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Umbrella Loads for Bridge Design

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ABSTRACT

Recent legislation allowing heavier vehicles on the highway system in Pennsylvania has been assessed for its impact on bridge design. The effect that permit traffic loads and heavy industrial or construction equipment have on bridges has also been assessed. Bending moments for various highway vehicles are illustrated graphically for easy visual comparison. As a result of these studies, Pennsylvania has adopted new umbrella loads for bridge design. The umbrella loads consist of two loads for design purposes (AASHTO HS 25 and 125 percent military) and one load for permit purposes (204,000-lb eight-axle superload).

Described in this paper is the engineering effort that led to replacement of the current AASHTO HS 20 design loading (1) for bridge designs in Pennsylvania with larger loads. Recent legislation allowing heavier vehicles on the state highway system has been assessed for its impact on the umbrella bridge design loads. Various engineering considerations are also outlined including the effect that permit traffic loads and heavy industrial equipment would have on the new design loads. The effect of bending moment for various highway vehicles is illustrated graphically for easy visual comparison.

PREVIOUS DESIGN LOADINGS

Since 1941 Pennsylvania has used the most conservative AASHTO HS 20 bridge design loading exclusively in the design of every type of state-owned bridge for all classes of highways. This design loading is routinely used by many other states, but some states use the lower class HS 15 loading.

The hypothetical HS loadings are defined in the AASHTO Standard Specifications for Highway Bridges (1). The HS 20 loading is comprised of a single tractor and trailer weighing 36 tons, or an equivalent uniform load with a concentrated load (to simulate a truck train), whichever produces the maximum

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stresses. For bridges carrying the Interstate highway system, an alternate military loading of two axles 4 ft apart with each axle weighing 24 kips is also considered.

In 1982 Pennsylvania bridge engineers changed the live load design criteria for all state-owned bridges to the governing AASHTO HS 20 or alternate military loading. This design loading was previously used only on the Federal-Aid system. Bridges on the local system can be designed using the minimum loadings stated in the AASHTO Standard Specifications for Highway Bridges (1).

For the last several years, AASHTO bridge engineers have debated the need to increase the AASHTO bridge design loads to fit actual conditions. Recently, several states have adopted the HS 25 design loading, and Ontario adopted the Ontario Code (2), and California adopted a new concept of "P-load" design (3).

LEGAL LOADS

Legal loads are those maximum weights and dimensions of motor vehicles that can operate on highways without special approval from authorities. Legal vehicles are of different types that can be separated into trucks and combinations. Over the years, legal loads have increased to a level that now demands the attention of bridge engineers.

In 1970 the Pennsylvania Legislature legalized a four-axle truck with a maximum gross weight of 72,000 lb. In 1980 the Legislature with Senate Bill 10 and House Bill 34 (4) further increased the maximum gross weight of the four-axle vehicle to 73,280 lb. The axle weight distribution of the four-axle truck was also revised from 18,000 lb each to 20,000 lb each for the three rear axles. In the 1980 legislation, 80,000-lb combinations were also made legal with weight distributions complying to the National Bridge Formula (5). The weight and size limits for trucks and combinations in Pennsylvania since 1980 are shown in Figure 1.

Legal loads vary somewhat from state to state in total weight, weight control on internal axles, and overall truck dimensions. However, in most states they are quite similar to those shown in Figure 1, which satisfy the requirements of the Federal Highway Administration for travel on the Interstate highway system. Federal-Aid Amendments of 1974 increased the permissible weight of vehicles operating on Interstates to 20,000 lb for a single axle, 34,000 lb for tandem axles, and 80,000 lb total gross weight (5). The National Bridge Formula (5) which requires longer axle spacing and lower axle loads for combination vehicles in the 72,000 to 80,000 lb range, was also

