Turner Truck Impact on Washington State Bridges

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16. ABSTRACT

Values of various impacts associated with the concrete bridges in the State of Washington as related to the operation of trucks with configurations as proposed by Francis C. Turner have been determined. These cost estimates are presented in matrix form and are based on permutations involving four basic Turner prototype trucks, a range of values for the bridge design life and a range of values for bridge live load overload. The various cost estimates were compiled for a population of 2024 concrete bridges and were based on the assumption that each bridge in the population had a controlling maximum length simple span which was used in a failure criterion. The largest value of the cost estimate for the replacement of all deficient bridges in the population is $2.643 billion which resulted from the calculations involving the most severe Turner protype truck loading (11AD), a 75 year design life, and a 0% live load overload. Several courses of action are postulated, and recommendations for further studies are given.

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TURNER TRUCK IMPACT ON WASHINGTON STATE BRIDGES

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SUMMARY

The objective of this study was to determine the cost impact on bridges if new trucks with various wheel load configurations as proposed by F.C. Turner in 1984 are allowed to be driven on Washington highways.

The above objective was achieved by performing the following tasks: 1) a literature search; 2) numerous mathematical analysis calculations; 3) several discussions with personnel in the WSDOT; 4) calculations for various cost estimates.

Various cost impacts on bridges were determined for each of the four basic Turner prototype trucks (7-axle Tractor-Semi; 9-Axle Double; 9-Axle B-Train Double; 11-Axle Double). The cost impact analyses for each prototype truck involved various values for live load overload and various values for the design life of each deficient bridge. The cost analyses, which involved existing bridges with existing operating ratings, yielded replacement cost estimates (based on a 75 year useful life) ranging from $0 (for the 7-Axle Tractor-Semi and a 5% allowance for live load overload) to $2.643 billion (for the 11-Axle Double and a 0% allowance for live load overload). The cost estimates were for concrete bridges only and were based on a failure criterion associated with the maximum moment in a simple span bridge. Several potential courses of action relative to the Turner Proposal are as follows:

1. Reject the Turner Proposal on the basis that it is too expensive.
2. Approve only specific types of truck wheel load configurations given in the Turner Proposal and upgrade the bridge system accordingly.

3. Approve the Turner Proposal (in total or in parts) but restrict the new trucks to only certain specified routes, such as the interstates and some primary routes, and upgrade the bridge system on those routes accordingly.
4. Approve the Turner Proposal (in total or in parts) and charge large use fees for the new trucks (in the short term) to help offset the cost of upgrading the bridges on the system.
5. Any combination of these or other potential courses of action.

CONCLUSIONS AND RECOMMENDATIONS

This study represents an attempt to quantify for the WSDOT the cost impact on concrete bridges which would result from the approval of the Turner Proposal. If the Turner Proposal were approved in total, the cost of replacing the deficient bridges in the Washington state highway system is in the two to three billion dollar range. A relatively simple failure criterion, which was based on the analysis of a simple span bridge, was used to evaluate the entire population of concrete bridges in the state. It is tacitly believed that the various cost estimates which were determined during this study tend to be upper bound values because of the various simplifying assumptions that were used. If a more refined cost impact is desired in order to give a greater confidence level to the value of the estimate, a different procedure must be used which should include the following items.

1. The long term accumulated damage to the bridges caused by fatigue resulting from loads which are greater than the design loads.

2. An upgraded data base which contains more information on the bridges, such as, lengths of spans, construction costs, maintenance costs, and actual inventory rating.
3. More rigorous analysis procedures which include the continuity conditions with regard to the number and length of spans and type of bridge, such as, slab, slab/girder, box, composite, etc.

The following potential future studies are also recommended:

1. Fatigue effects on concrete bridges due to overloads.
2. Bridge deck wear due to the application of a greater number of lighter loads.
3. A complete assessment of the values contained in the data base.
4. Determination of specific routes which could be approved for some of the Turner prototype trucks.
5. Development of a more rigorous analysis procedure for cost estimating.
6. Determination of the impact of Turner Trucks on steel bridges, and the effects on fatigue life of these bridges.

INTRODUCTION

THE PROBLEM

In 1984, Francis C. Turner (a former Federal Highway administrator) advocated a new approach to truck size and weight regulation, which has become known as the Turner Proposal. He suggested a variety of new truck configurations which have different numbers of axles, total lengths and total weights. Subsequently, the American Association of State Highway and Transportation (AASHTO) officials asked the Transportation Research Board (TRB) to evaluate several proposals, including the Turner Proposal, for new approaches to the regulation of the lengths and weights of trucks which are driven on U.S. highways.

Conclusions which have been derived from these preliminary evaluations indicate that there are potential positive benefits related to the roadway pavements, but that there may be detrimental effects (such as, increased maintenance costs and costs for strengthening or replacement) with regard to the bridge structures on the system. The Turner Truck Proposal has gained support with Federal Highway Administration (FHWA) and AASHTO members. Therefore, an evaluation of the economic impact on the bridge structures in the Washington State highway system resulting from the Turner truck wheel load configurations is needed.

RESEARCH OBJECTIVES

The objective of this study was to determine the cost impact on bridges to the Washington State Department of Transportation (WSDOT) if Turner trucks are allowed to be driven on Washington highways. To achieve this objective the following tasks were accomplished:

1. A literature review was conducted and the findings were summarized.
2. Mathematical calculations were performed in order to identify failure conditions due to the applications of a variety of old and new wheel load configurations.
3. Discussions were held with WSDOT representatives in order to identify the types of and costs associated with bridge maintenance that would be increased due to the application of the new truck wheel loadings.
4. Various cost estimates were developed which represent the cost impact on bridges to the WSDOT if Turner trucks are permitted to be driven on Washington highways. These cost estimates were summarized in tabular form.
5. Meetings were held with WSDOT personnel to discuss the results of this study and to formulate potential courses of action with regard to the Turner Proposal.

REVIEW OF PREVIOUS WORK

Three publications have been prepared by the TRB that give the results of evaluations of proposals for new approaches to regulating the size and weight of trucks which are driven on U.S. highways. These publications are Special Report 223, "Providing Access for Large Trucks" (1); Special Report 225, "Truck Weight Limits: Issues and Options" (2); and Special Report 227, "New Trucks for Greater Productivity and Less Road Wear: An Evaluation of the Turner Proposal" (3). Each of these reports was prepared by a committee which was formed by the TRB.

Committee members included experts on traffic and safety, pavements, bridges, freight transportation economics, and motor vehicle design; state transportaion officials; and transportation industry executives.

The proposal, which was evaluated and discussed in Special Report 227, was presented to AASHTO in 1984 by Francis C. Turner, a former FHWA administrator. Mr. Turner advocated a new approach to truck size and weight regulation, which has come to be known as the Turner Proposal. He called for the use of trucks with lower axle weights on more axles, thereby increasing gross vehicle weight. AASHTO asked the TRB to convene a committee to undertake a comprehensive study of the proposal and to advise the individual states whether or not it should be put into effect.

The Turner Proposal contains new truck configurations with a variety of axle weights and length limits. The many possible configurations were condensed to four basic prototypes; namely,

1. Seven-Axle Tractor-Semitrailer with a wheel base equal to 54.0 ft and a gross vehicle weight equal to 91,000 lb.
2. Nine-Axle Double with a wheel base equal to 77.4 ft and a gross vehicle weight equal to 111,000 lb.
3. Nine-Axle B-Train Double with a wheelbase equal to 78.9 ft and a gross vehicle weight equal to 111,000 lb.
4. Eleven-Axle Double with a wheelbase equal to 77.5 ft and a gross vehicle weight equal to 141,000 lb.

With regard to pavements, the committee concludes that the net effect associated with the use of Turner trucks would be a 19 percent reduction in the rate of wear caused by traffic. The committee also concludes that the major cost to highway agencies associated with the

Turner Proposal would be to raise the required design capacity of new bridges and to require replacement of many existing bridges to meet safety margins dictated by current bridge design and capacity rating criteria.

Moses (4), under the sponsorship of the National Cooperative Highway Research Program (NCHRP) and the National Academy of Sciences, has prepared a Draft Final Report entitled "Effects on Bridges of Alternative Truck Configurations and Weights". The primary objective of Moses' bridge study was to determine the effect of different truck weight regulations on bridge costs. Moses determined in his study that bridge costs would increase significantly with either increases in permitted gross vehicle weight (GVW) and/or decreases in overall vehicle wheel base dimensions. He stated in his report that any increment in truck weight will affect some group of bridges, since the operating ratings of the nation's bridges, when plotted on a horizontal axis of HS capacitiy levels, will be almost uniformly distributed along this HS axis. Moses states that " this conclusion emphasizes a finding that arbitrary identification of bridge types (e.g., H-15 or HS-20) and associated allowable overstress criteria (5% or 30%) by itself does not adequately predict either bridge safety or the costs associated with increased truck weights." He also concluded that any increase in truck weight must be accompanied by accelerated bridge replacement programs to ensure that more bridge deficiencies and postings do not curtail the productivity benefits of larger truck weights. There are approximately 600,000 bridges in the United States. Moses estimated bridge costs for more than 20 different scenarios: e.g., $2.6 billion per year on the national system for a Turner B type vehicle with 141,000 lbs on a 73 feet wheel base. The conclusions given by Mr. Moses in his report associated with the Turner Proposal are based on calculations for all 600,000 bridges which include, as a majority, steel bridges. His calculations involved overstress, fatigue, maintenance and remaining life with regard to retrofitting or replacement of existing bridges and construction of new bridges.

