Actual Traffic Loadings on Highway Bridges and Stress Levels in Bridge Members

Charges de trafic actuel sur ponts-routes et niveaux de sollicitations dans les membrures des ponts

Gegenwärtige Verkehrslasten auf Strassenbrücken und Beanspruchungs-Niveau in Brückenelementen

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1. Introduction

The design live load specified in the design specifications for highway bridges in Japan, as shown in Fig. 1 and Fig. 2, is fundamentally based on a 20 ton truck and traffic rows composed of a 20 ton truck and 15 ton trucks. The T-load in Fig. 1 is used for design of slab and floor system, while the L-load shown in Fig. 2 is used for design of main girder and main truss. These loads have been used since 1956, but the increase in both weight and number of trucks in these years is so remarkable that the loads shown in the current specifications have reached the state which may not be necessarily appropriate in contrast with the actual traffic situation. Besides, there exist a great number of old bridges which were designed for smaller load, than that of current specifications, and the safety of those bridges under the present heavy load is posing a problem.

In Japan, various surveys of actual traffic loadings and stress levels in highway bridge members are being carried out for the purpose of obtaining the data in re-examination of design live load, and also for control of safety of existing bridges.

2. Stress levels in bridge members[1)]

Stress levels caused in the main girder of 18 plate girder bridges (with span length of 20 to 60 m) and for each member of a truss bridge (with span length of 80 m) under the ordinary traffic loading were measured.

In measuring, the device enabling to automatically count up the frequency by each stress level separately was used. This device is composed of the strain detector in which differential transformer is used and recording device which classifies the detected strain separately by four class levels, and count up the respective frequency.

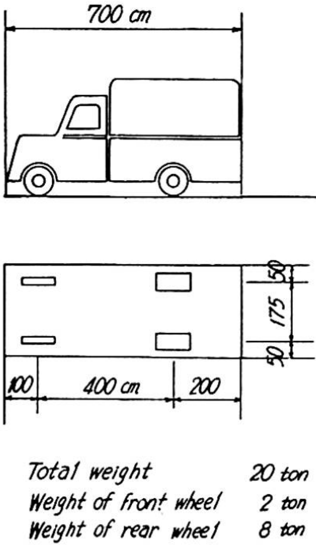

Fig. 1 T - load

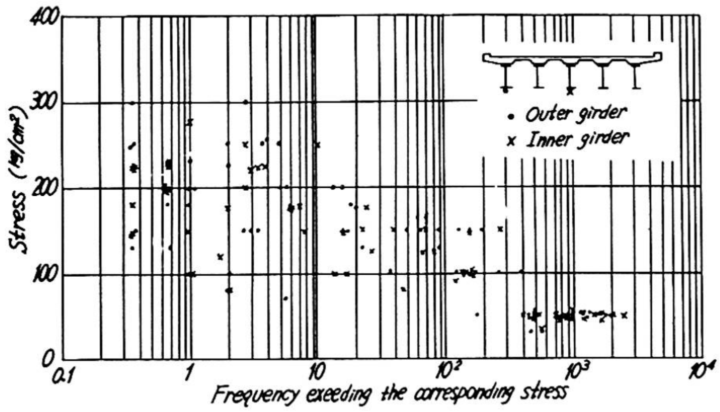

Fig. 3 Stress frequency (Plate girder bridge)

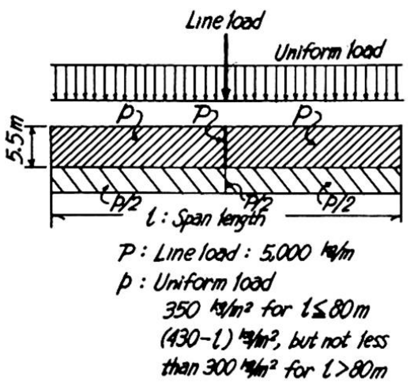

Fig. 2 L - load

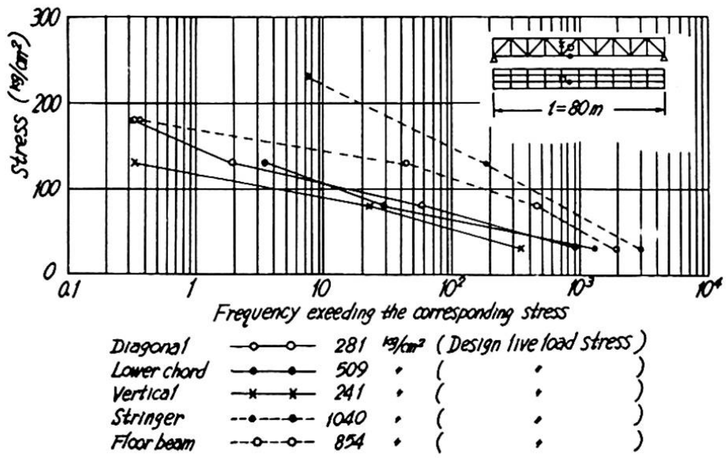

Fig. 4 Stress frequency (Truss bridge)

