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Impact in Highway Bridges

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In the United States of America, a considerable amount of experimental work has been done on impact in highway bridges but no investigation of sufficient magnitude has been carried out to deduce satisfactory laws of a general nature.

Floors

Sources of Information

Researches have progressed farther for impact upon highway bridge floors than upon trusses. The most extensive investigation, which is known to the author and for which results are available, is the one conducted at Ames, Iowa, under the direction of the author as a cooperative project between the U. S. Bureau of Public Roads, the Iowa State Highway Commission and the Iowa Engineering Experiment Station. Field data were secured during the summers of 1922 to 25 inclusive. Results of these investigations have been published as bulletins Nos. 63 and 75 of the Engineering Experiment Station of Iowa State College, in "Public Roads" (a monthly publication of the U. S. Bureau of Public Roads) for September 1924 and in the Proceedings of the American Society of Civil Engineers for March 1923 and March 1926.

Data on the impact of trucks on pavements, secured by the U. S. Bureau of Public Roads, have been published in "Public Roads" for March and December 1921 and for June 1926. These data have been of value in interpreting and in supplementing the work done on bridges.

Conduct of the work at Ames, Iowa

The field work at Ames, Iowa, was done on five modern steel bridges having floors consisting of reinforced concrete slabs resting upon steel stringers which were riveted to steel floor beams; and upon seven light steel bridges with timber floors upon steel stringers.

The loads were standard Liberty trucks of rated 3,5 tons capacity, with dual solid rubber tires. The loads varied from 5,5 tons for the unloaded truck to a maximum of 15 tons. Speeds were attained up to 15 miles an hour.

Throughout the experiments, stresses were measured on the bottom flanges of the steel stringers and floor beams, by means of various extensometers; and in portions of the work the force of the blows of the truck wheels upon the bridge floor was determined by means of specially designed accelerometers.

The essential data concerning the bridges, the loads, and the instruments are given in bulletin No. 75 previously referred to. More specific data concerning various extensometers are given in bulletin No. 63.

In order to reach general conclusions concerning the impact produced by different types of bridge floors, loads, tires, chains and various vehicle speeds, it seemed desirable to so direct the investigation as to make use of the results of the impact on road surfaces by the Bureau of Public Roads and any other available data.

Previous work had indicated that for floors of usual dimensions greater impact was produced by a single blow of heavy wheels than by accumulative vibration, as in railway bridges. It was planned therefore, to attempt to establish a relationship between the intensity of a blow from a truck wheel and the resultant stress.

In order to standardize the conditions of the road surface and to give each writer of specifications a basis for choosing impact factors to suit his individual views concerning irregularities of road surface and accidental obstructions, runs were made on the bare floor, over 1 inch by 2 inch obstructions and over 2 inch by 4 inch obstructions.

Results

About one hundred diagrams were plotted showing the relation between speed of the truck and the stresses in stringers and floor beams. Fig. 1 (fig. 45 of bulletin 75) is an illustration of these diagrams. The relation between speed and stress was so nearly a straight line that the straight line interpretation was generally made. The curves (straight lines) from the various diagrams for any one stringer were reproduced upon one diagram such as fig. 2a and 2b (fig. 14 and 16 bulletin 75).

The comparative weights of trucks are suggested by the stresses for static load (zero speed). The increase in stress (impact increment of stress) naturally becomes greater with increase in speed and height of obstruction. It may be noted from fig. 2 (as from all of the similar ones in bulletin 75) that all of the lines representing the relation between speed and stress for any given obstruction have about the same inclination, thus indicating about the same increases in impact stresses for the same speed and obstruction regardless of the total load. The differences in weight of trucks are due to the load above the springs. The weight below the springs, the unsprung weight, was the same in all instances.

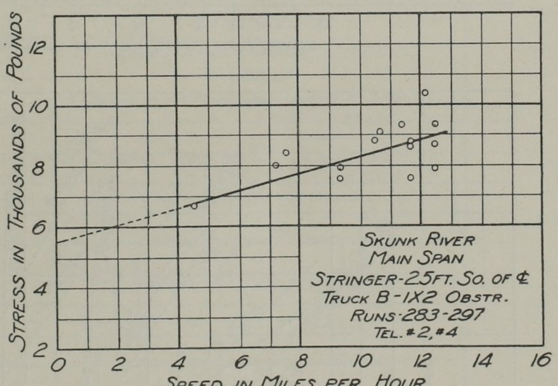

Fig. 1. Typical record showing relationship between speed of truck and stress in stringers

In interpreting, to a high precision, the behavior of a truck on a bridge floor, it is necessary to consider the movement of the truck body and the manner it synchronizes with the vibrations of the wheel. This has been done in a large number of cases. A study of these cases and of the diagrams similar to fig. 2 leads to the conclusion that, for practical purposes within the justified limits of precision, the impact increment upon a bridge floor may be considered as due only to the unsprung weight of the truck.

