Dynamic Load Testing of Swiss Bridges

Essais dynamiques des ponts Suisses

Dynamische Versuche an Schweizer Brücken

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Summary

The paper presents results obtained using a simple dynamic testing procedure frequently used in Switzerland for highway bridges. Typical results are shown and tendencies observed in the dynamic behavior of highway bridges are presented. For a deteriorated pavement, the dynamic impact of heavy vehicles is shown to be larger at lower truck speeds. Some correlation is shown between the dynamic properties of the bridge and its stiffness, as measured in a static load test.

Résumé

L'article présente les résultats obtenus à l'aide d'une méthode d'essai dynamique simple fréquemment utilisée pour les ponts routiers en Suisse. Le comportement typique des ouvrages, ainsi que les tendances générales des ponts routiers sont présentés. Dans le cas d'un revêtement détérioré, il est montré que le coefficient d'amplification dynamique est plus grand lorsque la vitesse de passage des véhicules est plus faible. Quelques corrélations sont présentées entre les propriétés statiques et dynamiques des ponts.

Zusammenfassung

Im vorliegenden Bericht werden die Ergebnisse einer einfachen Testprozedur für dynamische Belastungsversuche präsentiert, die in der Schweiz oft für Brücke verwendet wird. Typische Versuchsergebnisse und Tendenzen der Autobahnbrücken werden präsentiert. Bei beschädigter Fahrbahnfläche ist der dynamische Amplifikationsfaktor bei kleineren Fahrgeschwindigkeiten oft größer. Gewisse Korrelationen zwischen den statischen und dynamischen Brückeneigenschaften werden aufgezeigt.

1. Introduction

Dynamic load testing is an important part of the acceptance process for new bridges in Switzerland [8]. As a complement to static load tests, dynamic tests yield useful information about the actual behavior of the bridge under traffic. This information is usually difficult to obtain analytically, because of the complexity of the actual structure. The effect of pavement deterioration on the dynamic response of the bridge is of particular importance for the management of the structure. This information can be easily and realistically obtained from a dynamic test, and thereafter used by the highway authorities to organize the pavement maintenance.

Drawing on the large number of tests performed by IBAP over the past twenty years, the paper describes the general dynamic characteristics of highway bridges. Some correlation is shown between the stiffness obtained in a static load test and the measured eigenfrequencies. The influence of the speed of a vehicle crossing the bridge is discussed. In particular, the effect of an artificial damage in the pavement on the dynamic behavior is presented.

2. Dynamic Load Testing

The purpose of the dynamic load test is to determine the controlling parameters of the dynamic behavior of the bridges. The main dynamic characteristics of the structure are the fundamental vibration frequency, the dynamic amplification factor and the logarithmic decrement. These properties are usually not analyzed in detail in the design phase of small and middle sized structures. Some parameters, such as the logarithmic decrement or the dynamic amplification factor, can only be roughly estimated at the time of the design. However, these quantities are relatively easy to obtain experimentally, and can give valuable information for the exploitation and maintenance of the bridge.

The general methodology used in the dynamic load test of a bridge will be presented using as an example the bridge shown in figure 1. The Riddes-Leytron bridge is a cable-stayed structure with a slender deck, supporting two lanes of traffic and a sidewalk. The bridge was built from 1991 to 1992 and tested in the summer of 1992.

