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Highway Design for Motor Vehicles: A Historical Review

Cornell Local Roads Program
Tech Tips

PART 8: THE EVOLUTION OF HIGHWAY STANDARDS

Highway standards in the United States are the distilled essence of the experience and judgment of hundreds of engineers and administrators - a consensus of many informed people. Highway standards change continually, though slowly, to adjust to changes in vehicle and driver capabilities, as well as the changing economic status of society.

Earliest Standards in Legal Form

For the earliest standards the informed consensus was expressed in laws. The Twelve Tables of 450 B.C. (the earliest Roman legal code) legally distinguished roads by their width. The *semita* or foot path was only 1 foot[1] wide; the *iter* for horseman and pedestrians was 3 feet; and the two - lane via was 8 feet wide.[(1)] These specific dimensions were modified in the course of the evolutionary changes all standards seem

1. The Roman Foot was about 11.66 English inches or 295 mm

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to experience, the via being established as about 12 feet wide when straight or 16 feet when crooked.[2]

A Norse law of the year 950, required that a main road should be as wide as a spear was long, the shaft of which rested on the ground and the head of which a mounted man could reach with his thumb.[3]

Under the laws of Napoleon I, French highways of the first class were required to have rights-of-way of 20 meters, with the 7 meters in the center stoned or paved. Roads of the second and third classes had rights-of-way 15 and 10 meters wide, while roads of the fourth class - the town and local service roads - were required to be only 8 meters wide.[2]

In England in 1839, the legally prescribed width for turnpike roads at the approaches to populous cities was 60 feet. The less important or byroads were 20 feet wide for carriage roads, 8 feet for horse roads, and 6½ feet for footpaths.[2]

The act authorizing construction of the National Road in 1806 specified that the road should have a right-of-way of 80 feet, be paved with stone to a width of 20 feet, and that the gradient should not exceed 5 degrees from the horizontal (8.75 percent).

According to the 1845 statutes of New York State, ordinary public roads were required to be at least 3 rods or 49.5 feet wide: “This is to be the width between fences; and no more of it need be worked, or formed into a surface for travelling upon, than is deemed necessary.” By the same statute turnpike roads were required to be 4 rods or 66 feet wide, “and twenty-two feet of such width shall be bedded with stone.”[2]

Some of these legal road standards were negative: Rhode Island’s original State highway law of about 1900, for example, restricted the width of the metaled surface to 14 feet.

The standards governing size, weight, and maximum speed of vehicles are still in legal form in most countries, but the determination of other standards has for the most part been delegated to highway departments and similar administrative bodies.

The Repositories of Good Practice

The writings of Trésaguet, Telford, and McAdam are a possible exception to the rule that standards are established by consensus. The reports and treatises of these eminent road builders were so widely circulated and read in the 19th century that their recommendations became in effect international standards.

Other repositories of the standards of good practice were the manuals of organizations such as the French Corps of Bridges and Roads and the U.S. Army Corps of Engineers, and books compiled by eminent professors of civil engineering in technical colleges. These last, in particular, kept the art of roadbuilding alive in the United States during the “dark age of roadbuilding” from 1860 to 1880.

In the early 20th century a few publishers produced handbooks authored by prominent highway engineers or teams of highway engineers, each of whom was an expert in some aspect of highway theory or practice. These handbooks were widely used and were influential in developing a consensus on many aspects of highway engineering. Revised editions generally appeared at 5-year intervals to keep up with rapidly changing developments. These comprehensive handbooks, with the equally valuable college textbooks on engineering, still play an important part in refining, winnowing, and concentrating the fruits of research and practice which eventually find expression in standards.

Beginning in 1891 the *Good Roads Movement* revived interest in roadbuilding. In 1891 the State of New Jersey authorized financial aid to counties to help them improve their roads. In 1893 Massachusetts authorized the construction of State highways and set up a State highway department to do the job. Other States, mostly in the East, soon followed this example, and by 1910 over 25 States had their own highway systems and departments. These highway departments drew up standard cross-sections to guide their engineers and designers, and those of the wealthier, more advanced States were widely copied by other States and by counties and cities. This tendency to treat the practices of important States as “standards” was deplored by many engineers:

> It is perhaps somewhat unfortunate that the word “standards” should have been chosen to designate these plans. Strictly interpreted, the meaning would indicate that the standard design was the best design. This is by no means the case - nor is it intended to mean this. Standards are merely recommended designs which are to be adhered to unless conditions indicate that a variation in the design would meet them better.
>
> As a rule they are designs prepared by engineers of wide experience ... and they represent the crystallization of ideas tempered by mature judgment and years of observation...
>
> There is, however, a grave danger attendant on the use of standards of any kind. The temptation is to neglect the detailed study of local conditions and use a standard structure. This often results not only in an unwarranted increase in ... cost, but may result in a type of construction which fits but poorly the location where used.(4)

This is good advice today.

