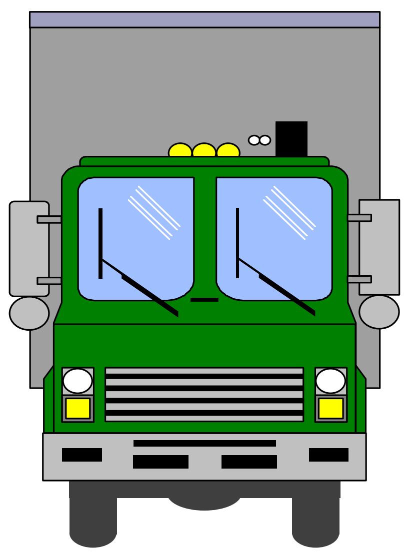
CHAPTER 6

Bridge



INTRODUCTION

The Department, in its report to Congress on the "*1997 Status of the Nation's Surface Transportation System*," found that 11.7 percent of the bridges on the Nation's arterial (including Interstate) and collector highway systems are structurally deficient and 15.2 percent are functionally deficient (see "Structurally Deficient versus Functionally Obsolete Bridges" box, below). The estimated annual cost to maintain current bridge structural and functional conditions is $5.6 billion (1995 dollars). This leads to the question: How much will changes in truck size and weight (TS&W) limits impact the current and future condition of our existing bridges. Also of interest are the cost implications of any change in condition.

This Study includes estimates of the change in bridge structural requirements that could result from TS&W policy changes. The study does not address functional impacts, as increases in vehicle width or height limits are not evaluated.

BASIC PRINCIPLES

TRUCK-BRIDGE INTERACTION

The impact of trucks on bridges varies primarily by the weight on each group of axles on a truck and the distances among these axle groups. The number of axles in each group is less important than the distance between adjacent groups. Generally, except for some continuous bridges with long spans, the longer the spacing between two axle groups the less the impact.

An increase in stress generally tends to stretch bridge girders or beams. However, the maximum stress can be reduced by spreading the load among more axles or by spreading axles or axle groups further apart (see "Moment" box, page 6-2).

The above described interaction of axle groups holds true for all "simply supported" span bridges and many "continuously supported" spans. However, depending on the axle group spacing and length of continuous spans, the stresses in the span resulting from longer axle spacings can have a combined effect and increase the stresses at the bridge pier. Continuous span bridges are designed to take advantage of the interactions that occur when axle groups are on the opposite side of

<u>STRUCTURALLY DEFICIENT VERSUS FUNCTIONALLY OBSOLETE BRIDGES</u>

There are two types of deficient bridges, structurally deficient (SD) and functionally obsolete (FO). An SD bridge, as defined by the Federal Highway Administration, is one that (1) has been restricted to light vehicles only, (2) is closed, or (3) requires immediate rehabilitation to remain open. An FO bridge is one in which the deck geometry, load carrying capacity (comparison of the original design load to the State legal load), clearance, or approach roadway alignment no longer meets the usual criteria for the highway of which it is an integral part.

MOMENT

One way to think of a moment is as two forces that tend to rotate a body, such as a bridge beam. This tendency may be one source of stress in a bridge beam (the major one in a long bridge span) as the material properties and beam connection resist the rotational tendency. Further, this rotational tendency becomes stronger the farther the two forces are spread.

One of these forces results from an axle load and the other from the support at one end of the beam. One force acts in the opposite direction of the other giving rise to the rotational tendency of the two acting together. As these two forces are moved closer together, their rotational tendency is reduced. Consequently, when axle or axle groups are spread farther apart, for any given position of the truck on the bridge, the axle loads are closer to the supports which reduces the maximum moment induced by the vehicle load and the stresses in the beam.

the fixed beam connection on the central pier (see Exhibit 6-1). This allows the use of smaller beams or girders to reduce bridge costs. However, if the two-axle loads are far enough apart and the two spans long enough, the beneficial effects will be negated.