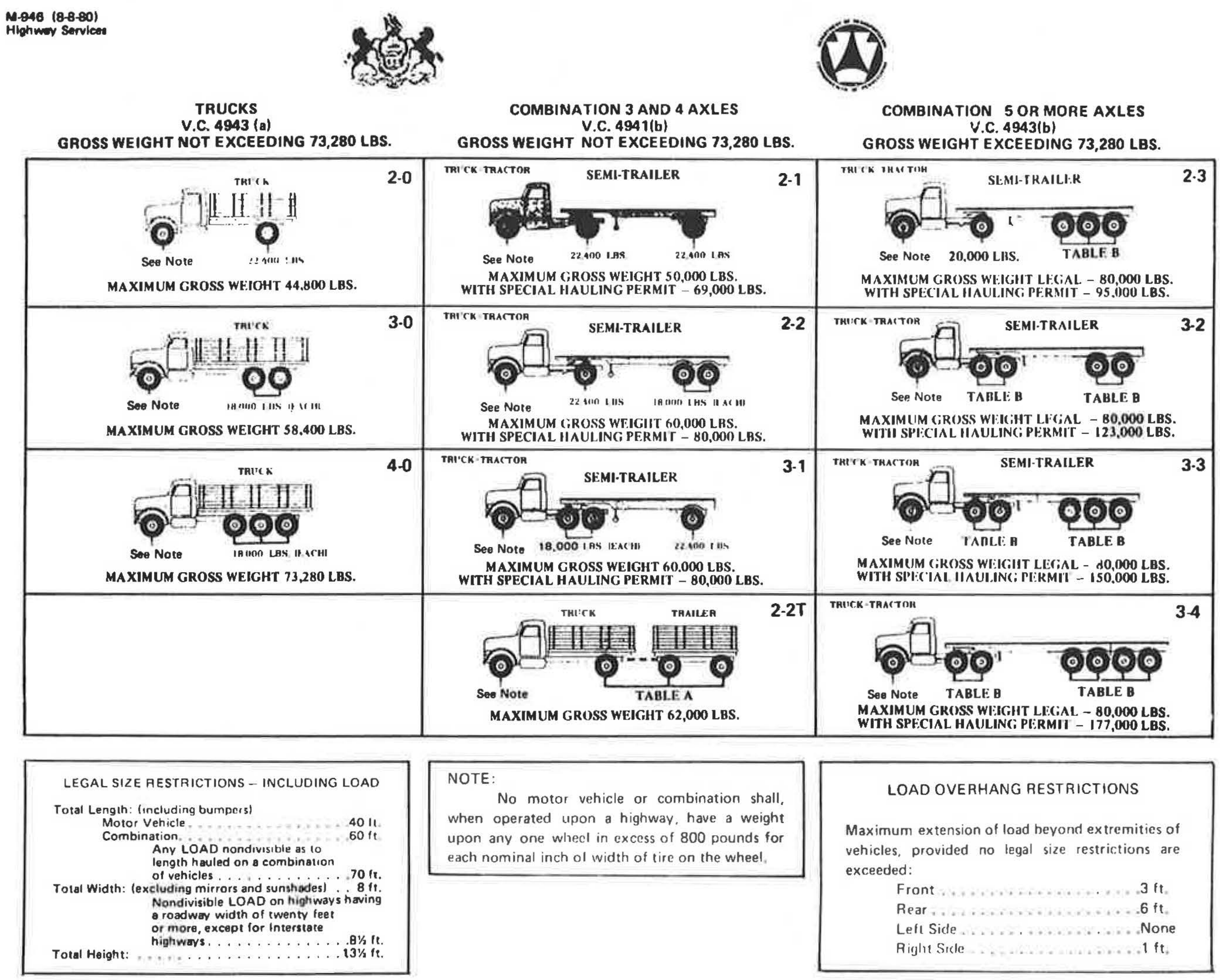

FIGURE 1 Weight and size limits for trucks and combinations in Pennsylvania.

TABLE A AXLE WEIGHT LIMIT WHEN GROSS WEIGHT DOES NOT EXCEED 73,280 POUNDS

Maximum axle weights are as shown provided all other requirements are met as outlined in the Vehicle Code such as manufacturer's rated axle capacity, tire size, etc.

If the Center-to-Center Distance Between the nearest Adjacent Axle is:	Maximum Axle Weight in Pounds Upon:	
	One of Two Adjacent Axles	Other of Two Adjacent Axles
Under 6 feet	18,000	18,000
6 to 8 feet	18,000	22,400
Over 8 feet	22,400	22,400