Influence of the Federal Government on Standards

Until 1916 there was no central clearinghouse in the United States for road policy and standards. The Federal Government had relinquished responsibility for roads in 1838, turning the Old National Pike, which had been built with Federal funds, over to the States through which it passed to be operated as a toll road. Each State, county, and city had its own standards and rules for roadbuilding. Consulting engineers, college professors of engineering, and the private publishers of engineering handbooks played a vital role by disseminating the best features of current experience.

With the Federal Aid Road Act of 1916 the Federal Government again asserted an influence on road policy, but with regard to physical standards this influence was muted. The 1916 Act authorized grants-in-aid to the States for roadbuilding and directed that the Secretary of Agriculture and the State highway department of each State should agree upon the roads to be constructed "and the character and method of construction" and further, that the Secretary "shall approve only such projects as may be substantial in character."

The Secretary, operating through the Bureau of Public Roads (BPR), interpreted the word *substantial* with admirable flexibility. The BPR recognized that:

> An improvement which is substantial for one density and kind of traffic may not be substantial for another ...the types of roads which it is desirable to construct in New York, Massachusetts, and Pennsylvania are not suitable or necessary for Nevada, Idaho, and the Dakotas ...the decision as to the type of road which the Secretary will approve for a given locality has been based in every case upon the traffic which is using the existing road and which is estimated will use the improved road.(5)

The result of this policy was that the BPR "approved roads of all types and widths, from graded earth roads to concrete, brick, or bituminous concrete, narrow as well as wide." Over 66 percent of these roads were earth, sand-clay, or gravel and located largely "in sections of the country where the pioneering work required to open up new territory yet remains to be done. Earth, sand-clay, and gravel surfaces have also been approved in many instances for projects which it is intended at a later date to surface with a more durable material. Whatever money is expended upon such projects for grading and drainage, which represent the major work involved in them, is money well spent for permanent improvement."(5)

The requirement that plans for Federal-aid projects be approved by the Secretary gave the BPR a unique opportunity to review standards in all parts of the United States. The BPR in turn was able to influence design policy in the States by passing on to all the highway departments those 95 designs that had proved effective or economical. This liaison was not, however, equivalent to recommending or enforcing standards.

AASHO Becomes Clearinghouse for Standards

Even before the Federal Aid Road Act, the State highway departments had felt a need for a way to come together in an atmosphere free from political and commercial pressures to discuss the many legislative, economic, and technical problems which all of them faced as a result of the headlong motorization of highway traffic that was taking place in the United States. In answer to this need they formed the American Association of State Highway Officials (AASHO) in 1914. Initially, AASHO's Committee on Standards confined itself to disseminating information on design to its members, but in 1928 it proposed that the Association adopt “standards of practice” to guide the member States in technical matters in which some uniformity from State to State was urgently needed. As a result, on March 1, 1928, AASHO approved its first four standards which read as follows:

- That wherever practicable shoulders along the edges of pavements shall have a standard width of not less than 8 feet
- That on pavements 10 feet shall be considered as the standard width for each traffic lane
- That the crown of a two-lane concrete pavement shall be 1 inch
- That no part of a concrete pavement shall have a thickness of less than 6 inches, and that all unsupported edges shall be strengthened(6)

Cautiously, almost reluctantly, AASHO moved to fill what had become a widening gap between the technical knowledge of highway engineering and actual design practice by issuing “Standards of Practice” and “Policies” from time to time which summarized the state of the art and set forth what its members considered to be good practice. These standards and policies were revised or updated over the years to keep pace with the evolution of highway design.