The bridge impact analysis for this Study considered both simple and continuous span bridges. The Federal Bridge Formula (FBF) was developed based on the assumption that all bridges were simple span bridges. Consequently, the FBF allows trucks to operate that could, under certain conditions, overstress continuous spans.

For short bridge spans, axle weights and the weight of the span components are important. For longer spans, axle spacing becomes important in addition to the axle loads (see Exhibit 6-2). For still longer spans, those longer than the overall length of the truck on the span, the gross weight of the truck and its length is important along with the dead load of the span. For very long spans, the weight of the traffic is much less significant than the weight of the bridge span itself (that is, the dead load).

BRIDGE IMPACT CRITERIA

Previous TS&W studies have used bridge ratings, either the operating rating which is set at 75 percent of the yield stress, or inventory rating, which is set at 55 percent of the yield stress (see "Relationship of Overstress Criteria to Design Stress and Bridge Ratings" box, page 6-6). These ratings were used to determine if a bridge should be posted for a maximum load and, in some cases, replaced if heavier truck loads are expected to use it. The choice of which rating to use has a marked effect on the estimated bridge impact.

This Study uses different criteria to trigger the requirement for bridge replacement. These follow the "overstress criteria" on which the FBF is based. These are the same as 30 percent overstress for H-15 bridge designs and 5 percent

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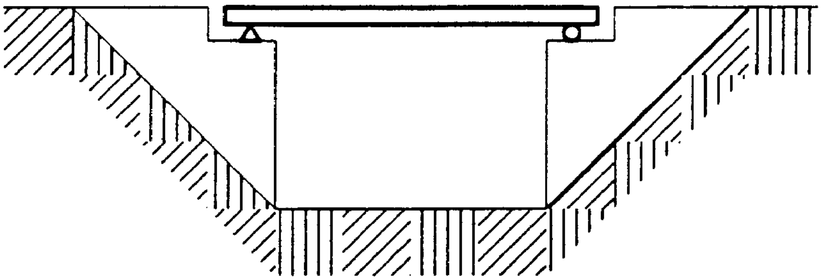
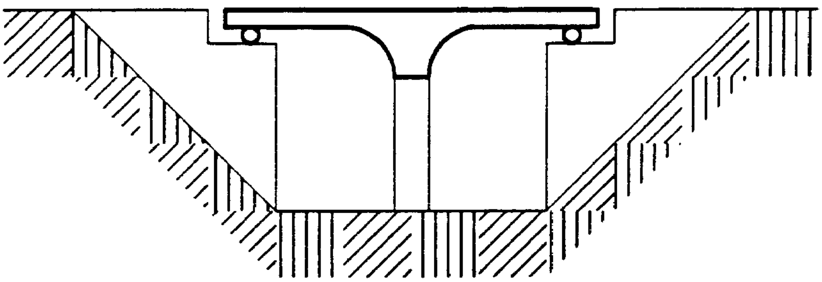
EXHIBIT 6-1
SIMPLE AND CONTINUOUS SPAN BRIDGES



