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DETERMINATION OF FATIGUE CURVES OF THE BRIDGES WITH MEMBER DECKS

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1. Introduction

When fatigue lifetime evaluation is determined through cumulative damage theory [1], important material characteristics, given by so called Wöhler's fatigue curve (or S-N curve), are taken into account. In simple cases of structural details and simple types of loads could be these material characteristics given by codes [2]. Using codes for fatigue curves determination (***Fig. 1***) of complicated structural details is questionable by reason of simplifications, which has to be accepted (use of interpolations, approximations).

Other way of fatigue curve determination leads to use of empirical equations [3.4]. This approach allows determination on the base of general material characteristics (ultimate strength, yield strength), on the type of structure (welded, bolted, riveted), on the geometry shape (geometry breaks, notches).

The last and the best approach of fatigue curve determination of complicated structures is through experimental fatigue tests of their critical structural details (Fig.2). However, also in this case are final results only assessments. The reason consist in simplifications of tested specimens, which has to be applied (more or less) during their fabrication, fixation to testing stand or by mode of loads. Experimental determination is expensive and time-consuming. In spite of that, experimental determination of fatigue curve is the best way to achieve qualitatively best results (exactness).

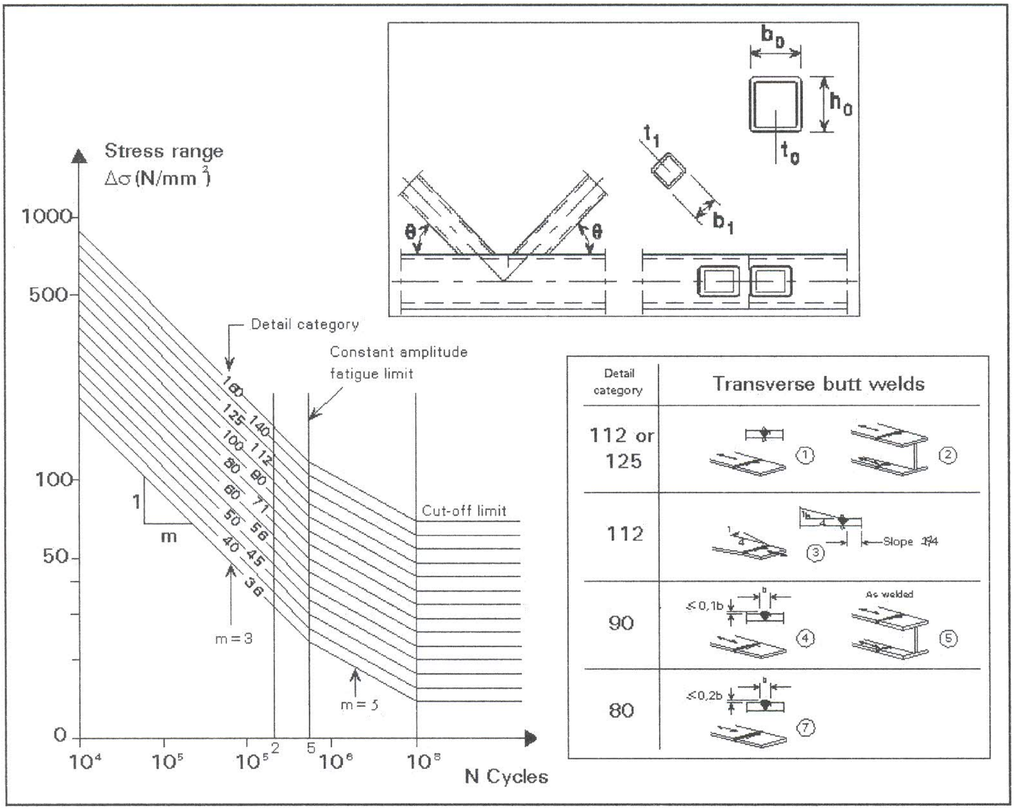

Fig. 1 Example of S-N detail categories (Euro codes)