TABLE B AXLE WEIGHT LIMIT WHEN GROSS WEIGHT EXCEEDS 73,280 POUNDS

Center-to-center distance in in feet between the first and last axles of any group of 2 or more consecutive axles	Maximum load in pounds carried in any group of 2 or more consecutive axles					
–	2 axles	3 axles	4 axles	5 axles	6 axles	7 axles
4	34,000					
5	35,000					
6	36,000		AXLE GROUPS IN			
7	37,000					
8	38,000	42,000	THESE SPACINGS			
9	39,000	43,000				
10	40,000	43,500	IMPRACTICAL			
11		44,500				
12		45,000	50,000			
13		46,000	50,500			
14		46,500	51,500			
15		47,500	52,000			
16		48,000	52,500	58,000		
17		49,000	53,500	58,500		
18		49,500	54,000	59,500		
19		50,500	54,500	60,000		
20		51,000	55,500	60,500	66,000	
21		52,000	56,000	61,000	66,500	
22		52,500	56,500	62,000	67,000	
23		53,500	57,500	62,500	68,000	
24		54,000	58,000	63,000	68,500	74,000
25		55,000	58,500	63,500	69,000	74,500
26		55,500	59,500	64,500	69,500	75,000
27		56,500	60,000	65,000	70,000	76,000
28		57,000	60,500	65,500	71,000	76,500
29		58,000	61,500	66,000	71,500	77,000
30		58,500	62,000	67,000	72,000	77,500
31		59,500	62,500	67,500	72,500	78,000
32		60,000	63,500	68,000	73,000	78,500
33			64,000	68,500	74,000	79,500
34			64,500	69,500	74,500	80,000
35			65,500	70,000	75,000	
36			68,000	70,500	75,500	
37			68,000	71,000	76,000	
38			68,000	72,000	77,000	
39			68,000	72,500	77,500	
40			68,500	73,000	78,000	
41			69,500	73,500	78,500	
42			70,000	74,500	79,000	
43			70,500	75,000	80,000	
44			71,500	75,500		
45			72,000	76,000		
46				77,000		
47				77,500		
48				78,000		
49				78,500		
50				79,500		
51-and over				80,000	80,000	80,000

NOTES:

A) Use this TABLE only when both of following conditions apply:

1) Combination Gross Weight must exceed 73,280 lbs.

2) Combination must have at least five (5) axles.

B) No axle weight shall exceed the lessor of the manufacturer's rated axle capacity or 20,000 Lbs.

C) All lengths shall be measured longitudinally to the nearest foot.

AXLE WEIGHT LIMIT WITH SPECIAL HAULING PERMIT

1. Unloaded Motor Vehicles must be hauled on a combination when any axle weight exceeds 50,000 pounds.
2. Combinations hauling a nondivisible load may not exceed 27,000 pounds on any axle.
3. No vehicle or combination shall have a weight upon any axle in excess of the manufacturer's rated axle capacity.

FIGURE 1 (continued)

introduced. It is a simple engineering fact that if loads are distributed over a larger area, they have a smaller effect on bridges.

Figure 2 shows a comparison of bending moments for simply supported spans between AASHTO HS 20 design loading and the critical maximum legal loads. The HS 20 design load is used as a base for ease of comparison and is represented by the 100 percent line. All moment curves falling below the 100 percent baseline are not overstressing bridges designed after 1949 when the HS 20 loading was adopted. Load Configuration G representing AASHTO alternate military loading is also shown in Figure 2. From the plot it is apparent that this load governs HS 20 loading in the span range of from 11 to 37 ft and peaks at about 127 percent of HS 20. All moment curves falling below the combined 100 percent baseline and alternate military curve G are not overstressing bridges designed after 1982. Single vehicles rather than the equivalent uniform load with a concentrated load will govern for simply supported spans of up to approximately 145 ft.

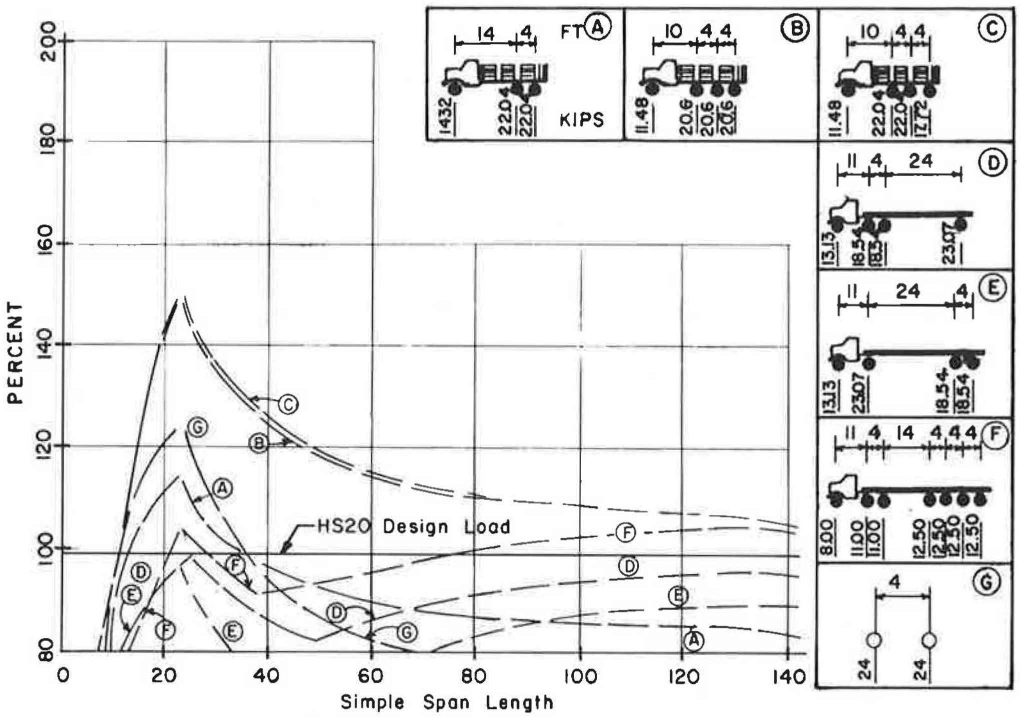

FIGURE 2 Bending moment expressed as percentage of HS 20 for maximum legal loads (1980).