Simple
One-Span Bridge



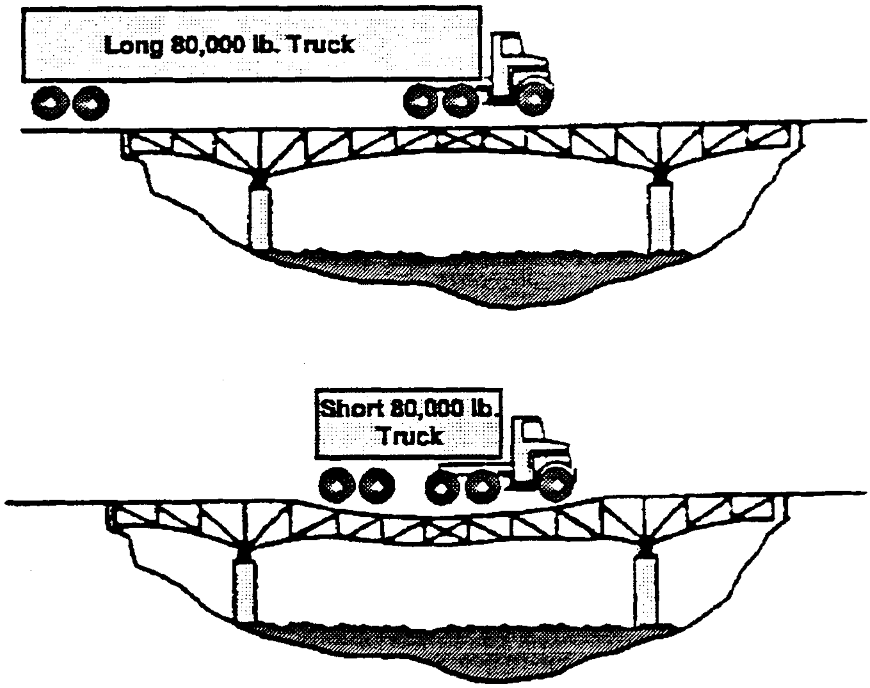
Continuous
Two-Span Bridge

Note: The small triangle in the Simple-Span Bridge illustration represents a pin connection which allows the be girder to rotate at that connection.

The small circles in both illustrations represent roller connections which allow the beams or girders to change in (expand or contract due to changes in temperature).

overstress for HS-20 bridge designs. The overstress terms are defined in the "Relationship of Overstress Criteria to Design Stress and Bridge Ratings" box on page 6-6. Also, see the "H-15 and HS-20 Bridge Loading" box on page 6-5. The Study used the FBF overstress criteria because they reflect current truck weight regulation policy. If a truck (given its weight, number of axles, and the spacing of these axles) conforms to the FBF, it is not considered overweight under current weight regulations, nor does it result in an expedited program to replace H-15 bridges.

EXHIBIT 6-2
INTERACTION OF BRIDGE SPAN LENGTH AND SPACING OF TRUCK AXLE GROUPS



ANALYTICAL APPROACH

The Bridge Analysis and Structural Improvement Cost (BASIC) model was used to estimate bridge impacts. This model was specifically designed to evaluate alternative TS&W policy options. It estimates bridge replacement costs as well as associated user delay costs.

Bridge impact is a function of a particular bridge loading condition and not an accumulation of loads as is the case for pavements. This is to say that the analysis of bridge impact does not require truck travel (vehicle-miles-of-travel) estimates to determine when a bridge needs to be replaced.

Important to the analysis is the determination of whether the worst expected loading condition results in a stress above the stress criterion used to determine the bridge's safe load carrying capacity.

While it is true that larger trucks increase stress ranges and, consequently, have the potential to increase fatigue damage, fatigue is a secondary problem for several reasons. First, it generally affects only steel bridges and the steel "share" of the NBI is decreasing. Secondly, fatigue damage can generally be repaired inexpensively, assuming the

H-15 AND HS-20 BRIDGE LOADINGS

Most steel bridges (49 percent of all bridges) in the United States were designed to accommodate either an H-15 or HS-20 loading. An H-15 loading is represented by a two-axle single unit truck weighing 30,000 pounds (15 tons) with 6,000 pounds on its steering axle and 24,000 pounds on its drive axle. An HS-20 loading is represented by a three-axle semitrailer combination weighing 72,000 pounds with 8,000 pounds on its steering axle and 32,000 pounds on its drive axle and 32,000 pounds on the semitrailer axle. The "20" in HS-20 stands for 20 tons (4 tons on the steering axle and 16 tons on the drive axle). The "S" stands for semitrailer combination which adds in the additional 16 tons for the third axle to give a total of 36 tons or 72,000 pounds.

Actually, there are other steel bridge types closely related to H-15 and HS-20 bridges. These are H-10, HS-15, H-20, and HS-25. In addition, once in service for a time, bridges may be found with reduced capacity, and their initial ratings in tons may be reduced to values less than 15 tons or 20 tons. Approximately 28 percent of the U.S. steel bridges are rated at either 10 tons or 15 tons and the remaining 72 percent are rated at either 20 tons or 25 tons.

