Updating the School Bus Standard Vehicle for Load Rating Alabama Bridges

By

Dr. Jim Richardson
Department of Civil, Construction, and Environmental Engineering
The University of Alabama
Tuscaloosa, AL

Prepared by

UTCA

University Transportation Center for Alabama
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16. Abstract

The objective of this project is to identify a representative school bus (weight and axle spacing) for load rating highway bridges. The ALDOT Bridge Rating and Load Test Section currently uses a 12.5-ton school bus (four tons on the front axle and 8.5 tons on the rear axle) as one of its seven standard bridge load-rating vehicles. However, 99% of the buses in Alabama have a gross vehicle weight rating (GVWR, provided by the bus manufacturer) greater than 13 tons and the average GVWR is 14.5 tons. This project will compile a database of axle weights and spacings for all Alabama school buses, measure axle weights and spacings of selected school buses loaded with school children, and perform bridge rating analyses on a set of critical Alabama bridges to determine a representative school bus for bridge load rating.

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Executive Summary

The Alabama Department of Transportation (ALDOT) calculates the safe load capacity of Alabama bridges using seven different standard vehicles. One of those standard vehicles represents a school bus and has a gross weight of 12.5 tons. School bus manufacturers provide a gross vehicle weight rating (GVWR) for every bus. These ratings have increased over the years, so that now most Alabama school buses have a GVWR of 15 tons or more. The purpose of this project was to determine if the school bus standard vehicle used to rate bridges should be updated to reflect the increased GVWRs of modern school buses.

In the first step, the population of Alabama school buses was characterized by collecting data on every bus in the state. Information from 8,922 bus inspection reports was entered into a database and analyzed to determine the bus configurations with the largest load effect on bridges. Three bus configurations were selected for the next step in the project.

Next, several buses of each of the three configurations were weighed both with and without students using ALDOT weigh crews. Analysis of the weight data yielded the axle weights of the empty buses and the load per passenger to the front and rear axles. In the next step, bus ridership data was examined to base a conservative yet reasonable estimate of the likely maximum number of students on a loaded school bus. Based on the information above, maximum likely axle weights for three different loaded school buses were calculated.

The project results were presented in a meeting with ALDOT engineers on June 26, 2009. An ALDOT engineer made the point that the GVWR for a bus represents its legal maximum operating weight. Setting the gross weight of the bridge-rating vehicle to the maximum GVWR of Alabama buses would be logical and easy to defend. However, this approach could be overly-conservative if the maximum likely weight of a loaded school bus is significantly less than its GVWR. For example, some school districts order buses with more durable heavy-duty suspensions, never intending to load the buses to their rated capacity.

To answer the questions posed in the preceding paragraph, actual bridge load ratings were calculated for a set of 52 bridges with current load ratings ranging from 12.5 to 17 tons, the bridges likely affected by switching to a heavier school bus bridge-rating vehicle. Four bus configurations were selected based on the GVWR data for all Alabama buses. The current (12.5 ton) rating vehicle and a two-axle truck (designated H 15) configuration were also included making a total of six different vehicle configurations.

This analysis supported the final recommendation of this report: A Type C school bus with a GVWR of 15.5 tons could be used as the new school bus standard vehicle.

The project results can be summarized as follows:

1. The GVWR of many Alabama school buses is significantly higher than 12.5 tons.
2. Two types of full-size school buses are used in Alabama – Type C and Type D. Type C buses are by far the most common bus type in Alabama, making up 75% of the bus population.
3. Based on data collected for this project, a fully-loaded, 72-passenger, Type C school bus may weigh up to 15 tons.
4. The heaviest bus type, the 84-passenger Type D bus, is used primarily in urban and suburban areas and constitutes only 2% of the bus population. Based on data collected for this project, a fully-loaded, 84-passenger Type D bus may weigh up to 16.5 tons.
5. The fully-loaded Type C and D buses described above have similar effects on short-span bridges because the weight of the heavier Type D bus is more evenly distributed between the front and rear axles. Most of the bridges affected by increasing the weight of the bus rating vehicle from 12.5 tons to 17 tons are in this category (span lengths < 40 ft). Therefore, a single bus rating vehicle can be used to represent both types of buses. The Type C bus is the logical choice since it represents the majority of buses in Alabama, especially in rural areas.
6. The maximum axle weight rating for the Type C bus is 15.5 tons, only 0.5 tons more than the approximate maximum likely weight of a loaded Type C bus. (See Item 3 above.)
7. Since the data set of weighed school buses is too small for basing a reliable estimate of maximum likely axle weights, it is recommended that the Type C school bus with the heaviest gross vehicle weight rating, GVWR = 15.5 tons, be used as the new standard vehicle for school buses.

Details of the data collection and analysis for this project are discussed in the following Sections 1 through 7. Conclusions are presented in Section 8.

1.0 Data from Bus Inspection Reports

School bus inspection reports housed at the Pupil Transportation Section of the Alabama Department of Education were reviewed in August 2006. Information from all bus inspection reports (8,922 reports) filed for the 2005 inspection cycle was tabulated. An example of the data collected is shown in Table 1-1.

In Table 1-1, "type" refers to the chassis type. Type "C" is the conventional school bus design with a hood that extends out in front of the driver. Type "D" is also known as a transit style school bus and has a flat front end. The distance between the front and rear axles (axle spacing) is typically shorter for Type D school buses, as indicated in Table 1-2, making it easier to turn around on city streets.

Axle spacing information for this table was obtained from Alabama Department of Education personnel who telephoned several bus manufacturers and school district bus supervisors. This data is shown in Table 1-2. Axle spacing is not included on bus inspection reports. Axle spacing data was therefore assigned based on the chassis type, bus manufacturer, and capacity.

Table 1-1. Typical Data Recorded from Bus Inspection Reports (Source: Bibb County School District)

Chassis	Type	Capacity	GVWR (lb)	FR (lb)	RR (lb)	Number of Buses
International	C	72	27500	10000	17500	8
International	C	72	2900	10000	19000	3
International	C	72	28960	10000	18960	4
International	C	72	29760	10000	19760	13
International	C	72	29800	10000	19800	1
Freightliner	C	72	30320	10000	20320	23
Freightliner	C	72	28960	10000	18960	1
Other						6

Table 1-2. Axle Spacings for Buses by Chassis, Bus Type and Capacity

Chassis	Type	Capacity	Axle Spacings (in inches)
International	C	71	276
International	C	72	276
International	C	78	276
International	C	66	254
Genesis	D	65	198
Genesis	D	71	198
Genesis	D	72	198
Genesis	D	77	216
Genesis	D	78	216
Genesis	D	84	234
Freightliner	C	66	252
Freightliner	C	71	276
Freightliner	C	72	276
Thomas (transit)	D	66	174
Thomas (transit)	D	71	193
Thomas (transit)	D	72	193
Thomas (transit)	D	78	212
Thomas (transit)	D	84	231
Thomas C-2	C	72	278
Ford	C	71	276
Ford	C	72	276
GMC/Chevrolet	C	66	259
TC2000	D	66	190
TC2000	D	71	190
TC2000	D	72	190
TC2000	D	78	211
Vision	C	71	253
Vision	C	72	253
All American	D	71	190
All American	D	72	190
All American	D	78	190
All American	D	84	232

The distribution of Alabama buses by capacity and type is shown in Table 1-3. Type B buses are smaller buses typically used to transport special needs children. “Other” buses represent bus inspection reports that did not list a bus type. By far the most common type of bus in Alabama is a 72-passenger Type C bus. Type C 71 or 72 passenger buses represent 74% of the “typical” school buses in Alabama (not considering Type B or “other”).

