4.5	35.6	16	5.7	55.2	21.3
616	65	65	24.4	12	4.4	36.6	16	5.7	55.6	21.2
566	65	65	28.7	10	3.9	39.0	14	5.1	61.4	21.6
622	1D	65	40.1	13	4.8	57.0	17	5.8	83.9	21.4
1102	2D	65	14.9	13	4.7	23.8	17	6.1	38.2	21.6
568	2D	65	53.7	14	4.9	75.6	18	5.8	108.0	21.4
1129	3	65	31.5	11	3.9	44.0	14	5.1	67.2	21.5
222	3	65	48.0	12	4.2	72.2	16	5.2	106.4	21.8
422	3	65	16.1	12	4.5	25.0	17	5.9	39.5	21.4
		Average	31.7	12.4	4.6	46.8	16.4	5.7	70.1	

TABLE A-2. BOGIE VEHICLE TESTS OF GRADE 1D POSTS

Post Number	Grade SPIB	Grade No Wane	Peak Force Force (kips)	Peak Force Time (ms)	Peak Force Defl (in)	Peak Force Energy (kip-in)	Rupture Time (ms)	Rupture Defl (in)	Rupture Energy (kip-in)	Impact Velocity (MPH)
613	1D	1D	14.5	10	3.6	22.1	14	5.0	35.5	20.8
626	1D	1D	14.8	10	4.0	27.5	14	5.4	41.4	22.4
504	1D	1D	11.1	10	3.7	19.5	14	5.2	31.5	21.8
1407	1D	1D	10.9	10	3.9	20.3	14	5.5	32.4	22.6
1151	1D	1D	12.0	10	3.9	22.8	15	5.6	36.6	22.6
209	1D	1D	17.3	12	4.3	30.4	16	5.4	43.6	20.6
168	1D	1D	20.6	12	4.3	37.0	16	5.5	53.1	21.3
314	1D	1D	22.6	13	4.8	41.2	16	6.1	60.3	22.7
704	1D	1D	14.2	10	3.7	24.0	14	5.1	36.9	21.3
620	1D	1D	11.7	10	3.8	19.4	15	5.4	32.3	22.0
559	1D	1D	15.1	11	4.0	25.4	15	5.2	39.4	21.5
176	1D	1D	9.9	9	3.4	15.4	14	5.1	27.3	21.5
8	1D	1D	20.4	12	4.3	33.4	16	5.7	51.9	21.8
1222	1D	1D	17.5	11	4.1	30.4	15	5.4	46.2	22.0
1128	1D	1D	12.1	9	3.4	19.1	14	4.9	30.4	20.4
1419	3	1D	8.9	10	3.6	16.0	15	5.1	24.9	20.6
		Average	14.6	10.5	3.9	25.2	14.8	5.4	39.0	

TABLE A-3. BOGIE VEHICLE TESTS OF GRADE 1 POSTS

Post Number	Grade SPIB	Grade No Wane	Peak Force Force (kips)	Peak Force Time (ms)	Peak Force Defl (in)	Peak Force Energy (kip-in)	Rupture Time (ms)	Rupture Defl (in)	Rupture Energy (kip-in)	Impact Velocity (MPH)
1209	1		Results not decipherable							
1106	1	1	8.6	12	4.4	17.0	16	5.8	24.7	21.4
1180	1	1	11.0	12	4.3	20.3	16	5.6	29.8	20.9
1170	1	1	7.2	11	4.1	16.0	16	5.6	23.5	20.8
178	1	1	13.8	12	4.3	24.5	16	5.8	37.2	21.6
715	1	1	15.7	12	4.2	24.5	16	5.5	38.3	20.9
627	1	1	10.6	12	4.4	19.5	16	6.0	29.8	21.6
1108	3	1	17.5	11	4.3	26.0	16	5.8	43.1	22.2
1168		1	9.7	8	3.2	14.5	13	4.8	25.8	21.9
1058		1	9.2	10	3.5	16.8	15	5.1	27.8	20.6
		Average	12.1	11.6	4.3	21.1	15.5	5.6	31.1	
			Random Selected							
1027		1	11.5	11	4.1	22.6	15	5.4	32.8	21.6
657		1	13.8	12	4.5	28.8	15	5.7	40.0	22.5
773		1	9.8	11	3.9	21.2	15	5.2	30.1	21.3
303		1	9.5	11	4.1	19.5	15	5.5	29.1	21.6
1112		1	19.7	12	4.7	39.0	16	5.8	54.0	22.6
179		1	15.5	11	4.4	29.4	15	5.8	44.2	23.5
14		1	13.0	11	4.4	28.1	15	5.8	39.5	22.5
		Average	13.3	11.2	4.3	26.9	15.1	5.6	38.5	