States are performing adequate inspections to identify problems early in their development. Third, most bridges have been designed with an adequate fatigue code.

OVERVIEW

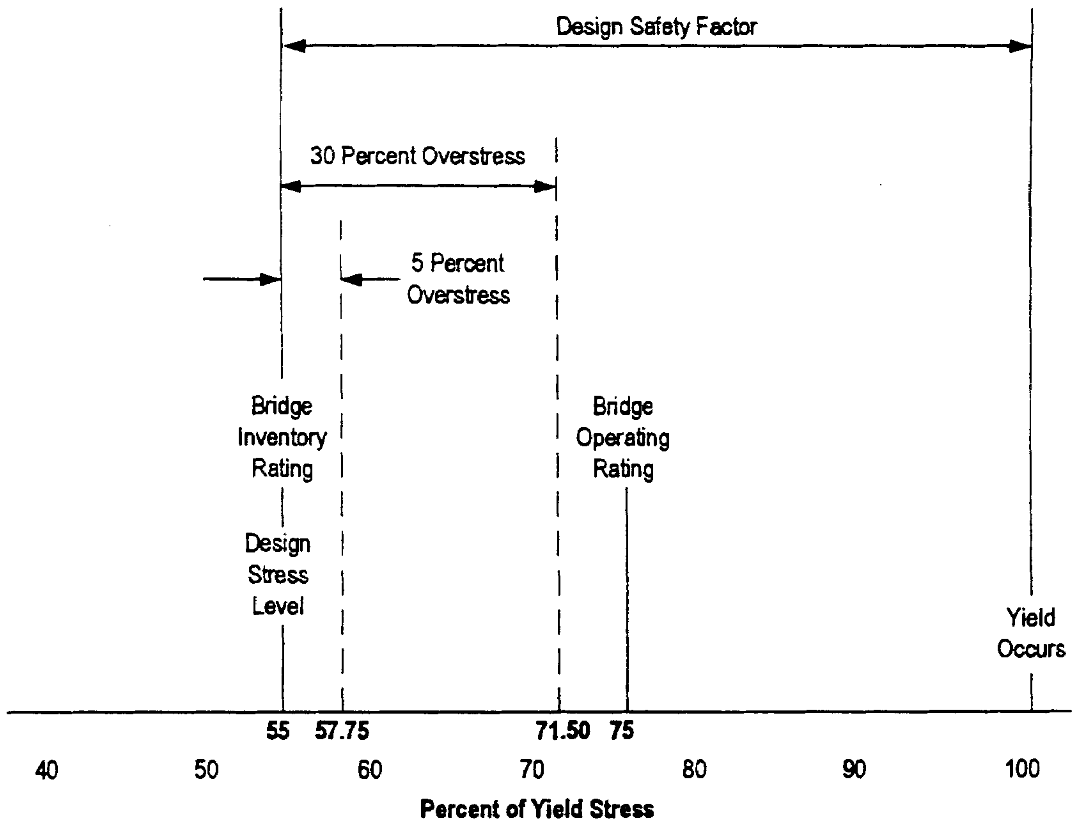
The BASIC input data set is a sample of State bridges created from the National Bridge Inventory (NBI) data set. For each bridge, BASIC requires the bridge type and the inventory rating. The inventory rating provides the safe load carrying capacity of the bridge (see "Relationship of Overstress Criteria to Design Stress and Bridge Ratings" box, page 6-6). The inventory rating was used as opposed to the operating rating as it is considered relatively more reliable.

For each bridge, BASIC computes the bending moment (see "Moment" box, page 6-2) for the rating vehicle, the status quo set of vehicles and the scenario set of vehicles. The bending moment calculations are based on both the live and dead loads for the bridge. "Dead load" refers to the weight of the bridge span components; the "live load" refers to the weight of the traffic on the span. The representative sets of scenario vehicles generally include seven or eight truck configurations.

Based on user defined allowable stress levels, bridges requiring replacement are identified. If the appropriate criterion for the bridge design type is exceeded, the bridge is determined to require replacement. The cost of replacing each bridge is estimated and summed for the total bridge replacement cost impact. The user costs associated with replacing the deficient bridges are also calculated.

