Corrugated Steel Bridge Fatigue Vehicle Analysis

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Abstract

For the increase of bridge span, the generation of new technology provides theoretical support for a variety of cross-sea bridges, and the research of corrugated steel structure bridge gets more people's attention. In this paper, from the perspective of fatigue research, when analyzing the fatigue load spectrum of corrugated steel bridge, it also involves the determination of standard fatigue vehicle types. The investigation and division of fatigue vehicles types, and the determination of equivalent load of representative vehicle types, together with the determination of wheelbase and wheel track, according to the assumed fatigue damage conditions in line with Miner linear damage cumulative rule, will deduce the calculation formula of simplified fatigue vehicles equivalent cyclic number.

Keywords

corrugated steel girder bridge, the equivalent load, fatigue damage conditions, the fatigue vehicles equivalent cyclic number.

1. Introduction

1.1 Development and status quo of the fatigue study of single box girder bridge with corrugated steel

As early as in 1950s to1960s, people found in the work that corrugated web has a strong advantage in shear capacity, later they also studied the bending and fatigue resistance of the corrugated web. In order to solve the prestress loss of combined box girder, and improve the stress conditions of the bridge at the same time, the French company in 1975, for the first time put forward the idea of using corrugated steel web to replace flat steel web. Successfully from 1985 to 1986 they built the first bridge Cognac combining box girder with corrugated steel webs. In 1984, the Canadian professor analyzed corrugated plate H type girder in conditions of uniform distributed load and concentrated load, and through that, under the two loads he deduced the calculation formula of various physical quantities in web area. Since then, the innovative corrugated webs began to be used in the actual bridges, and other countries started buckling analysis of corrugated webs under various conditions.

The study on corrugated web in China was later than foreign countries. Professor Fu-qing Chang made numerical simulation analysis of strength and stiffness under the condition of static load, and calculated the buckling strength of sinusoidal corrugated web H type girder in the condition of uniformly distributed load. The results prove that the regular volatility of the web has good effect on enhancing the lateral bending stiffness and stability of the web, so corrugated web H type steel to a certain extent alleviates the contradiction between the strength and the overall stability of the structure [1].

1.2 Fatigue research significance of single box girder bridge with corrugated steel

In the 1980s new type of corrugated web box girder bridge improves the spanning capacity of the structure. The birth of corrugated web just came from the container appearance, which has the following advantages:

(1) Dead-weight has been greatly reduced, which can effectively improve the seismic performance[2]. Shear force of corrugated web girder bridge is mainly suffered by corrugated web.

(2) Longitudinal stiffness of the corrugated steel web is very small, so the axial force generated by longitudinal stiffness on the bridge can be ignored, and it can prevent to produce stress on web caused by shrinkage, creep and temperature difference of upper and lower flange concrete[3]. In addition, the construction is simple, standard, which will improve the economic effect.

(3) Corrugated steel web, to a certain extent, avoids the premature buckling caused by geometric defects and drastically reduces the sensitivity of thickness defect of corrugated steel web[4].

1.3 Main research work in this paper

Based on the analysis of fatigue research of single box girder bridge with corrugated steel structure at home and abroad, combining the actual situation in China at present, through the theoretical analysis and the research method, this paper mainly studied the present situation of fatigue vehicle in China, and according to the related statistical calculations, it tells that the actual distribution of different types of cars and trucks on roads, and the uses of reasonable representative ones when conducting fatigue research. It derives the equivalent load of the representative types of vehicles, wheel track and wheelbase, and in line with the Miner linear damage cumulative rules, it can also derive the calculation formula of simplified fatigue vehicles equivalent cyclic number.

2. Research of Fatigue Vehicle Load Model in China

2.1 Traffic condition investigation and analysis in China

For drawing up the traffic load spectrum for bridge fatigue calculation, it must first investigate traffic condition of the bridge or road in China. If the weight of a light vehicle is o.1 times of a common heavy one, according to the proportional relation between fatigue tolerance and m times of the stress, the damage caused by a light vehicle is just 0.001 times of the latter one (when m = 3), so compared with the heavy one, the fatigue damage effect caused by the light vehicle is usually very small. After referring for related research at home and abroad, this paper argues that the fatigue damage effect produced by the vehicles with total weight less than 30 kn is not considered, all these vehicles including passenger cars and the small cars, mini trucks, mini cargo-bus for commercial use, etc., so the key objects of traffic survey are medium-sized passenger cars, large passenger cars, light truck, medium truck and heavy truck and other vehicles that are heavier than 30KN.

2.2 Investigation and division of car types

According to the Type Dividing and Class Rating for Commercial Motor-vehicles of Passenger Transport (JT/T325 2006)[5], highway operating passenger cars in China can be classified into three categories in accordance with the body length L: small passenger cars ($L < 6$ m), middle bus($6 < L < 9$ m) and large passenger cars($L > 9$ m). By statistical data it can be seen that the sum of medium and large passenger cars account for about 5% to 8%[6] in the total traffic volume. By analyzing the survey data of medium and large passenger cars on highway,it can draw the following conclusion:

(l) middle car with length of 7 ~ 8 m has the highest proportion;

(2) large passenger car with length of 11 ~ 12 m has the highest proportion;

(3) the large-scale passenger car with length more than 13m has extremely low proportion in the total traffic volume, so it can not be considered, and it may deem that all the number of medium and large cars' axis is 2.