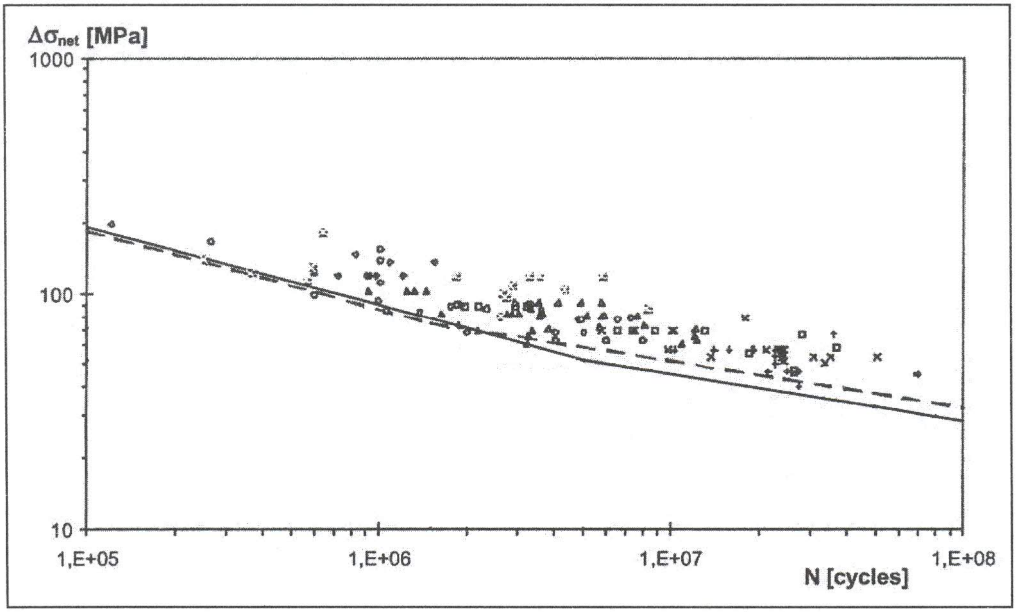

Fig. 2 Experimental determination of S-N curve

2. Structural detail

Importance of fatigue structural detail shall be always taken into account. In the case of investigated steel bridge was critical structural detail given by type of the bridge structure – full plated main girders with member deck (*Fig. 3*).

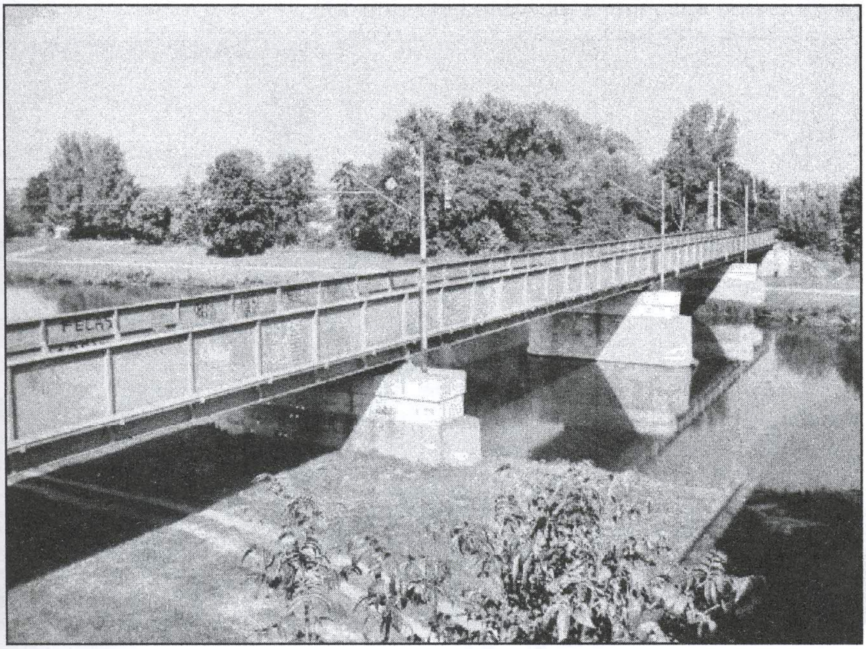

***Fig. 3** Railway bridge, Rosice nad Labem – Hradec Králové (Czech Republic)*

A fatigue crack occurred in the member deck at the place of connection between longitudinal and cross beams (*Fig. 4*)

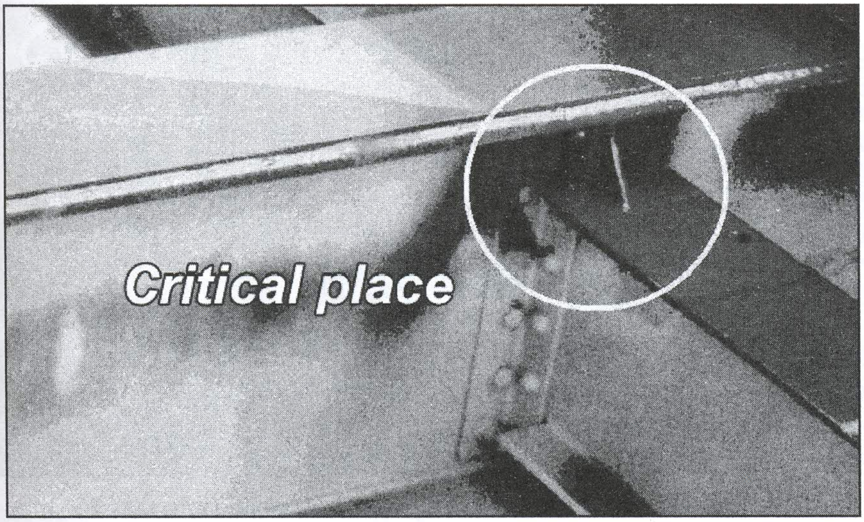

***Fig. 4** Critical fatigue construction detail of the bridge*

3. Tested specimens

To determine the material characteristics, the Wöhler curves in case of fatigue strain, physical samples were prepared with a shape corresponding to the monitored structural intersection. By reason of spatial arrangement and force limits of dynamic stand (***Fig. 5***) were tested specimens fabricated in scale 1:2.