The AASHO standards and policies are not obligatory on the States, but they have acquired such prestige over the years that they have in effect become national standards. In practice, each State establishes its own standards which are generally in accordance with the AASHO recommendations but may vary. After approval by the BPR these standards are required to be used for roads financed by Federal aid funds in that State. The AASHO standards have influenced the practice of many other countries, especially those of the Western Hemisphere.

Today all countries have their own highway standards. There are strong similarities between these national standards, which should not be surprising since motor vehicles and their drivers are quite similar the world over. The activities of international associations such as the Permanent International Association of Road Congresses, the International Road Federation, and the Pan American Highway Congresses have produced a healthy cross-fertilization of engineering thought and practice which has found expression in national road standards. Another strong influence in recent years has been the activity of international engineering consultants who do a worldwide business, have an opportunity to study and evaluate standards in different countries, and introduce values being used elsewhere. The international lending organizations and the agencies for bilateral and multilateral economic aid exert yet another leveling influence on standards.

Standards and Road Classification

In the past, road standards were often closely tied to the roads' strategic and political importance. In France, for example, Napoleon's decree of December 16, 1811, established Imperial roads of the First Class extending from Paris to the more important cities on the frontier, roads of the Second Class from Paris to the less important frontier cities, and roads of the Third Class joining the interior cities. Roads of the First Class had a right-of-way width of 20 meters of which 7 meters in the center were stoned or paved. These dimensions were reduced to 15 meters and 6 meters for Second Class roads and 10 meters and 5 meters for Third Class roads. Also, steeper grades could be used on roads of the Second and Third Classes. A Fourth Class of local roads and village streets had even lower standards.(2)

To some extent, the standards for the German *Autobahnen* and the low-traffic sections of the U.S. Interstate System were established in the same manner, that is, by the supposed importance of the road, rather than by the requirements to serve present and forecasted traffic.

For most roads such a system is inadequate for classifying road standards, because it does not recognize the great variations in traffic volume that occur from place to place on the same road. The same can be said of functional systems such as "primary" and "secondary" and "feeder"; nevertheless, function is probably still the most widely used basis for classifying road standards.

Traffic is the Primary Determinant for Standards

Most engineers acknowledge that traffic is the primary determinant for road standards, overriding all others. Apparently this was first recognized by AASHO, which set up five classes of roads according to their traffic volumes in its standards of September 30, 1931:

Class	Traffic volume (ADT)
A	4,000 or more
B	750 to 4,000
C	300 to 750
D (minor trunkline)	300 maximum
E (local roads)	200 maximum

For each class AASHO recommended "desirable standards of practice applicable, except under extraordinary or special conditions" for width of right-of-way, pavement, shoulders and bridges, gradient limits, pavement type, and minimum radius of curvature.

AASHO's standards for 1941 introduced two new elements into standards classification: *design speed* and *character of traffic*. The design speed was an indirect recognition of the influence of topography on highway design. Passing and non passing sight distance and horizontal curvature were directly related to design speed, so by selecting a lower design speed the designer automatically adjusted his design to rougher topography.

The *character of traffic* parameter was an attempt to recognize the effect of trucks and buses on design standards. Roads were to be classified as *passenger traffic* (*P*), *mixed traffic* (*M*), or *truck traffic* (*T*) roads, according to whether the percentage of trucks and buses in the traffic stream was low, moderate, or large. High-speed roads of the *T* type justified pavement widths as great as 24 feet, while low-speed, passenger-type roads might get by with as little as 16 feet of pavement.

AASHO introduced topography directly as a design parameter in its 1945 standards for interstate highways and secondary and feeder roads. These standards assumed three types of topography - *flat*, *rolling*, and *mountainous* - with varying design speeds and gradients for each type. A second innovation was the sanctioning of what amounted to two levels of design: one using 11 minimum" standards and the other "desirable" standards. Classification by type of traffic - (*P*), (*M*), (*T*) - was abandoned at this time and its design function has since been accomplished by expressing heavy vehicles as a percentage of the total ADT. With these new features the content of geometric road standards became essentially what it is today.