RELATIONSHIP OF OVERSTRESS CRITERIA TO DESIGN STRESS AND BRIDGE RATINGS

The terms "overstress criteria," "design stress," "bridge inventory rating," and "operating rating" relate to the point at which a structural member (a load-carrying component) of a bridge undergoes permanent deformation, that is, the bridge member does not return to its original size or shape after the load is removed. The level of stress at which this permanent deformation occurs is called the "yield stress." Each of the related terms can be expressed as a percentage of this stress level. It is useful to do this to observe how each of the terms relate to each other as well as to the yield stress. Also, it is important to observe that, depending on the type of steel, a bridge member ruptures after considerable deformation relative to that which occurs at its initial point of yielding.



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RELATIONSHIP OF OVERSTRESS CRITERIA TO DESIGN STRESS AND BRIDGE RATINGS CONTINUED

It can be noted in the sketch that the standard stress level for the design of bridge members is 55 percent of the stress at which yield occurs. This leaves a design safety factor of 45 percent of yield. This safety factor provides a contingency for weaknesses in materials, poor quality of construction, noncompliance with vehicle weight laws, and future increases in bridge loads.

Bridges are rated by the States at either of two yield stress levels: the inventory rating, which is 55 percent of the yield stress (the same as the design stress) or the operating rating, which is 75 percent of the yield stress. These ratings are used to post bridges and for inventory purposes.

Past truck size and weight (TS&W) studies have used either of these two ratings to determine when a bridge should be replaced, given alternative TS&W policy options. A 1991 study of TS&W policy impacts on bridges used a 65-percent criterion to identify bridges needing replacement. It can be seen that bridge replacement needs would vary considerably depending on which rating was used.

The Federal Bridge Formula (FBF) is based on stress levels (overstress criteria) related to the design stress. When the FBF was formulated, a decision was made to allow loads to stress bridges designed for an H-15 loading at levels up to 30 percent over the "design stress." This type of design was used for bridges prior to the Interstate Highway Program, and these bridges are primarily located on lower functional class highways. Their early replacement was anticipated such that some shortening of bridge life could be tolerated. Bridges expected to have heavy truck traffic were designed with an HS-20 loading. The decision to allow loads no more than 5 percent over the design stress was intended to ensure that these bridges would function satisfactorily for their expected service life, 50 or more years, without the need for replacement.

This study used the FBF overstress criteria, rather than either the inventory or operating rating used in past studies, to indicate the need for bridge replacement, but with two exceptions. First, the criteria were applied to the design stress level, and second the loads were permitted to exceed the inventory stress levels on H-17.5 (or higher H rating) bridges by only 15 percent versus the FBF's 30 percent. In terms of the yield stress, the 30 percent "overstress" is 71.5 percent, the 15 percent overstress is 63.5 percent, and the 5 percent overstress is 57.75 percent of the yield stress (see sketch). These criteria fall between the two bridge rating stress levels, and further they replicate the FBF criteria, which today allow a truck to exceed a bridge's inventory rating and not be considered overweight, that is, be found illegal or required to obtain an overweight permit.

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BRIDGE REPLACEMENT

MODEL INPUTS

In order to properly assess which bridges need to be replaced, a representative bridge sample was selected. An 11 State sample was drawn from the National Bridge Inventory (NBI) (see "National Bridge Inventory" box, below). The States included Alabama, California, Colorado, Connecticut, Missouri, North Dakota, South Carolina, Texas, Virginia, Washington, and Wisconsin.

The sample included almost 30 percent of all the bridges in the NBI and results were ultimately expanded to include all States based on the deck area of the bridges in the sample States and the deck area of the bridges in the remaining States.

Dead loads for the bridges were estimated based on detailed design information for 960 bridges of different types and span lengths. Given the type and span length of a bridge of interest, the dead load may be estimated from a table look-up feature in the model.