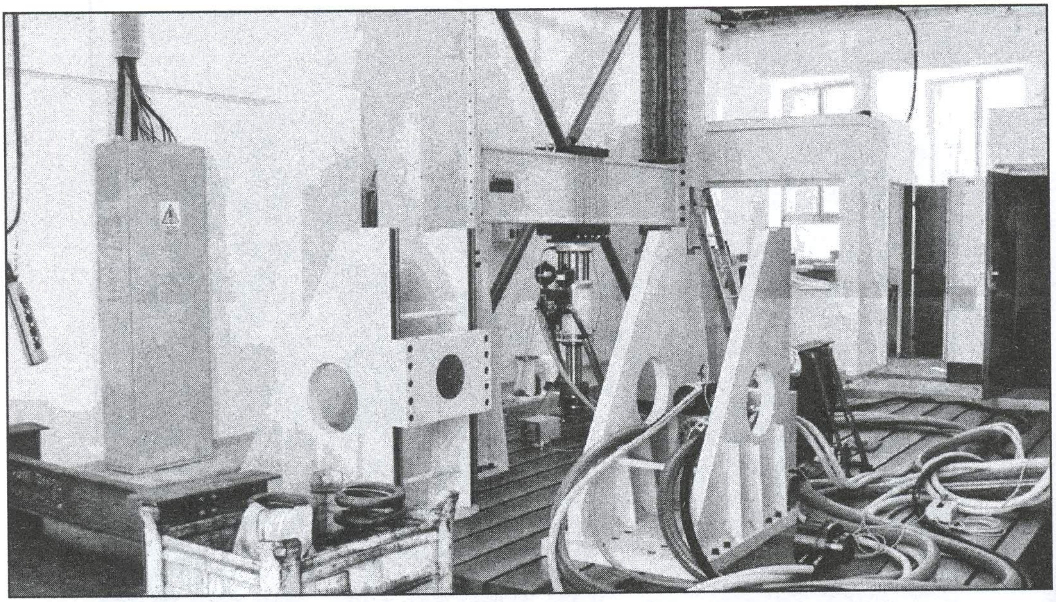

Fig. 5 *Dynamic stand*

Final shape of specimens was designed as two armed cantilever given by one cross beam and two half-armed longitudinal beams (***Fig. 6***, ***Fig. 7***).