For many years AASHTO HS 20 bridge design loading has been considered conservative by bridge engineers. This is no longer true because of periodic increases in legal load limits. From Figure 2 it can be seen that the most critical maximum legal load is the four-axle truck that is represented by Curves B and C. These curves peak at about 151 percent of HS 20. Such trucks could be coal, gravel, and ready-mixed concrete trucks frequently used in Pennsylvania. It can also be seen from Figure 2 that maximum legal loads represented by Curves B, C, and F are over-stressing bridges designed after 1982. Furthermore, maximum legal loads represented by Curves A, B, C, and F are overstressing bridges not on the Interstate system designed before 1982. Figure 2 also demonstrates that the maximum legal combinations of 72,000 lb generated moment curves (D and E) less than the design load before 1982. In accordance with federal regulations, a bridge must be posted if it cannot handle the maximum legal load at the operating stress level.

The reader must keep in mind that the curves shown in Figure 2 represent only one parameter of many that severely influence the strength of a bridge. In this case, the live load bending moment was used as a basis for comparison. The effect of impact loads, multiple loaded traffic lanes, shear, dead load-to-live load ratios, and frequency of loadings have not been included in this comparison.

PERMIT LOADS

Permit loads are loads that exceed legal limits but are allowed to operate on the highway under a permit issued by a regulatory agency. These loads are quite heavy--often between 2 to 3 times the design live loads. Permit loads, because of their large gross weights or extremely heavy axle weight or axle group weight, produce stresses much higher than the stresses used for the design of bridges.

The weight and size limits for trucks and combinations that can operate with special permits in Pennsylvania are also shown in Figure 1. These limits went into effect in 1980 along with the increase to 80,000 lb for the maximum gross legal weight for combinations.

There has been a significant increase in the number of vehicles that exceed legal loads. The frequency and magnitude of various permits issued in Pennsylvania during 1 recent calendar year are given in Table 1. It can be safely assumed that the numbers given in Table 1 reflect combinations because weight permits are not regularly issued for trucks and construction load permits are rather infrequent. The data in Table 1 indicate that approximately 8,210 permits were issued yearly for vehicles in excess of 123,000 lb, 653 permits yearly for vehicles in excess of 150,000 lb, and 39 permits yearly for vehicles in excess of 204,000 lb. The 204,000-lb load is designated as a "Superload" in Pennsylvania and is subject to various other permit limitations.

TABLE 1 Frequency and Magnitude of Various Permits Issued During 1 Calendar Year

Category	Weight Range (lb)	No. of Permits
1[a]	0-73,281	108,704
2	73,281-95,000	24,547
3	95,001-123,000	18,989
4	123,001-150,000	7,557
5	150,001-177,000	435
6	177,001-204,000	179
7	More than 204,000	39
Total		160,450

[a]Category 1 consists of over-width permits.

The results of a study of 1980 permit loads are shown in Figure 3. This figure shows a comparison of bending moments for simply supported spans. Again, the HS 20 design load is used as the base and is represented by the 100 percent line. Load Configuration 5 representing AASHTO alternate military loading is also shown in Figure 3. The sketches on the right side of Figure 3 depict five-axle combinations (123,000 lb), six-axle combinations (135,000 lb) and seven-axle combinations (172,000 lb). These vehicles are based on the maximum axle loads of 27,000 lb permitted by regulations put in force in 1980. It was the thinking before 1983 that moment curves produced by legal loads should not exceed the HS 20 design moment curve to any large degree, because legal loads are frequent loads. However, permit loads are considered rather infrequent loads; therefore, 160 percent of the design moment, which is equivalent to an HS 32 design moment, would be tolerable. If these limits are exceeded for a given bridge, the structure must be individually investigated by a bridge engineer.

From the study depicted in Figure 3, it can be seen that permit loads for which permits were routinely issued after 1980 cause stresses much larger than the 160 percent design moment values. Stresses substantially higher than design stresses will reduce the service life of the bridge, may cause an increase in maintenance costs, and could lead to fatigue failures in frequently loaded steel elements. From these curves it is apparent that the practice of indiscriminately issuing permits for 27-kip axle vehicles is detrimental to bridges.

