
The United States Bridge Formula

Claude S. Napier, Jr.¹ Dr. John P. Eicher²

Major importance is placed on truck size and weight issues by highway engineers and officials, legislative bodies, commercial truckers, the manufacturers of heavy motor vehicles and others. The issue of truck size and weight regulation has and still is a very controversial one. For the past 30 years, since the passage of the Federal-aid Highway Act of 1956, the Federal government has regulated truck size and weight on the Interstate System. Our present Bridge Formula was adopted for the Interstate System by the Federal-aid Highway Amendments of 1974.

$$W = 500 \frac{(LN + 12N + 36)}{N-1}$$

W = overall gross weight on any group of two or more consecutive axles to nearest 500 pounds.

L = distance in feet between the extreme of any group of two or more consecutive axles.

N = number of axles in group under consideration.

Before addressing the specifics of the Bridge Formula, a little background on some of the history of size and weight policy and legislation in the United States may be helpful.

The problem now and always has been is how to rationalize design load with safe load carrying capacity or regulatory loading. Engineers in our country have worked since before the turn of the century to agree on an appropriate design vehicle, or umbrella loading for bridge design. One of the first issues faced by the members of the AASHO Committee on Bridges and Structures after its formation in 1921 was determination of design vehicles for bridges. In the 1920's many bridge engineers considered that a truck with a total weight of 10 tons (designated H10) was adequate.

Later in the 1930's AASHO's bridge engineers agreed that a total load of 15 tons (designated H15) was adequate. However, the Second World War, with its great need for mobilization of the country's industrial and military might and consequent increase in truck size, influenced AASHO's decisionmakers to agree on an HS20-44 (H20-S16 original designation) truck in 1944. The "HS" stands for "heavy semi" or "highway semi." The "20" means that the tractor weighs 20 tons and the "44" is the year the umbrella vehicle was adopted. This loading was used for bridges that would be included in the Interstate System. After the war, there was a trend toward the use of heavier loadings to design bridges on all highway systems.

Today, most bridges on the highway systems are designed for the HS20-44 truck and there is discussion about a higher design load, like the HS25 which some States are already using.

The standard design loading in the AASHO (AASHTO) design specifications has been increased in the past to accommodate the evolution of heavier trucks and still protect our existing highway system. The changes in design loadings have required corresponding changes in State policies and regulations, as well as Federal regulation. In 1932, AASHO issued its first policy statement recommending the following weight limitations:

- Single axle - 16,000 lbs
- Tandem axle (under 8' spacing) - Formula
- Axle group - Formula

$$W = C(L + 40)$$

(also known as the Gemeny formula)

W = total gross weight in pounds on any two or more consecutive axles

1 Structural Engineer, Bridge Division, Office of Engineering, Federal Highway Administration, Washington, D.C.

2 Director, Office of Motor Carrier Transportation, Federal Highway Administration, Washington, D.C.

C = a coefficient to be determined by the individual States

L = the distance between the first and last axles of the group of axles under consideration

A value of 700 was recommended for C, as the lowest which should be imposed. Mr. Albin Gemeny, Senior Structural Engineer, U.S. Bureau of Public Roads, had recommended the following equations for W:

- W = 670 (L+40) for H10 bridges
- W = 1000 (L+40) for H15 bridges
- W = 1300 (L+40) for H20 bridges

Since 1932, AASHO has subsequently issued several other policies as follows:

1. 1942 Emergency Regulation
2. 1946
3. 1963
4. 1964 Policy and Revision in 1968
5. 1973 - Truck limits same as 1963 Limits
6. 1974
7. New policy is currently being prepared.

A brief review of each policy may be of interest. On May 17, 1942, AASHO recommended an interim substitute policy that was applicable for the duration of the war emergency. Then in August 1, 1946, the 1932 policy, the 1942 emergency regulations, and results of extensive studies by AASHO and others were formulated into a new policy. The single axle load was increased to 18,000 lbs., the tandem axle retained at 32,000 lbs., and the gross weight of axle groups was based on a table which was based on the formula

$$W = 1025 (L + 24) - 3L^2$$

The maximum gross weight was 73,280 lbs. for L = 57 feet.