Table 1-3. Distribution of Alabama Buses by Capacity and Type

	- - - - - - - - - - - Type - - - - - - - - - - -				
Capacity	B	C	D	Other	Total
60		21			21
63		2			2
65		584	1		585
66	46	469	3		518
67		2			2
69			8		8
71		1322	77		1399
72		4269	428		4697
74			10		10
75	20		3		23
76			1		1
77		30			30
78	3		150		153
81	22		12		34
84			186		186
Other				1253	1253
Total	**91**	**6699**	**879**	**1253**	**8922**

2.0 Vehicle Rating Candidates

The bus inspection report data was analyzed to identify preliminary candidates for bridge rating vehicles. Possible candidates were identified based on two criteria:

1. Does the configuration produce a “large” structural response?
2. Is the configuration representative of Alabama school buses?

The philosophy was to select a rating vehicle that was conservative yet reasonable. The vehicle should produce a structural response on the high end for typical Alabama buses. The final rating vehicle may be a composite of several actual bus configurations.

Structural response was represented by the maximum bending moment caused by a bus on a simply-supported span. The bending moment was a function of four numbers:

1. the front-axle rated weight (FR),
2. the rear-axle rated weight (RR),
3. the axle spacing (AS) and the
4. bridge span (L).

The front and rear rated weights were stamped by the bus manufacturer on a metal plate in the front of each bus and recorded during the annual bus inspections. The axle-spacing information was provided by bus manufacturers (for newer buses) and by school district bus supervisors for older buses.

The distribution of buses by GVWR and axle spacing is shown in Table 2-1. The most common axle spacing is 23.0 feet (for a typical Type C bus) and the most common GVWR range from 27.5 k (an older Type C bus) to 30.0 k (a newer Type C bus).

The maximum bending moment caused by each bus configuration is shown in Table 2-2 for a 20-foot simple span, and in Table 2-3 for a 60-foot simple span. As expected, heavier buses and shorter axle spacings tend to cause larger bending moments. Another factor affecting simple-span bending moment is the distribution of GVWR to the front and rear axles. For example, Type D buses tend to distribute axle weight more evenly between front and rear axles which yields a somewhat smaller bending moment.

Three bus configurations were selected as potential rating vehicle candidates. Boxes are drawn around these bus configurations in Tables 2-1, 2-2 and 2-3 and the three configurations are summarized in Table 2-4. A typical Type C bus was selected because it is by far the most common bus configuration in Alabama. These buses are easier for mechanics to work on because the engine is easily accessible.

A typical Type D (72 passenger) was selected because these buses have shorter axle spacings. The shorter turning radius of these buses makes them popular for bus routes in cities. This bus was selected for weighing to determine the actual distribution of axle loads when loaded with passengers.

Finally, one of the newer 84-passenger Type D buses was selected because this bus had one of the highest GVWRs.

Table 2-1. Number of Buses by Axle Spacing and GVWR

	Axle Spacing (in feet)																	
GVWR k	15.83	16.08	16.50	17.58	17.67	18.00	19.25	19.33	19.50	19.75	21.00	21.08	21.17	21.58	22.67	23.00	23.17	Total
2.90																3		3
3.30							1											1
17.50													1					1
23.50														1				1
25.00													12	13				25
25.08														1				1
25.38													1					1
25.50											4		77			7		88
25.58														4				4
26.00													11					11
26.50	15												42	5	1	464		527
26.72																2		2
27.00	2																	2
27.06														3				3
27.08													1	24		1		26
27.50											10		327			1170		1507
27.80	54																	54
27.95														1				1
27.96	1												3	29		29		62
27.98														1				1
28.00																189		189
28.50																2		2
28.96													7	1		229		237
29.00											20					187		207
29.00			2									1	140			1849		1992
29.50			6						1							14		21
29.75																1		1
29.76											2		8			156		166
29.80													6			**306**		312
29.90																1		1
30.00											4					19		23
30.00	224	15	24	69	13				18		66	61				448		938
30.20																6		6
30.22			1															1
30.32																80		80
30.35									1									1
31.00	7		14								11	18				153	17	220
31.24	71			3				3										77
31.35					5				5									10
31.80																8		8
32.00			6													2		8
32.20	5	25	**64**		22													116
33.00			1				6									6		13
33.20	3																	3
33.35									6									6
34.00								5										5
34.20							5											5
34.22						3			2									5
35.00								1										1
35.35			1													4		5
36.00	23	2	5				4	17	7	2								60
36.20	3			1	1			39		**15**								59
36.22						2			1									3
Total	408	42	124	73	41	5	16	65	41	17	117	80	636	83	1	5336	17	7102

Table 2-2. Bending Moment (k-ft) in 20-foot Simple Span by Axle Spacing and GVWR

	Axle Spacing (in feet)																
GVWR, k	15.83	16.08	16.50	17.58	17.67	18.00	19.25	19.33	19.50	19.75	21.00	21.08	21.17	21.58	22.67	23.00	23.17
2.90																95	
3.30							105										
17.50													48				
23.50														90			
25.00													85	86			
25.08														90			
25.38													81				
25.50											88		88			87	
25.58														90			
26.00													85				
26.50	85												78	90	88	88	
26.72																88	
27.00	85																
27.06														95			
27.08													90	90		90	
27.50											88		88			101	
27.80	86																
27.95														95			
27.96	85												95	93		95	
27.98														90			
28.00																95	
28.50																98	
28.96													95	100		95	
29.00											95					95	
29.00			95									95	95			95	
29.50			88						88							95	
29.75																99	
29.76											99		99			99	
29.80													99			**99**	
29.90																100	
30.00											100					105	
30.00	92	95	87	95	95				107		103	104				103	
30.20																102	
30.22			95														
30.32																102	
30.35									93								
31.00	105		95								105	105				105	105
31.24	100			100				100									
31.35					10				95								
31.80																99	
32.00			100													100	
32.20	95	95	**95**		95												
33.00			99				105									105	
33.20	95																
33.35									105								
34.00								105									
34.20							105										
34.22						105			105								
35.00								115									
35.35			115													115	
36.00	115	115	115				115	115	115	115							
36.20	115			115	115			115		**113**							
36.22						115			115								
Total																95	