A contact with permit offices in Pennsylvania revealed that trucks would not be given overload permits, but combinations and construction vehicles subject to a maximum axle load limitation would.

In 1984 the weight and size limits for trucks and combinations with special hauling permits changed (6). The policy of permitting maximum axle loads of 27,000 lb was revised, and maximum axle loads were determined using the National Bridge Formula (4).

Figure 4 shows a comparison of bending moments for simply supported spans for 1984 permit vehicles with up to seven axles and a maximum gross weight of 136,000 lb. It should be noted in this figure that the moments do not exceed approximately 160 percent of the design moment (HS 32). This led to the department's requirement that bridge engineers must review permit loads of 135,000 lb or larger for combinations with a maximum of seven axles. Figure 5 shows the results of a similar study using two-axle recommended construction loads. Even though the loads peaked in the short span range of approximately 30 ft, they did not exceed the effect of approximately 160 percent of the design moment (HS 32).

Pennsylvania's heavy haulers and heavy industry wanted assurances that the department would promptly issue permits for heavy industrial loads without the lengthy delay that may result if bridge engineers review the many permit applications for loads of 135,000 lb or larger. This request led the department to initiate a study of the feasibility of developing an automated permit routing system.

PRESENT DESIGN LOADINGS

In 1983 the Pennsylvania Department of Transportation made the decision to change from working stress design to load factor design (7). At the same time, it was decided to change the design loading for state-owned bridges.

A study comparing design live load moments for various vehicle configurations was made and the results are shown in Figure 6. The HS 20 design load is used as a base and is represented by the 100 percent line. The alternate military loading and the four-axle truck (ML 80 loading), which is the critical maximum legal load that can use the highways today without special approval from authorities, are also shown in Figure 6. Truck axle loads and dimensions are shown on the right side of the figure. From the lower portion of the figure it can be seen that the moments from the HS 25 design loading (125 percent line) and increased military design loading (125 percent times military load) almost completely envelop the moments caused by the ML 80 critical legal

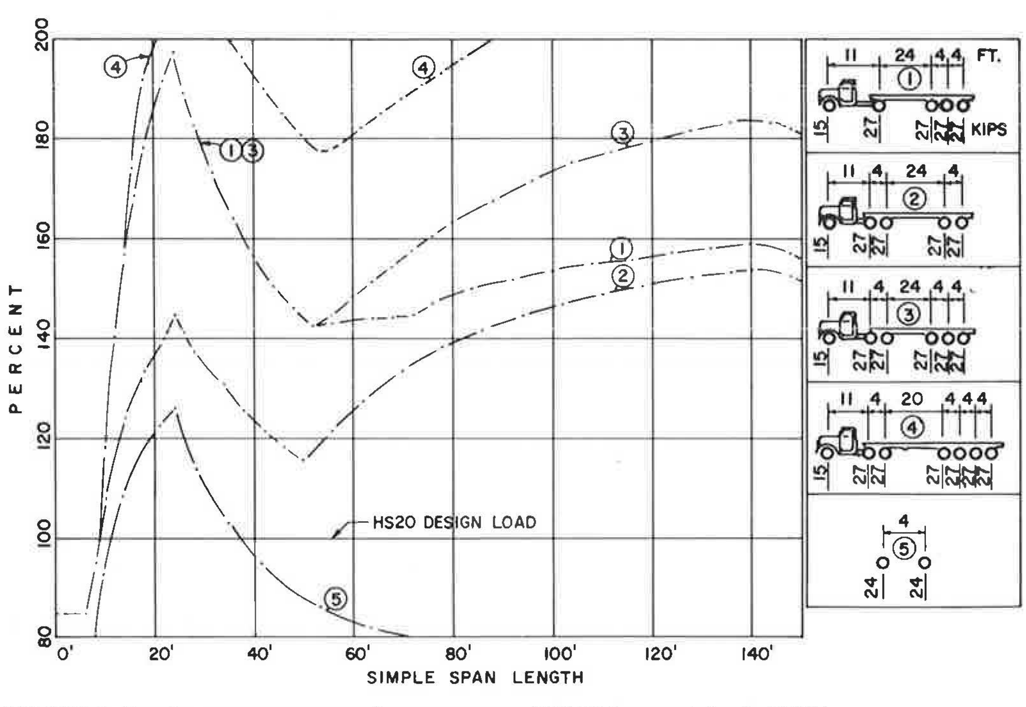

FIGURE 3 Bending moment expressed as percentage of HS 20 for permit loads (1980).