Type of Vehicles	Passenger Car	Bus	Small Size Truck (Gross Weight of 7.5 ton or less)	Large Size Truck (Gross Weight of 7.6 ton or more)	Total
Ratio (%)	67.9	18.1	1.5	12.5	100

Table 1. Percentage of various vehicles

The bridges for which the survey was made were selected from those which are located on the main national highways served for heavy traffic. The traffic amount per 24 hours at the survey point counts 10,000 to 40,000 vehicles, and the average traffic volume for the entire survey points was about 20,000 vechicles, the percentage of various types of vehicles being as shown in Table 1.

The measurement was curried out for 3 to 5 consecutive days. The result of measurements for plate girder bridges and a truss bridge are indicated in Fig. 3 and Fig. 4, respectively. In those figures, the frequency at each stress level is shown per one day (24 hours). The relation between the range of the ratio of stress level measured in girder bridges to the calculated stress due to the current design live load (L-load) and the frequency caused per the traffic volume of 10,000 vehicles is shown in Fig. 5.

In the case of truss bridge shown in Fig. 4, the values of measured stress of floor system is greater than those of truss members. However, the ratio of measured stress level to design live load stress for floor system is smaller than that of truss members. This is supposed to be due to the fact the reinforced concrete slab supported by the stringers and floor beams may take charge a portion of the function of stringers or floor beams. Such a function of reinforced concrete slab was not considered in the design calculation.

According to the fact mentioned above, it is known that the live load stress caused in each member of bridge under ordinary traffic load is some 300 kg/cm^2 at most, which is fairly at lower level as compared with the calculated stress level due to design live load.

3. Actual status of wheel load[2)3)]

For the purpose of confirming the actual weight of wheel load of vehicle having great influence on the slab and floor system, measurement of weight of wheel load was carried out at 34 points on national highways in Japan.

The device used for the measurement is composed of weighing part and recording part. The weighing apparatus is the weighing meter consisting of a sheet of steel plate and four loadcells

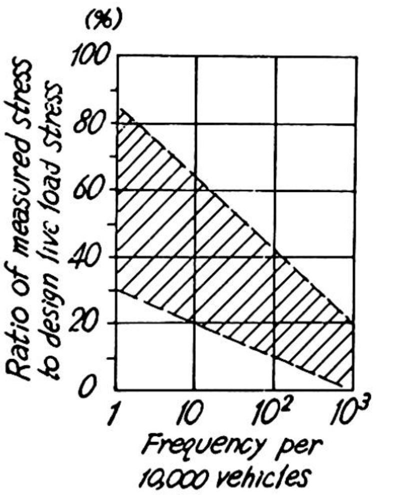

Fig. 5 Ratio of measured stress to design live load stress

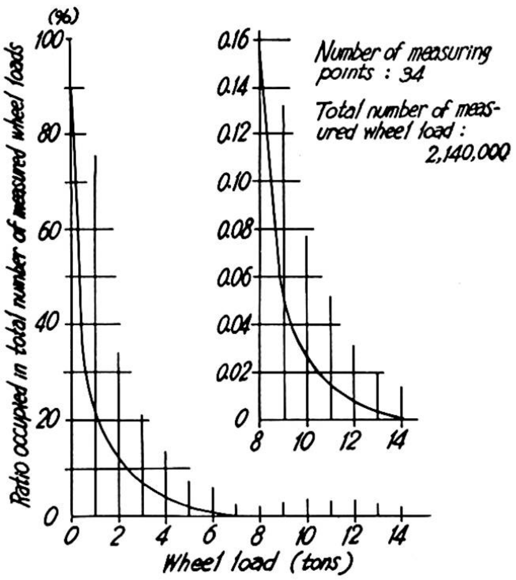

Fig. 6 Cumulative frequency distribution of wheel load

supporting the plate on its four corners. The weighing meter is installed in the reinforced concrete pit in such a way that the loading plate makes a part of the road surface covering the pit, so that the weight of wheel passing over the plate is detected without stopping the vehicles. The recording part has the function of classifying counting automatically each frequency of the detected weight by every 12 classes of level.