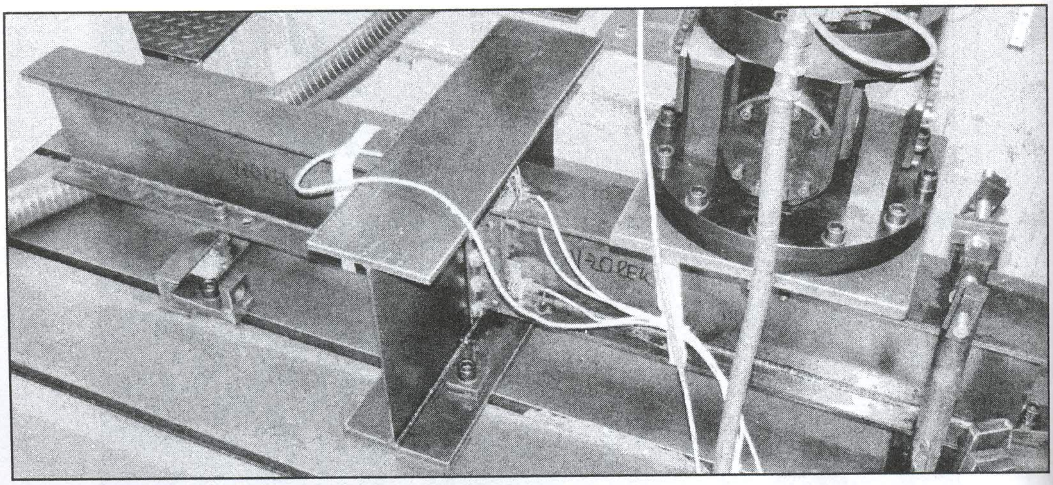

Fig. 6 *Axonometric view on specimen installed into stand*

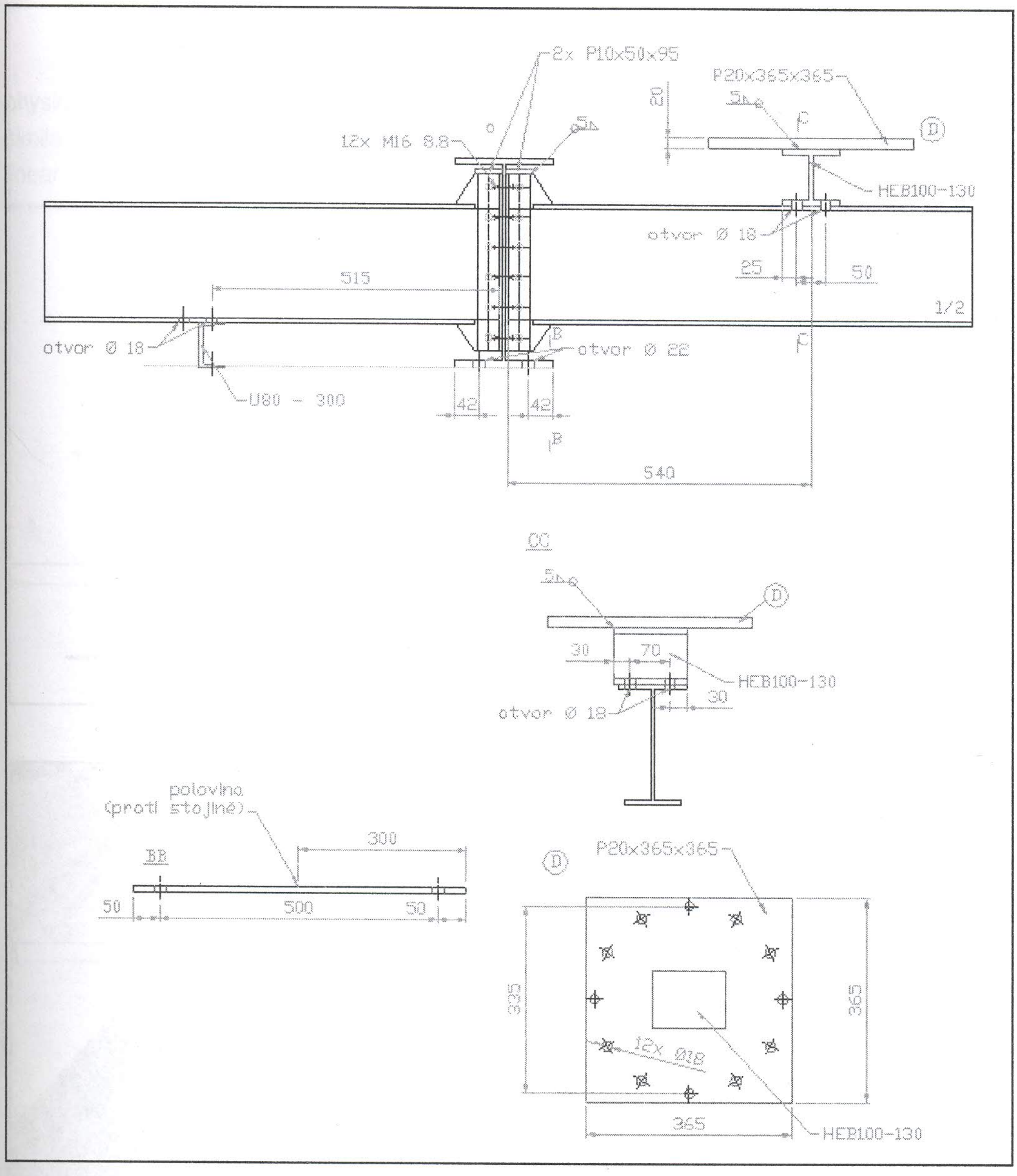

Fig. 7 Design of specimen

The manner of loading is described on the schema (***Fig. 8***). Longitudinal beam in this case worked as cantilever, which was unstable under load (cross drifting, twisting). On this account was accepted solution called "fork" with special fixation of beam, which allows vertical displacement and fixed others (***Fig. 9***).