It has been suggested that, due to the variable distribution of bridge types in each state (i.e., steel, concrete, wood, etc.), each state conduct an independent factual assessment of the cost impact of the Turner Proposal to their bridge program.

For the study reported herein, a simple survey of the states was taken via AASHTO electronic mail. The question posed to each state was: "Has your agency conducted any studies concerning the effects the Turner Truck Proposal would have on your bridges?". Sixteen responses were obtained. Seven responses were positive, and nine responses were negative. One could only assume that no response at all by some states should be interpreted as a negative response. Hence, only seven states, other than Washington, have conducted studies pertinent to the Turner Truck Proposal. The more significant positive responses are as follows.

Bridge engineers in Michigan have made a relatively extensive study concerning the effects the proposed Turner Trucks will have on their structures. Since the Michigan legal truck is an 11 axle vehicle weighing up to 84 tons, all four of the Turner Proposal prototypes have gross vehicle weights less than the Michigan legal load and, hence, are acceptable.

Bridge engineers in Pennsylvania conclude that the Turner Truck configuration that they investigated (the short turnpike double or 9 axle 3S2-4) exceeds their current controlling design loading of HS 25 at operating rating (1.67*HS 25) for bridges with spans exceeding 110 feet. A greater concern to these engineers are the older bridges which were designed for HS 20 loading. They conclude that this Turner Truck loading (9 axle 3S2-4) exceeds HS-20 at operating rating (1.67*HS 20) at 70 feet.

PROCEDURES

SELECTION OF BRIDGE TYPES FOR ANALYSIS

There are 3079 bridges on the Washington State roadway system as given in the 1989 Washington Bridge List (5). Approximately 80 percent of these bridges are made of concrete. The largest category of concrete bridges is associated with pre-tensioned concrete beams (PCB) in which there are 867 bridges. Of these PCB bridges, 863 are less than 150 ft long. Because the scope of this project was limited to several primary bridge types, it was concluded that an analysis should be made for the PCB bridge category for both one simple span and two equal span continuous configurations. This decision was reinforced by the fact that many PCB bridges in the 100-150 ft range exist in the Washington segments of the Interstate routes.

This study was based on the configuration of State Highways that existed on February 1, 1991 which was the start of work for the study. This study was subsequently updated in July-August, 1992 to be consistent with the bridge data base as of June 29, 1992.

SIMPLE SPAN ANALYSES

Simple span bridges with spans in the 40-150 ft range were analyzed for nine Turner Truck configurations, three existing AASHTO legal load types, and eight special load types as requested by the Washington State Department of Transportation (WSDOT).

Turner Truck Configurations (see Figure 1 and Figure 2)

1. Seven-Axle Tractor-Semitrailer (7ATS)
2. Nine-Axle Double (9AD)
3. Nine-Axle B-Train Double (9ABTD)
4. Eleven-Axle Double (11AD)
5. Nine-Axle Double Plus 15 Percent in Length
6. Nine-Axle Double Minus 15 Percent in Length
7. Nine-Axle Double Plus 15 Percent in Weight
8. Nine-Axle Double Minus 15 Percent in Weight
9. Nine-Axle Double Plus 15 Percent in Length and Weight

Existing Trucks: ASSHTO Typical Legal Load Types (see Figure 3)

1. Type 3 Unit
2. Type 3-S2 Unit
3. Type 3-3 Unit

WSDOT Special Load Types (see Figure 4)

1. OL-1
2. OL-2
3. Scraper (single axle)
4. CL-8
5. 8L Trailer

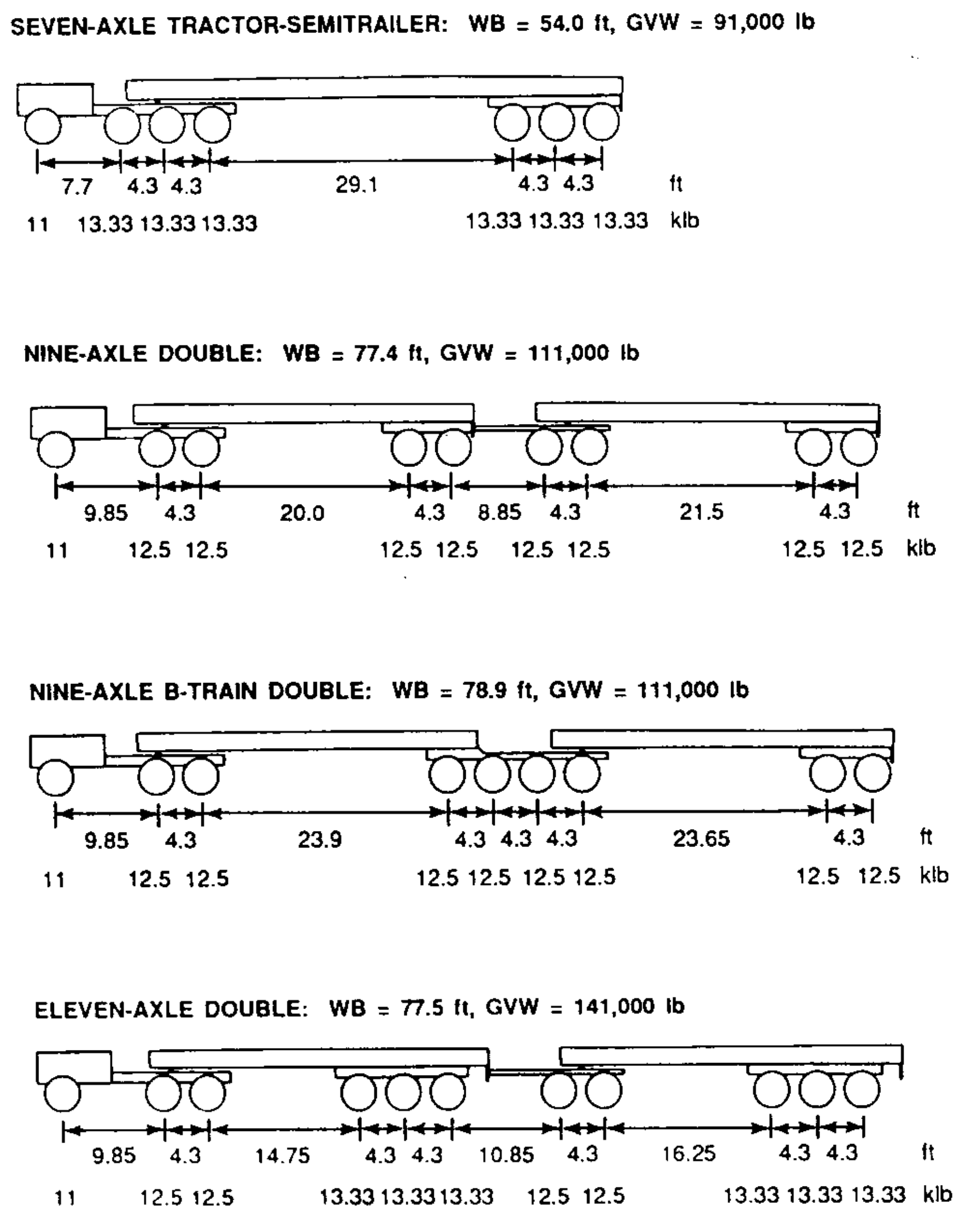
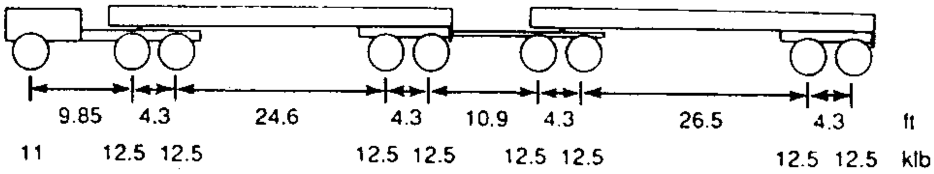
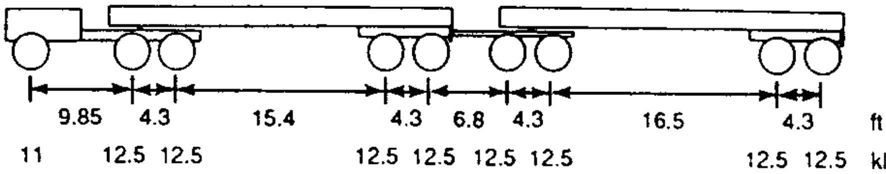