This Study considered both live and dead loads for the first time in an assessment of TS&W policy impacts on bridges at the National level. In the past only live loads have been considered. However, with bridges of longer span length, the dead load becomes increasingly important, and in fact, the significance of the live load is reduced. In other words, the portion of total stress in a beam that results from the traffic load is less important than the portion of the stress resulting from the weight of the bridge span components.

NATIONAL BRIDGE INVENTORY

The National Bridge Inventory contains records of 581,862 bridges. The database is updated continuously and includes detailed information about all highway bridges in the country, on all functional systems. This information is used in the monitoring and managing of the Highway Bridge Replacement and Rehabilitation Program, as well as to provide the condition information presented in the biennial *Status of the Nation's Surface Transportation Report to Congress*.

OVER STRESS CRITERIA

In the Study analysis, for the most part, two criteria were used based on the bridge inventory rating (57.5 percent of the yield stress for an HS-20 bridge and 71.5 percent of the yield stress for an H-15 bridge). To account for bridges in the NBI other than those rated as H-15 and HS-20 bridges, an additional overstress criterion was used. The 5 percent overstress criteria was used for all HS-rated bridges, the 30 percent criteria for all H-rated bridges up to H-17.5, and a 15 percent overstress criteria for H-17.6 and above rated bridges.

ANALYTICAL PARAMETERS

Available Routes

For the LCVs Nationwide Scenario, the truck configurations—the Rocky Mountain and Turnpike Doubles (TPDs)—were assumed to be restricted to a 42,500-mile system; only bridges on that system were tested for these configurations. Other truck configurations in the scenario—single-unit trucks and semitrailer, heavy short double, and triple-trailer combinations—were evaluated on all bridges in the sample States as they have the potential to use all the nonposted bridges in the NBI for access to terminals, places for loading and unloading, and places for food, fuel, rest, and repairs.

Specifications

Exhibit 6-3 presents the parameters for the truck configurations tested and the TS&W policy scenarios in which they are included. The GVWs are the weights for which the impacts were estimated. The "maximum weight for no impact" is given to compare how one configuration compares with another in terms of bridge impact. The scenario impacts are given in a subsequent section. Those configurations tested with GVWs greater than the weight shown in the last column exceed at least one of the overstress criteria and would result in the need to eventually replace bridges.

USER COSTS

In addition to the capital cost to replace bridges, the analytical approach estimated the costs accruing from traffic congestion during the reconstruction of the bridges. The user delay costs are those above the costs for operation without the effect of the bridge reconstruction workzone.

The assumptions for accommodating traffic through the workzone are: (1) for twin bridges typically found on freeways, one bridge is taken out of service and all traffic uses the other; (2) for multilane bridges, one or two lanes are closed while traffic uses the remaining lanes with perhaps one being reversible to accommodate the predominant direction of the travel for the time of day; and (3) for a bridge with one lane in each direction, the procedure assumes either the new bridge is constructed before the old one is closed, a temporary bridge is provided while the bridge being replaced is built, or that there are adequate bypass opportunities and consequently no significant change in user costs.

ASSESSMENT OF SCENARIO IMPACTS

The estimated costs, in 1994 dollars, for replacing bridges that would be stressed at levels above one of the three overstress thresholds discussed earlier and the user delay costs during bridge reconstruction are given in Exhibit 6-4. Also provided are the estimated costs to bring all existing bridges up to standard to accommodate existing truck traffic in the Base Case. It is important to note that these bridge costs are one time only costs (not annual costs).

For all scenarios, the delay costs are at least as high as the capital costs, and for the scenarios with significant increases in GVWs, the delay costs are much higher.