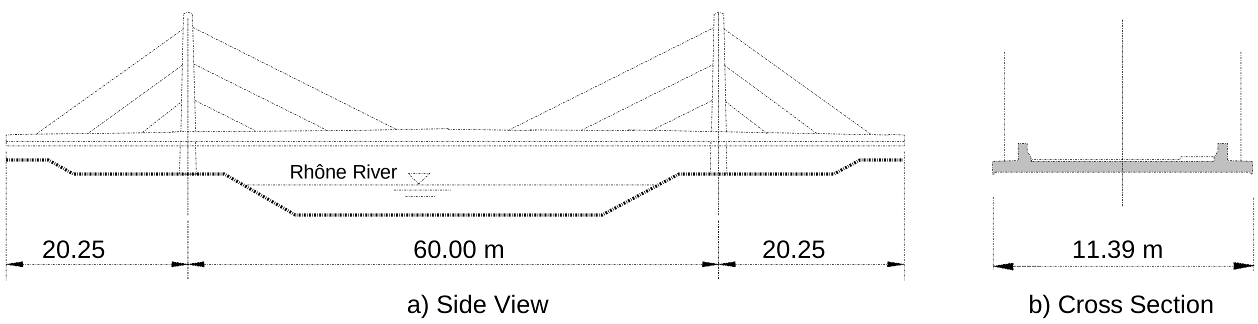


Figure 1: Geometry of the Riddes-Leytron bridge

3. Methodology

Dynamic load testing is performed by exciting the vibration of the bridge and by measuring its properties after the excitation has ceased. Several methods are available for the excitation of the bridge, in particular: eccentric rotating masses, impact of a heavy weight and passage of a loaded truck. This last method is often preferred for the dynamic load testing of bridges because it gives, along with reasonably accurate values of the above mentioned quantities, a good approximation of the effect of the actual traffic on the structure. By varying the speed of the truck on the bridge, the full range of traffic speeds can be investigated. Furthermore, this method is easily implemented while some of the other ones necessitate more complicated installation procedures. The measurements are taken and recorded by a dynamic data acquisition system with integrated Fast-Fourier Transform (FFT) analyzer, allowing an immediate interpretation of the results during the test.

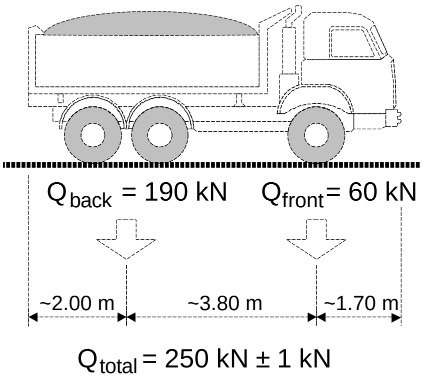
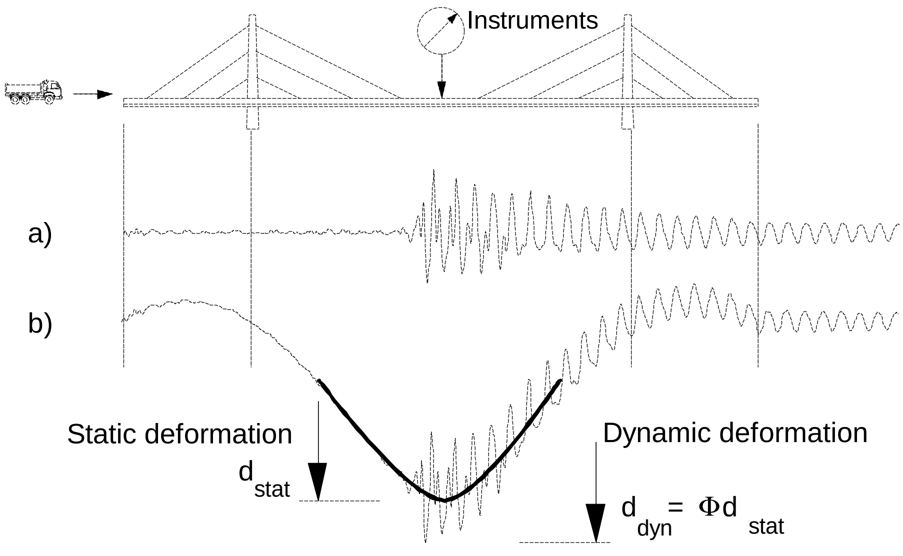