Table 2-3. Bending Moment (k-ft) in 60-foot Simple Span by Axle Spacing and GVWR

	Axle Spacing (in feet)																
GVWR, k	15.83	16.08	16.50	17.58	17.67	18.00	19.25	19.33	19.50	19.75	21.00	21.08	21.17	21.58	22.67	23.00	23.17
2.90																328	
3.30							394										
17.50													185				
23.50														306			
25.00													295	296			
25.08														304			
25.38													289				
25.50											303		303			294	
25.58														307			
26.00													301				
26.50	336												274	310	302	300	
26.72																302	
27.00	340																
27.06														323			
27.08													317	315		309	
27.50											314		313			347	
27.80	341																
27.95														328			
27.96	340												330	323		324	
27.98														315			
28.00																323	
28.50																330	
28.96													335	343		327	
29.00											336					328	
29.00			356									336	336			328	
29.50			353						333							328	
29.75																339	
29.76											348		347			339	
29.80													347			**337**	
29.90																341	
30.00											351					357	
30.00	359	376	340	353	372				396		359	364				352	
30.20																347	
30.22			380														
30.32																347	
30.35									356								
31.00	389		371								366	366				357	356
31.24	384			375				366									
31.35					119				358								
31.80																349	
32.00			386													352	
32.20	384	383	**380**		374												
33.00			392				394									367	
33.20	384																
33.35									387								
34.00								393									
34.20							394										
34.22						401			392								
35.00								415									
35.35			433													398	
36.00	443	441	438				422	422	421	419							
36.20	444			433	433			423		**413**							
36.22						431			422								
Total																328	

Table 2-4. Three Rating Vehicle Candidates

	GVWR	Axle Spacing	- - - Bending Moment, k-ft - - -	
Bus Type	k	ft	**20-foot-span**	**60-foot span**
Typical Type C (72 passenger)	29.8	23.0	99	337
Typical Type D (72 passenger)	32.0	16.5	95	380
New 84-passenger Type D	36.2	19.8	113	413

3.0 Measured Bus Weights

Seven 72-passenger Type C buses and six 72-passenger Type D buses were weighed on January 11, 2007. All buses belonged to the City of Tuscaloosa School District. The data is summarized in Table 3-1. For each bus, the axle spacing was measured and the rated axle weights (FR and RR) and gross vehicle weight rating (GVWR) were copied from the plate in the front of the bus. Each bus was weighed empty and with students. The bus drivers reported the number of students on each bus. On lightly-loaded buses with some empty seats, students were asked to distribute evenly throughout the bus. The weight of the rear axle for Bus #11 with students (boxed in Table 3-1) was unreasonably low. The average front axle load, rear axle load, and total loads were calculated without the Bus #11 data.

On April 10, 2007 four 84-passenger Type D buses from the Pell City School District were weighed. A similar procedure was followed as used for the Tuscaloosa buses.

Ultimately, the goal was to calculate the front and rear axle loads from a loaded school bus of a certain configuration. Toward this end, the average front and rear axle loads from unloaded buses was calculated for each configuration. These are shown in Table 3-1. To calculate the front and rear axle loads from a loaded school bus, the average passenger weight and the distribution of passenger weight to the front vs. rear axles were needed. These numbers were calculated by subtracting the axle loads without students from the axle loads with students, as shown in Table 3-2.

Table 3-2 shows that the average high school student weighed 160 lbs. Also, the table indicates that 90% of the weight of students was distributed to the rear axle for the Type C bus, while 70% and 76% of the student weight was distributed to the rear axles of Type D, 72-passenger and Type D- 84 passenger buses, respectively.

The last piece of information needed to predict the axle loads of a loaded school bus is the maximum likely number of students on the bus. Bus occupancy data is discussed in the next section.

Table 3-1. Measured Axle Spacing (AS), Front Axle Loads (FL), Rear Axle Loads (RL) and Gross Vehicle Loads (GVL)

Bus #	# Students	AS ft	Rated Weight, k			Measured Weight w/Students, k			Measured Weight w/o Students, k		
			FR	RR	GVWR	FL	RL	GVL	FL	RL	GVL
72-Passenger, Type C: Central HS, Tuscaloosa											
61	16	23.00	10.00	19.80	29.80	8.85	12.30	21.15	8.40	10.15	18.55
63	26	23.00	10.00	19.80	29.80	8.75	14.00	22.75	8.45	10.20	18.65
64	23	23.00	10.00	19.80	29.80	8.90	13.65	22.25	8.35	10.20	18.55
57	26	23.00	10.00	19.80	29.80	7.80	16.20	24.00	7.50	12.15	19.65
54	22	23.00	10.00	19.80	29.80	7.80	15.00	22.80	7.50	11.95	19.45
62	27	23.00	10.00	19.80	29.80	9.10	14.00	23.10	8.40	10.20	18.60
55	35	23.00	10.00	19.80	29.80	7.95	16.65	24.60	7.55	12.10	19.65
Avg						8.45	14.54	22.95	8.02	10.99	19.01
72-Passenger, Type D: Bryant HS, Tuscaloosa											
3	46	16.50	13.22	19.00	32.22	12.70	12.20	24.90	10.25	7.30	17.55
8	52	16.50	13.22	19.00	32.22	12.85	13.60	26.45	10.30	7.30	17.60
14	48	16.50	13.22	19.00	32.22	12.15	13.25	25.40	10.40	7.50	17.90
11	44	16.50	13.22	19.00	32.22	12.50	9.35	21.85	10.35	7.45	17.80
22	41	16.50	13.22	19.00	32.22	12.15	12.05	24.15	10.15	7.30	17.45
53	33	16.50	13.22	19.00	32.22	12.15	11.30	23.45	10.30	7.95	18.25
Avg						12.40	12.48	24.87	10.29	7.47	17.76
84-Passenger, Type D: K-12, Pell City											
1	42	19.75	13.20	23.00	36.20	10.60	14.60	25.20	8.95	10.45	19.40
2	28	19.75	13.20	23.00	36.20	9.75	13.25	23.00	8.85	10.30	19.15
3	41	19.75	13.20	23.00	36.20	10.50	14.30	24.80	9.25	10.10	19.35
5	52	19.75	13.20	23.00	36.20	10.25	14.10	24.35	9.15	10.10	19.25
Avg						10.28	14.06	24.34	9.05	10.24	19.29

Table 3-2. Average Student Weight and Distribution of Student Weight to Rear Axle

Bus #	# Students	FL, k (With Students - Without Students)	RL, k	GVL, k	Wt per Student		% Student Wt to Rear Axle
72-Passenger, Type C: Central HS, Tuscaloosa							
61	16	0.45	2.15	2.60	163		83%
63	26	0.30	3.80	4.10	158		93%
64	23	0.55	3.45	3.70	161		93%
57	26	0.30	4.05	4.35	167		93%
54	22	0.30	3.05	3.35	152		91%
62	27	0.70	3.80	4.50	167		84%
55	35	0.40	4.55	4.95	141		92%
						Avg	90%
72-Passenger, Type D: Bryant HS, Tuscaloosa							
3	46	2.45	4.90	7.35	160		67%
8	52	2.55	6.30	8.85	170		71%
14	48	1.75	5.75	7.50	156		77%
11	44						
22	41	2.00	4.75	6.70	163		71%
53	33	1.85	3.35	5.20	158		64%
				Avg HS Student Wt	160	Avg	70%
84-Passenger, Type D: K-12, Pell City							
1	42	1.65	4.15	5.80	138		72%
2	28	0.90	2.95	3.85	138		77%
3	41	1.25	4.20	5.45	133		77%
5	52	1.10	4.00	5.10	98		78%
				Avg K-12 Student Wt	124	Avg	76%

4.0 Bus Ridership Survey Data

The Alabama Department of Education asked all bus drivers in the fall of 2005 to record the number of students riding their bus on one particular day. The resulting database contained information for 9,588 buses.