The survey points were selected from among the points located on main national highway, and besides, where the traffic is especially crowded. The traffic volume per 24 hours for the lane where the wheel load was measured indicated about 5,000 vehicles at point where the traffic volume was the least, and about 28,000 vehicles where the traffic volume was the most.

The measurement was carried out for 1 to 7 days for each point. It was made clear, as the result of the survey, that the frequency by different level of wheel load showed considerable difference according to the survey point, but on the same point, approximately the same frequency distribution was observed.

Fig. 6 represents the frequency measured by various weight of wheel load. As known from Fig. 6, although about 80% of the whole number of wheel load measured is one ton or less, and the number of heavier wheel load decreases rapidly, the fact that the number of wheel load exceeding design wheel load of 8 ton (which is approximately the same as the wheel load of HS20 of AASHO, see Fig. 1) amounts to 0.16% of whole number of wheel load, namely, that there exist about 32 vehicles of which wheel load exceeds design wheel load of 8 ton, per 10,000 vehicles, may not be ignored from the point of view of design of new bridges or maintenance and safety of the existing bridges. The reason of the existence of wheel loads heavier than design wheel load is due, needless to say, to the operation of large size trucks which are loaded more than the statutory loading limit.

In Japan, the expansion of truck size has been advanced in these years to reduce the cost of transportation. At the same time, the instances of damages of reinforced concrete slab have become remarkable. As one of the causes thereof, the operation of vehicles with weight heavier than design wheel load may be mentioned.

Besides, on account of the fact that the weight and number of wheel loads of trucks increased, the importance of performing fatigue design came to be claimed on steel plate deck where welding is used abundantly. In applying fatigue design, it is necessary to know the value and number of repetition of stress imposed during the expected life of bridge. From the point of view of fatigue, the effect of random wheel loads with different weights and numbers of repetition on steel plate deck may be evaluated by means of "equivalent number of repetition" of design live load stress due to design wheel load (8 ton), denoted by the following expression:

$$N_{eq} = K_1 \cdot K_2 \cdot N_t \qquad (1)$$

Where N_{eq} : Equivalent number of repetition of design live load stress

N_t : Number of total passing wheel loads during the expected life of the bridge

K_1, K_2: Coefficients

K_1 in Equation (1) is the coefficient used for converting the wheel load with certain weight into design wheel load of 8 ton, which may be expressed as Equation (2):

$$K_1 = \sum P(T) \left(\frac{T}{8}\right)^{\frac{1}{k}} \cdot \Delta T \qquad (2)$$

Where T : Weight of wheel load

P(T): Probability of occurrence of T

k : Coefficient determined from S-N diagram (the slope of S-N diagram in logarithmic sclae.)

The position where wheel loads pass in certain traffic lane is not stationary. Fig. 7, illustrated as an example, shows that the distribution of passing positions of wheel loads in a traffic lane may be regarded as a normal distribution with the standard deviation of approximately 35 cm. Fig. 7 was obtained as the result of observation at 20 different points on national highways with two or four lanes, all over Japan. K_2 in Equation (1) is the coefficient to be multiplied with the number of repetition determined on the assumption that the all wheel loads pass on a fixed position, and is given from the following equation:

$$K_2 = \sum \left(\frac{R(x)}{R_o}\right)^{\frac{1}{k}} \cdot P(x) \cdot \Delta(x) \qquad (3)$$

Where Ro : Design live load stress

R(x): Stress of member under the design wheel load passing on certain position, x

P(x): Probability of occurrence of R(x)

The value of K_2 for the longitudinal rib of steel plate deck which is commonly used in Japan, is approximately 0.2.

P(T) in Equation (2) is given by Fig. 6, and P(x) in Equation (3), by Fig. 7. Such data, actually observed concerning the weight and the passing position of wheel load are indispensable for the fatigue design.