Figure 2: Typical truck used in dynamic load testing

The trucks used for the dynamic excitation of the bridge are usually 3-axle trucks, as shown in Figure 2, with a total weight of 250 kN (total mass of 25 metric tons), traveling on the bridge at several speeds. The effect of a deterioration of the pavement is simulated by the introduction of a normalized plank on the path of the truck. This induces a strong impact when the trucks passes at mid-span, that represents the effect of a pothole in the pavement, or the irregularity of the surface caused by packed snow. Figure 3 shows the location of the instruments and the results for the dynamic testing of the Riddes-Leytron bridge. Absolute displacement sensors are used for the measurements, and therefore only components with a relatively high frequency (larger than 0.2 Hz) are recorded, as shown in Figure 3a (vertical dispacement at mid-span as a function of the truck position). The static influence line of the truck passing on the bridge is then added to obtain the complete dynamic influence line shown in figure 3b.



a) Relative vertical deflection at mid-span caused by the passage of the truck
b) Dynamic influence line of the passage of the truck. Determination of the dynamic amplification factor.

Figure 3: Description of the dynamic load test

4. Results

Because a lot of information is gathered in the course of dynamic load testing, the results are usually presented graphically. First, as shown in figure 3b, the dynamic influence line of the bridge subjected to the passage of a truck is drawn for all travel speeds, with and without plank. This allows a simple visual determination of the dynamic amplification factor Φ. The natural frequency of the bridge is obtained from acceleration spectra performed by the FFT analyzer. The logarithmic decrement is obtained from the decay of the bridge free oscillations, after the truck has left the bridge, or at least when it is far enough from the instruments (figure 3a).

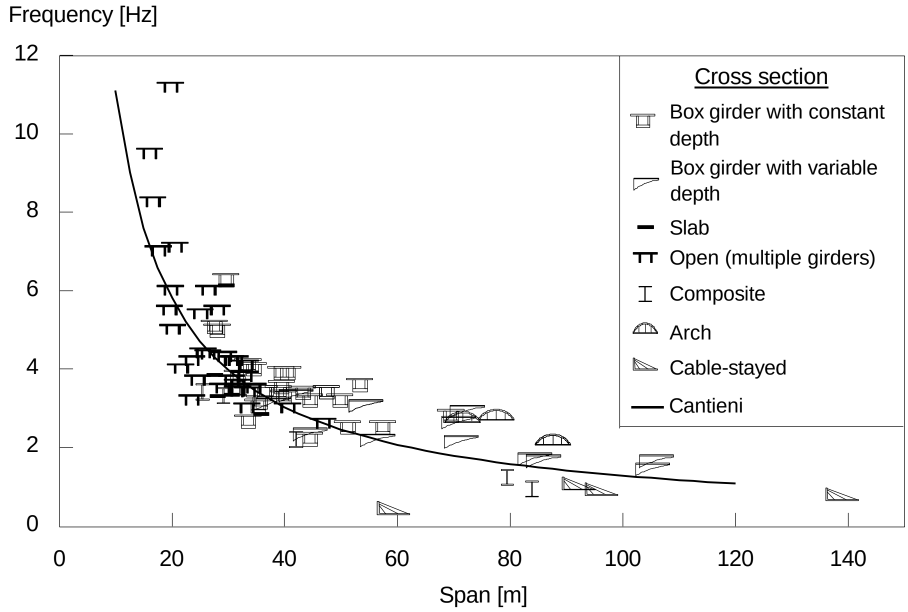


Figure 4: Natural frequency as a function of bridge span

Figure 4 shows the natural frequency as a function of bridge span for approximately ninety bridges tested by IBAP. The regression line was proposed by Cantieni in [5, 6], based on over 200 dynamic load tests of Swiss bridges. A good correlation has been found between his data and data gathered by IBAP. Figure 5 shows histograms of the dynamic amplification factor for the bridges tested over the past twenty years. Some bridges are not included in the graphs because of incomplete measurements in the early years of dynamic testing. The Swiss code for bridges specifies a constant dynamic amplification factor for bridges of 1.8. It is interesting to note that a significant number of bridges indicated higher values. Most bridges had a small damping, with logarithmic decrements smaller than 0.1.