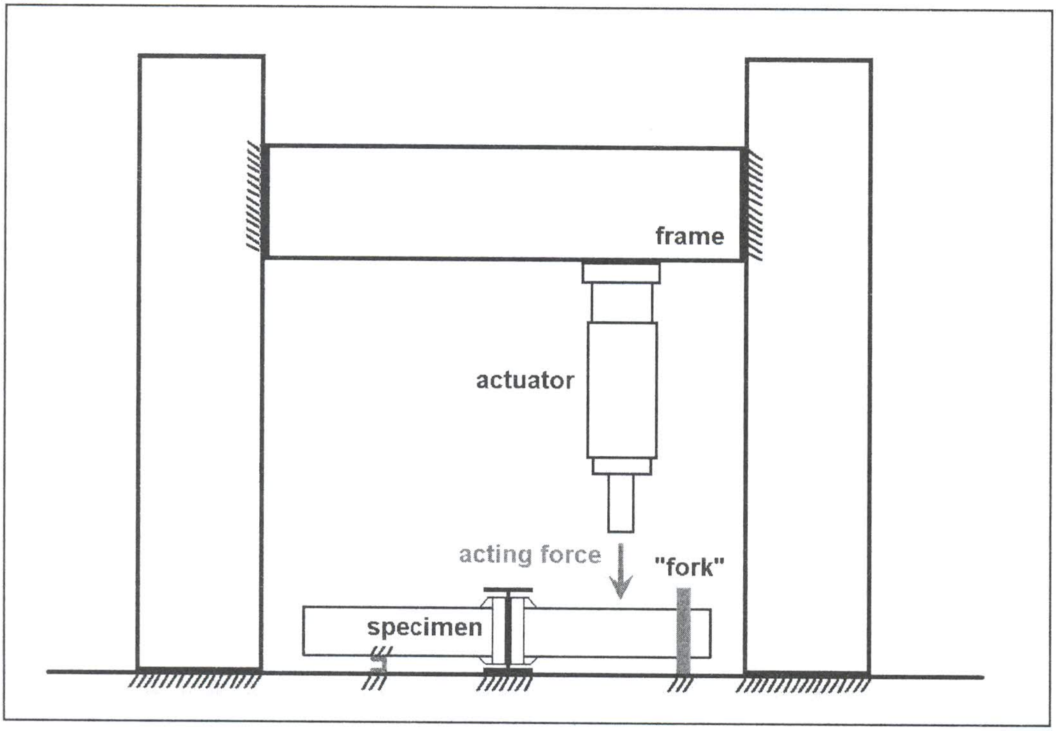

Fig. 8 Load set

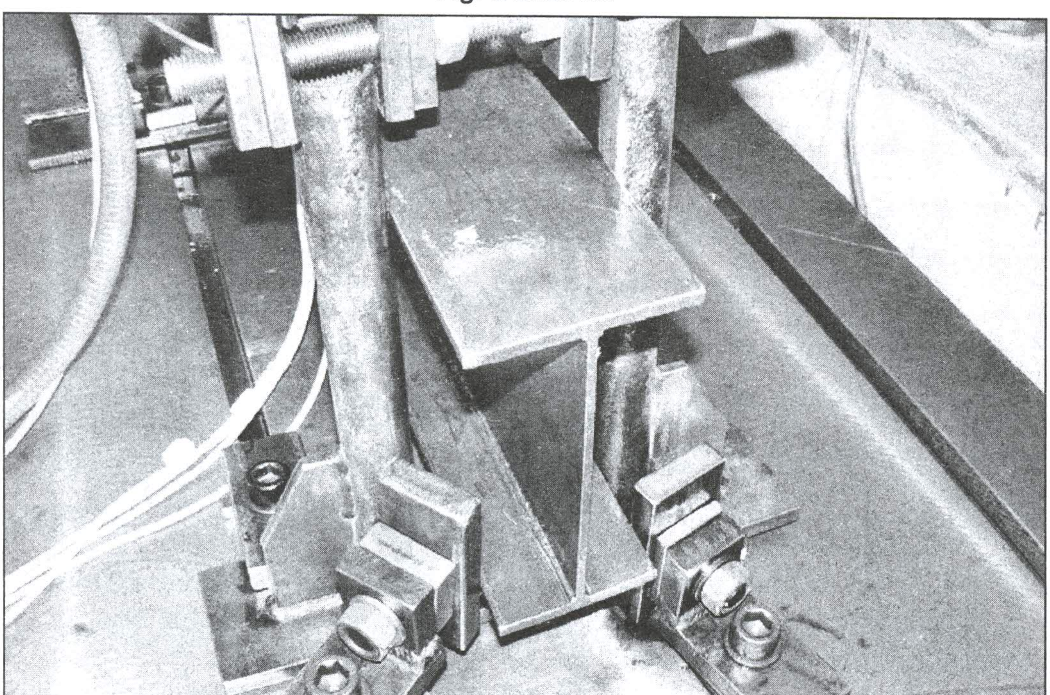

Fig. 9 "Fork"

4. 3D models

The purpose of the 3D - FEM modeling was to determine stress flow at the physical model and on the base of FEM results to modify physical model in shape with similar behavior as real structural detail afterwards. All FEM models were solved as linear. By gradual progress were three FEM models compiled (***Fig. 10***).