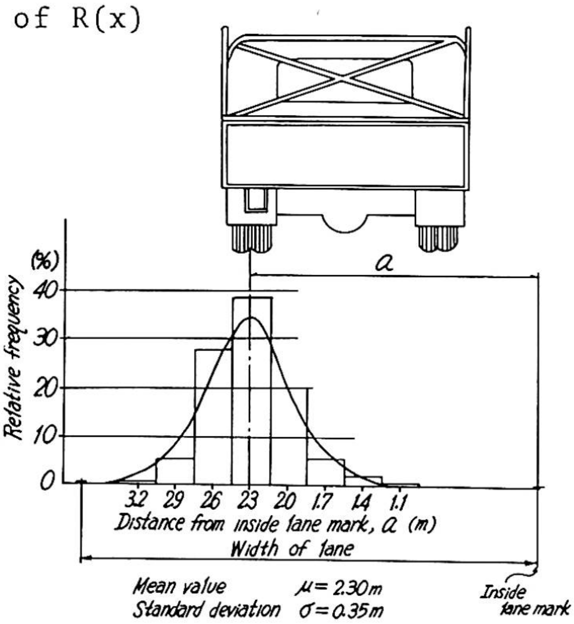

Fig. 7 Distribution of passing position of wheel

4. Actual status of vehicle row load[2),3)]

L-load, shown in Fig. 2, depends upon the vehicle row load such as shown in Fig. 8.

In order to ascertain the magnitude of actual vehicle row

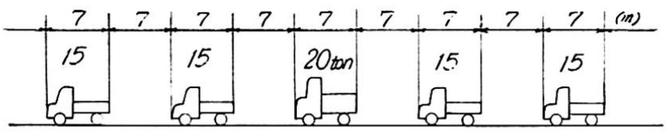

Fig. 8 Basic traffic pattern of L - load

Number of lanes	Number of points
2	25
4	40
6	8
	73

Table 2. Number of traffic pattern survey points

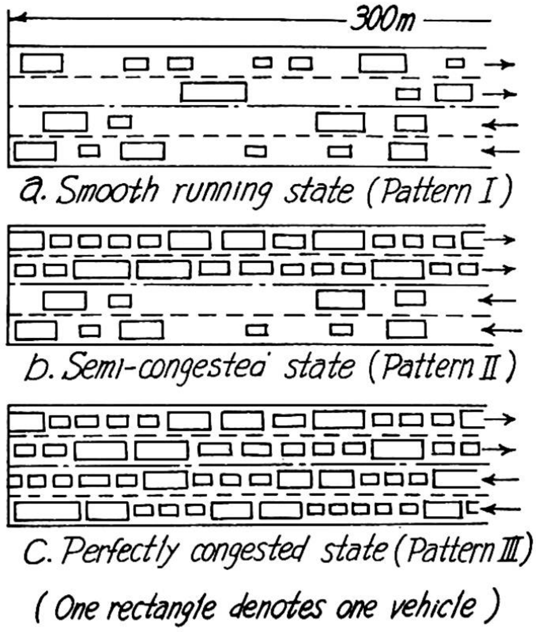

Fig. 9 Traffic patterns

load in comparison with the above design L-load, a survey on traffic pattern was carried out in the following procedure:

1) 73 survey points were selected (Table 2). These points are the places on the main national highways where the traffic is crowded and apt to be congested including a lot of large size vehicles.

2) At each survey point, traffic pattern extending over 300 m on the roadway was photographed intending to take as many heavy trucks as possible in the overlooked picture. Ten times of the photographing was carried out, and selected one case of pictures which appeared to be most congested in traffic, as they were assumed to represent the maximum of vehicle row load at the point.

3) Distinguishing the loading condition of each vehicle with or without cargo, as well as the type of each vehicle from the photograph, the figure of traffic pattern (Pattern I), as illustrated in Fig. 9a, which shows exactly same arrangement of vehicles as on the photograph was prepared. For the weight of different types of vehicles and different loading conditions, corresponding average values were established referring to the table of size and weight of motor vehicles in Japan.

4) On the basis of Pattern I, hypothetic pattern such as Fig. 9b (Pattern II) in which the half of traffic lanes is congested, while the opposite half lanes is smooth, and Fig. 9c (Pattern III) in which the whole lanes are perfectly congested, were prepared. In this case, the clear distance between two consective vehicles in the congested state was taken as 1 m, with reference to the vehicle distance observed on highways actually at the time of congested. Pattern II is the state which is usually observed in Japan, and Pattern III is the state which is very rarely observed.

5) In regard to Pattern I, II and III, the maximum bending moment Mo and maximum shear force So, which are imposed in a simply supported girder under each loading pattern, were calculated by means of electronic computer. In this case, Mo and So were obtained for nine cases of the span length of 20, 40, 60, 80, 100, 150, 200, 250 and 300 meters.