Figure 1. Basic Turner Prototype Trucks

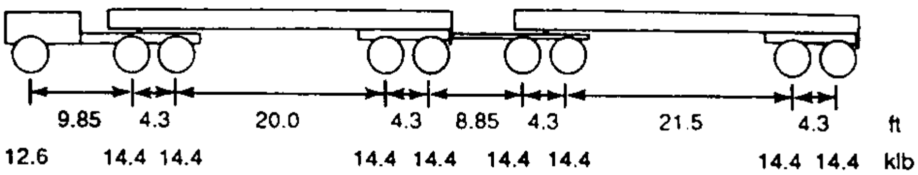
NINE-AXLE DOUBLE PLUS 15 PERCENT IN LENGTH:WB = 89.05 ft, GVW = 111,000 lb



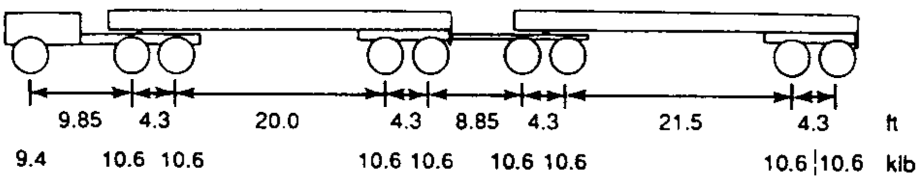
NINE-AXLE DOUBLE MINUS 15 PERCENT IN LENGTH: WB = 65.75 ft, GVW = 111,000 lb



NINE-AXLE DOUBLE PLUS 15 PERCENT IN WEIGHT: WB = 77.4 ft, GVW = 127,800 lb



NINE-AXLE DOUBLE MINUS 15 PERCENT IN WEIGHT: WB = 77.4 ft, GVW = 94,200 lb



NINE-AXLE DOUBLE PLUS 15 PERCENT IN LENGTH AND WEIGHT:
WB = 89.05 ft, GVW = 127,800 lb

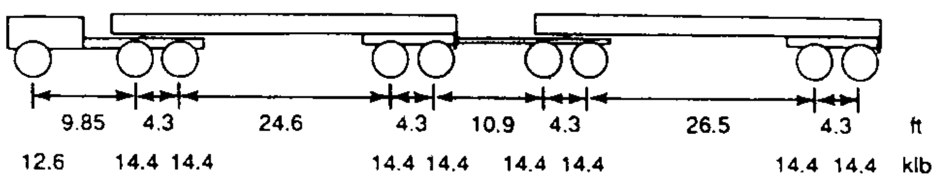
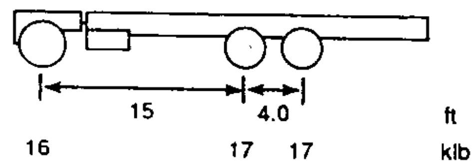
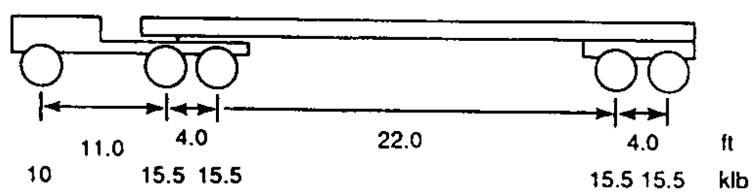


Figure 2. Variations in Nine-Axle Double Loads

TYPE 3 UNIT: WB = 19.0 ft, GVW = 50,000 lb



TYPE 3-S2 UNIT: WB = 41.0 ft, GVW = 72,000 lb



TYPE 3-3 UNIT: WB = 54.0 ft, GVW = 80,000 lb

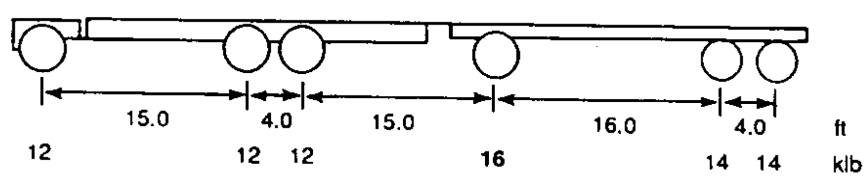


Figure 3. AASHTO Typical Legal Loads Types

Figure 4 (Continued). WSDOT Special Load Types

6. BB CT

7. DB Logging

8. 80T LS

Each of the twenty load configurations was applied in turn to a simple span bridge with varying length, and the supporting beam was analyzed for the absolute maximum moment which existed due to the passage of the wheel loads over the bridge. The results of each set of load calculations were then normalized to the standard HS 20 truck design load for each span in order to obtain a ratio (in percent) of the difference between the maximum bending moment for the special loading and that for the HS 20 loading divided by the corresponding bending moment for the HS 20 loading. Because each of the various loadings was applied to the same bridge, the lateral distribution of the wheel loads was not considered. This lateral distribution factor cancelled out of the equation in the normalizing process. Hence, no adjustment was made in any of the moment calculations.

The resulting values for the twenty load configurations are presented in graphical form in Figures 5-8. The values for the standard HS 20 design truck were obtained directly from the AASHTO Standard Specifications for Highway Bridges (6).

The critical point in each of the graphs in Figures 5-8 is where the graph crosses the horizontal reference axis which corresponds to the HS 20 design load. Any point above this reference line indicates that the simple span bridge of that length is deficient relative to the load type which is represented by that curve. For example, in Figure 5, bridges with span lengths greater than 113 ft are deficient relative to the HS 20 design load for the seven-axle tractor-semitrailer (7ATS)

