Monitoring the big bridges across the Danube in Austria

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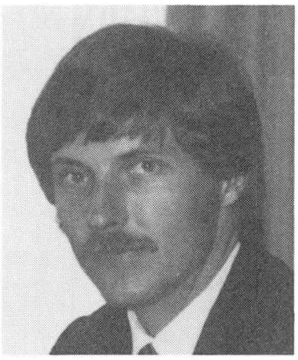

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Summary

Since the spectacular collapse of the famous Reichsbrücke in Vienna in the year 1976, the attention of Austria Bridge Engineers is very much focused on the big bridges across the Danube. The frequency of traffic on most of the bridges has reached the limit, touching some 140.000 vehicles per day in the extreme cases. This vital lifelines have to stay open under any conditions. Therefore the assessment of the structural condition of the bridges is of upmost importance. This paper reports on the works carried out on the bridge assessment covering 9 major bridges with the use of the dynamic characteristic method BRIMOS developed by VCE. The potential of the method is demonstrated and relevant tests are provided.

1. Introduction

The main target of the works was to create a numerical tool for the assessment of the structural stability of the major bridges across the Danube. As a basis the tools of the vibration characteristic method was used. It is based on Ambient Vibration Tests carried out on the bridges frequently. They are compared to analytical calculations with Finite Element computer models, which represent the planned condition of the structure.

The Bridge Monitoring System BRIMOS has been developed over the past 2 years to carry out ambient vibration tests economically. Useful results for the assessment are provided. The major mile stones of the program are:

- Recording of the characteristic through 8 accelerometers which are moved over the bridge to cover the whole area
- Calculation of a representative spectrum, which represents the dynamic characteristic
- Calculation of structural damping by filtering out certain Eigenfrequencies and extraction of damping with the use of the Random Decrement Technology (RDT)
- Numerical assessment on structural integrity under consideration of the measured values
- Determination of the Eigenform as a confirmation for the fitting of calculation and measurement
- Search for damage indicators in the signals and location of the damages

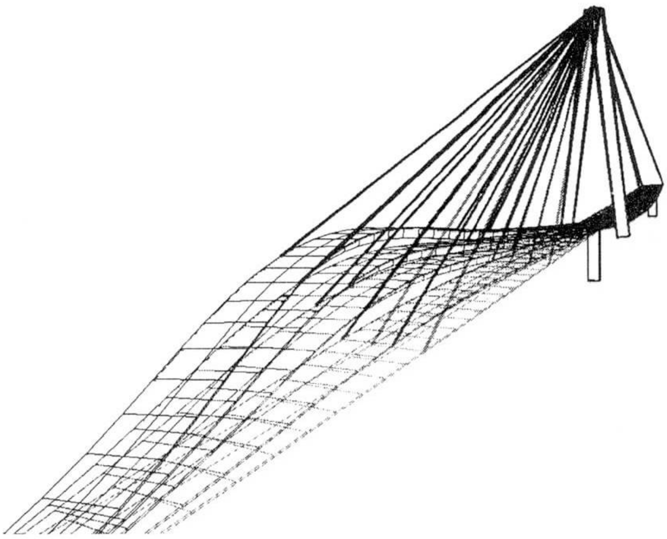

Fig. 1 Eigenmode animated from measurement

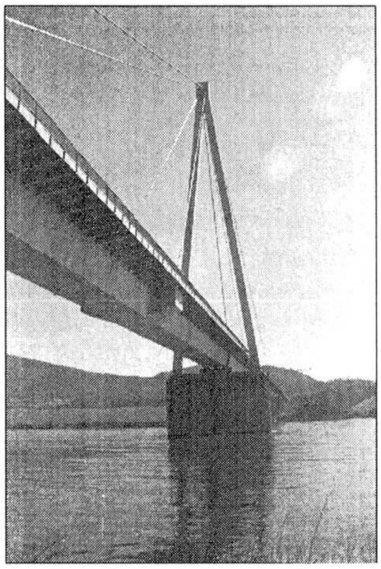

Photo 1 Hainburg bridge

For each structure a report is prepared providing the basic dynamic characteristic, an assessment of structural safety, the values of damping for the structure and the assessment of eventual hidden damages. In the long-term it is intended to undertake measurement frequently and to calculate trends from the results.