6) M/M_D and So/S_D were calculated, which are the ratio of Mo and So due to "actual vehicle load" obtained in 5), to beinding moment M_D and shear force S_D due to "design load" showed in Fig. 2.

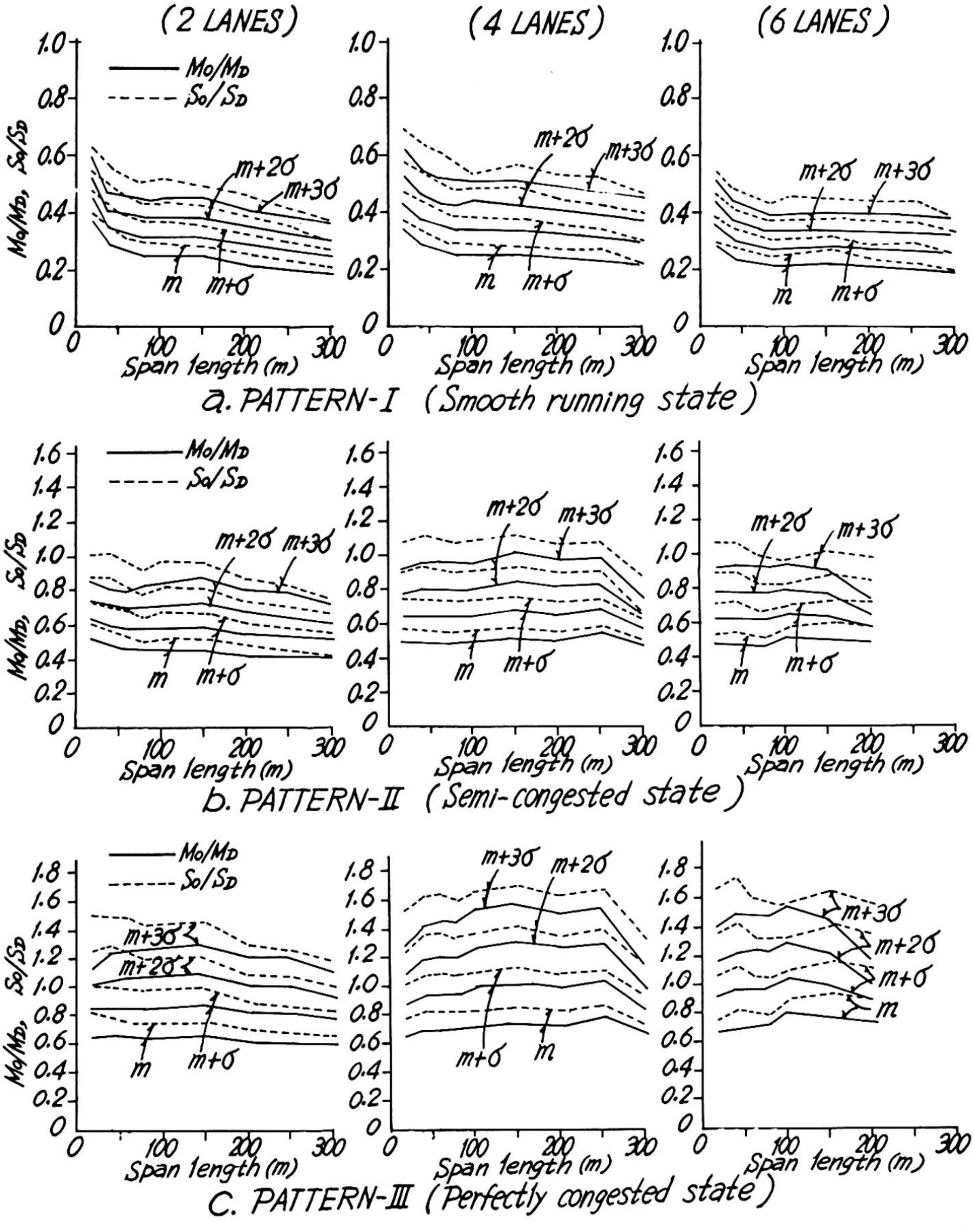

Fig. 10 Ratio of measured value to calculated value due to design load

The values of M_o/M_D and S_o/S_D thus obtained for all of observed points were gathered up for different number of lanes, and a histogram of M_o/M_D and S_o/S_D was drawn. The histogram showed that the form of distribution of M_o/M_D and S_o/S_D may be regarded as the normal distribution. Thereupon, the mean value "m" and the standard deviation "σ" of the values of M_o/M_D and S_o/S_D for different numbers of traffic lane and for different span lengths were calculated, then the relation between different expected magnitudes of the vehicle row load and their frequencies was presumed.