Highway Bridge Standards

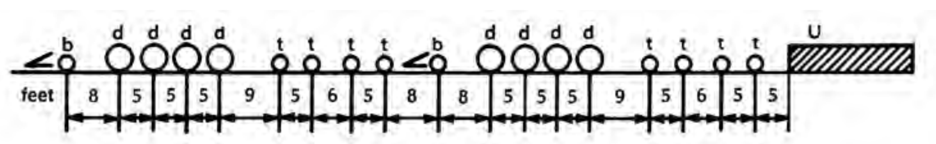
In the 1800's, bridges were described or classified by their shape - trabeate or beam-shaped, arcuate or bow-shaped, or suspension - and by the material of which they were made. They were designed to carry the greatest loads that could be placed upon them in addition to the dead load of the structure itself. The greatest possible live load for a highway bridge was a crowd of people, equal to 70 pounds per square foot of deck. A drove of cattle was 40 pounds per square foot and a double row of heavily loaded wagons, with horses, was 600 pounds per running foot, or 50 pounds per square foot. For railroad bridges a heavy freight train weighed half a ton per running foot and a row of steam locomotives 1 ton per running foot. There were rules of thumb for estimating the dead-load weights of bridges (of which there were dozens of types and sub-types) and for the "increase of weight by velocity" (impact stress).(2)

The sizing of bridge members depended not only on the estimated dead and live loadings but also on the assumed strength of the materials of which they were made. Materials, especially metals, were less reliable then than now, so it was common practice to subject bridges to test loads before acceptance. In France, iron railroad bridges were required by law to sustain a test load of 5,000 kg per linear meter for structures under 20 meters span and 4,000 kg per meter for longer spans, but not less than a total of 100 metric tons. For highway bridges, in France and elsewhere, test loads were 200 to 400 kg per square meter of deck depending on the importance of the bridge, and the probability of heavy loads.[2]

In the late 1800's a number of American railroads published "General Specifications" to govern the design, fabrication, and erection of their bridges. Consulting bridge engineers and manufacturers such as the American Bridge Company also published specifications, among which were those of Theodore Cooper, first published in 1894. In the United States these standard specifications became the repositories of the fundamentals of the rapidly evolving science of bridge design - the essence of what had been learned in nearly a half-century of experience with modern structures and materials.

Standard live loadings introduced

Vehicles on railroads and highways were of many sizes and wheel arrangements, so Cooper and others introduced *standard live loadings* to help designers. Cooper's standard steam railroad loadings of 1901 assumed two consolidation locomotives, each with its tender, pulling a train of unlimited length. This produced a series of concentrated wheel loads at fixed spacings, followed by the train, assumed to be a uniformly distributed load (fig. 1).



Load in lbs. on one pair of wheels for each track

Class	Truck (bogie) b	Driver d	Tender t	Train load lbs. per lin. ft U
E 27	13,500	27,000	17,550	2,700
E 30	15,000	30,000	19,500	3,000
E 35	17,500	35,000	22,750	3,500
E 40	20,000	40,000	26,000	4,000
E 50	25,000	50,000	32,500	5,000

Figure 1: Cooper's standard live loading for steam railroad bridges

The loading class was designated by the letter E (for engine) followed by two digits which represented the load on one pair of driving wheels in thousands of pounds. Thus, Cooper's E-50 loading meant the load imposed by two locomotives each with four pairs of drivers, each pair carrying 50,000 pounds, and the two locomotives pulling a train weighing 5,000 pounds per linear foot.(7) There were at least four systems of standard railroad loadings other than Cooper's each differing slightly from the others in the distribution and magnitude of the concentrated loads, but these are seldom used today, Cooper's loadings having become the "standard."

Standard live loadings simplified the work of bridge designers. More importantly, they provided an easily understood measure of the capacity of bridges to support loads, and therefore the train capacity of lines and systems.

Cooper also published standard live loadings for highway bridges. These varied with the bridge class, of which there were four, ranging from *Class A* for city bridges capable of carrying the heaviest loads, down to *Class D* for light duty, country roads. Class A loading, for example, assumed a concentrated load of one 24-ton wagon on two axles 10 feet apart positioned anywhere on the deck, or a uniformly distributed load of 100 pounds per square foot.(7)

For each of these classes vertical and horizontal clearances were specified. The usual vertical *headway* dimensions were 14.0 to 15.0 ft for Classes A, B, and C, and 12.5 ft for Class D. Horizontal clearance was specified as 14 inches greater than the width of roadway between wheelguards or curbs.(7)

In 1919 the Illinois Highway Department's standard loading for concrete bridges was a uniformly distributed load of 125 pounds per square foot, or the concentrated loads imposed by a 24-ton steam traction engine, whichever produced the greatest stress.(8) This loading was essentially the same as Cooper's Class A highway loading, except for the increase in the alternative uniformly distributed load. When Illinois adopted this specification, steam plowing engines were fairly common; but after 1918 they were replaced by gas or oil tractors weighing only half as much.