The method has been proven by a number of tests in the laboratory and by a major number of tests on bridges on site.

2. The Bridges across the Danube

In Fig. 6 of this paper the bridges considered in this report are described. All kind of structures are represented. There is a number of cable stayed bridges made from steel or concrete or even composite deck structures, a number of steel bridges with various spans, a major composite bridge and a long span concrete bridge. Due to the huge amount of structures and data only representative results can be provided.

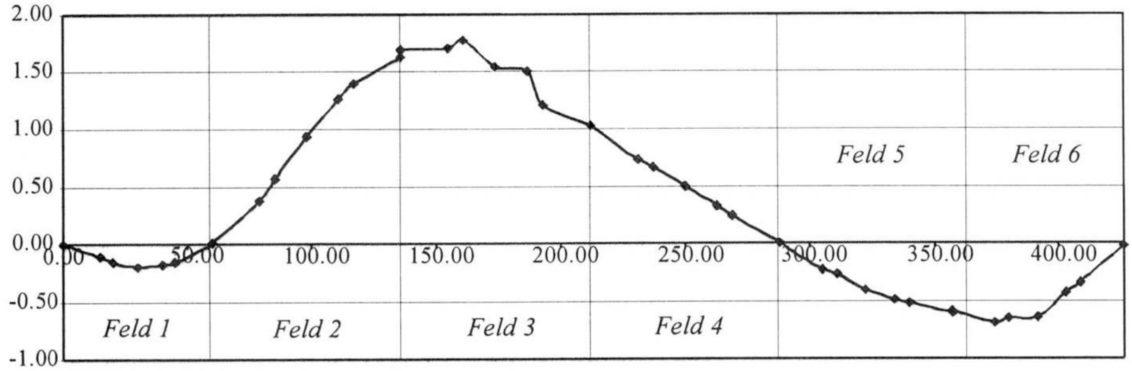

Fig. 2 1. Vertical Eigenmode of the Hainburg bridge

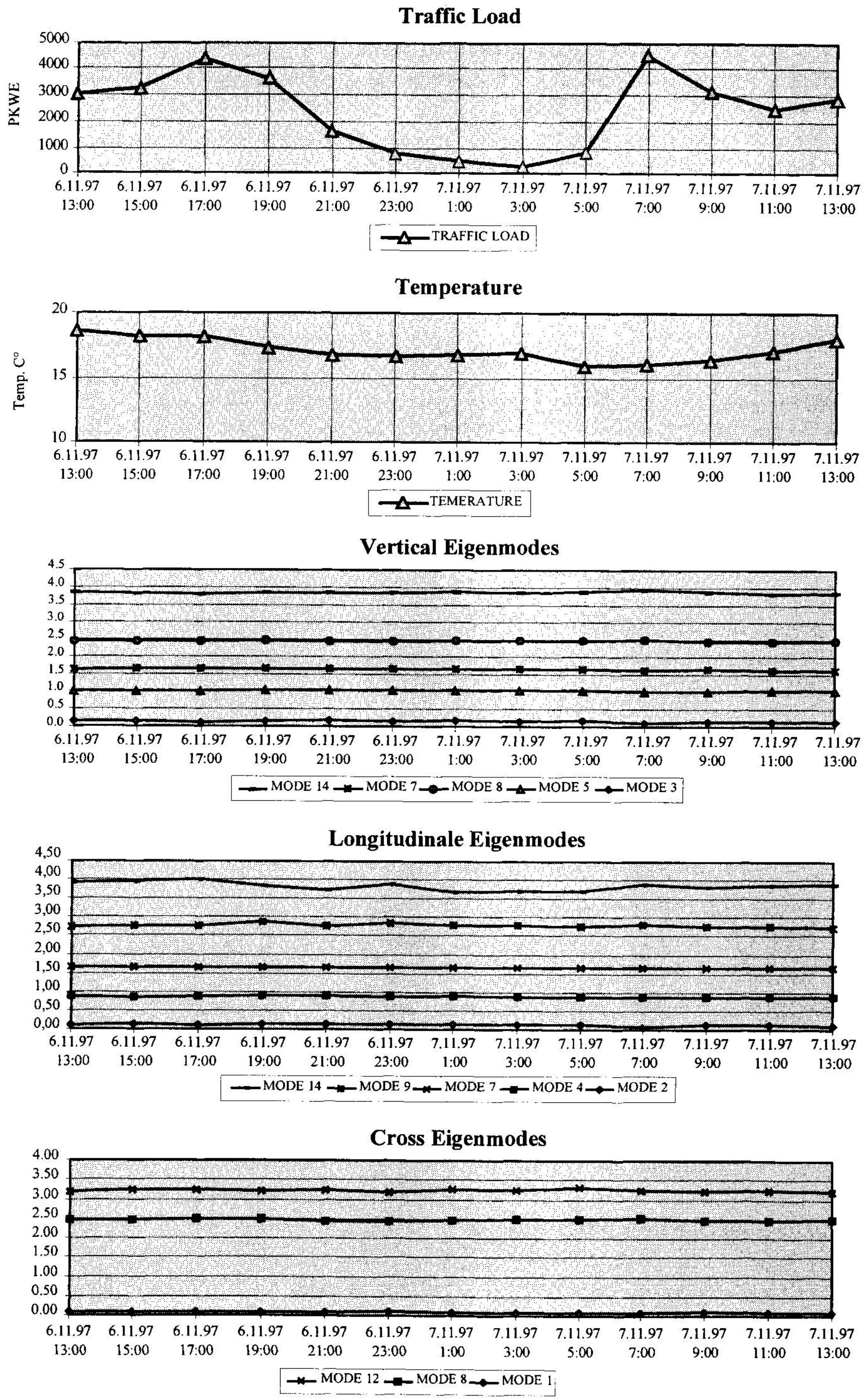

Fig. 3 24 hour test results, traffic load, temperature, frequencies

3. Tests and Calculations

For each of the structures a base measurement has been established. It consist of a minimum of 5 measurement points per span and side of each deck structure. The time requirement for a serious test of a bridge of 200 meter length is approximately 10 hours. The characteristic is recorded at a Sampling – Rate of 100 Hertz and per measurement 50.000 points are stored. Amplifiers and filters are used according to the requirement of each structure. The system is calibrated by a laser displacement device, which provides actual displacement in millimeters. For each of the bridges a dynamic Finite Element Calculation is carried out. It concentrates on the idea of the designers and follows strictly the drawings. Therefore it will be representative for the "should be" case. It serves to define the starting point of the life time performance check.

4. Major Results

The Eigenfrequency of a structure is depending on a couple of items out of which the most important are: The mass, the stiffness, super imposed dead loads, traffic loading both static and dynamic, strain from temperature difference, internal stresses from prestressing and some minor other phenomena not yet fully understood. The method had to be calibrated against those influences to focus the results on the most useful influences, which are stiffness and damping.

One of the most important items was to demonstrate, that the ambient vibration method produces reliable results independent from the traffic loads applied. This was done by means of a 24^h test on one of the representative bridges, which is the Nordbrücke. Permanent measurement has been carried out on a day, where the change in air temperature was only 2°C. The traffic on the bridge varied from 130 vehicles at 3 o'clock in the night to almost 5.000 vehicles per hour during the peak traffic at 7 o'clock in the morning. The variation in the results, considering more than ten fundamental modes is in average below 1 %. This means, that ambient vibration data can be extracted almost under any traffic conditions. The enclosed Fig. 3 show the results over 24 hours including the temperature change, the vehicle loading and some of the relevant eigenfrequencies.