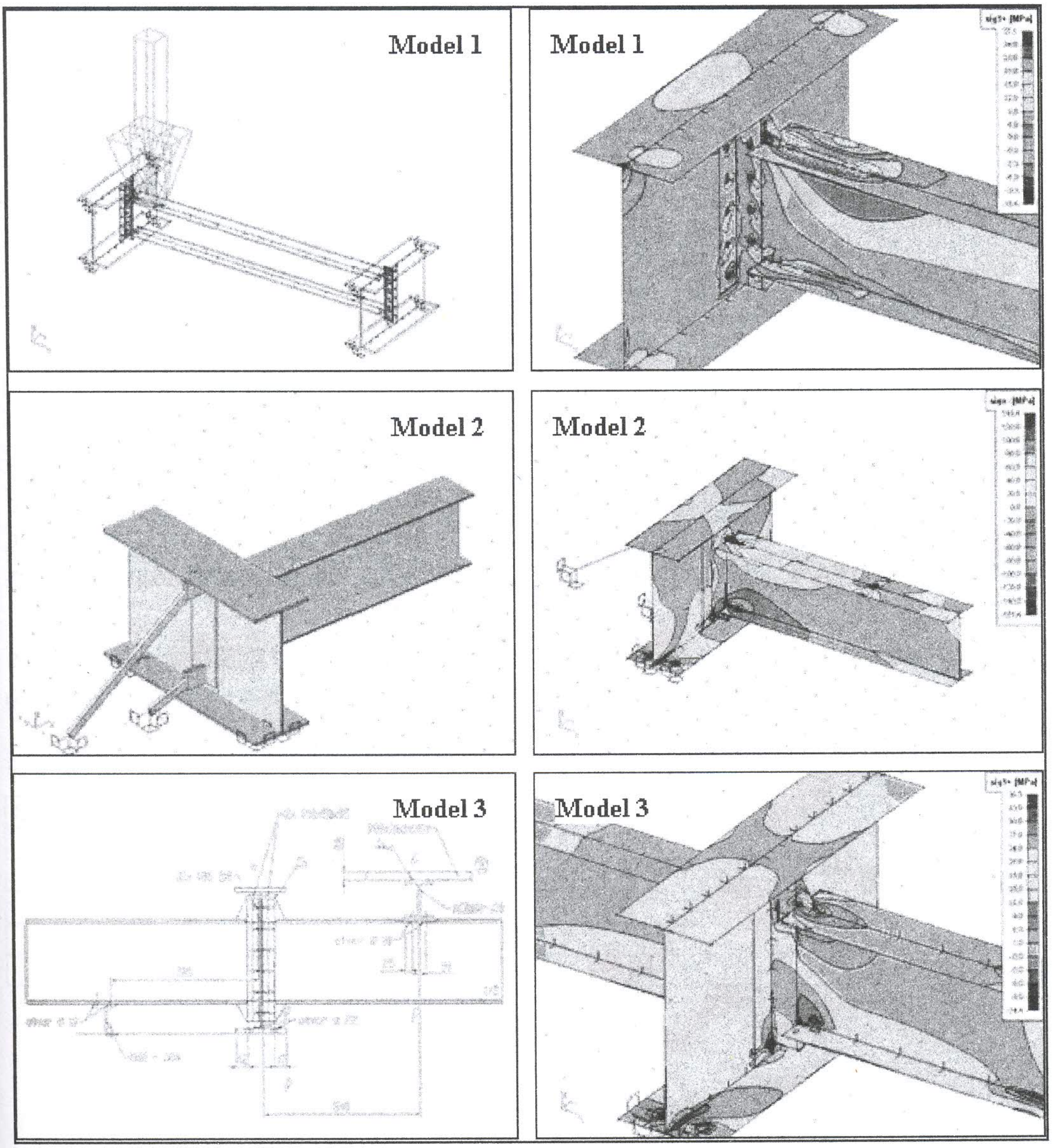

Fig. 10 *FEM models*

Stresses at the critical place and at the place of reference strain gauge were determined due to FEM model (***Fig. 11***).

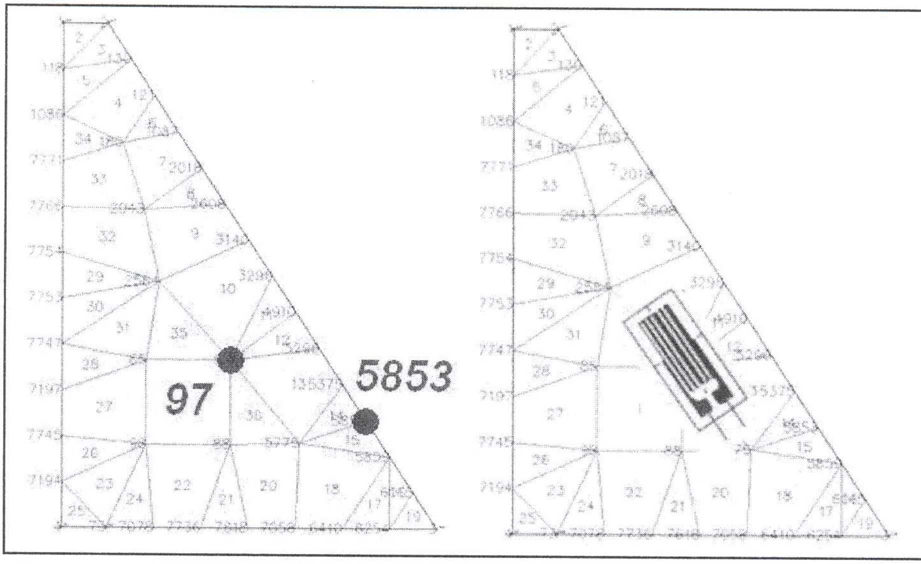

Fig. 11 *Identification of stresses at the reference place, location of strain gauge*