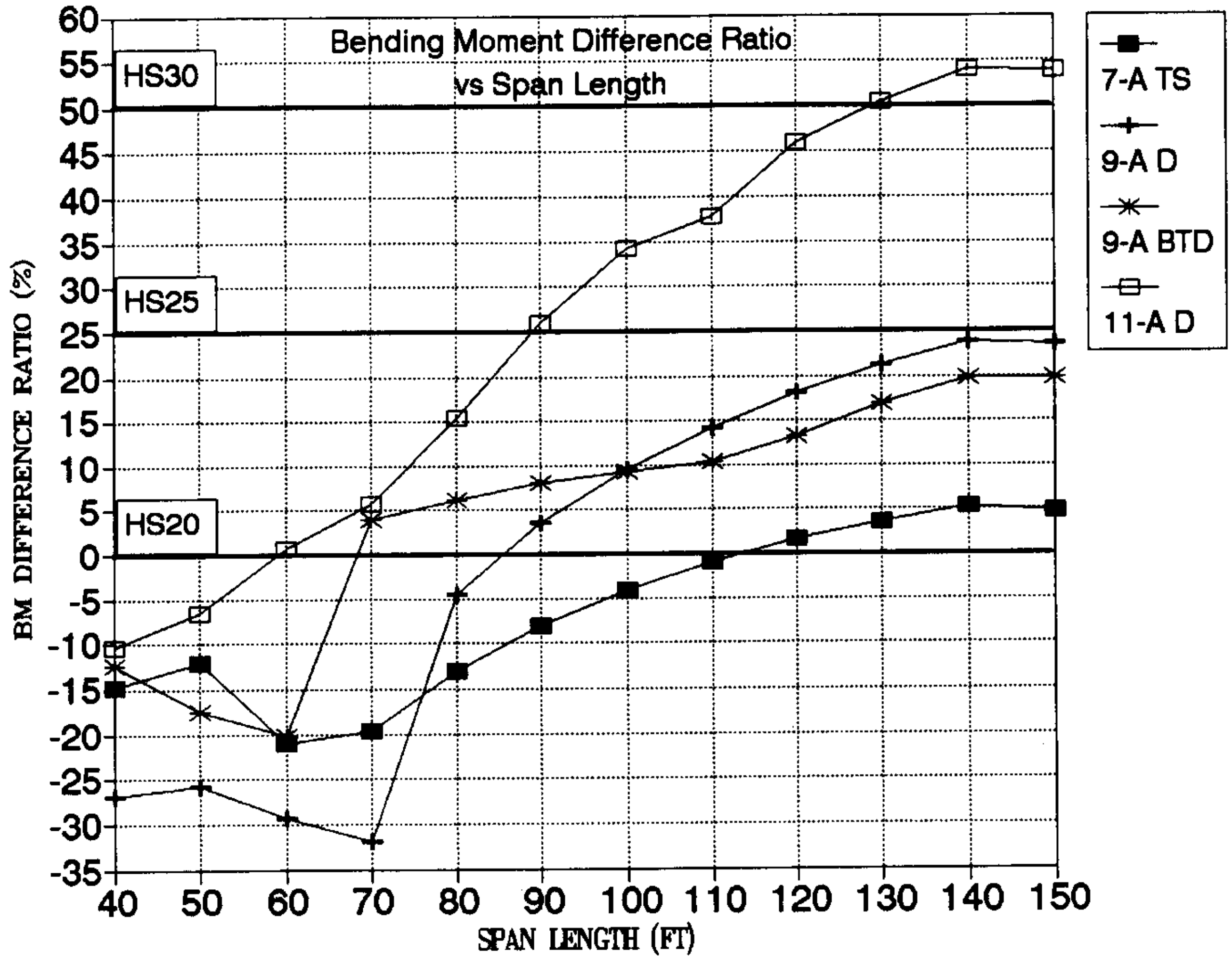


Figure 5. Moment Ratios for Basic Turner Prototype Trucks

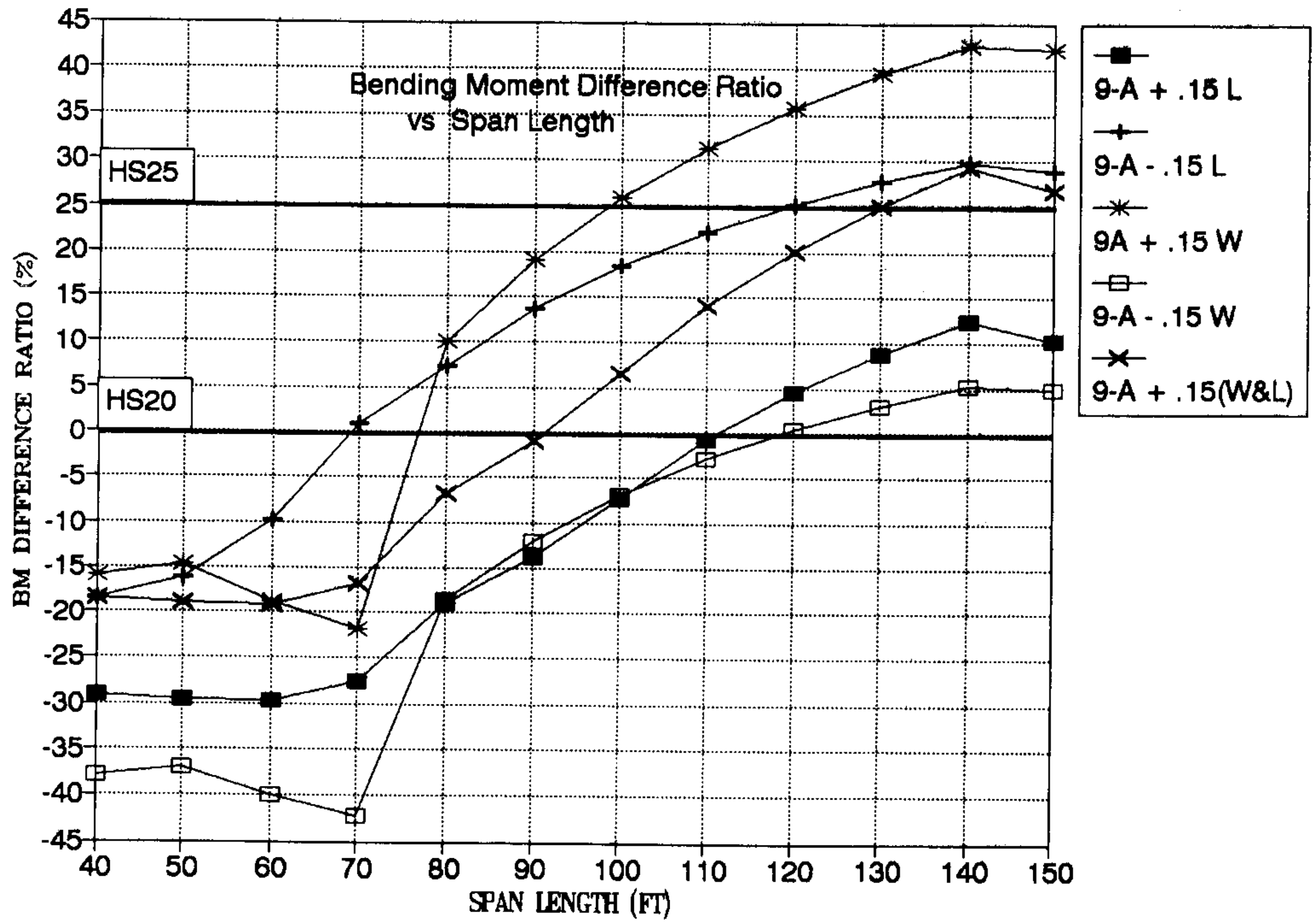


Figure 6. Moment Ratios for Variations in Nine-Axle Double Load

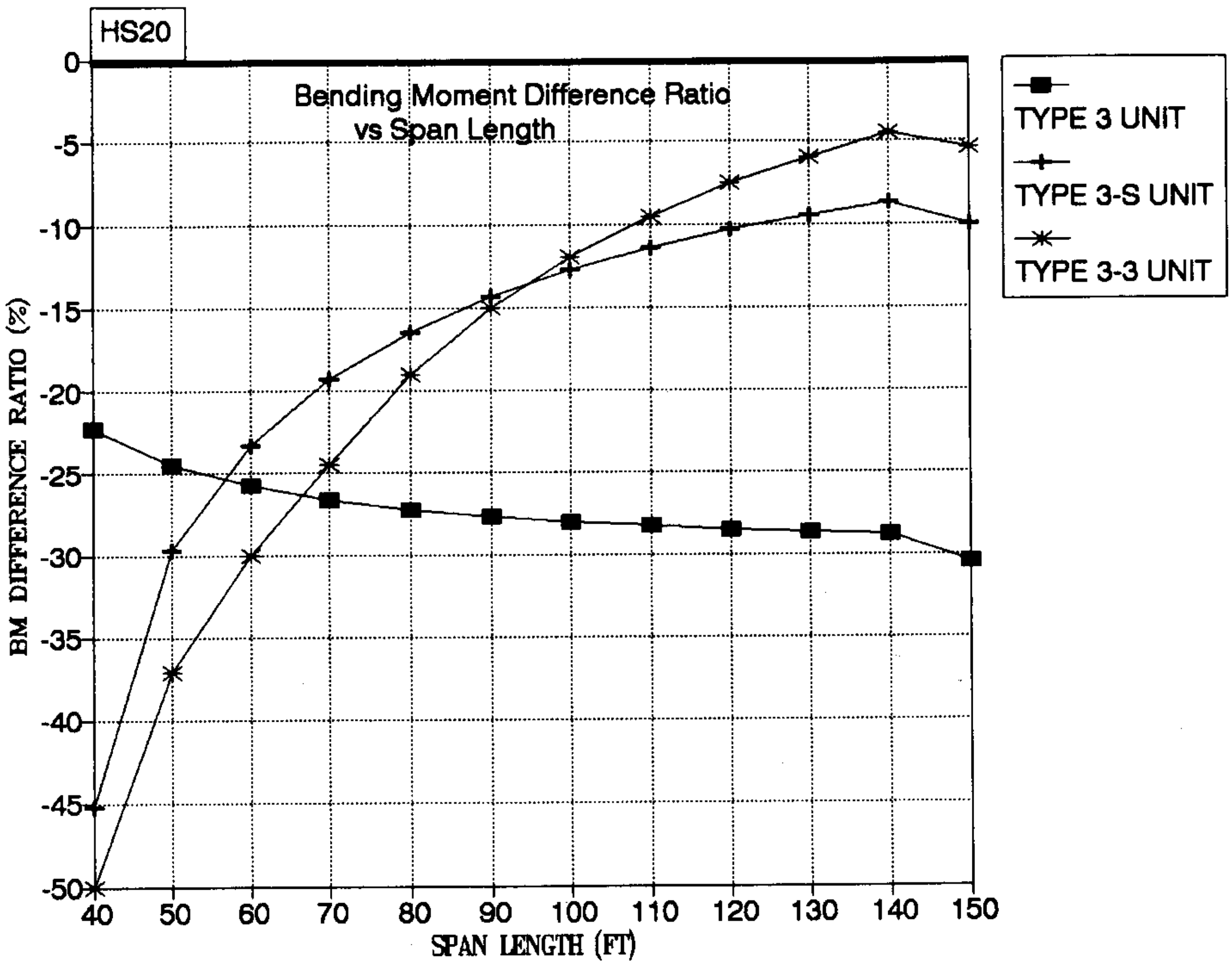


Figure 7. Moment Ratios for AASHTO Legal Loads

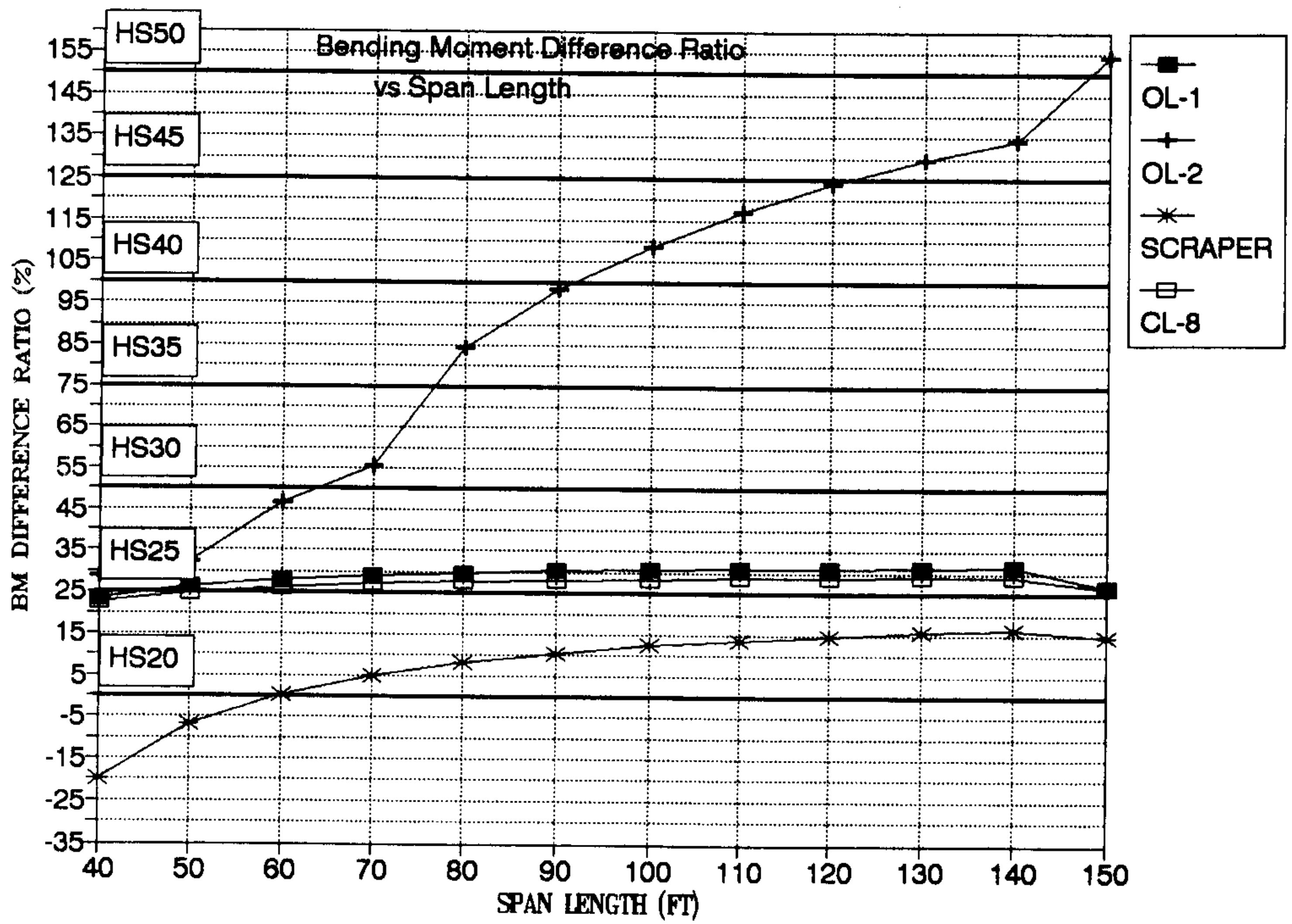


Figure 8. Moment Ratios for WSDOT Special Loads

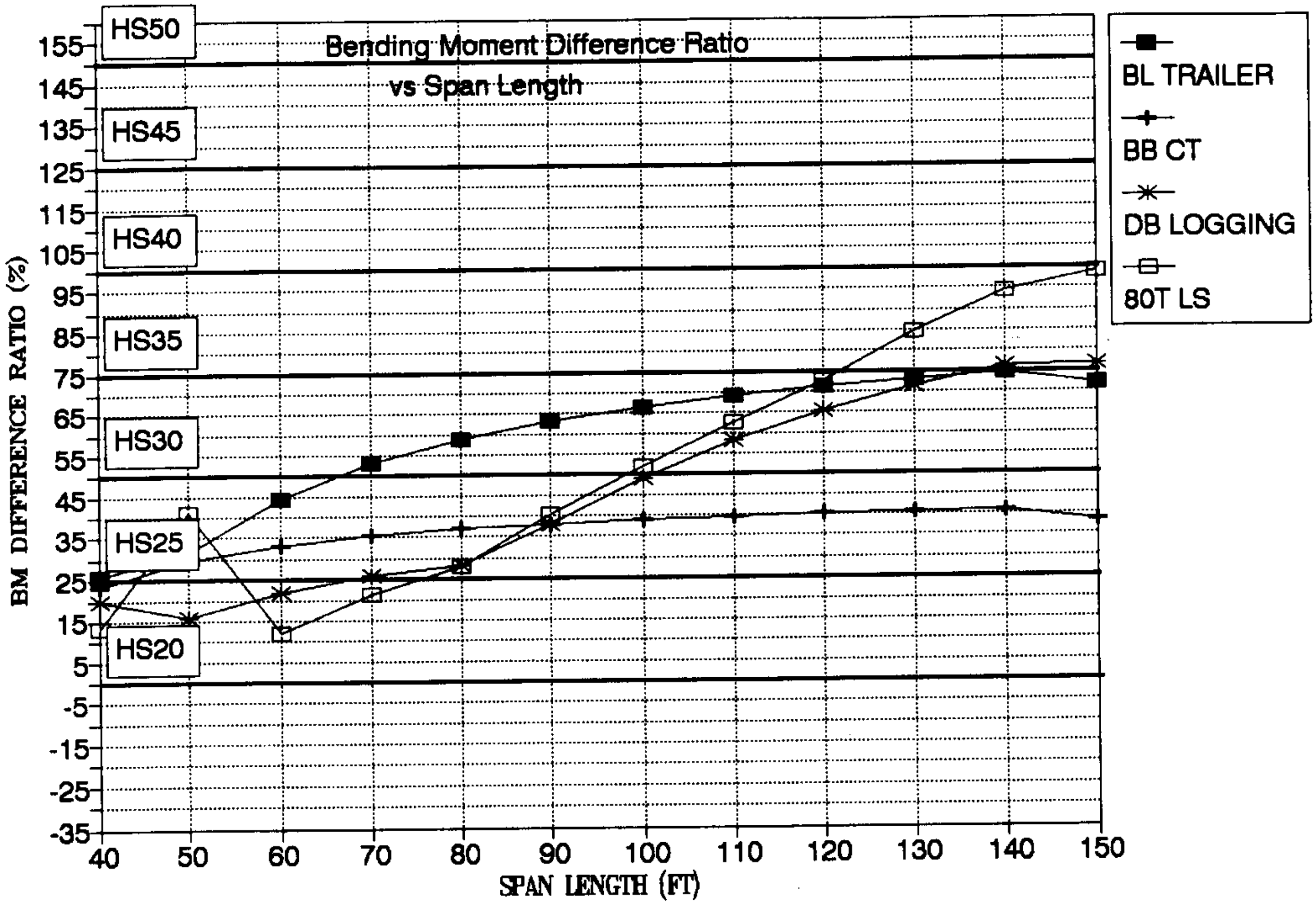


Figure 8 (Continued). Moment Ratios for WSDOT Special Loads

wheel load distribution. The other specific loadings are shown in Figures 5-8, and similar conclusions for these other loadings can be obtained.

TWO EQUAL SPAN CONTINUOUS ANALYSES

Analyses were performed on continuous bridges with two equal spans for only three load types; namely, the seven-axle tractor-semitrailer, the nine-axle double, and the nine-axle B-train double. The individual span lengths varied from 40-150 feet for total bridge lengths from 80-300 ft. The maximum bending moment in each bridge due to each load type was obtained with the use of an influence line for the maximum positive moment which occurs near midspan. The moments due to the HS 20 design load for each span length was also obtained with the use of the same influence line. The results were again normalized to the HS 20 design load and are shown in graphical form in Figure 9. As expected, the critical span length for two equal continuous spans is larger than the critical span length for the simple span.

DETERMINATION OF COST ESTIMATE

The cost impact on the WSDOT due to the presence of Turner Trucks on the highways in the state was obtained first by determining the number of deficient bridges. Then, for each bridge, the total bridge length of each deficient bridge was multiplied by an age related reduction factor and by the curb-to-curb width of the bridge and by a per square foot replacement cost. The cost estimate was then based on the accumulated total sum of the replacement costs for all deficient bridges. The cost per square foot was provided by WSDOT personnel. The