Bridge	1. Vertical	Damping	max. span	Deck
Hainburg	0.53	1.12%	228.00	steel
Donaustadt	0.67	0.44%	1.86.00	composite
Reichsbrücke	0.83	0.68%	170.00	concrete
Brigittenau	0.75	1.67%	175.00	steel
Floridsdorf	0.77	1.44%	167.50	steel
Nordbrücke	0.86	2.30%	83.40	composite
Tulln	0.53	1.60%	176.00	concrete
Melk	0.70	1.64%	190.00	concrete
Steyregg	1.23	1.63%	181.00	composite

Tab. 1 Vertical frequency and corresponding damping

Another major task was to perform the identification of the Eigenmodes from the measured data. This is demonstrated at the Hainburg Cable Stayed Bridge. The Fig. 1 and 2 show the calculated Eigenmode as well as the measured one. It is obvious that the results are very good. The measured modes are carried on to an animation program, which produces real time or accelerated demonstrations of that measurement. These are compared with the calculations and the differences are identified. Very often the interpretation is simple. It gives an idea about the function of important parts of the structure. Both, calculation and measurement, can be superimposed to demonstrate the differences.

5. Damage Identification

The identification of damages beyond the results of visual inspection are the development area of the future. It is well established, that any damage is represented in the signals. The difficulty hides in the interpretation. It was observed, that the results are varying very much depending on the qualification of the operator. Very good results have been achieved by bridge engineers, which learned to handle a monitoring system. Monitoring engineers normally failed to assess abnormal recordings, which they tended to identify as problems with the monitoring system.

Therefore the main task shall be to identify patterns of signals, which indicate a normal condition. A typical example is shown in Fig. 5, which represents a crack in a prestressed concrete structure. The so called double peak in the 1. vertical Eigenfrequency, effected are mainly the lower frequencies, indicates a variation of stiffness with a variation of amplitude, i.e. traffic loading. In this case the evaluation of periods with passenger car loading provides the lower frequencies as the case with truck loading. This indicates, that the crack is open under normal conditions and closes when trucks excite this structure. Feeding this information into the finite element model it can be calculated that a crack, reaching from the bottom of the structure 60 cm into it, is active. The location of the crack was also determined, to be a construction joint. This theory has been confirmed through measurement on other structures, with well known active cracks.

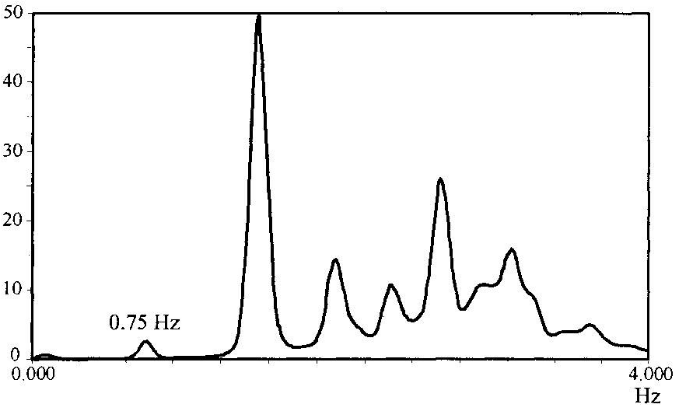

Fig. 4 ANPSD of Brigittenau

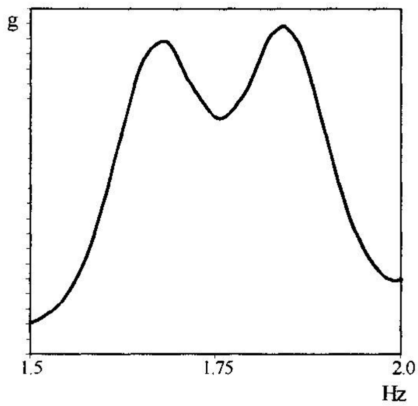

Fig. 5 Double peak

6. Conclusion

The promising results of the ambient vibration tests make it necessary to invest in further development of the damage identification tools. It will not be possible to find easy and closed solutions for most of the problems. Therefore an identification routine based on Fuzzy Logic will be necessary. It has been started already to collect relevant results of bridges as many as possible. These will be stored in a data bank, which will form the basis for comparison of cases. Although it is clear, that it will still take a long time to make these methods simple, the proof has been provided, that it works. A key issue of the subject is the education of bridge engineers in dynamics and monitoring to provide the basis for the understanding of the procedures and physics. For this purpose more major demonstration projects shall be implemented.