The greatest impact from a wheel passing over an obstacle may be from shock as the wheel strikes the obstacle, or from drop as the wheel again strikes the floor.

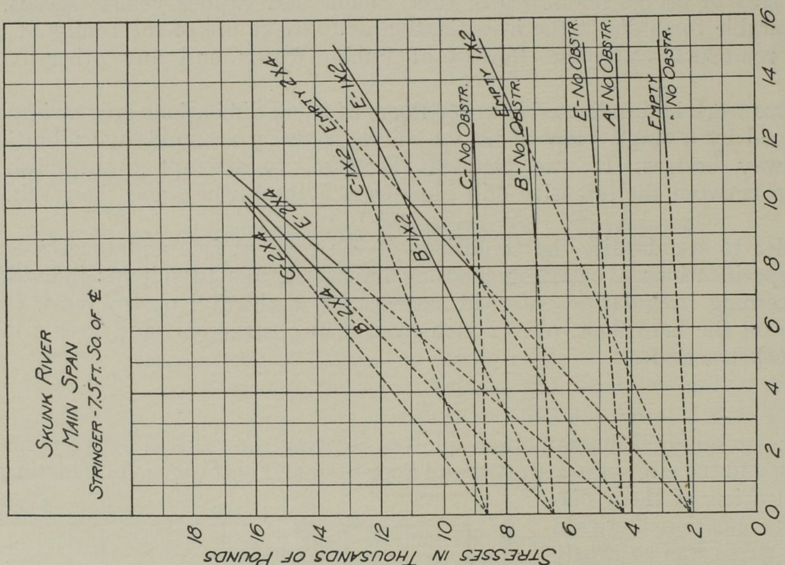

Fig. 2 b. Skunk River approach span, stringer 7.5 feet south of center line. Relationship between speed of truck and stress in stringers. Six-inch concrete floors.

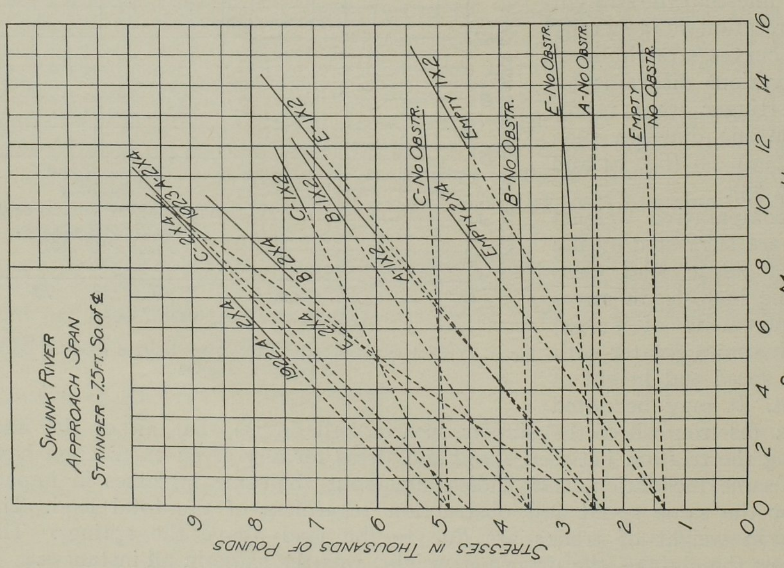

Fig. 2 a. Relationship between speed of truck and stress in stringers. Six-inch concrete floors, Skunk River main span, stringer 7.5 feet south of center line.

In the available data, drop impact is greater for loaded trucks and therefore is the more important.

No general laws have been deduced for the force of a wheel blow upon a pavement or upon a bridge; or for the relation between the two. The researches of the U. S. Bureau of Public Roads include a large number of experimental results of the force of wheel blows upon pavements for a large range of trucks with tires from pneumatics down to badly worn solid rubber. (Public Roads, March and December 1921 and March 1926.) In order to make use of these data to obtain impact stresses in bridges, it was necesary to establish (1) a relation between impact blow upon a pavement and upon a bridge floor and (2) a relation between the stress produced by a blow and by a static force.

Relation between blow on pavement and on bridge

The author was able to make a few runs in the summer of 1927 in which the force of the blows from truck wheels was measured successively upon concrete pavement and upon several bridges with concrete floors. Two types and three weights of trucks were used. The data were too few and too much scattered to indicate any consistent relationship. They indicate a tendency however, for the impact to vary inversely with the flexibility of the floor. Of the 18 available points of comparison, 13 indicate a ratio of impact on bridge to impact on pavement above $80^0/_0$. The average of the 18 was about $85^0/_0$.

