Applications of Statistics and Probability in Civil Engineering – Faber, Köhler & Nishijima (eds)
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In-situ dynamic behavior of a railway bridge girder under fatigue causing traffic loading

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ABSTRACT: Stresses in bridges due to traffic loading need to be determined as accurately as possible for reliable fatigue safety verification. In particular, the dynamic traffic effect due to running vehicles has to be considered in a realistic way. In-situ measurements of the dynamic behavior of a one-track railway bridge have been performed to analyze the complex elastic dynamic system consisting of running trains—railway track—bridge structure. The main causes for dynamic effects for fatigue relevant bridge elements have been identified to be the vertical track position, i.e. track irregularities. The dynamic behavior has been modeled with sufficient accuracy using simple models when fatigue relevant dynamic effects are studied. The results of this study allow for the consideration of realistic dynamic amplification factors for fatigue verification.

1 INTRODUCTION

For the examination of existing bridges, dynamic amplification factors for updated traffic loads need to be derived for the deterministic verification of each the structural safety, serviceability and fatigue safety. This paper concentrates on realistic dynamic amplification factors to be deduced considering elastic structural behavior of bridge elements under fatigue loading.

Stresses in the fatigue vulnerable steel reinforcement of concrete railway bridges due to traffic loading have to be determined as accurately as possible for reliable and realistic fatigue safety verification. Therefore, the dynamic traffic effect due to running trains has to be considered in detail.

The aim of this paper is to show that the complex elastic dynamic system consisting of running train—railway track—bridge may be modeled with sufficient accuracy using simple models when fatigue relevant dynamic effects are studied. These simple models may then allow the study of the effect of other velocities and increased trainloads on fatigue relevant bridge elements.

In view of this objective, dynamic measurements are conducted on a one-track railway bridge. First, the measured behavior is compared with the dynamic behavior of a model taking into account only train velocity. Then the dynamic behavior due to railway-track irregularities is investigated with simple models.

2 MAIN RESULTS AND DISCUSSION

Modeling of dynamic behavior: The presented study shows that the dynamic behavior as measured from a prestressed concrete bridge girder is well represented by simple models which allow identifying fatigue relevant dynamic effects. It may be noticed that the dynamic bridge behavior has no significant influence on the dynamic behavior of the car because of the high difference in stiffness between the car suspensions and the bridge structure. Also, it is sufficient to represent the first vibration mode of the bridge girder. The bridge structure may be attributed to a rigid base for the car, and car and bridge may be modeled separately.

Fatigue relevant dynamic actions: Track irregularities are found to be the main cause leading to amplifications of the bridge dynamic response. Typical cases are local settlements in the transition zone embankment-bridge or a difference in elevation of the railway track due to a rail joint (misalignment) or bad welding. The wheel force variation due to railway track depressions leads to an almost immediate bridge response.

As observed in the measurements and simulations, the dynamic amplification factor varies with varying train velocity. A maximum occurs at the resonance speed for maximum car excitation due to track irregularities. High contact force amplitude leads to high action effect amplitudes. Maximum dynamic wheel forces do however not necessarily occur always at the location leading to maximum action effect such as the bending moment.

It should be noted that maximum dynamic amplifications due to both train velocity and track irregularities should actually not just be added to obtain the total dynamic amplification factor, since it is rather unlikely that the maximum dynamic effect of both effects occurs at the same time for the occasional case of a carriage with a high fatigue relevant load.

Fatigue relevant action effect: The action effect of interest (i.e. the maximum moment) is caused by more than one bogie. It must not be expected that all the bogies increase due to dynamic effects their contact force at the same time. Consequently for fatigue loading, the sum of the contact forces leads to lower amplification factors than those for single bogies.

For the investigation of the fatigue safety, the dynamic effect of high traffic loads rather than medium or lightweight cars running at high speeds are of interest.

Dynamic amplification factors for high traffic loads are distinctly lower than for trains with lighter carriages as has been shown by many investigations. In particular, wheel force amplification and corresponding action effects (forces) in the bridge element due to track irregularities decrease with increasing weight of carriage [Herwig 2008, Ludescher & Brühwiler 2009] and it may be deduced:

- In the case of dynamic amplification due to *excitation from train movement* (train velocity), maximum dynamic effects occur only with regular axle spacing in narrow velocity domains. Other velocities lead to moderate dynamic effects. Here the effect of carriage weight is less pronounced.
- In the case of dynamic effects due to *track irregularities*, one needs to consider that the track quality varies over time, and since the overloaded carriage (as leading action) is an *occasional* event, it is reasonable to consider track irregularities as a quasi-permanent state.

Application: As a consequence and since the static load considered in the FLS verifications is extreme (high), the dynamic amplification factor according to EN 1991-2 may be reduced accordingly. At fatigue limit state FLS, frequent values of dynamic action effects are considered to represent service load conditions. Based on the foregoing considerations, the following dynamic amplification factor φ_{FLS} is suggested [SB4.3.3 2007]:

$$\varphi_{FLS} = 1 + 0.5(\varphi' + 0.3\varphi'') \qquad (1)$$

with φ' and φ'' according to EN 1991-2.

3 CONCLUSIONS

The following conclusions are valid for the investigated bridge as well for fatigue relevant shorter bridges:

- The dynamic behavior of a bridge can be represented by simple models when fatigue relevant action effects are studied. It is sufficient to represent the first vibration mode of the bridge girder.
- Track irregularities are the most important cause for fatigue relevant dynamic amplifications of action effects. This effect occurs at each train passage for each car.
- Dynamic amplification factors for elastic structural behavior at fatigue limit state shall consider the effects of two main parameters involved, i.e. (1) train velocity and (2) track irregularity.

The investigated prestressed concrete bridge girder itself is actually only little fatigue vulnerable due to its relatively long span and the fully prestressed concrete cross section. Since the investigated bridge was rather stiff, the assumptions on the modeling are however applicable for bridges of shorter spans.