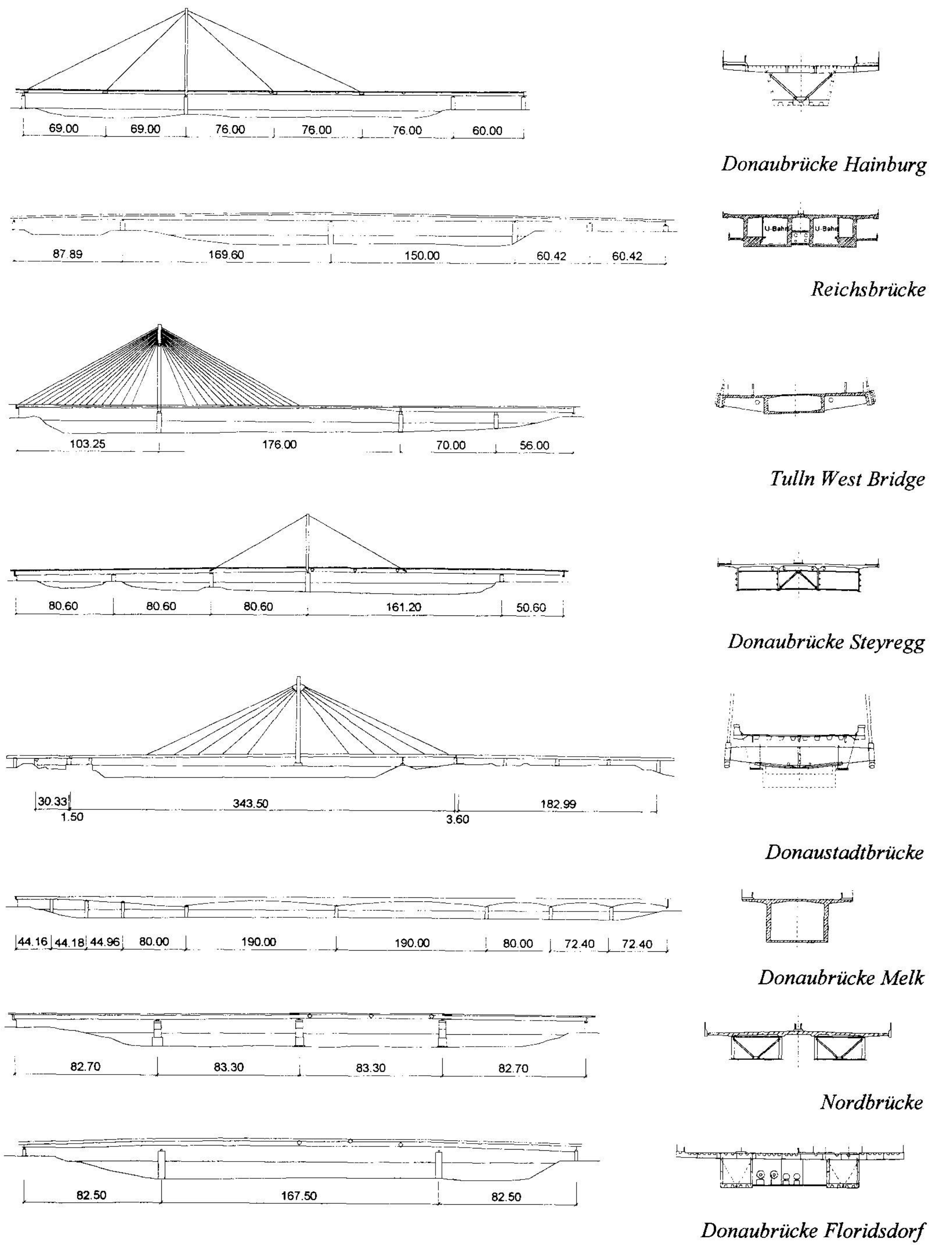

Fig. 6 Bridge dimensions