This data was analyzed by first removing data for buses with capacities less than 60 since these smaller buses were not likely candidates for a standard bridge rating vehicle. Next, the number of students transported was divided by the bus capacity to yield a "% full" for each bus. The distribution of the "% full" data is shown in Figure 4-1. The mean and standard deviation (st dev) are also indicated in the figure. If the data is assumed to be normally distributed, the probabilities of non-exceedence associated with an assumed occupancy level can be calculated as shown in Table 4-1.

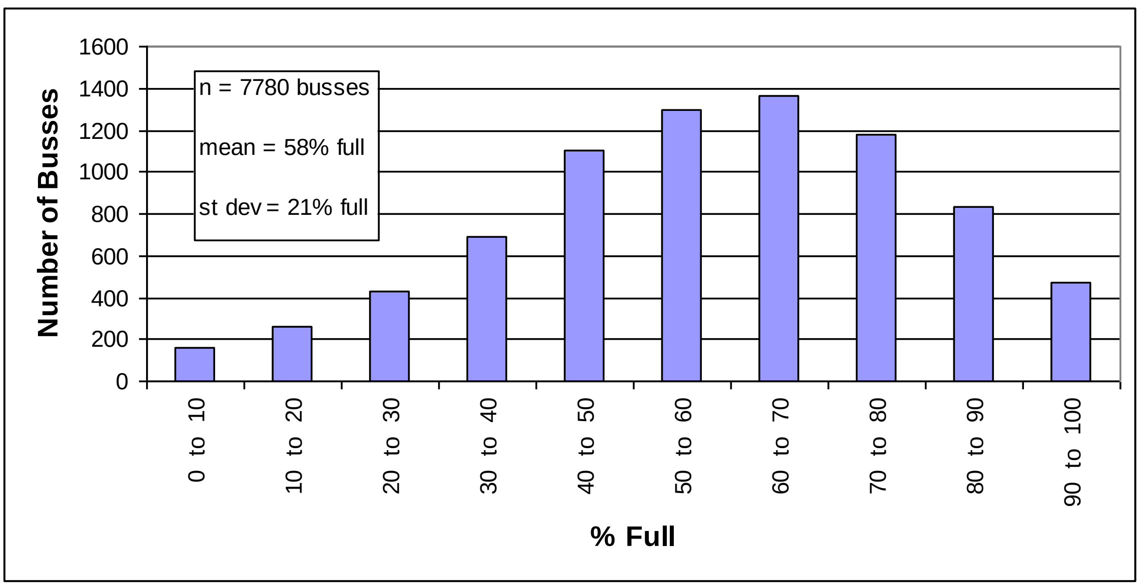

Figure 4-1. Results of bus ridership survey.

Table 4-1. Probabilities of Non-exceedence

	Occupancy (% full)	Probability of Non-exceedence
mean	58%	50%
	67%	33%
mean + 1 st_dev	79%	16%
Mean + 2 st_dev	99%	4%

5.0 Estimated Axle Loads of Loaded School Buses

The loads from the front and rear axles of the three school bus configurations weighed were calculated assuming a student weight of 160 lb and the student weight to rear axle proportions indicated in Table 3-2. For example, the axle loads for a bus 67% full are shown in Table 5-1. Bus manufacturers assume three passengers per seat, but bus supervisors say that they try to put no more than two students per seat. Three students per seat is possible with smaller children, but bus supervisors say that control of students and route duration are other factors limiting bus occupancy.

Table 5-1. Front and Rear Axle Loads for Buses 67% Full

	FL, k	RL, k	Total, k	
Type C, 72-passenger	8.0	11.0	19.0	Empty
	0.8	6.9	7.7	Students
	8.8	17.9	26.7	Total
Type D, 72-passenger	10.3	7.5	17.8	Empty
	2.3	5.4	7.7	Students
	12.6	12.9	25.5	Total
Type D, 84-passenger	9.1	10.2	19.3	Empty
	2.2	6.8	9.0	Students
	11.2	17.1	28.3	Total

The load to the front axle, load to the rear axle and the total load were calculated for each of the three buses for different occupancies (Table 5-2). The rated axle weights and gross vehicle weight rating (GVWR) are shown in the table for comparison. The following observations can be made:

- The total weight of the school buses with 100% occupancy and 160 lb. students is equal to the GVWR of the Type C bus, slightly below the GVWR of the Type D 72-passenger bus, and significantly below the GVWR of the Type D, 84-passenger bus. The GVWR is therefore usually an over-conservative estimate of the weight of a loaded school bus.
- The rear axle of the Type C bus is loaded much more than for the Type D buses. The fully occupied Type C bus also had a larger axle load than even the fully-occupied, 84-passenger, Type D bus. The Type C bus can therefore cause a larger structural response on short-span bridges then even a larger-capacity Type D bus.

The Type C bus and the 84-passenger Type D bus were selected as possible bus-rating vehicles. The 72-passenger Type C bus was eliminated because the other two buses represented worse-case scenarios in terms of high gross vehicle weight, short axle spacing, and uneven distribution of passenger weight.

Table 5-2. Axle Loads for Different Bus Occupancies

	FL, k	RL, k	Total, k	
Type C, 72-passenger	10.0	19.8	29.8	Rated
	8.7	17.0	25.7	58% full
	8.8	17.9	26.7	67% full
	8.9	19.2	28.1	79 % full
	9.2	21.4	30.5	100% full
Type D, 72-passenger	13.2	19.0	32.2	Rated
	12.3	12.1	24.4	58% full
	12.6	12.9	25.5	67% full
	13.0	13.8	26.9	79 % full
	13.7	15.5	29.3	100% full
Type D, 84-passenger	13.2	23.0	36.2	Rated
	10.9	16.2	27.1	58% full
	11.2	17.1	28.3	67% full
	11.6	18.3	29.9	79 % full
	12.3	20.5	32.7	100% full

The axle loads and axle spacings of the Type C 72 passenger (hereafter called Type C 15^T) and the Type D, 84-passenger bus (hereafter called Type D 16.5^T) are shown in Figure 5-1. Axle loads due to near 100% occupancy were used. Based on the ridership data, there is a 4% chance that a bus will be 99% or more full. The probability that the students in a bus will weigh more than an average of 160 lbs. could not be calculated with the small amount of data collected. However, the probability of squeezing three 160-lb. students on every seat of a bus is likely very low.