Relation between stress produced by a blow and by static load

In bulletin No. 75 (previously referred to) is developed from experimental work, a relation of the impact increment of dynamic force in percent which is de-

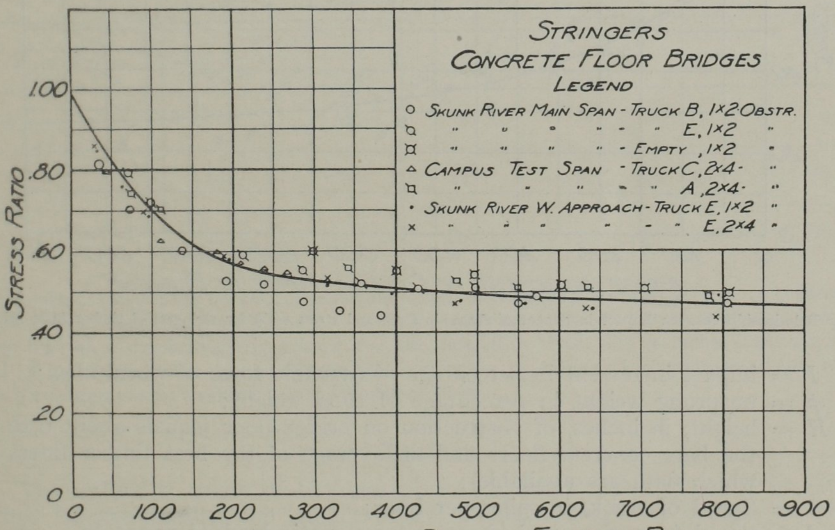

Fig. 3. Relationship between impact increment of dynamic force and stress ratio for stringers of concrete floor bridges.

veloped upon a bridge floor to a "stress ratio" which is described as "the ratio of actual dynamic stress developed in a member to the stress that would have occurred had a static load equal to the dynamic force been applied, at the same place as the dynamic force was applied". Fig. 3 and 4 shows the stress ratio curves (fig. 29 and 30 in bulletin No. 75) for stringers in reasonably heavy bridges with concrete floors and for stringers in light steel bridges with timber floors. A similar curve is given in bulletin No. 75 for floorbeams of the light bridges. This curve is very nearly identical with the one for stringers of the same structures. Existing data suggest that the curve in fig. 3 as well as in fig. 4 may be used for floorbeams as well as for stringers without appreciable error. These stress ratio curves provide the means for determining a static force, which will produce the same stresses as a given dynamic force. The stresses themselves may be computed from the "static force".

In a report[1] of the Committee on Impact in Highway Bridges of the American Society of Civil Engineers, a formula is given which expresses fairly well the impact force upon a bridge floor. The formula is

$$I = \frac{1{,}8\, H\, S\, (p)^{0{,}625}}{(d)^{0{,}45}} \quad \text{in which,}$$

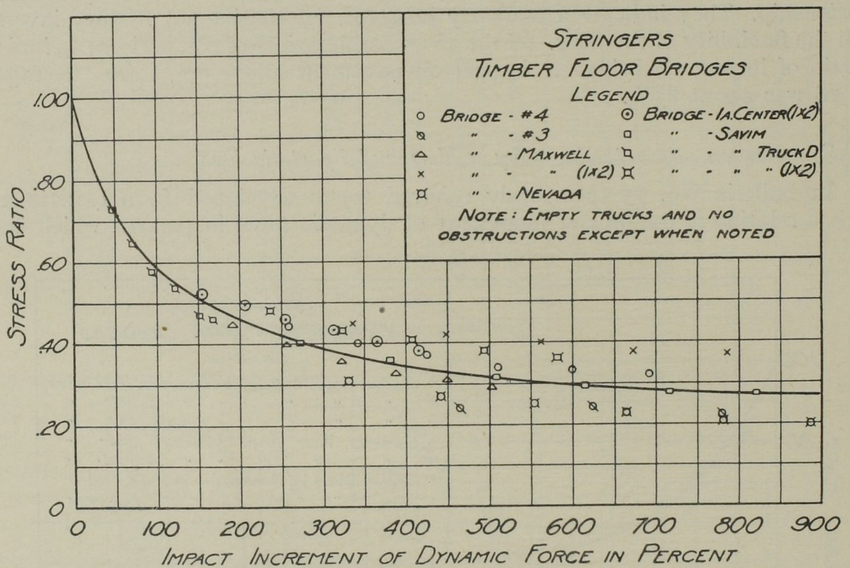

Fig. 4. Relationship between impact increment of dynamic force and stress ratio for stringers of timber floor bridges.