Standard Bridge Specifications Issued by AASHO

In 1921 AASHO created a Committee on Roads and Bridges to promote more uniform practice in the design and construction of highway bridges. This Committee published preliminary specifications in mimeograph form from time to time, which were used extensively by many States in preparing their own bridge specifications. The Committee assembled these preliminary specifications and much additional material into a book which AASHO published in 1931 under the title "Standard Specifications for Highway Bridges and Incidental Structures." This publication was very well received in the United States and in a remarkably short time it became the standard for practically all new highway bridges. It was also widely used or copied abroad.

The 1931 Specifications proposed four standard classes for highway bridges:

Class AA - Bridges where the passage of very heavy loads is frequent.

Class A - Bridges for normally heavy traffic with occasional very heavy loads.

Class B - Temporary or semi-permanent structures for light traffic with occasional normally heavy loads.

Class C - Bridges for both highway and electric railroad traffic.

These specifications also proposed three standard live loadings to simplify the computation of stresses:

H 20 Loading for Class AA Bridges

H 15 Loading for Class A Bridges

H 10 Loading for Class B Bridges.

For spans under 60 feet, the H 20 loading assumed a 20-ton truck with 14-foot wheelbase to be on the bridge, preceded and followed by an indefinite number of 15-ton trucks, all spaced 30 feet apart (fig. 2). For spans of 60 feet or longer the Committee provided an equivalent H 20 uniform loading of 640 pounds per linear foot of lane combined with a single concentrated load which could be placed anywhere on the span to produce maximum stress (fig. 3). H 15 loading was three-fourths of H 20 loading, and H 10 was one-half of H 20 loading.