6.0 Bridge Load Ratings for Six Possible School Bus Rating Vehicles

ALDOT bridge load rating software (Virtis) was used to calculate the operating rating for six different possible rating vehicle configurations on 52 bridges. The axle loads and axle spacing are shown for each of the configurations in Figure 6-1. The first vehicle is the current school bus standard vehicle for load rating bridges. It was labeled Type C 12.5^{T} because the axle spacing is very similar to that for Type C buses and the total weight is 12.5 tons. The second vehicle is the Type C 15^{T} bus described in the preceding paragraph.

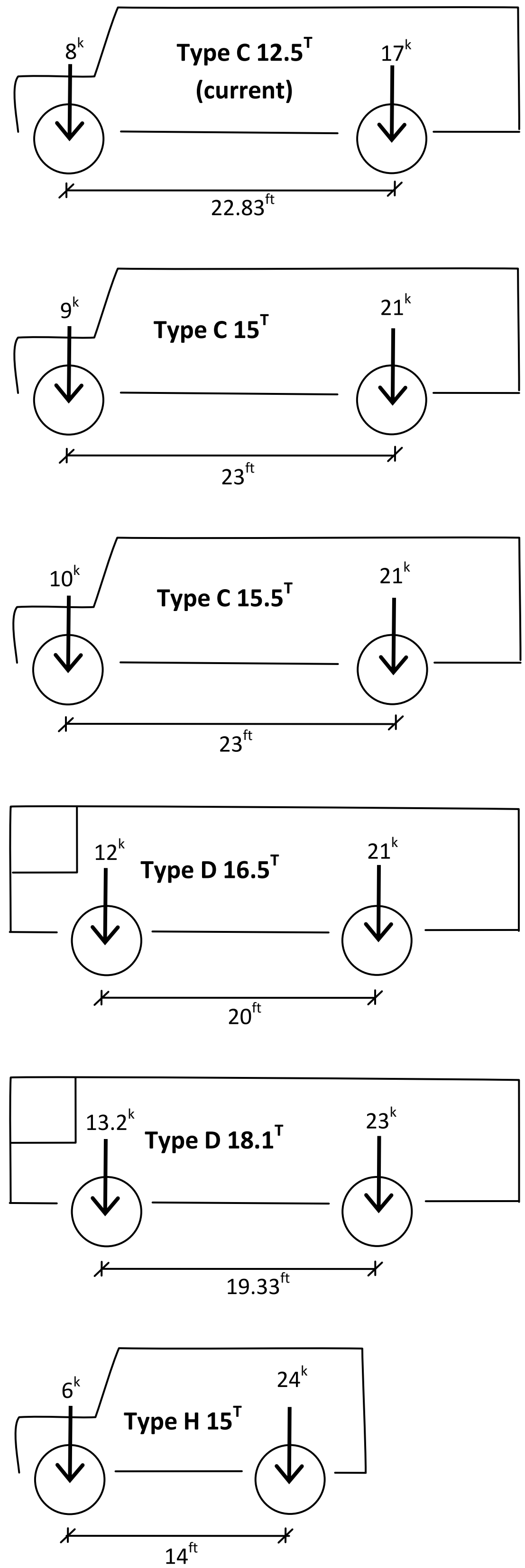

Figure 6-1. Six possible rating vehicle configurations used to calculate bridge load ratings.

The third vehicle, Type C 15.5^T, has the maximum rated axle weights (from manufacturers) of the Type C bus. This configuration is represented at the intersection of the shaded column and row of Table 2-1. The fourth vehicle, Type D 16.5^T in Figure 6-1, represents the maximum likely axle weights of an 84-passenger Type D bus, based on the data collected with the ALDOT weigh crews. The fifth vehicle, Type D18.1^T, represents the maximum rated axle weights (from manufacturers) of the Type D bus (See Table 2-1.). And finally, the sixth vehicle in Figure 6-1 is the standard AASHTO H15 truck.

Bridges were selected which had a school bus load rating between 12.5 tons and 17 tons since it is these bridges that are expected to be affected by a heavier school bus rating vehicle. The selected bridges also had to have been rated using Virtis and had to have a load rating controlled by the superstructure. Bridges with wooden decks are rated using a program other than Virtis. A total of 52 bridges were analyzed.

The load ratings of the 52 bridges for each of the six possible rating vehicles are summarized in Table 6-1. These ratings represent the safe gross load on the bridge for each vehicle configuration. Shaded regions in the table indicate vehicles which would not rate legal for a particular bridge. Three of the possible school bus rating vehicles had similar results: the C 15, the C 15.5, and the D 16.5. With one exception, bridges were either rated legal for all three of these vehicles or for none of these vehicles.

The numbers in Table 6-1 have nothing to do with the weight of the particular rating vehicle. Each number represents the maximum load that the bridge can safely carry *for the particular load configuration* of the load rating vehicle. The factors affecting load configuration are:

- the distribution of load between front and rear axles, and
- the axle spacing between front and rear axles.

The ratios of the each vehicle to the current school bus rating vehicle are shown in Table 6-2. These ratios are overall very consistent from bridge to bridge and the average for each vehicle shown at the bottom of Table 6-2 is a good representation for all bridges. The ratios indicate that the C 15 bus results in slightly lower load rating per pound of vehicle than the current school bus, and that the H 15 truck results in much lower load ratings per pound of vehicle. The H 15 truck has a very uneven distribution of load between front and rear axles, and has a very short axle spacing.

Both the D 16.5 and the D 18.1 vehicles have higher load ratings per pound of vehicle, and the C 15.5 has the same load ratings per pound of vehicle as the current school bus.

The ratios were used to calculate approximate equivalent load ratings for each of the standard vehicles based on the load ratings for the current school bus (C 12.5^T) in the bridge database. For example, the minimum C 12.5^T load rating required for a bridge to rate legal for a C 15^T vehicle would be

$$\text{equivalent C12.5 rating for the C15 vehicle} = \frac{15^T}{0.97} = 15.4^T$$

The process was repeated for the other possible bus rating vehicles.

Table 6-1. Bridge Load Ratings (Operating Rating in Tons) for Six Vehicles on 52 Bridges (Shaded cells represent load ratings less than the gross weight of the rating vehicle.)