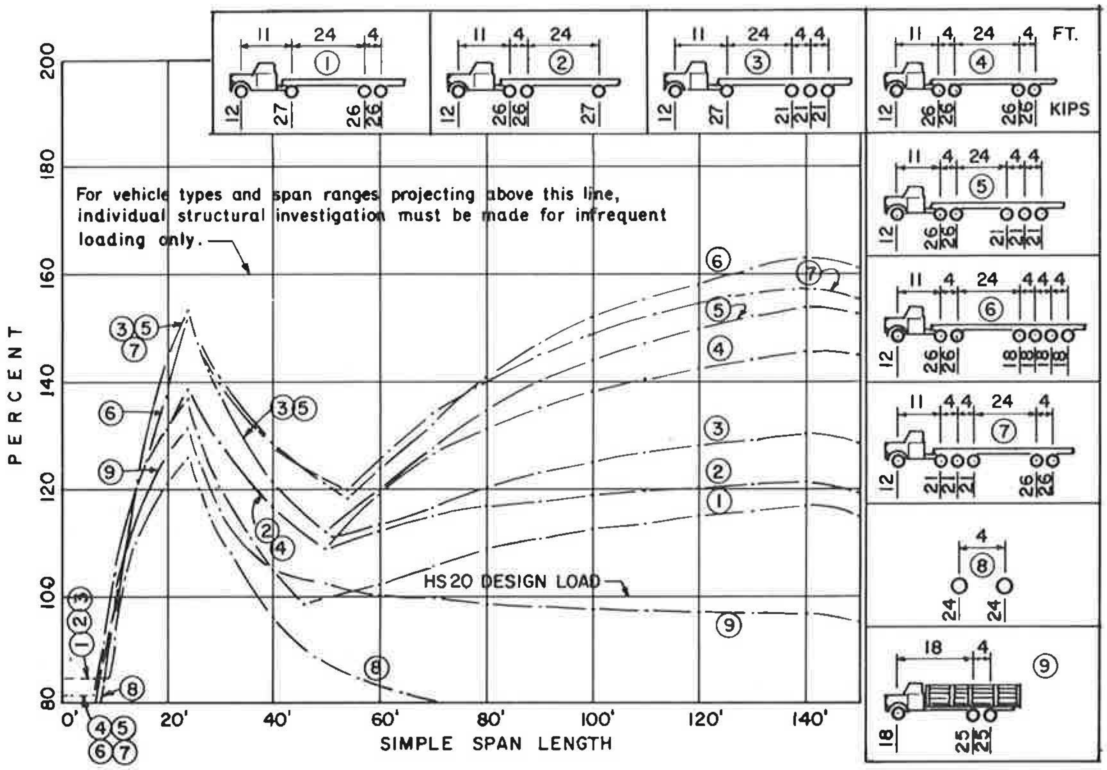

FIGURE 4 Bending moment expressed as percentage of HS 20 for permit loads (1984).

loading. From the lower portion of Figure 6 it can also be seen that the increased military load governs for simple spans of from 11 to 37 ft. For the remainder of the simple span lengths, the HS 25 truck loading governs. It should also be mentioned that HS 25 equivalent lane load, which is 125 percent of AASHTO HS 20 lane loading, should be considered for simple spans longer than approximately 140 ft. All truck and lane loadings will have a width of 10 ft.

The only way to correlate design practice directly with permit policy is to check or design the structure for the permit load that is expected to be applied to it. In other words, attaining the desired permit load capacity becomes one of the performance conditions in the design procedure. Using the load factor design method, which includes a permit load check, should produce structures with a more uniform overload capacity. Being able to use every structure