5. Fatigue curve determination

Experimental determination of fatigue curve for given structural detail (tested specimens) was provided by use of laboratory for dynamic and static tests, located in experimental base of Jan Perner Transport Faculty. This laboratory was established in 2006.

Tested specimens were equipped by strain gauges (***Fig. 12***). Function of gauges was to determine stress flow at gauges positions and to verify suitability of specimens in connection with real behavior of structural detail on the real bridge.

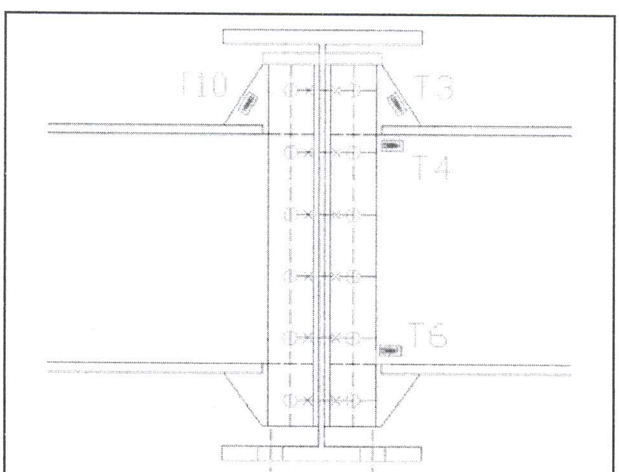

Fig. 12 *Strain gauge positions*

Test results

A total number of five testing samples (physical models) was prepared and one sample was eliminated during dynamic testing (***Fig. 13***).

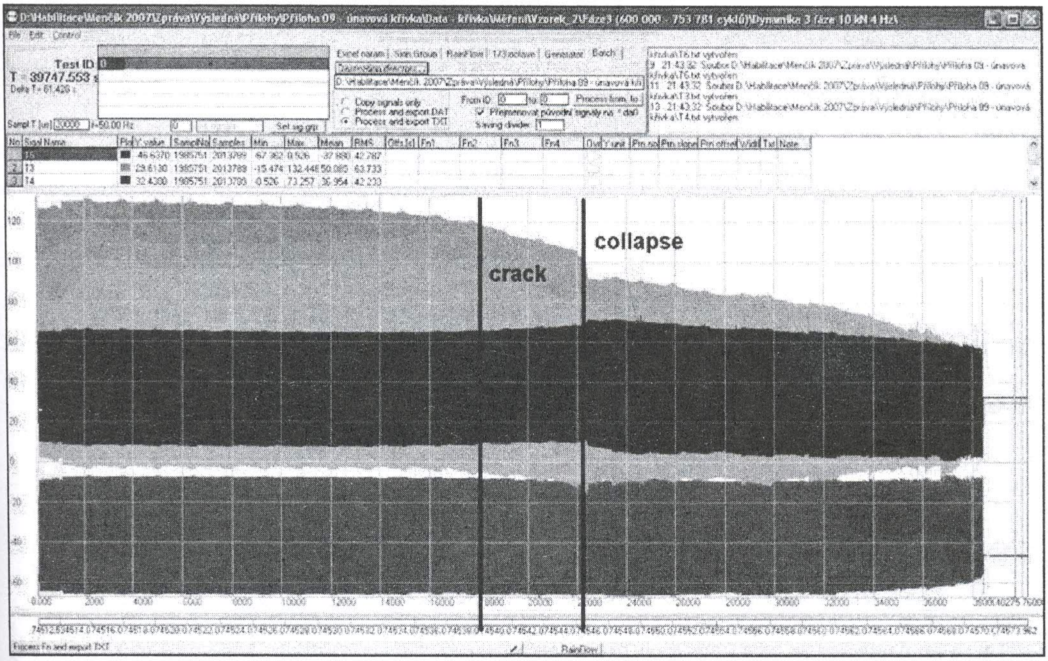

Fig. 13 *Partial stress data record*

Resultant values of loads, stresses in critical detail and experimentally determined numbers of cycles were:

Tab. 1 *Test results*

Specimen	Load [kN]	Stress in critical place [MPa]	Cycles till a crack
1	10	222	630 000
2	15	312	75 000
3	8	183	2 115 000
4	9	204	1 150 000
5	11	237	420 000

Fatigue curve

Fatigue curve determined experimentally:

$$\log N = \log a - m \times \log \Delta\sigma_R , \qquad (1)$$

On the base of results mentioned above (***Tab. 1***) was fatigue constructed as regression curve (***Fig. 14***, ***Fig. 15***).