	Rating Vehicle					
Bridge	Current School Bus	School Bus C 15	School Bus C 15.5	School Bus D 16.5	School Bus D 18.1	H 15 Truck
B000141	15.83	15.38	15.89	16.91	16.94	13.45
B000742	15.81	15.36	15.87	16.89	16.92	13.44
B001181	14.27	13.87	14.33	15.25	15.28	12.13
B001436	13.65	13.26	13.70	14.58	14.60	11.60
B001455	13.08	12.71	13.13	13.98	14.00	10.69
B001729	11.76	11.42	11.80	12.57	12.59	10.00
B002056	15.38	14.94	15.44	16.43	16.46	13.07
B002173	13.62	13.23	13.67	14.56	14.58	11.58
B002260	16.49	16.02	16.55	17.62	17.65	14.02
B002637	16.01	15.55	16.07	17.10	16.91	12.78
B003126	13.11	12.73	13.16	14.01	14.03	10.92
B004638	14.07	13.67	14.12	15.03	15.06	11.96
B004860	14.07	13.67	14.12	15.03	15.06	11.96
B005349	15.73	15.28	15.79	16.81	16.84	13.37
B005379	14.46	14.05	14.52	15.45	15.48	12.29
B005961	14.07	13.67	14.12	15.03	15.06	11.96
B005962	14.07	13.67	14.12	15.03	15.06	11.96
B005967	14.45	14.03	14.50	15.44	15.46	12.28
B005997	14.07	13.67	14.12	15.03	15.06	11.96
B006281	14.07	13.67	14.12	15.03	15.06	11.96
B006311	14.76	14.34	14.81	15.77	15.79	12.49
B006312	14.07	13.67	14.12	15.03	15.06	11.96
B007651	14.13	13.73	14.19	15.10	15.13	12.01
B008215	13.70	13.31	13.75	14.64	14.66	11.64
B009032	16.62	16.15	16.69	17.76	17.79	14.13
B009146	14.07	13.67	14.12	15.03	15.06	11.96
B009553	13.44	13.06	13.49	14.36	14.39	11.43
B009556	16.84	16.36	16.90	17.99	18.02	14.31
B010159	14.06	13.66	14.11	15.02	15.05	11.95
B010210	16.19	15.93	16.36	16.21	15.96	12.81
B010332	13.72	13.33	13.77	14.66	14.69	11.66
B010334	13.64	13.25	13.69	14.41	14.11	10.73
B010511	13.70	13.31	13.75	14.64	14.66	11.64
B010840	13.47	13.08	13.52	14.39	14.41	11.93
B010894	13.44	13.06	13.49	14.36	14.39	11.43
B010901	16.55	16.07	16.61	17.68	17.71	14.07
B011137	13.44	13.06	13.49	14.36	14.39	11.43
B011878	13.30	12.92	13.35	14.21	14.24	11.31
B013468	16.35	15.88	16.41	17.47	17.50	13.89
B013481	12.92	12.55	12.97	13.80	13.82	10.98
B013482	12.92	12.55	12.97	13.80	13.82	10.98
B013784	13.94	13.54	13.99	14.89	14.92	11.85
B015308	15.81	15.35	15.87	16.89	16.92	13.44
B016001	15.67	15.22	15.73	16.74	16.77	13.32
B016729	12.78	12.41	12.83	13.65	13.67	10.86
B016730	13.36	12.98	13.41	14.27	14.30	12.41
B016731	13.79	13.39	13.84	14.73	14.76	12.70
B016869	13.15	12.77	13.20	14.05	14.07	11.17
B017015	12.55	12.19	12.60	13.41	13.43	10.67
B017027	9.96	9.68	10.00	10.64	10.66	8.47
B017206	12.62	12.26	12.67	13.48	13.51	10.52
B019335	13.30	12.92	13.35	14.21	14.23	11.30

Table 6-2. Ratios of Vehicle Load Rating/Current School Bus Load Rating

	- Ratios -				
Bridge	**School Bus C 15**	**School Bus C 15.5**	**School Bus D 16.5**	**School Bus D 18.1**	**H 15 Truck**
B000141	0.97	1.00	1.07	1.07	0.85
B000742	0.97	1.00	1.07	1.07	0.85
B001181	0.97	1.00	1.07	1.07	0.85
B001436	0.97	1.00	1.07	1.07	0.85
B001455	0.97	1.00	1.07	1.07	0.82
B001729	0.97	1.00	1.07	1.07	0.85
B002056	0.97	1.00	1.07	1.07	0.85
B002173	0.97	1.00	1.07	1.07	0.85
B002260	0.97	1.00	1.07	1.07	0.85
B002637	0.97	1.00	1.07	1.06	0.80
B003126	0.97	1.00	1.07	1.07	0.83
B004638	0.97	1.00	1.07	1.07	0.85
B004860	0.97	1.00	1.07	1.07	0.85
B005349	0.97	1.00	1.07	1.07	0.85
B005379	0.97	1.00	1.07	1.07	0.85
B005961	0.97	1.00	1.07	1.07	0.85
B005962	0.97	1.00	1.07	1.07	0.85
B005967	0.97	1.00	1.07	1.07	0.85
B005997	0.97	1.00	1.07	1.07	0.85
B006281	0.97	1.00	1.07	1.07	0.85
B006311	0.97	1.00	1.07	1.07	0.85
B006312	0.97	1.00	1.07	1.07	0.85
B007651	0.97	1.00	1.07	1.07	0.85
B008215	0.97	1.00	1.07	1.07	0.85
B009032	0.97	1.00	1.07	1.07	0.85
B009146	0.97	1.00	1.07	1.07	0.85
B009553	0.97	1.00	1.07	1.07	0.85
B009556	0.97	1.00	1.07	1.07	0.85
B010159	0.97	1.00	1.07	1.07	0.85
B010210	0.98	1.01	1.00	0.99	0.79
B010332	0.97	1.00	1.07	1.07	0.85
B010334	0.97	1.00	1.06	1.03	0.79
B010511	0.97	1.00	1.07	1.07	0.85
B010840	0.97	1.00	1.07	1.07	0.89
B010894	0.97	1.00	1.07	1.07	0.85
B010901	0.97	1.00	1.07	1.07	0.85
B011137	0.97	1.00	1.07	1.07	0.85
B011878	0.97	1.00	1.07	1.07	0.85
B013468	0.97	1.00	1.07	1.07	0.85
B013481	0.97	1.00	1.07	1.07	0.85
B013482	0.97	1.00	1.07	1.07	0.85
B013784	0.97	1.00	1.07	1.07	0.85
B015308	0.97	1.00	1.07	1.07	0.85
B016001	0.97	1.00	1.07	1.07	0.85
B016729	0.97	1.00	1.07	1.07	0.85
B016730	0.97	1.00	1.07	1.07	0.93
B016731	0.97	1.00	1.07	1.07	0.92
B016869	0.97	1.00	1.07	1.07	0.85
B017015	0.97	1.00	1.07	1.07	0.85
B017027	0.97	1.00	1.07	1.07	0.85
B017206	0.97	1.00	1.07	1.07	0.83
B019335	0.97	1.00	1.07	1.07	0.85
Average	**0.97**	**1.00**	**1.07**	**1.07**	**0.85**

7.0 Other Comparisons of the Six Possible School Bus Rating Vehicles

The equivalent C 12.5 ratings for each possible bus rating vehicle were compared against the bridge school bus load ratings in the bridge database obtained in June 2009. The number of bridges affected by changing the school bus load rating vehicle is summarized in Table 7-1. Only bridges with an operational status = "O," a posting status = "A," "B," or "P" and a rating analysis method not equal to "NR" or "visual" were included in the analysis.

As of June 2009, there were 902 bridges with load ratings less than the current legal limit for school buses. If Alabama bridges were rated using either the proposed C 15, the C 15.5, or the D 16.5 vehicles as the standard school bus, an additional 252 bridges would be restricted for school buses. Even more bridges would be restricted if either the D 18.1 or the H 15 vehicles were used to represent school buses.