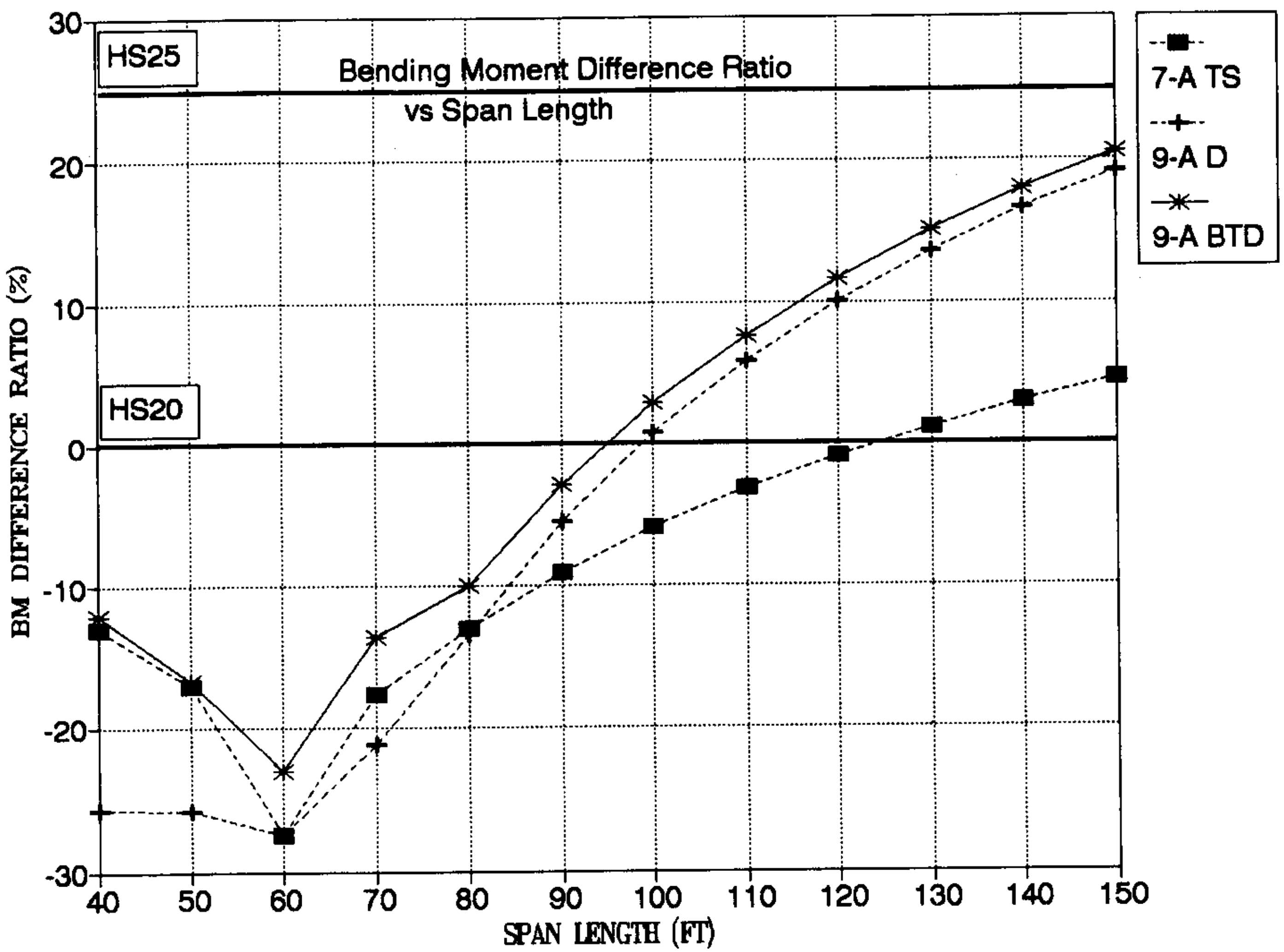


Figure 9. Moment Ratios for Two Equal Continuous Spans

age of the bridge was taken into consideration in order to assign the appropriate proportionate replacement cost attributed to the Turner Proposal. The cost of maintenance due to the Turner Proposal was based on a percentage of present maintenance expenditures which was provided to the authors by WSDOT personnel.

There are 2091 records for concrete bridges in the 40-150 ft. span length range in the data file which was provided to the authors by WSDOT personnel on June 29, 1992. (Bridges less than 40 ft. long were excluded from consideration in the analyses because these very short bridges were deemed to not be susceptible to failure from the Turner truck loadings.) Concrete tunnels and pedestrian bridges were eliminated from the study which resulted in 67 records being subsequently deleted from the data base. Hence, the remaining 2024 bridges became the population on which the cost impacts on the WSDOT associated with the Turner Proposal were developed. The procedure for estimating the cost is as follows. For each of four primary Turner Truck prototypes and for the population of 2024 bridges:

1. The data base was searched for the span length of the bridge. Two values were available: total length and maximum span length. The data base also contained the number of spans in the bridge and some information as to the continuity conditions. Because of the complexity in developing a failure criterion for continuous bridges, the focus of this study was centered on a cost estimate using a failure criterion based on a simple span analysis. Hence, it was assumed that the span with the maximum length was a simple span regardless of the continuity conditions in the actual bridge.

The failure criterion was then applied to this assumed maximum length simple span.

2. The data base was searched for two bridge ratings: the inventory rating and the operating rating. The rating that was used in conjunction with the failure criterion was one that varied incrementally (due to live load overload allowances in the analyses) from the inventory rating to the operating rating.
3. The failure criterion for each of the four prototype load types in the Turner Proposal was applied to the data obtained from the data base for a specific design load. (For example, if a bridge has a maximum span length of 120 feet and an inventory rating of 36 (which corresponds to an HS 20 design load), it would be considered deficient for the Seven-Axle Tractor-Semitrailer (7ATS) loading because the point on the 7ATS loading curve which corresponds to 120 feet in Figure 5 is above the HS 20 reference design load. The failure criterion for the 7ATS loading is satisfied for any length of bridge greater than 113 feet (where the curve for the 7ATS loading crosses to the upper side of the HS 20 reference line) as shown in Figure 5.)
4. An internal array containing the data for the deficient bridges was then created and stored in the computer memory. (The failure criterion was developed for simple span bridges, but the criterion was applied equally to all 2024 concrete bridges in the data base.)
5. The age of the bridge was used to determine a remaining life factor (RLF) for the bridge. The purpose of the RLF is to assign an appropriate portion of the replacement cost to the Turner Proposal.

(The RLF = $[1-(1+i)^{-rl}]$ where i = inflation rate (5.5%) and rl = remaining life of the bridge.)

6. The replacement cost was obtained by accumulating the costs for the deficient bridges. The cost of each bridge is the product of the roadway area times the cost per square foot times the remaining life factor. (The cost per square foot was based on replacement cost only.)

DISCUSSION

REPLACEMENT COST ESTIMATE

There are 3079 bridges in the Washington State roadway system as given in the 1989 Bridge List of the WSDOT. These bridges have been designed to carry one of several design loads and built in a variety of lengths, widths, span arrangements and materials. These bridges are different ages, having been built over a time span of a half century or more. A complete, sophisticated analysis involving the Turner Proposal and all of these bridges would be very time consuming and complex. Hence, a representative bridge type was chosen from which the results could be extrapolated to include a majority of bridges on the state roadway system.

The majority of the bridges in Washington are made of concrete. One major category of bridges in Washington involves a concrete deck on a supporting system of pre-tensioned concrete beams (PCB). Many of these PCB bridges have one simple span or multiple spans with a continuous deck. This study centered on PCB bridges with "assumed" simple spans from 40-150 ft regardless whether the individual bridge was continuous or not. The results of the various analyses involving the different wheel load distributions were extrapolated to include <u>all</u> of the concrete bridges in order to determine the cost impact of the Turner Proposal. Hence, the cost estimate involves 2024 concrete bridges.

Calculations were performed to ascertain the maximum bending moments (BM) in simple span bridges of specified lengths due to various wheel load configurations. These moments were then converted to bending moment difference ratios (given in percent) involving the standard HS 20 design truck for which the appropriate maximum bending moment was obtained from the AASHTO Bridge Design Specifications (6). The formula used to obtain this BM difference ratio is

$$\text{BM Difference Ratio (\%)} = \frac{\text{Calculated BM - HS 20 BM}}{\text{HS 20 BM}} * 100 \qquad \text{(Equation 1)}$$

With the use of this equation, the deficiency criterion can be easily applied. A <u>negative</u> ratio means that the calculated maximum bending moment due to the particular wheel load configuration is <u>less than</u> the corresponding maximum bending moment due to a standard HS 20 design load and, hence, the failure criterion is <u>not</u> exceeded. A <u>positive</u> ratio means that the calculated maximum bending moment <u>exceeds</u> the value associated with the failure criterion based on the HS 20 loading. Values for the BM difference ratio were plotted for 20 different wheel load configurations as shown in Figures 5-8. However, only the four wheel load configurations associated with the Basic Turner Prototype Trucks were used in the determination of the various cost impacts because the focus of this study was associated with the effect of the Turner Proposal on Washington bridges.

This study did not involve fatigue. It was concluded by the authors in consultation with WSDOT representations after the completion of the literature review that the effects of fatigue in prestressed concrete girder bridges were unknown at this time. The WSDOT has no known documented case histories of fatigue problems or failures in prestressed concrete girder bridges. Moses (4) states that, generally, only steel bridges are susceptible to fatigue, although some recent work suggests commonly used prestressed concrete spans, if overloaded, are also susceptible to fatigue damage.

The cost impact as determined during the course of this study was based on several assumptions. One assumption was that retrofitting of prestressed concrete girder bridges was not possible; hence, only replacement of deficient bridges was considered.