The scenario analysis assumes that no bridges are posted or otherwise unavailable for the scenario vehicles. Although most of such bridges will be available for use by heavier trucks—the degree of overstress is not critical—many will need to be replaced. As this would occur over many years, the assumption results in outcomes that would not likely occur as States would restrict the use of bridges expected to experience high-overstress levels until they are replaced. Until the needed funds are available and the bridges are replaced,

EXHIBIT 6-3
TRUCK CONFIGURATION PARAMETERS FOR ANALYSIS OF BRIDGE IMPACTS

Configuration	Scenarios	Gross Vehicle Weight (pounds)	Trailer Lengths (feet)	Outside Axle Spread (feet)	Highways Assumed Available	Maximum Weight for "No Impact" (pounds)
Three-Axle Truck	Uniformity	54,000	--	24.0	All	54,000
Four-Axle Truck	North American Trade	64,000	--	24.5	All	63,500
		71,000	--		All	63,500
Five-Axle Semitrailer	Uniformity	80,000	40	54.3	All	80,000
Six-Axle Semitrailer	North American Trade	90,000	40	54.8	All	90,300
		97,000	40	54.8	All	90,300
Five-Axle STAA double	Uniformity	80,000	28, 28	64.3	All	92,000
Seven-Axle Rocky Mt. Double	LCVs Nationwide	120,000	53, 28	94.3	42,500-mile System	115,300
Eight-Axle B-Train Double	North American Trade and LCVs Nationwide	124,000	33, 33	79.3	All	111,600
		131,000	33, 33	79.3	All	111,600
Nine-Axle Turnpike Double	LCVs Nationwide	148,000	40, 40	119.3	42,500-mile System	122,200
Seven-Axle C-Train Triple	LCVs Nationwide and Triples Nationwide	132,000	28, 28, 28	97.2	65,000-mile System	116,100

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heavier trucks must use routes without deficient bridges, carry lighter loads, or not be used at all.

UNIFORMITY SCENARIO

The impact of this scenario on bridges (see Exhibit 6-4) would be to reduce current bridge investment requirements (by $20 billion). This savings results from the rollback of State weight limits that apply to the NN, which includes Interstate highways, that are higher than the Federal limits.

NORTH AMERICAN TRADE SCENARIOS

The bridge impacts of these two scenarios (see Exhibit 6-4) are dominated by the weight (44,000 pounds and 51,000 pounds) allowed on the tridem-axle for the noted configurations. The bridge impacts are $51 billion and $65 billion for capital costs and $203 billion and $264 billion for user delay costs for the scenarios with the 44,000-pound and 51,000-pound tridem limit, respectively.

EXHIBIT 6-4
SCENARIO BRIDGE IMPACTS

Analytical Case		Costs ($billion)			Change from Base Case ($billion)		
		Capital	User Delay	Total	Capital	User Delay	Total
1994		154	175	329	0	0	0
2000 Base Case		154	175	329	0	0	0
Scenario							
Uniformity		134	133	267	-20	-42	-62
North American Trade	44,000-pound tridem axle	205	378	583	51	203	254
	51,000-pound tridem axle	219	439	658	65	264	329
LCVs Nationwide		207	441	648	53	266	319
H.R. 551		154	175	329	0	0	0
Triples Nationwide		170	276	446	16	101	117

LONGER COMBINATION VEHICLES NATIONWIDE SCENARIO

The bridge impact for this scenario, is $53 billion in capital costs and $266 billion in user delay costs (also a one-time cost). It is dominated by the nine-axle TPD at 148,000 pounds distributed across a length of 119.3 feet, and as in the previous scenario, the eight-axle B-train double-trailer combination at 124,000 pounds distributed over 69.3 feet.

H.R. 551 SCENARIO

Theoretically, this scenario would increase bridge impacts (see Exhibit 6-4) as after a period of time the lengths of some semitrailer combinations would be reduced as semitrailers longer than 53 feet would be phased out of service. Decreasing the length of a truck at a given weight increases the stress on bridges. Nevertheless, this effect is very small for two reasons—the number of trucks affected is very small and the commodities carried in extra long semitrailers are generally very light such that they have no impact on bridges. Therefore, this scenario has virtually no impact on bridges.

TRIPLES NATIONWIDE SCENARIO

For this scenario all the net bridge costs ($16 billion in capital and $101 billion in delay costs) result from the use of the seven-axle triple-trailer combination at a GVW of 132,000 pounds distributed over a length of 97.2 feet.