Table 7-1. Number of Bridges Affected by Changing School Bus Load Rating Vehicle

Rating Vehicle	Bridge Load Rating Criteria	No. Restricted Bridges	No. Over Current
Current School Bus	C 12.5 Rating < 12.5[T]	902	+ 0
Proposed C 15, C 15.5 or D 16.5	**C 12.5 Rating < 15.4[T]**	**1154**	**+ 252**
Proposed D 18.1	C 12.5 Rating < 17.0[T]	1227	+325
Proposed H 15	H Truck < 15[T]	1200	+ 298

The simple-span bending moments for each of the possible school bus standard vehicles were calculated for different span lengths and are shown graphically in Figure 7-1. For long spans (Figure 7-1a), bending moments are controlled by gross vehicle weight. For shorter spans (Figure 7-1b), load distribution and axle spacing also affect bending moment. Note that the bending moments for the current school bus standard vehicle (C 12.5) are lower for all span lengths, and that the bending moments for the C 15, the C 15.5 and the D 16.5 vehicles are nearly identical up to span lengths of 37 feet. Most of the bridges affected by increasing the weight of the school bus rating vehicle are shorter spans, as seen in Figure 7-2.

All of the analyses discussed in this and the previous section show a similar trend: the current school bus standard vehicle has the smallest effect on bridges, the C 15, C 15.5 and D 16.5 vehicles have a larger and similar effect on bridges, and the D 18.1 and H 15 vehicles have the largest effect.

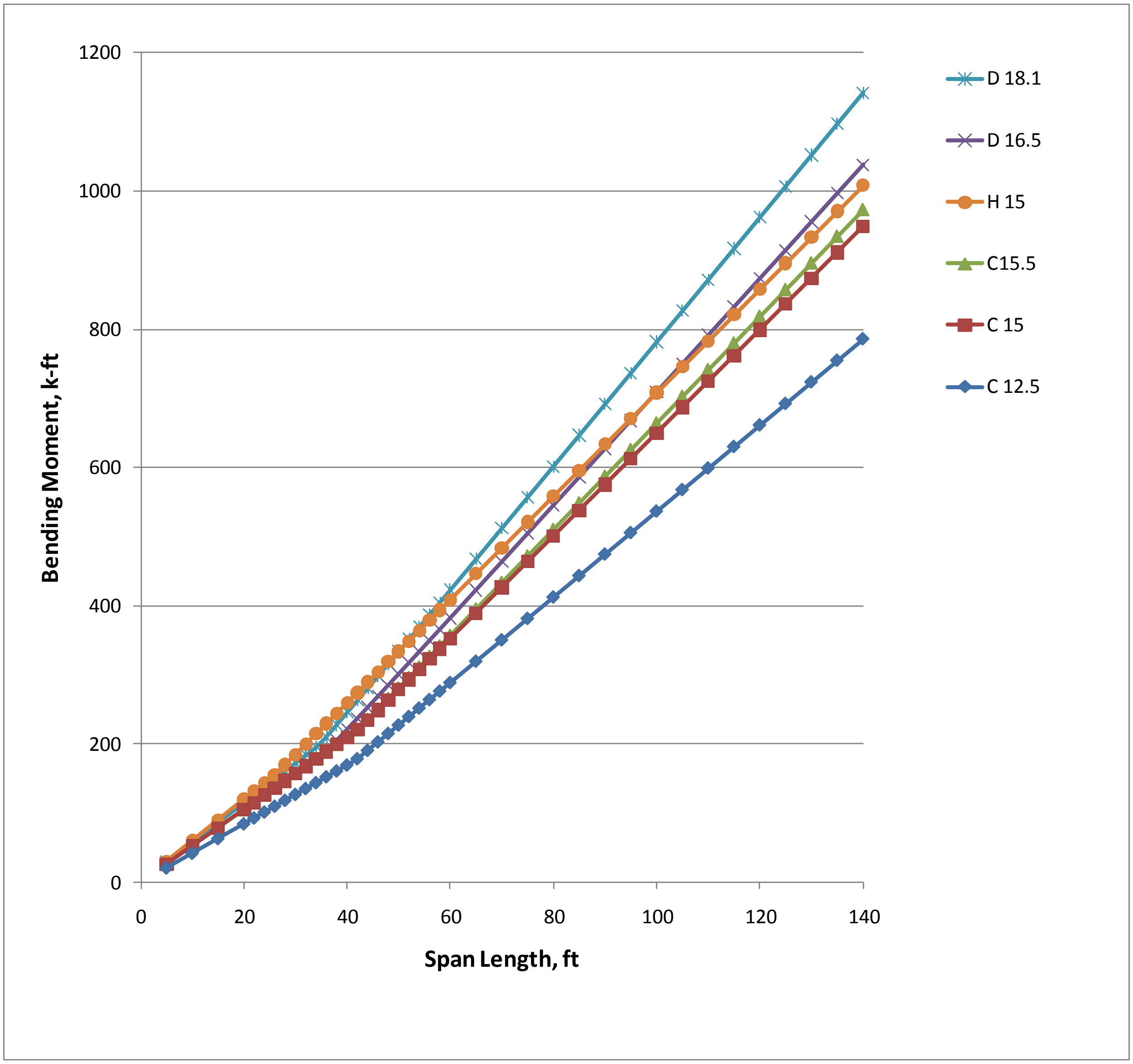

Figure 7-1a. Simple-span bending moments for six possible rating vehicles for span lengths from 5 to 140 ft.