I = impact increment in percentage of dynamic force of wheel blow;
p = unsprung weight in percentage of total weight;
H = height, in inches, of obstruction on bridge floor (equals about 0,16 for the bare concrete floors and an average of the best timber floors for which data are available);
S = Speed of truck, in miles per hour;
d = tire deformation, in inches, under a static load of 10000 lb.

Conclusions are drawn by the author as follows:

1. Data are not available for deducing general laws governing the impact of trucks upon highway bridge floors.

2. Data are available for determining the approximate impact of various type of trucks upon various bridge floors. These approximations are of sufficient accuracy for writing specifications for designing bridge floors, when they are used with judgment.

[1] Proceedings, American Society of Civil Engineers, March 1926.

3. Available data indicates that:

a) Impact stresses vary directly with the speed of the truck, up to a limit of 15 miles per hour.

b) Impact stresses increase but slightly with the speed on clean floors (no obstructions other than natural roughness of floors and tires).

c) Impact stresses increase considerably with the speeds when the truck wheels run over obstructions.

d) The increase in impact stresses for given obstructions and speeds, is approximately the same for heavy or for light loads on the same truck. This indicates that the increase in stress (impact increment of stress) is caused primarily by the unsprung weight of the truck.

e) Impact varies inversely with the softness of truck tires and with the flexibility of the bridge floor. For this purpose, it may be assumed that the governing flexibility occurs when the unit stresses reach allowable limits.

f) It follows from d) and e) that the impact increment in percent varies inversely with the load on any given truck.

4. An engineer with judgment who notes the above general conclusions may provide for the proper impact by making use of the data in table 1.

TABLE 1

Impact increments of stress in percent, in highway bridge floors for trucks, with various tires unsprung weights and obstructions

15 Miles Per Hour

HEIGHT OF OBSTRUCTION	$d = 0{,}1$		$d = 0{,}6$		PNEUMATIC TIRES	
	$p = .20$	$p = .33$	$p = .20$	$p = .33$	$p = .20$	$p = .33$
None	14.	31.	4.	12,	1.	4.
1″	160.	286.	44,	77.	20.	38.
2″	362.	610.	87.	170.	38.	80.

In the table, p is the percent of unsprung weight to total weight of truck. ($p = .33$ represents a normally loaded heavy truck and $p = .20$ represents an overloaded truck such as a live load of 10 tons on a truck weighing 5 tons) $d =$ the deflection of the tire in inches due to a static load of 10 000 lbs. ($d = 0{,}1$ represents the hardest worn rubber tire which has been noted. $d = 0{,}6$ represents an average new solid rubber tire).

Trusses

The author is aware of but two pieces of experimental work in the United States for determining the impact in the trusses of highway bridges for which published data are available, those of F. O. DUFOUR[1] and the author.[2]

In all of these experiments, the loads have been too small to even approach the capacity of the bridges. The results show that impact decreases as unit stresses increase. The highest static live load stresses which have been developed, were due to trucks weighing 15 tons and were but slightly over 5000 pounds per square

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[1] Proceedings, American Society of Civil Engineers, October 1926. Journal, Western Society of Engineers, Vol. 18, 1913.

[2] Bulletins 63 & 75, Engineering Experiment Station, Iowa State College, and "Public Roads", September 1924.

inch. For this load, with the maximum attainable speed of about 15 miles an hour, the impact increment in trusses of bridges with clean concrete floors and smooth timber floors for reasonably hard solid rubber tires, is below 25%.

As impact is important as a factor in design, only when the total unit stresses approach design values, and as the results show that impact decreases as unit stresses increase, 25% is apparently the maximum impact for which it is necessary to provide even for short spans under normal unit stresses. A higher impact due to obstructions, which might be suggested by the data in table 1 might be recognized as possible and be provided for by an increased unit stress.

Existing data are too meagre to establish a relation between impact and span length. The established reduction in impact for increased spans for railroad bridges may be the best guide for reductions for highway bridges and perhaps an adequate one for practical purposes.

Culverts

A series of experiments conducted by the Engineering Experiment Station of Iowa State College[1] reported in bulletin 79 of that organization, indicate a very wide range of impact factors on highway culverts under shallow depths of cover. These factors vary from zero in the case of smooth roadway surfaces to several hundred percent of the static load effect for various obstructions in the path of a truck wheel. The impact factor when considered as a percentage of the static load effect on the culvert, does not vary appreciably with the depth of cover. However, the static load effect decreases quite rapidly as the depth of cover increases so that for the greater depths, the increase in effect on the culvert due to impact is quite small in relation to the actual wheel weights.

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[1] Co-operative work with the U. S. Bureau of Public Roads.