2.3 Investigation and division of truck types

As is known to all, truck load has the greatest impact on fatigue damage of steel bridge, so it is the main investigation object of the vehicle load spectrum. Compared with passenger cars, there are many different kinds of trucks with different numbers of axles and various total weight, so it is very important to classify the trucks for making the right vehicle load spectrum.

(l) Two-axle trucks running long and short distance is the main type of road cargo transport in China.

(2) Three-axle semi-tractor has an extremely low proportion in the total traffic volume, and it is mainly composed of three-axle single bus.

(3) Four-axle semitrailer is the main type of long- and medium- distance cargo transportation.

(4) Five- and six- axle semi-trailer is mainly used for container transport of long- and medium-distance.

2.4 Determination of equivalent load of representative vehicles

First the recorded vehicles data by WIM equipment should be classified in accordance with the classification in section 2.2 and 2.3, that is, the similar types should be classified in one category. Then according to the principle of equivalent fatigue damage, the equivalent axle load of each axle should be calculated in each category. The sum of each equivalent axle load is the total equivalent axle load of each type of representative vehicles. Calculation formula of equivalent axle load of each type of vehicles is:

$$W_{ei}=\left(\sum_{j=1}^{n} f_j W_{ji}^3\right)^{\frac{1}{3}}$$

W_{ei}: number i equivalent axle load of one type vehicle

f_j: relative frequency of number j vehicle in one category

W_{ji}: actual measurement axle load of the number i axle in number j vehicle in one category

n: the total number of vehicles of all categories

2.5 Determination of the wheelbase and wheel track of representative vehicles

Take relative frequency of each vehicle in same category as the weight, and according to the weighted average of each vehicle's measured wheel base calculate each wheel base of the same category. The average wheelbase calculation formula is:

$$C_i=\sum_{j=1}^{n} f_j C_{ji}$$

C_i—represent number i average wheel base of one category

f_j—the relative frequency of the number i vehicle in one category

C_{ji}—the number i axle' actual measured wheelbase of the number j vehicle in one category;

n— a total number of vehicles of all categories.

Survey data show that all kinds of vehicles' wheel tracks are mostly in the range of 1.70 ~ 2.10m, and most are 1.80m or so. Considering that the subtle differences in the vehicle wheel tread has a little influence on fatigue damage of the bridge, moreover, BS5400 and AASHTO also take 1.80m as its standard fatigue car wheel base, so 1.80m as a representative wheel tread has its significance.

2.6 Miner Linear damage cumulative rule

Steel bridge fatigue belongs to the scope of amplitude of variation, low stress, long cycle life. The key for the fatigue strength calculation under variable amplitude load lies in how to build a connection between variation amplitude fatigue strength and constant amplitude fatigue strength. In currently available models, Palmgre—Miner linear damage accumulation principle is simple and easy to use, and also a large number of studies have shown that the criterion can provide most typical bridge of steel structure with reasonable fatigue damage assessment, so it has been widely used in the calculation of fatigue damage of steel bridge. The conditions of the assumed fatigue damage are:

$$D=\sum\frac{n_i}{N_i}=\frac{n_1}{N_1}+\frac{n_2}{N_2}+\cdots+\frac{n_n}{N_n}=1$$

n_i—The number of the stress pulse $\Delta\sigma_i$

N_i—Fatigue life corresponding to stress pulse $\Delta\sigma_i$ in constant amplitude S-N curve

2.7 Calculation of simplified equivalent cyclic number of fatigue vehicles

Influenced by a number of vehicle axle, line length and shape, the stress generated by the vehicles running through the bridge is a complex process. When calculating the fatigue cumulative damage, it usually needs rain-flow counting method to calculate all the stress pulse Sn and the corresponding cycles Ni in the stress process, which brought inconvenience to the calculation of fatigue cumulative damage. To simplify the calculation, Schilling proposed that fatigue cumulative damage generated by every car running on the bridge can be showed by maximum stress pulse Srp and the equivalent cyclic number Ne. The equivalent cyclic number Ne can calculate by the following:

$$N_e = 1 + \left(\frac{S_{r1}}{S_{rp}}\right)^m + \left(\frac{S_{r2}}{S_{rp}}\right)^m \dots + \left(\frac{S_{ri}}{S_{rp}}\right)^m$$

M: negative reciprocal of slope of S-N curve;

S_{rp}: maximum stress pulse in the stress process;

S_{ri}: other stress pulse except the maximum one in the stress process

According to the formula and the rule of Miner, fatigue cumulative damage D caused by simplified standard vehicles when across the bridge can be easily calculated using the following formula:

$$\mathrm{D} = \sum \frac{1}{N_i} = \sum \frac{S_{ri}^m}{C} = \frac{N_e S_{rp}^m}{C} = \frac{NC \times S_{rp}^m}{C}$$

N_i: corresponding fatigue strength (cyclic number) of each stress pulse Sri in the process;

NC: equivalent cyclic number produced by simplified standard fatigue vehicles when across the bridge;

C, m: the material constants.

3. Summary

Getting the right vehicle load spectrum is the premise of bridge structure fatigue damage calculation or fatigue life assessment, but in China the existing highway bridge design specification is not to make clear the vehicle load spectrum, and studies in this respect are also very few. This standard fatigue vehicle models, in the research of equivalent load and equivalent cyclic number simplification, and the calculation formula of simplified fatigue vehicles equivalent cyclic number deduced from the Miner linear fatigue damage cumulative rule, can be used in a wide range of span fatigue cumulative damage assessment conveniently.

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