The estimated cost to be determined during this study was to be based on the effects of the Turner Proposal only and not on normal replacement schedules. Therefore, the age or remaining life of the bridge had to be taken into consideration. The effect of the remaining life is accounted for with the use of Eq. 2.

$$PC = RC\,[1 - (1+i)^{-rl}] = RC * RLF \qquad \text{(Equation 2)}$$

where

PC = present cost

RC = replacement cost

i = inflation rate = 5.5% for this study

rl = remaining life of deficient bridge

RLF = remaining life factor

The replacement cost is obtained for each deficient bridge by multiplying the roadway area of the bridge by a cost per square foot as given by Eq. 3.

$$RC = L * W * C \qquad \text{(Equation 3)}$$

where

L = length of bridge

W = width of the roadway

C = cost per square foot

Substituting Eq. 3 into Eq. 2 gives

$$PC = L * W * C * [1-(1+i)^{-rl}] = L * W * C * RLF \qquad \text{(Equation 4)}$$

An average cost of $120.00 per sq. ft. (which is the 1991 average total construction cost of various concrete bridges) was used. Since the WSDOT has adopted the use of an HS 25 loading in the design of future bridges, a five percent increase in the average cost was used to determine the additional cost of construction attributed to the design upgrade to HS 25. In this study in determining the effect of the Turner Proposal, a 1% increase in the average cost was used in the replacement cost calculations for each 5% increment of live load overload.

Each of the 2024 bridges in the population set was evaluated relative to the failure criterion (which is based on the HS 20 loading) for each of the four basic Turner prototype loads. For each of the four prototypes, the deficient bridges were identified. For each deficient bridge, the total length, the roadway width and the remaining life were obtained, and the cost estimate was determined per prototype. At the request of WSDOT representatives, several permutations were performed to obtain various cost estimates. One permutation involved a variable design life for each bridge. The design life was chosen as 25, 40, 50, 60 or 75 years. A second permutation involved the concept of an allowable live load overload in a bridge in order to mitigate the effects from the Turner prototype trucks.* The allowable live load overload value was chosen as 5, 10, 15, 20 or 25 percent. (Note that a 5% live load overload corresponds to an HS 21 design load, while a 25% live load overload corresponds to an HS 25 design load.) The costs resulting from the basic calculations which include the two permutations are shown in matrix form in Table 1 and in graphical form in Figure 10. Figure 10 shows curves associated with "envelope" (maximum) values for the costs that are contained in the various overload data rows in Table 1 for the 7ATS, the 9AD, and the 9ABTD configurations. The values for the 11AD are shown in Table 1, but the deletion of this type of loading from consideration has been recommended in TRB Special Report 227 (3). Hence, the values for the 11AD have been excluded from the curves shown in Figure 10.

*This second permutation was performed for information only in order to ascertain the potential effect of an allowable live load overload.

1	2	3	4	5	6	7	8
TURNER TRUCK	L.L. OVLD. INCREMENT	# OF DEF. BRIDGES	COST IN MILLIONS AT DIFFERENT VALUES OF USEFUL LIFE (YRS)				
			$L(75)	$L(60)	$L(50)	$L(40)	$L(25)
7ATS SEVEN AXLE TRACTOR SEMI	0	485	1180.7	1105.8	1009.7	847.1	411.4
	5	0	0	0	0	0	0
	10	0	0	0	0	0	0
	15	0	0	0	0	0	0
	20	0	0	0	0	0	0
	25	0	0	0	0	0	0
9AD NINE AXLE DOUBLE	0	951	2005.1	1854.1	1660.4	1332.1	557.1
	5	841	1854.5	1719.1	1545.4	1250.3	534.6
	10	747	1718.6	1595.9	1438.4	1171.2	510.1
	15	498	1240.5	1161.7	1060.7	889.8	431.8
	20	498	1240.5	1161.7	1060.7	889.8	431.8
	25	0	0.0	0.0	0.0	0.0	0.0
9ABTD NINE AXLE B-TRAIN DOUBLE	0	1300	2379.1	2189.1	1945.6	1533.5	612.6
	5	1128	2238.9	2063.9	1839.5	1459.6	588.9
	10	568	1333.2	1246.5	1135.1	946.6	450.0
	15	328	909.0	855.1	785.9	669.4	353.7
	20	328	909.0	855.1	785.9	669.4	353.7
	25	0	0.0	0.0	0.0	0.0	0.0
11AD ELEVEN AXLE DOUBLE	0	1498	2642.9	2428.0	2152.3	1686.2	663.8
	5	1301	2493.2	2294.6	2040.0	1609.2	643.0
	10	1180	2400.1	2211.7	1970.1	1561.0	628.7
	15	1089	2301.5	2124.0	1896.3	1511.1	614.4
	20	1089	2301.5	2124.0	1896.3	1511.1	614.4
	25	916	2051.9	1898.2	1700.9	1366.7	576.3
	30	818	1909.3	1770.4	1592.1	1289.3	554.3
Envelope FOR 7ATS 9AD 9ABTD ONLY	0	1300	2394.5	2203.5	1958.5	1544.1	617.3
	5	1128	2254.4	2078.3	1852.4	1470.1	593.6
	10	747	1718.6	1595.9	1438.4	1171.2	510.1
	15	498	1240.5	1161.7	1060.7	889.8	431.8
	20	498	1240.5	1161.7	1060.7	889.8	431.8
	25	0	0.0	0.0	0.0	0.0	0.0

LL OVLD Increment	
0% =	HS20
5% =	HS21
10% =	HS22
15% =	HS23
20% =	HS24
25% =	HS25

Table 1. Replacement Cost Estimate

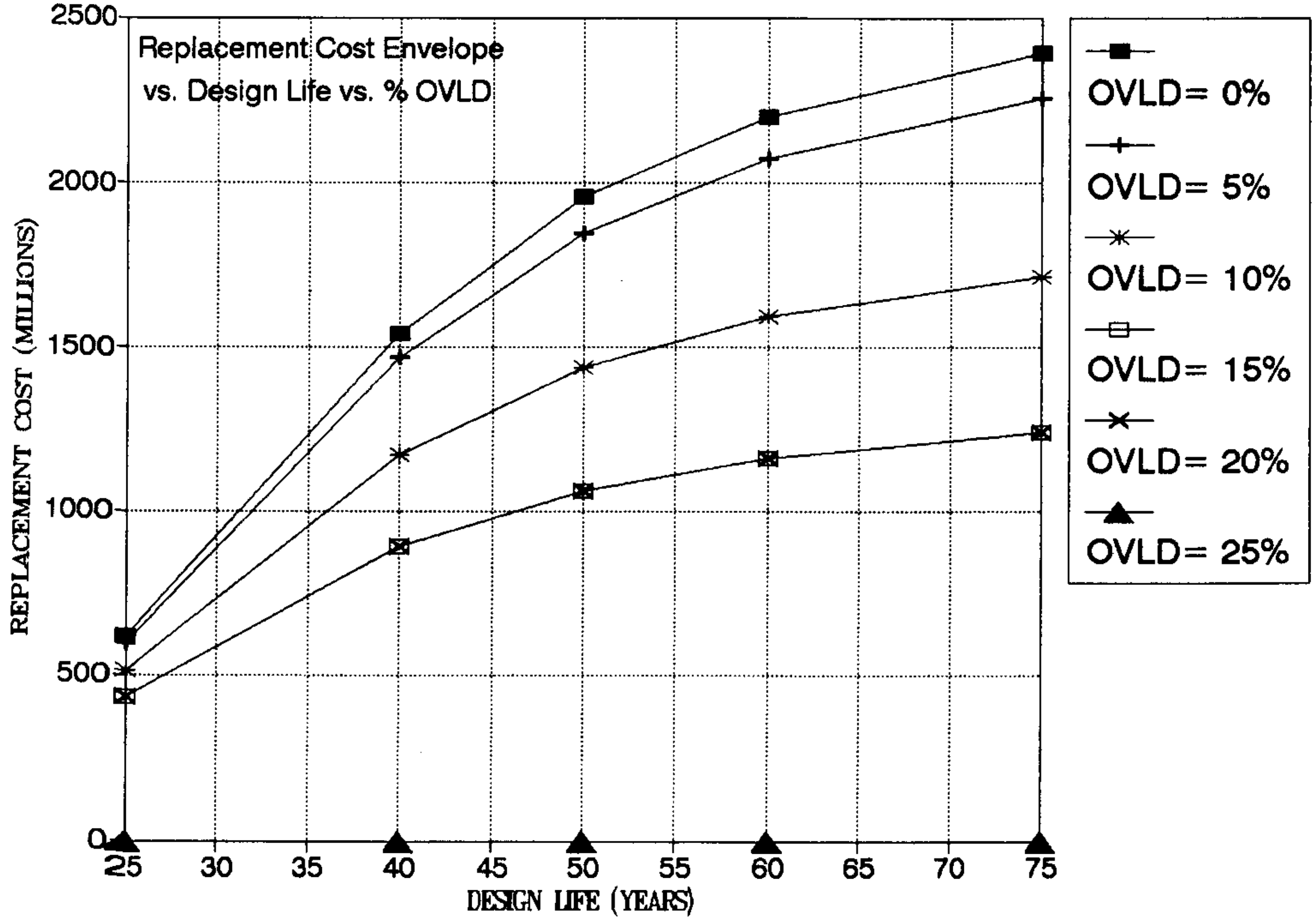


Figure 10. Replacement Cost Estimate

The columns in Table 1 are as follows:

1: Type of basic Turner prototype truck

2: Live load overload increment in percent

3: Number of bridges which are deficient for the prototype truck and the live load overload value

4-8: Estimated replacement cost for the deficient bridges in millions for each design life category

In searching the table for the 9ABTD values corresponding to 0% live load overload and a 75 year design life, one can see that the estimated cost is $2,379.1 million for replacing the 1300 bridges which are deficient. If one looks at the table at the values in the "envelope" section, one would see, that for a 25% live load overload allowance and a 75 year design life, that the replacement cost is $0.0, since none of the bridges in the data base are deficient for these two specific conditions. As a comparison, Moses(4) in his research work used the operating rating (OR) as the condition for bridge replacement because he found that a majority of states post bridges on the operating rating. The design load for concrete bridges which is equivalent to the OR is approximately an HS 30 or approximately 50% greater than the HS 20 design load which is equivalent to the inventory rating (IR). However, if trucks which are equivalent to loads which are greater than an HS 20 design load are allowed to operate on Washington's highways on a daily basis, damage to any bridge would be greatly accelerated, and its useful life would be greatly reduced.