TABLE A-4. BOGIE VEHICLE TESTS OF GRADE 2D POSTS

Post Number	Grade SPIB	Grade No Wane	Peak Force Force (kips)	Peak Force Time (ms)	Peak Force Defl (in)	Peak Force Energy (kip-in)	Rupture Time (ms)	Rupture Defl (in)	Rupture Energy (kip-in)	Impact Velocity (MPH)
576	2D	2D	26.5	13	5.0	45.2	17	6.1	65.8	22.2
1423	2D	2D	8.7	11	4.2	16.8	16	6.0	27.5	22.6
111	2D	2D	26.5	13	4.6	40.6	17	5.7	57.8	20.4
518	2D	2D	13.2	12	4.6	25.0	16	6.0	36.4	22.0
501	2D	2D	20.8	13	4.8	33.6	16	6.0	50.9	22.4
207	2D	2D	28.8	14	5.5	53.7	18	6.8	76.2	23.0
156	2D	2D	18.1	13	4.9	31.1	17	6.1	46.2	22.0
1160	2D	2D	5.6	6	2.6	7.3	10	3.9	12.3	22.4
305	2D	2D	10.8	8	3.0	14.0	13	4.8	26.4	21.5
321	2D	2D	9.2	8	3.1	12.3	13	4.5	21.2	21.4
510	2D	2D	12.7	10	3.8	24.5	15	5.2	37.5	20.3
5	2D	2D	23.6	12	4.4	44.0	16	5.5	62.6	21.4
619	2D	2D	15.7	11	4.1	30.1	15	5.5	44.8	21.9
670	E	2D	9.2	8	2.9	12.9	13	4.7	24.0	21.9
603	3	2D	10.8	8	3.1	15.5	12	4.4	24.7	21.6
51	3	2D	16.9	12	4.4	26.3	16	5.8	42.8	21.9
		Average	16.1	11	4.1	27.1	14.9	5.4	41.1	

TABLE A-5. BOGIE VEHICLE TESTS OF GRADE 2 POSTS

Post Number	Grade		Peak Force				Rupture			Impact Velocity
	SPIB	No Wane	Force (kips)	Time (ms)	Defl (in)	Energy (kip-in)	Time (ms)	Defl (in)	Energy (kip-in)	(MPH)
676	2	2	17.9	12	4.2	29.3	16	5.5	43.8	21.0
425	2	2	11.6	10	3.7	18.7	15	5.3	31.1	21.6
630	2	2	18.3	13	4.7	34.1	17	6.0	50.0	21.4
306	2	2	8.5	12	4.8	21.0	16	6.5	31.8	23.8
426	2	2	7.8	12	4.5	17.8	17	6.2	26.9	21.9
768	2	2	8.8	9	3.5	14.7	14	5.5	26.4	22.3
572	2	2	13.0	11	3.6	22.1	15	4.8	32.8	19.7
625	2	2	19.6	12	4.4	37.0	16	5.6	52.4	21.1
609	2	2	11.8	10	3.8	21.3	15	5.4	34.2	21.9
109	2	2	10.7	8	3.1	15.4	13	4.7	25.6	21.8
669	3	2	13.0	10	3.8	23.0	15	5.3	35.6	21.6
766	3	2	11.6	9	3.4	17.9	14	5.2	31.7	21.9
662	3	2	8.8	11	4.3	18.5	15	6.0	29.4	23.1
74	3	2	13.1	13	4.9	27.6	18	6.5	40.6	22.2
763	3	2	19.8	13	4.8	32.2	17	6.0	48.5	21.1
407	3	3	8.5	8	2.9	11.0	13	4.8	22.5	21.4
		Average	12.7	10.7	4.0	22.6	15.3	5.6	35.2	