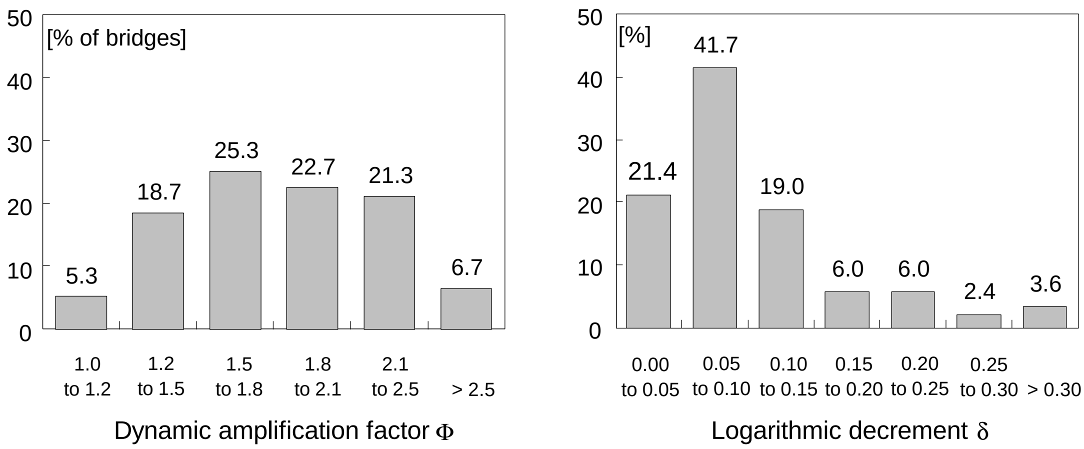


Figure 5: Histograms of the dynamic properties

Figure 6 shows the maximum measured vertical acceleration and displacement induced at mid-span of the Riddes-Leytron bridge by a passing truck, as a function of the truck speed. In the case of smooth riding surface, the response of the bridge is small and increases with increasing speed, while in the case of a deteriorated surface, the response is strong and the influence of the truck speed is less clear. It has been

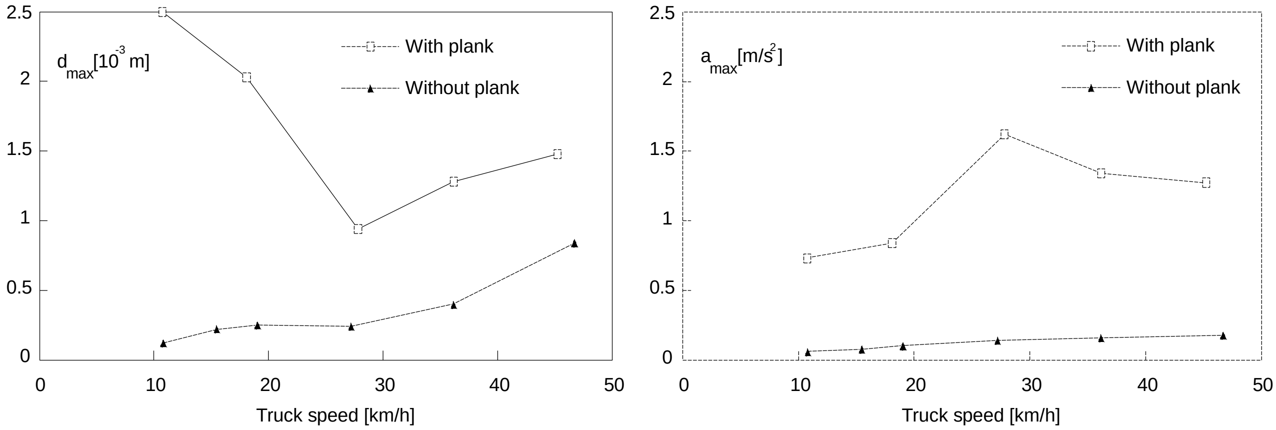


Figure 6: Dynamic response of the bridge as a function of the truck speed

observed in other structures that lower truck speeds can induce larger displacements (and accelerations) than higher speeds. One possible explanation is that a truck traveling at a lower speed will cause two distinct shocks as its two rear axles successively hit the plank. At low truck speeds, the two shocks occur approximately one second apart, which is close to the natural period of most bridges. At higher speeds, the two shocks are very close to one another, and remote from the natural frequency of the bridge

