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Design of Prestressed Concrete Bridges, based on the Fatigue Life for the expected Load Spectrum

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The author together with Professor E.I. Brown discussed this question in Chigaco this year (Ref. 1). There are two problems of probability, one relating to the random loading at highway bridges and the other to the fatigue resistance of prestressed concrete. The daily load frequency at 21 bridges over the Ohio river according to Lynch (Ref. 2) has shown that approx. 30,000 vehicles passed the bridge daily of which 85 % were cars and approx. 95 % had max. axle loads less than 9 kips (4.1 Mp). Only 0.1849 % had a max. axle load greater than 19 k. (8.6 Mp) and 0.032 % had a max. axle load greater than 21 k. (9.5 Mp). The last mentioned loading corresponds to about 9 vehicles per day. In the USA, the greatest specified axle load is 32 k. (14.5 Mp). However, infrequent "abnormal" loading may occur and there are overload provisions in the regulations by which the permissible design load may be increased by 100 % in a single lane, without loading in another lane, provided that the combined dead & live load and impact stresses are not greater than 150 % of the allowable stresses. However, with prestressed concrete only very limited tensile stresses are allowed for this abnormal loading.

In the United Kingdom higher loadings are specified than elsewhere. The abnormal HB loading relates to a max. axle load of 45 long tons (100.8 k. or 45.8 Mp)with a vehicle having 4 such axles, two pairs being 6 ft. apart (1.83 m) and the distance of the two inner axles being 20 ft. (5.18 m). However, these loads occur very rarely. In a Technical Memorandum of the Ministry of Transport provisional requirements are given for steel bridges. Whereas annually $2x10^6$ commercial vehicles should be considered at dual carriage ways and half of it at a single carriage way, the entire number of abnormal annual loadings is given as 4500. Of these only 30 are of the maximum abnormal load, whereas 70, 200 and 700 loadings are at 80 %, 60 % and 40 % respectively of the max. load and the bulk of 3500 loadings is of a weight of 20 % of the max. load. Based on these data it is possible to evaluate the number of loading cycles for different load intensities during the expected life time of the bridge and to design the bridge to withstand the cumulative effect of all these loadings. Increased stresses are permitted for steel and reinforced concrete, but this can not be applied to prestressed concrete.

In the paper (Ref. 1), five different design methods for prestressed concrete bridges are discussed. Method 1 relates to a design at which only compressive stresses occur at the maximum load; this ensures a safe but uneconomical solution. By method 2 limited tensile stresses are permitted under the maximum load, as employed by British Railways, Eastern Region 1948-62 during the author's activity (Ref. 3) and by A.A.S.H.O. in the United States (Ref. 4). Method 3 is based on a proposal by Professor C.E. Ekberg (Ref. 5) relating to the fatigue resistance of a definite stress range according to the Goodman diagram. Method 4 was suggested by the author in 1956 (Ref. 6)and relates to a design at which similarly to method 1 only compressive stresses occur under the normal loading, whereas temporary cracks may occur under the "abnormal" loading. Method 5 suggested in the paper (Ref. 1) is based on the cumulative fatigue resistance to the entire load spectrum during the bridge life, bearing in mind at random loadings.

In a paper (Ref. 7) tests have been reported which were carried out at DUKE University which showed that prestressed concrete can withstand a relatively large number of load cycles over a high loading range. For example it was found that about 200,000 cycles can be withstood over a range between 30 and 70 % of the static failure load. In this case the lower limit corresponds to the dead load and the upper to 1.82 times the maximum design load. Similarly 30,000 cycles were withstood to a loading range between 30 and 80 % of the static failure load, where the upper limit of the range corresponds to 2.27 times the max. design load. Even for a loading range between 30 and 90 % of the static failure load a few thousand cycles were recorded in which case the upper limit corresponds to 2.78 times the max. design load. The cumulative effect can be obtained from Miner's hypothesis (Ref. 8) according to which $\Sigma n_i/N_i = 1$ (where n_i is the number of cycles applied for a certain range, whereas N_i is the number of cycles which the construction can withstand). This results in a damage line which presents a curve of lesser capacity than the s-n curve or load-number of cycle curve. The applicability of Miner's hypothesis to steel construction, particularly to air craft, has been queried, but it can be assumed, based on the tests at DUKE University, that it is in good agreement with prestressed concrete with well bonded tendons.

Figs. 1 and 2 illustrate the design methods 4 and 5 respectively. In Fig. 1 two probable limits for the load-number curve are plotted from which the damage line is obtained. For example, on the assumption that 200,000 cycles between 30 and 70 % of the static failure load can be withstood (corresponding to an upper limit of 1.82 times the max. design load), but only a quarter of the number i.e. 50,000 cycles apply, a definite point of the damage line is obtained. This Fig. 1 is based on 500 million vehicle loadings and it is assumed that at 499 millions of these loadings only compressive stresses occur at which there are no open cracks, whereas under one million of abnormal loadings cracks may occur. It is further assumed that only 50,000 loadings are as high as 1.82 times the design load, the other abnormal loadings being less. Fig. 2 relating to method 5 is also based on 500 million loadings and a damage line is plotted which is based on the cumulative effect of loading.

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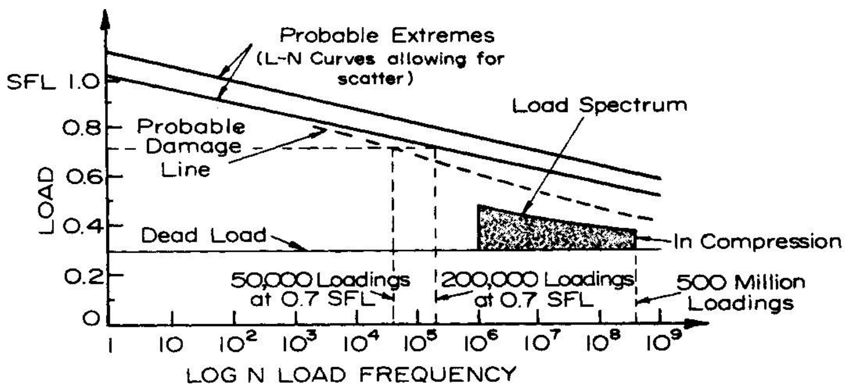

Fig. 1

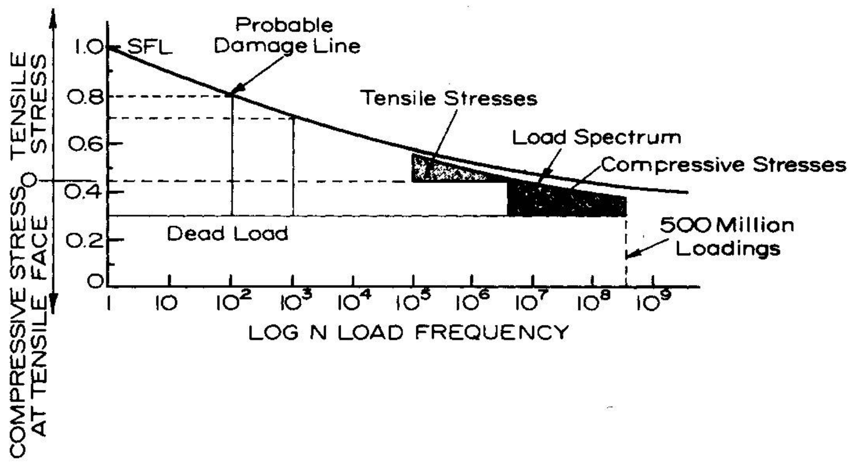

Fig. 2