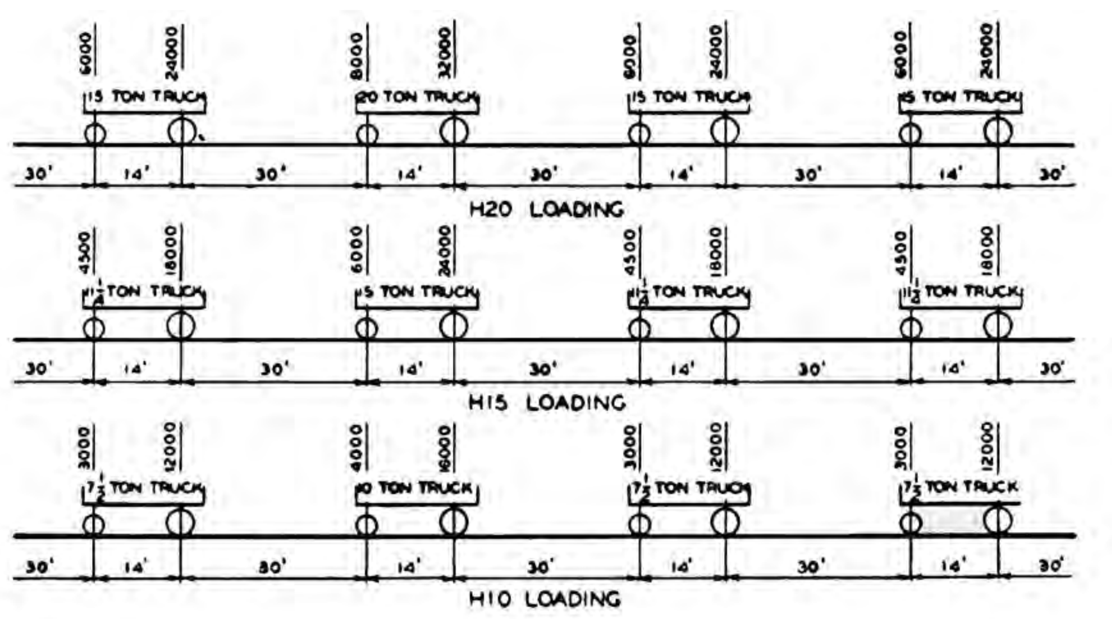


Figure 2: Truck train loading

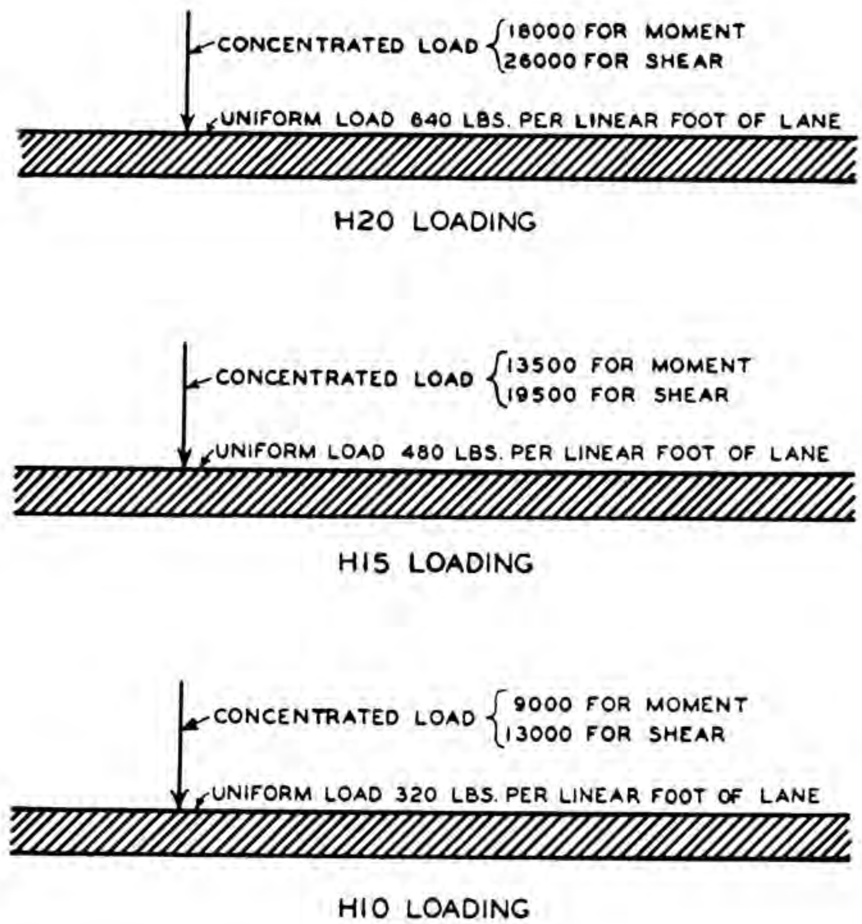


Figure 3: Equivalent loading

For two-lane bridges without railway tracks the AASHO specifications required a curb-to-curb deck width of at least 18.0 feet with not less than 6 inches horizontal clearance beyond the curb. The minimum vertical clearance was 14.0 feet.

The AASHO Committee on Bridges and Structures has kept the Standard Specifications up to date by frequent revisions, the latest being the eleventh, issued in 1973. The most extensive changes occurred in the 1944 edition which introduced two extra-heavy live loadings to provide for the larger and heavier vehicles such as tractor-semitrailer combinations; also, the 1944 specification required greater horizontal clearances.

Most countries have their own bridge specifications or permit the use of other established and recognized specifications such as those of the British or French governments or those of AASHO.[2] Standard design loadings are important features of all these specifications. These standard live loadings are much alike in principle, but the configurations of the design vehicles and their axle loads vary from country to country,

2. AASHO is now AASHTO, the name having been changed in 1974 to "American Association of State Highway and Transportation Officials."

as do the alternate uniform lane loadings which can be used in lieu of the design vehicles. Basically, all are variations of three general types; the type of loading which produces maximum stress controls the design:

- A simplified "design vehicle" of two or more axles with specified axle loadings and spacings. One or more of these vehicles may be placed anywhere on the bridge to produce maximum stresses in the bridge members.
- A uniform lane loading of a specified weight per square foot or square meter of deck.
- A single extremely heavy axle load (or knife-edge load or wheel load) which can be positioned anywhere on the bridge to produce maximum stress, usually in conjunction with a uniform lane loading.

The American Association of State Highway and Transportation Officials' specifications are the nearest approach to a world standard for bridge design. They have been adopted or copied in about two-thirds of all countries.

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