Human beings are especially sensitive to vibrations, particularly to accelerations. Some codes [2] give limiting values of acceleration as a function of the fundamental frequency. In practice, these limits are never reached if the riding surface is smooth, but they can be exceeded in the case of a deteriorated pavement. The results of the dynamic load tests give therefore useful information on the sensitivity of the bridge to deterioration, and can be used in defining the maintenance program for the pavement.

5. Comparison with the Results of Static Load Testing

Because dynamic loading testing is usually performed on bridges that have also been subjected to static load testing, comparisons can be made between the behavior of a bridge under static and dynamic loading. Clearly, the two behaviors are related, in that the bridge stiffness, or spring constant k appears in both the static load test and in the components of the natural frequency. Figure 7 shows the fundamental frequency of each of the

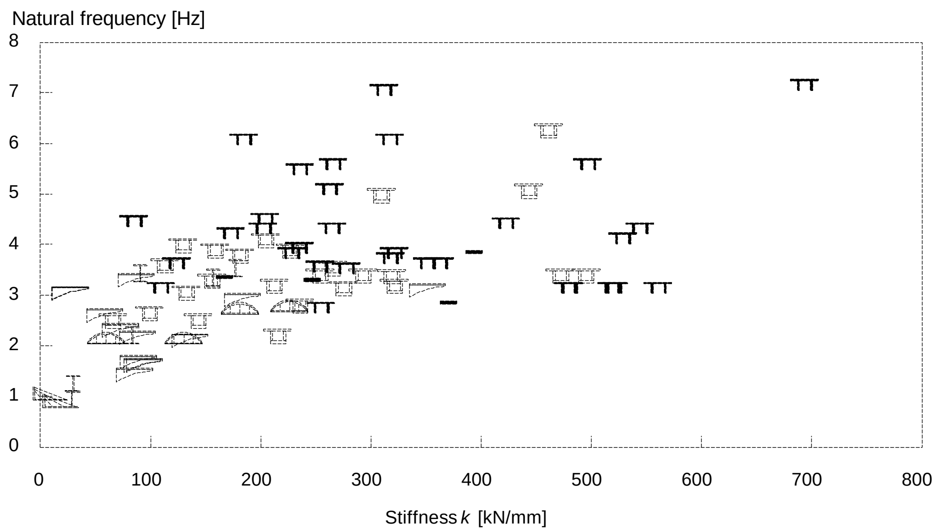


Figure 7: Natural frequency of the bridge as a function of the bridge stiffness

tested bridges as a function of its stiffness obtained from a static load test. As expected, there is on average an increase in natural frequency with an increase in stiffness. However, the scatter is rather large, especially for concrete bridges, as their mass strongly depends on the construction method and cross section. A similar scatter can be observed when looking at the correlation between the dynamic amplification factor and the bridge span or natural frequency. While some tendencies can be observed, the scatter of the data makes the derivation of a simple approximate formula impractical.

6. Conclusions

The paper presents results obtained from simple dynamic load tests of bridges. These tests are frequently performed in Switzerland as part of the acceptance process of new bridges. The main results are the natural frequency of the bridge, the dynamic amplification factor and the logarithmic decrement.

By using a truck to induce vibrations of the bridge, it is possible to simulate the effects of pavement deterioration. Bridges that are especially sensitive to pavement deterioration are identified, and this information can then be used in establishing of the maintenance program of the structure. Truck speed is shown as having a great importance on the dynamic response of the bridge, especially in the case of a deteriorated riding surface.

Some correlation is shown between the span and the natural frequency of a bridge, but a considerable scatter is observed. In a similar manner, there is some correlation between the bridge stiffness observed in a static load test and the dynamic properties of the bridge.

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