The results associated with the two equal span continuous beam analyses were not used in the determination of a cost impact to WSDOT because of the complexity of the calculations. These analyses were performed as part of this study to ascertain the completeness of the data base and to show that analyses for these types of continuous bridges could be performed.

MAINTENANCE COST ESTIMATE

The increase in maintenance costs due to Turner Trucks was estimated to be $1,125,000 per year which is 25% of the present expenditures for bridge maintenance.

ROUTE ANALYSIS

In order to demonstrate the cost estimate procedure, a complete highway route was analyzed to determine the cost impact on that route attributed to three Turner prototype trucks (7ATS, 9AD & 9ABTD). State route number 530 from Conway to Rockport in northwestern Washington was chosen because of the small number of bridges on the route. The results of the analysis for SR 530 are given in Table 2. In Table 2, col. 1 is the state ID number, col. 2 is the bridge number, col. 3 is the bridge type, col. 4 is the maximum span length which is assumed to be simply supported, col. 5 is the total bridge length, col. 6 is the roadway width, col.7 is the replacement cost per square foot and is increased incrementally for the various live load overloads, col. 8 is the year in which the bridge was built, and col.9 is the remaining life of the bridge based on a 75 year design life.

The bridge type (TYPE) which is in col. 3 is an acronym. The acronym designations were obtained from the 1989 Washington Bridge List (5) and are interpreted as follows.

ROUTE #530

1	2	3	4	5	6	7	8	9	10	11	1
ST. I. D.	BDGE. #	TYPE	S.L.	T. L.	WIDTH	$/ft^2	YEAR	RL(75)	0% OVLD	COST(M)	ST. I. D.
364A	530/109	CA	20	20	-	120	1919	2	0	0	364A
854A	530/104	CS	23	23	-	120	1925	8	0	0	854A
8804A	530/136	CS	33	86	-	120	1970	53	0	0	8804A
8804B	530/137	CS	36	94	-	120	1970	53	0	0	8804B
13135A	530/4	PCS	38	114	-	120	1987	70	0	0	13135A
364B	530/111	CA	40	40	19.7	120	1919	2	0	0	364B
13135B	530/5	PCS	40	81	37	120	1987	70	0	0	13135B
14Z	530/210	PCTB	40	80	28	120	1974	57	0	0	14Z
8389A	530/130	CS	42	106	34	120	1968	51	0	0	8389A
6897A	530/132	PCB	78	165	26	122.4	1962	45	1	0.48	6897A
16Z	530/289	PCTB	78	76	24	122.4	1961	44	1	0.20	16Z
7645A	530/115	PCB	80	279	45	122.4	1965	48	1	1.42	7645A
9119A	530/126	PCB	103	210	36	123.6	1972	55	1	0.89	9119A
9423A	530/138	PCB	108	113	36	123.6	1972	55	1	0.48	9423A
11411A	530/108	PCB	116	352	32	124.8	1979	62	1	1.35	11411A
8650B	530/1	PCB	117	240	59	124.8	1970	53	1	1.66	8650B
12113A	530/134	PCB	130	130	36	126	1982	65	1	0.57	12113A
704A	530/110	ST CS	140	186	-	126	1923	6	-	-	704A
17Z	530/290	SB PCTB	180	506	-	126	1961	44	-	-	17Z
4174A	530/128	CBOX	180	300	26	126	1949	32	1	0.81	4174A
7068A	530/120	ST SB TTT	200	394	-	126	1924	7	-	-	7068A
6038A	530/207	ST SB CTB	221	501	-	126	1958	41	-	-	6038A
7733A	530/124	SA PCB	279	377	-	126	1966	49	-	-	7733A
								TOTALS	9	$7.86	

Table 2. Replacement Cost Estimate for SR 530

ROUTE #530

1	12	13	14	15	16	17	18	19	20	21
ST. I. D.	5% 0VLD	COST(M)	10% OVLD	COST(M)	15% OVLD	COST(M)	20% OVLD	COST(M)	25% OVLD	COST (M)
364A	0	0	0	0	0	0	0	0	0	0
854A	0	0	0	0	0	0	0	0	0	0
8804A	0	0	0	0	0	0	0	0	0	0
8804B	0	0	0	0	0	0	0	0	0	0
13135A	0	0	0	0	0	0	0	0	0	0
364B	0	0	0	0	0	0	0	0	0	0
13135B	0	0	0	0	0	0	0	0	0	0
14Z	0	0	0	0	0	0	0	0	0	0
8389A	0	0	0	0	0	0	0	0	0	0
6897A	1	0.48	0	0	0	0	0	0	0	0
16Z	1	0.20	0	0	0	0	0	0	0	0
7645A	1	1.42	0	0	0	0	0	0	0	0
9119A	1	0.89	1	0.89	0	0	0	0	0	0
9423A	1	0.48	1	0.48	0	0	0	0	0	0
11411A	1	1.35	1	1.35	1	1.35	0	0	0	0
8650B	1	1.66	1	1.66	1	1.66	0	0	0	0
12113A	1	0.57	1	0.57	1	0.57	1	0.57	0	0
704A	-	-	-	-	-	-	-	-	-	-
17Z	-	-	-	-	-	-	-	-	-	-
4174A	1	0.81	1	0.81	1	0.81	1	0.81	0	0
7068A	-	-	-	-	-	-	-	-	-	-
6038A	-	-	-	-	-	-	-	-	-	-
7733A	-	-	-	-	-	-	-	-	-	-
	9	$7.86	6	$5.77	4	$4.40	2	$1.38	0	$0.00

Table 2 (Continued). Replacement Cost Estimate for SR 530

CA	-	Concrete Arch
CS	-	Concrete Slab
PCS	-	Pre-Tensioned Concrete Slab
PCTB	-	Pre-Tensioned Concrete T-Beam
PCB	-	Pre-Tensioned Concrete Beam
ST CS	-	Steel Truss/Concrete Slab
SB PCTB	-	Steel Beam/Pre-Tensioned Concrete T-Beam
CBOX	-	Concrete Box Girder
ST SB TTT	-	Steel Truss/Steel Beam/Creosote Treated Timber Trestle
ST SB CTB	-	Steel Truss/Steel Beam/Concrete T-Beam
SA PCB	-	Steel Arch/Pre-Tensioned Concrete Beam

With reference to Table 2, the numbers in the TOTAL line at the bottoms of columns 10-21 represent the total number of deficient bridges for the specified % of live load overload (OVLD) or the total replacement cost for the respective column. Each cost estimate was determined with the use of the previously described procedure associated with Replacement Cost Estimate. This study was concerned only with concrete bridges with span lengths 40 ft. or greater. Hence, a dash (-) in a location in the array means that the number that would normally exist there was excluded from the analysis, i.e., bridge less than 40 ft. long or contained steel members.

APPLICATION AND IMPLEMENTATION

COURSES OF ACTION

The objective of this study was to determine the cost impact on bridges to the WSDOT resulting from the approval of the Turner Proposal. Therefore, there are no formal applications or implementations which can be attributed to the results of this study.

However, the results of this study can be used by the appropriate decision makers in deciding whether or not to approve the use on Washington highways of the trucks which have been designated in the Turner Proposal.

There are some courses of action which can be postulated for further thought, such as:

1. Do not approve the Turner Proposal on the basis of excessive cost.
2. Limit the types of new trucks and upgrade the bridge system to accommodate these new trucks.
3. Limit the access of the new trucks to only specific routes (e.g., interstate and certain principal arterials) and upgrade the bridge system on the routes which are designated. The initial access routes to be approved might involve very specific ingress and egress routes to several large staging/storage or warehouse facilities in order to provide a "test segment" for which a "real" cost benefit ratio could be determined.
4. Allow the use of the new trucks and charge a large use fee for their operation. Use the money collected from these fees to offset the cost of upgrading and maintaining the bridge system during the transition period from the use of the present trucks to the use of the new trucks.

5. Any combination of these or other potential courses of action.

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