Several important research projects were initiated in the 1950's. The WASHO and AASHO road tests were started in 1950. These were extensive tests of pavement using test vehicles loaded with single axles from 2,000 to 30,000 pounds and tandem axles of 24,000 to 48,000 pounds. In addition, a

few tests were made of bridges as part of the AASHO tests at Ottawa, Illinois, using heavy trucks exceeding the design loading to induce gradual failure. In October 1952, the Texas Engineering Experiment Station of Texas A&M completed a research project on the "Method of Converting Heavy Motor Vehicle Loads into Equivalent Design Loads on the Basis of Maximum Bending Moments" for the Bureau of Public Roads. The report presented the results obtained from a rather extensive investigation of highway loads and their stress producing effects on simple span bridges of various lengths.

In July 1962, the Texas Transportation Institute of Texas A&M completed a research project on the "Truck Weight Trends Related to Highway Structures." The objective of the research was to develop a general formula that met the following requirements:

1. Can be adjusted to fit any desired level of heavy vehicle operation.
2. Will permit relatively heavy axle group loads.
3. Will encourage the use of multi-axle vehicles.
4. Will not only be in harmony with the economic principles of highway and bridge provision, but will also improve the payload opportunities for truckers through a freer choice of vehicle types.

The following general formula was developed:

$$W = A [f(NL) + BN + C] \quad \text{in which}$$

W = maximum load in pounds carried on any group of two or more consecutive axles.

L = distance in feet between the extremes of any group of two or more consecutive axles

N = number of axles in group under consideration.

A, B & C are constants which depend upon quality of highway and bridge provision and desired level of heavy vehicle operation.

f = some function involving "N" and "L"

The formula could be readily adjusted to any level of heavy motor vehicle operation as desired simply by adjusting the constants included in it. A

number of variations of the general formula were investigated, but the following one was recommended as the formula that appeared to be best suited for determining and regulating permissible vehicle weights, consistent with both heavy vehicle operation and the then present day highway provision.

$$W = 500 (NL + 12N + 32) \\ N - 1$$

The 1963 policy of AASHO recommended permissible single axle loads of 20,000 pounds and still limited tandem axle loads to 32,000 pounds. The gross weight on a group of axles was based on this formula.

The axle group loading for N from 2 to 6 allowed a considerable increase over that permissible by the 1946 AASHO policy. There were limitations to the use of the formula based on H15-44 design bridges.

The AASHO policy of 1964 and revision in 1968 for axle loads and gross weight were the same as stated in the 1963 policy recommendation. The 1974 policy recommended permissible single axle loads of 20,000 pounds and tandem axle loads of 34,000 pounds. The maximum permissible axle group weights were based on our current formula. However, the maximum permissible gross weight was limited by allowable length and axle weight controls for certain typical vehicle types. AASHTO's new proposed policy adopts the Federal weight limits for the Interstate System as its new guidelines.

So far only the State highway departments involvement in developing recommendations regarding weight and size limitations have been discussed. It should be noted that until 1956 there were no Federal weight limits. However, the Bureau of Public Roads was active in working with the States and AASHO on truck size and weight issues.

The first Federal size and weight laws were enacted in 1956 when the Interstate System program was first financed at significant levels. (The Federal-aid Highway Act of 1956, Pub.L. 84-627, 70 Stat. 374). The large financial interest in the Interstate System was the expressed reason for Federal involvement in vehicle size and weight regulation. It was felt that if the Federal government was to pay 90 percent of the cost of the Interstate System, then it was entitled to protection of its investment

against damage caused by heavy loads on the highways.

The Federal sizes and weight provisions in the 1956 Federal-aid Highway Act were limited to weight and width restrictions on the Interstate System. The weight limits (18,000 pounds on a single axle, 32,000 pounds on a tandem axle and 73,280 pounds gross vehicle weight) were those recommended in the 1946 AASHO policy. Provision was made in a "grandfather clause" permitting higher load values which were authorized under State laws in effect on July 1, 1956. Section 108(k) of the same act directed that road tests then underway be expedited and the Secretary of Commerce report to the Congress making recommendations on maximum desirable dimensions and weights.

In 1964 the Secretary of Commerce presented a report on "Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-aid System." The report was published as House Document 354, 88th Congress, 2nd Session and was based on studies conducted by the FHWA's predecessor, The Bureau of Public Roads in the Department of Commerce. The report recommended that larger vehicles be permitted on Federal-aid highways over a period of years. Specifically, it was recommended that the vehicle width limit be increased to 102 inches and that weight limits be raised to 20,000 pounds for single axles, 34,000 pounds for tandem axles, with gross vehicle weights to be determined by the formula (Bridge Formula B)

$$W = 500 (NL + 12N + 36) \\ N - 1$$

which is our current bridge formula. The relationship between vehicle dimensions and highway damage, highway improvement needs, and highway cost allocation were explicitly noted and size and weight increases were to be predicated on States instituting adequate construction, reconstruction, and maintenance programs.