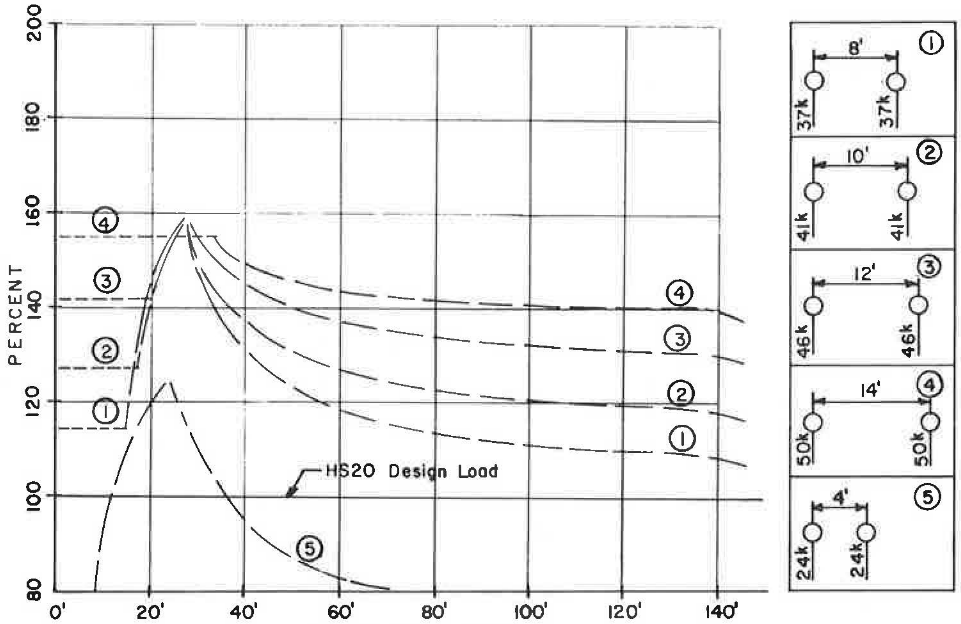

FIGURE 5 Bending moment expressed as percentage of HS 20 for recommended two-axle permit vehicle.

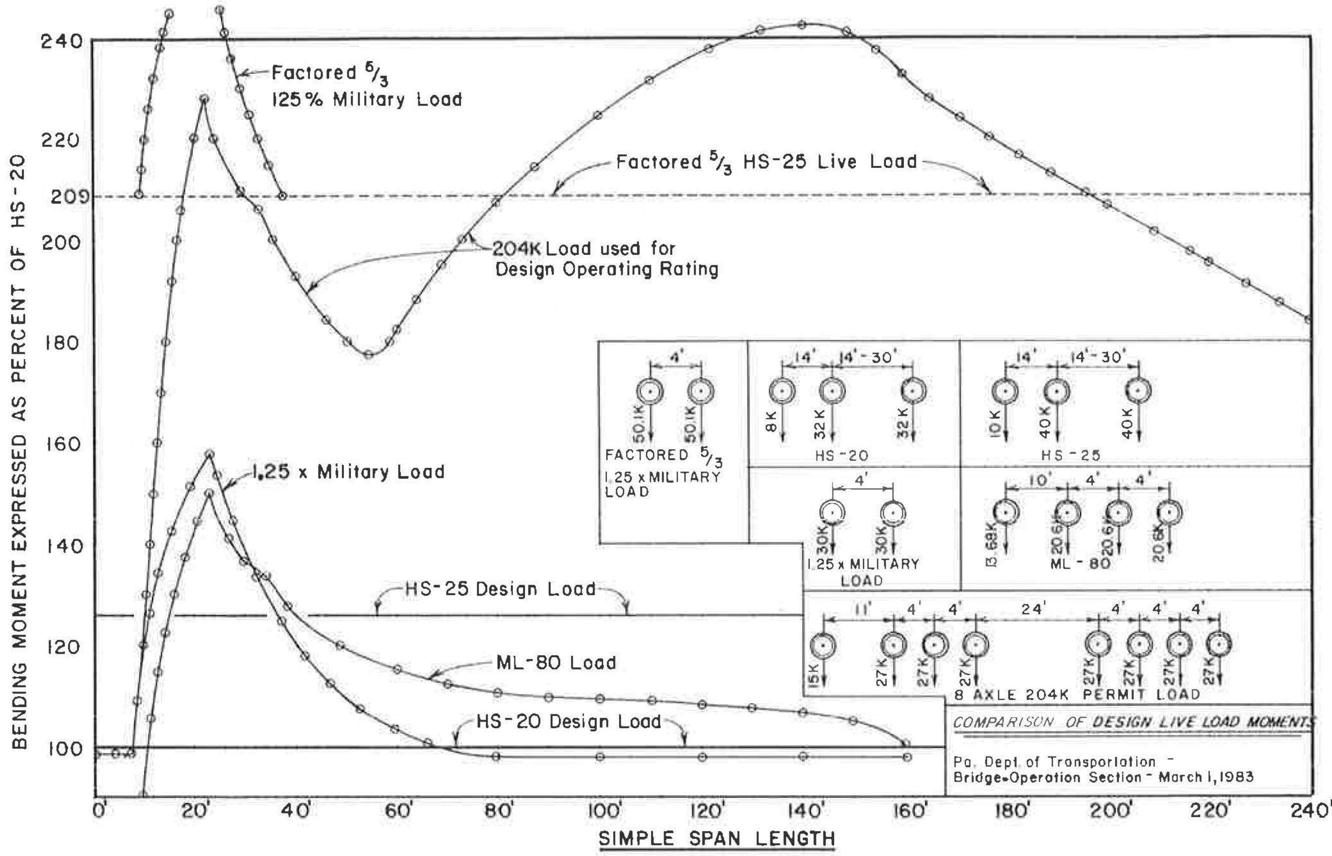

FIGURE 6 Comparison of design live load moments for various vehicle configurations.

along a route to its fullest provides maximum usability at minimum cost (3).