TABLE A-6. BOGIE VEHICLE TESTS OF GRADE 1 DOUGLAS FIR POSTS

Douglas Fir Grade 1 Bogey Tests: 10/24/95

Post Number	Grade		Peak Force				Rupture			Impact Velocity
	SPIB	Special	Force (kips)	Time (ms)	Defl (in)	Energy (kip-in)	Time (ms)	Defl (in)	Energy (kip-in)	(MPH)
2001	1		22.5	12	4.5	39.0	16	5.5	55.3	21.6
2002	1		12.8	11	4.3	26.0	15	5.6	37.4	22.2
2003	1		11.8	11	4.3	25.3	15	5.7	37.1	22.2
2004	1		12.3	11	4.1	24.0	15	5.4	35.4	21.6
2005	1		8.8	12	4.2	20.7	16	5.5	28.3	21.1
2006	1		13.1	11	4.2	24.8	15	5.5	35.3	21.5
2007	1		10.3	11	4.2	21.9	15	5.5	31.6	22.0
		Average	13.1	11.4	4.3	26.0	15.3	5.5	37.2	

TABLE A-7. STATIC TEST RESULTS

Static Post Testing

Post No.	GRADE SPIB	No Wane	Peak Load (kips)	Deflectio (in.)	Energy (kip-in)	Fracture Force (kips)	Fracture Deflectio (in.)	Fracture Energy (kip-in.)
1126	65	65	15.1	3.6	34.6	8.8	4.1	40.8
228	65	65	17.5	2.6	28.5	7.8	4.8	55.4
1420	65	65	15.7	2.8	29	8.4	5.1	54.1
602	65	65	12.3	1.7	13.5	1.8	9.9	75.8
524	65	65	17.4	2.8	29.1	3.9	9.1	74.7
215	65	65	15.7	3	32.4	1.8	8.6	79.1
22	65	65	16.0	3.4	35.8	1	8.4	71.4
1325	65	65	12.2	1.7	11.5	0.5	11.8	56.9
1159	65	65	12.1	1.9	13.1	0.4	9.6	43.4
320	65	65	17.2	3.5	41.3	2.9	9.4	84.3
1124	3	1	11.2	2.6	19	1.4	9.3	39.2
1073	2	1	5.4	2.6	10.3	2.6	9.3	33.9
1201	1	1	8.2	3.4	20.3	6.6	4.7	31.2
718	1	1	9.4	1.3	6.8	1.9	8.6	28.4
1323	1	1	8.9	1.7	9.4	0.1	10.4	18.8
652	1	1	9.0	1.3	7	0.5	11	17.4
418	1	1	10.7	1.9	13	0	9.4	37.6
712	1D	1D	16.3	3.7	43.3	2.4	9.1	63.5
563	1D	1D	9.8	1.3	8.2	0.2	8.8	21.2
113	1D	1D	11.4	1.2	7.6	0.2	10	14.9
1223	1D	1D	11.7	1.3	10	0	9.9	27.4
223	1D	1D	11.8	1.3	9.7	0.4	8.8	43.7
1063	1D	1D	12.7	1.9	15.7	0.8	9.7	41.9
1019	1D	1D	12.4	2.9	27.4	3.5	8.4	61.1