Congress did not implement any recommendations from the 1964 report until 1974 when the trucking industry was hurt by fuel shortage and programs to reduce fuel consumption, such as the 55 m.p.h. speed limit. Effective January 4, 1975, the Federal-aid Highway Amendments of 1974 increased the maximum permissible weight limits for the Interstate System and adopted the

use of our present bridge formula. The maximum allowable single and tandem weights were raised to 20,000 and 34,000 pounds respectively, and gross vehicle weights were controlled by Bridge Formula B to a maximum of 80,000 pounds. The new limits were permissive and the States could retain lower weights for the Interstate System because of a second grandfather clause included in the law which allowed the States to continue to use bridge formulas different from Bridge Formula B for determining the maximum gross vehicle weights.

The Surface Transportation Assistance Act of 1982 significantly increased the Federal role in regulating vehicle sizes and weights. It eliminated the barrier States and provided for a national uniform vehicle axle and gross weight limits for the Interstate System by requiring all States to adopt the Bridge Formula and axle and gross weight limits.

So much for the background and "legislative history" of vehicle size and weight. Consideration will now be devoted to the purpose and particulars of the current bridge formula. Enforcement of the Federal weight limits and the Bridge Formula protect our Nation's interstate bridges by controlling the vehicle loads. An important feature of the bridge formula was supposed to be the incentive to use longer vehicles with a greater number of axles.

During the period 1974 to 1982, there has been increasing emphasis on enforcement of the bridge formula by the States which has revealed a difficulty some vehicles have in complying with the bridge formula. Entire segments of certain industries like the construction industry and short wheel base container and tanker haulers cannot utilize full capacity efficiency within the requirements of the bridge formula. Also, for very long, many axle vehicles which are being studied under the provisions of the STAA of 1982, the formula would allow unreasonably high loads should the current 80,000 lb. maximum gross weight limit be increased or lifted. The expressed concerns have generated strong congressional and public interest which has stimulated the FHWA to re-examine the premise of the bridge formula.

In May 1984, the FHWA awarded a research contract entitled "Bridge Formula Development" to Texas Transportation Institute (TTI) of Texas A&M. The objective of the research was to evaluate the need and adequacy of the present bridge gross weight formula and develop a bridge formula for

application to bridges designed for H15 and HS20 loadings. The intent was to more fully utilize the capacity of existing bridges without significantly shortening the service life of any.

The study has resulted in the recommendation that a new formula, independent of the number of included axles on the vehicle, replace the current formula as follows:

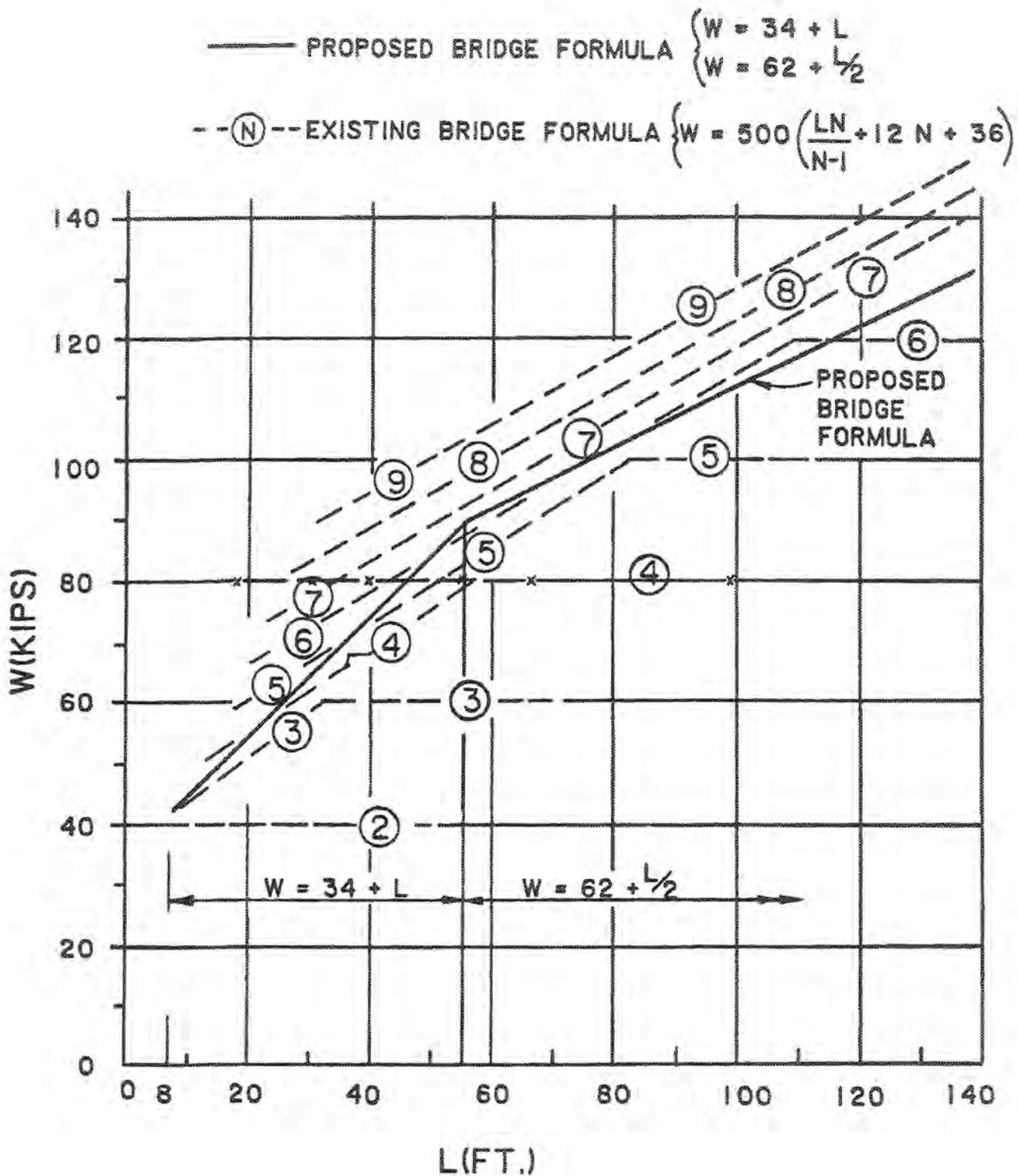
$$\begin{aligned} W &= (34 + L) 1000 \text{ lb.} & 8 \text{ ft.} \leq L \leq 56 \text{ ft.} \\ W &= (62 + L/2) 1000 \text{ lb.} & L \geq 56 \text{ ft.} \end{aligned}$$

Figure 1 shows a comparison of the proposed bridge formula to the existing bridge formula. In comparing the proposed formula with the current formula, 3, 4 and 5 axle vehicle load limits are generally increased by the proposed formula, except for the shorter axle groupings, whereas 6, 7, 8 and 9 axle vehicle load limits are generally decreased by the proposed formula. It is felt that the new formula will satisfactorily protect the bridge structures, but there is a real concern as to its effect on pavements.

A notice titled "Report on Bridge Formula Development for Regulating Vehicle Weight Limitations" which contained the new Bridge Formula and its supportive Executive Summary was published in the Federal Register, Vol. 50, No. 182 dated September 19, 1985, to solicit comments. In general, the responses reflected comments regarding a variety of items directly associated with the impact of the new formula. A majority of the respondents felt that more information and more study are needed, while less than half of the responses reflected opposition to the new formula with or without modification.

Further evaluation of the current formula, the proposed formula, and alternative bridge overstress procedures is being conducted as part of an overall truck size and weight research program within FHWA. Two particular studies that will include bridge formula analyses are:

- "Truck Size and Weight Policy Impact Study." This study will specifically analyze industry impacts of potential legislative changes in the gross weight cap, the Bridge Formula, and grandfather rights.
- "Impact of Truck Characteristics on Pavements." This study will further examine pavement aspects of truck size and weight policy. Much of the governmental highway cost



Graphical comparison of proposed bridge formula to existing bridge formula
 FIGURE 1

impacts of any change in size and weight policy are pavement related and yet little is really known about the relationships of various truck characteristics to pavement wear. This study will build on similar work being done by the Canadians and will provide damage relationships to better estimate pavement impacts of longer combinations. It also will address system wide procedures for assessing pavement costs of various size and weight policy options including alternative bridge formulas or procedures.

The future size and weight policy is a predominant truck issue currently facing FHWA. Recognizing this, a Truck Technical Coordinating Group (TTCG) has been established to review current truck size and weight related research in FHWA, NCHRP, and other work such as the Canadian Heavy Vehicle Weights and Dimensions Study, and to identify research needs where gaps currently exist.

FHWA believes that it is critical to focus FHWA truck research on the most important research gaps and coordinate it with SHRP, NCHRP, and other work such as the Canadian Truck Research.

SESSION 7

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