Concurrent with the adoption of load factor design and the heavier design loads, all structures will be checked to see if they can carry a 204,000-lb eight-axle permit load at operating rating in accordance with the 1983 AASHTO Manual for Maintenance Inspection of Bridges (8). This check is equivalent to designing for the 204,000-lb permit vehicles as Group IB loading in accordance with Article 3.22 of the AASHTO Standard Specifications (1). The axle loads and dimensions, as well as the relationship of live load bending moments for various span lengths, for the 204,000-lb permit load are also shown in Figure 6. Because the 5/3 B factor applies to the design loads and not the permit loads, the upper portion of the diagram in Figure 6 shows that the 204,000-lb permit load will govern for simple span lengths of from 85 to 195 ft. The check for the 204,000-lb superload applies to the superstructure only. Substructure and foundation need not be checked, except for pier caps under superstructures that exceed a 65-ft span length. Dead, live, impact, and centrifugal forces should be included in the check. Deflection and fatigue criteria are not applicable.

The 204,000-lb permit vehicle is assumed to have the same width as the 10-ft-wide standard AASHTO truck. When checking the bridge or its components, one 204,000-lb permit vehicle is placed in the worst position in one traffic lane and HS 25 design loading is placed in the remaining traffic lanes. Article 3.23 of the AASHTO Specifications can be used for the distribution of the wheel loads to stringers, longitudinal beams, and floor beams (1). Using these conservative methods would be equivalent to placing the permit loads in all lanes. Distribution based on established theoretical analysis can be used instead of AASHTO empirical formulas when it allows greater economy.

The 204,000-lb eight-axle permit load was developed by the permit regulatory office to facilitate the issuance of permits. This 204,000-lb superload is more critical than the 135,000-lb six-axle vehicle because the 27,000-lb maximum axle loads for permit vehicles have now been reduced in accordance with the National Bridge Formula (5). Permits will be issued routinely for new structures if the loads applied are smaller than the 204,000-lb superload. Permits may also be approved for heavier loads, but this will require a special analysis of each structure on the planned route for the specific loads and vehicle under consideration.

CONCLUSIONS

Pennsylvania has confirmed that a true umbrella load could be represented by two design loads for design purposes (HS 25 and 125 percent military) and one design load for permit load purposes (204,000-lb superload). By staying with the vehicle configurations previously used by AASHTO (HS and military), the designs have been kept simple.

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Application of Expert Systems in the Design of Bridges

JAMES G. WELCH and MRINMAY BISWAS

ABSTRACT

The principles of artificial intelligence have been used to develop an expert system for the design of bridge superstructures. The expert system developed, a Bridge Design Expert System (BDES), applies the ideas of artificial intelligence to the bridge design process. The result is a practical system capable of aiding any bridge designer. BDES at its preliminary stage considers superstructures of short- to medium-span bridges. It designs for structural steel and prestressed concrete girders. The developed BDES is a valuable design tool, but, more important, it has shown the potential applications of expert systems in bridge design.

The application of computers in engineering has aided in the solution of numerous problems. This is especially true for problems of analysis for which programs have been constructed to assist the engineer in determining stresses, strains, and strengths of structures. Computer systems are also available to aid in detailed drafting. However, computer applications for decision making in design problems have been limited. Programs to aid the designer proceed through different phases of the design process have been developed, but programs to carry out the entire design decision-making process are scarce. The designer is required to make various decisions throughout the design process (1,pp.3-6). Design decisions may include selecting feasible structure types, making appropriate approximations and assumptions, and sizing individual members to satisfy the design criteria. Such problems are "ill-structured" and are not well suited for conventional programming procedures (2).

However, a program capable of proceeding through the entire design process has been developed by applying a relatively new technology called expert systems. Expert systems, also called knowledge- or rule-based expert systems, are intelligent computer programs that are capable of solving practical problems that have heretofore been considered difficult enough to require human intelligence for their solution (3). The developed expert system, Bridge Design Expert System (BDES), was constructed to explore the applications of expert systems to the design of bridge superstructures.

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EMERGENCE OF EXPERT SYSTEMS

Interest in developing expert systems has greatly increased in recent years because of their advantages over more conventional computer programming procedures. The following table gives some expert systems and the problem domain that they attempt to address (3,4).

Expert System	Domain
MYCIN	Medical diagnosis
DENDRAL	Organic chemistry
MACSYMA	Symbolic mathematics
HEARSAY II	Speech understanding
PROSPECTOR	Exploratory geology
GENESIS	Genetic engineering

However, because the idea of expert systems is quite new, their potential use in many areas has not yet been investigated. This is certainly true for civil engineering applications, and especially in the area