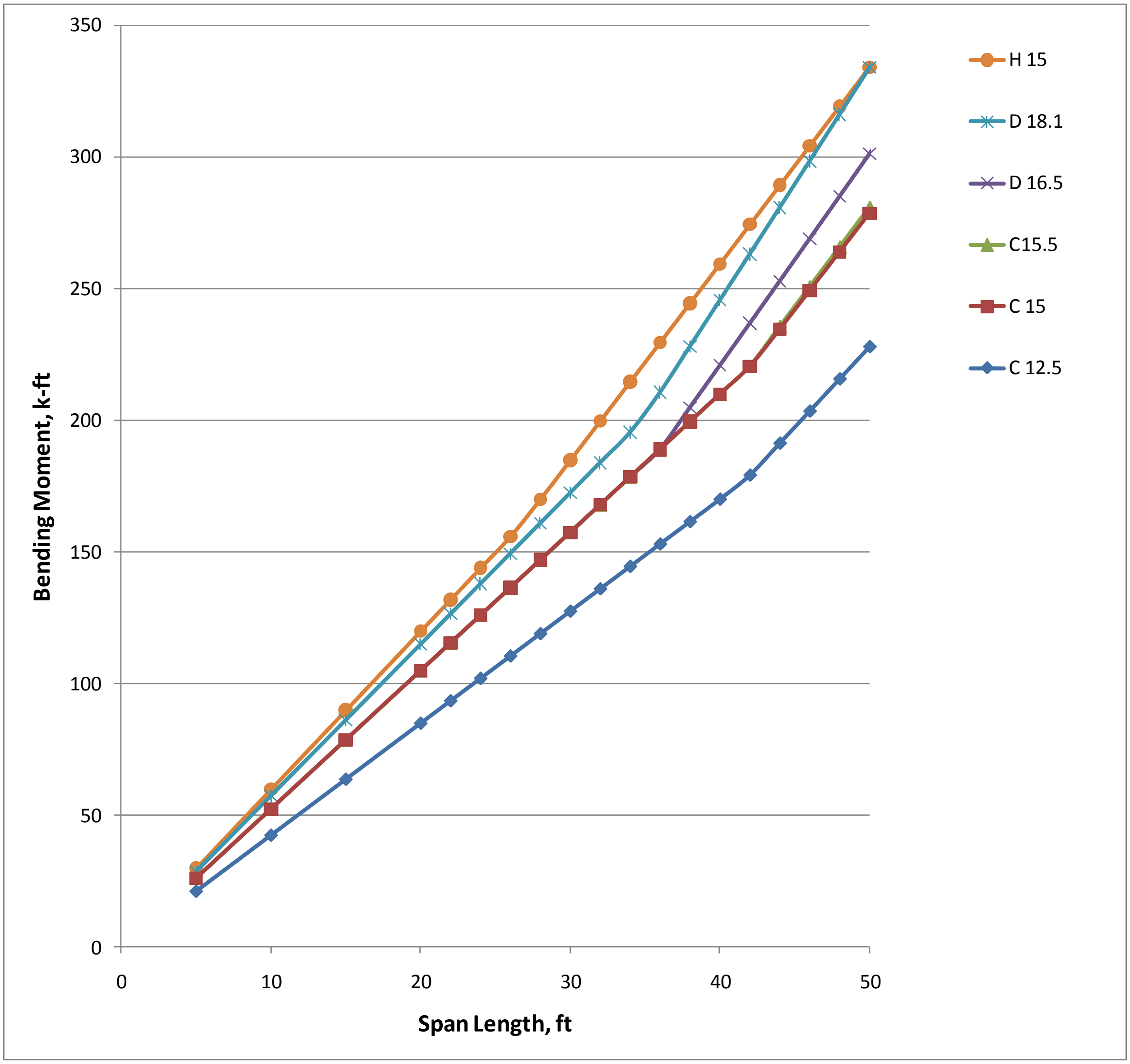

Figure 7-1b. Simple-span bending moments for six possible rating vehicles for span lengths from 5 to 50 ft.

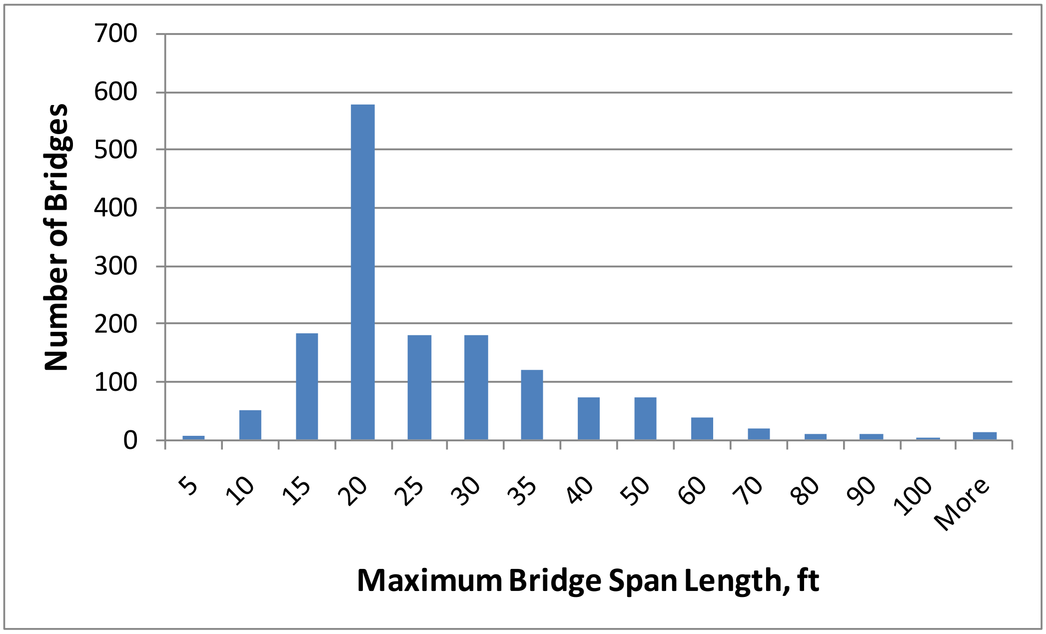

Figure 7-2. Distribution of bridge maximum span lengths for 1,540 bridges with current school bus ratings < 17 tons.

8.0 Conclusions

Based on the results and discussion above, the recommended new school bus rating vehicle is the C 15.5. The reasons for recommending the Type C 15.5^{ton} bus configuration are discussed below.

First, this bus type (Type C) is by far the most common type of school bus in Alabama and is expected to be even more common. School districts are ordering less of the other bus type (Type D), according to the Chief Mechanic for the Alabama Department of Education Pupil Transportation Section, due to difficulty accessing the engines on this bus type.

Also, the higher capacity and shorter wheel-base Type D bus is used primarily in urban or suburban settings which typically have a higher density of students and require tighter turning radiuses. Most of the approximately 250 bridges affected by a heavier school bus rating vehicle are likely located in rural settings.

The 15.5 ton (31 kip) GVWR of this vehicle represents the heaviest version of the Type C bus in Alabama. This configuration is shaded in gray in Table 2-1. There are a very small number (20) of heavier buses with the 23-foot wheel base in Table 2-1. These entries account for only 0.4% of the 5336 Type C buses in Alabama.

Type C buses were weighed empty and with students. The calculated maximum likely loaded weight of this bus configuration was 15 tons (assuming three 160 lb. students on every seat). The maximum GVWR of this bus type in Alabama was 15.5 tons. Adding a half ton to the bus rating vehicle will likely have minimal impact on the posting of additional bridges (See Table 7-1.) and puts ALDOT in a much more defensible position regarding its choice of a bus rating vehicle.

Type D buses were also weighed empty and with students. The calculated maximum likely loaded weight of this bus configuration was 16.5 tons (based on the same assumption of three 160 lb. students on every seat). The maximum GVWR of this bus was 1.6 tons heavier at 18.1 tons. Using an 18.1 ton Type D bus as the rating vehicle appears to be unreasonably conservative. Also, this configuration would cause significantly more bridges to be load posted (See Table 7-1.).

The H 15 truck, with its much shorter axle spacing and high rear axle load, is not a reasonable representation of an Alabama school bus. Using this vehicle to rate bridges for school buses would also cause significantly more bridges to be load posted than using the recommended vehicle.

To summarize, the Type C 15.5^{ton} school bus represents the heaviest configuration of manufacturer-supplied rated axle weights of the most common school bus in Alabama, particularly in rural areas. This configuration is 1,000 lbs. heavier than the maximum likely loaded bus of this type, based on a limited amount of measured axle weights of empty and loaded school buses collected as part of this project. Switching to this vehicle as the standard school bus will increase the number of Alabama bridges restricted for school buses from approximately 900 to 1,150.