Fig. 10 was obtained in this way, indicating the features of magnitude of actual vehicles load in Japan. From Fig. 10, the following facts may be understood:

1) The magnitude of vehicle row load under normal traffic condition (Pattern I) is considerably low, the average value of the loading effects (moment and shear) in main girder is equal to 30%, at most, of those due to design live load regardless of the number of traffic lane and of span length, and even at the level of $(m+3\sigma)$, it is only 60%, at most, of the loading effects due to design live load.

2) Under the semi-congested state of traffic (Pattern II), that is usally occured in Japan, the average value of the loading effect imposed in main girder ranges from 40 to 60% of that due to design live load, and the level of $(m+3\sigma)$,corresponds approximately to the level of design live load.

3) When vehicles are congested with clear distance of 1 m over the whole lanes (Pattern III), the average value of loading effect imposed in main girder is presumed to be 60 to 80% of that due to design live load, and the level of $(m+\sigma)$ corresponds approximately to the level of design live load.

4) S_o/S_D is usually larger than M_o/M_D. Namely, the current design live load in Japan is not well-balanced between bending moment and shearing force in main girder.

Fig. 11, comparison of loading effects due to design live load of well-known HS 20 Loading of AASHO (1969) and "Brücken Klasse 60" of DIN 1072 (1967) to those due to Japanese design live load, may facilitate understanding the consideration made in this report.

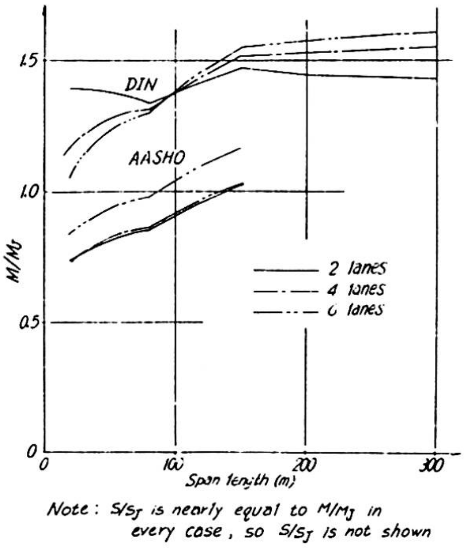

Fig. 11 Comparison of design loading effect in various countries

5. Conclusion

The following conclusion may be introduced concerning the load on highway bridges in Japan, on the basis of the results measured on the stress levels in bridge members, and on the wheel load and vehicle row load:

1) The live load stress imposed in main girder and main truss under usual traffic condition is 300 kg/cm^2 or so at most, which is considerably small as compared with the calculated design live load stress.

2) Vehicle row load under normal traffic condition is in considerably lower level as compared with the current design vehicle row load, but under the state in which the whole lanes are perfectly congested, there is a little chance that the vehicle row load may reach to the level of design load. Considering the fact that semi-congested state of traffic in which the half of traffic lanes are congested while the opposite half lanes are smooth is usually observed wherever in Japan, it seems to be suitable to determine the design load for main girder on the basis of such loading condition.

3) The relation between the weight and frequency of vehicle wheel load shows fairly big divergence according to area, but nearly constant trend on the same point. Generally speaking, the actual condition of wheel load is that it has no such allowance to design load as is seen in the vehicle row load, and the existence of such heavy wheel load exceeding design wheel load is amounting to a number which may not be ignored.

4) Since vehicle wheel load (single vehicle load) is in the severer condition than in the case of vehicle row load in comparison with the current design load, considerable unbalance of load carring capacity between main girder and floor system has been arisen. In order to design a bridge of which each member is well balanced in strength, it will be necessary, so long as the current design load is employed, to use larger safety factor for the floor system than that for main girder.

References

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Summary

As the result of our surveys of wheel load, row load of vehicles and of stress in bridge members, it was made clear that the magnitude of vehicle row load or corresponding stress in main girder has considerable allowance in comparison with the current design live load and corresponding stress, under any traffic loading condition except perfectly congested states, while the single vehicle load sometimes exceeds the design load and poses a problem in relation to the safety of slab and floor system.