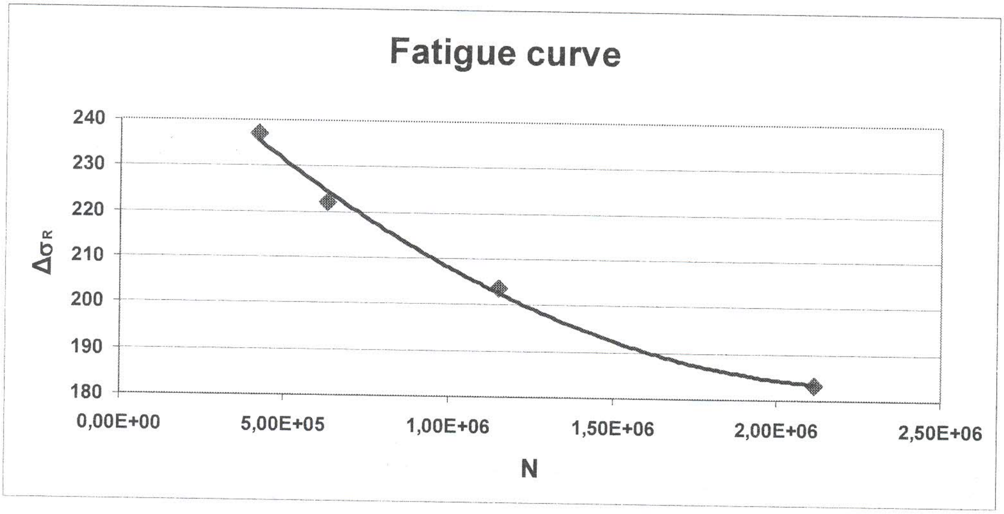

Fig. 14 Fatigue curve

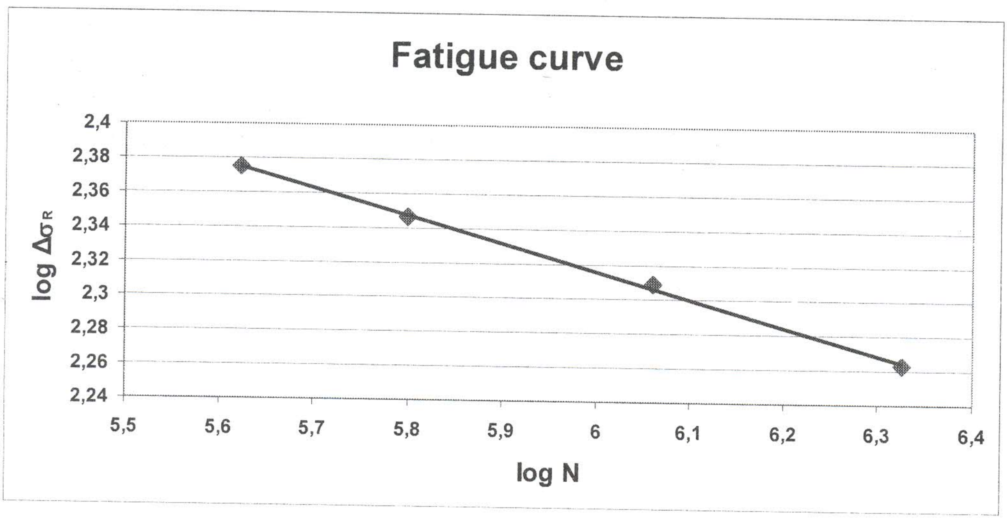

Fig. 15 *Fatigue curve – logarithmic expression*

Results fatigue curve characteristics (by use of regressive curve):

log a = 20,666 m = 6,337

6. Conclusion

Fatigue curve determination of structural detail is difficult from computer, experimental and financial point of view. With regard to geometry dimensions of bridge structure is mostly necessary take into account simplifications, which may not influence quality of results.

Important aspect of fatigue curve determination is referential place of structural detail in which is possible presume fatigue crack growing. The fatigue curve shall be determined for this specific place. In many cases is not possible to measure stresses exactly in mentioned place. The way of exact determination could be to measure close to given detail and by use of FEM model to recalculate stress values into critical place afterwards.

These conditions were met in given example of experimental fatigue curve determination. As a result we obtained fatigue characteristics, which were different to standards.

Acknowledgment

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References

1. FRÝBA L. *Dynamics of railway bridges*, Thomas Telford, London 1996,
2. Eurocode 3: *Design of steel structures – Part 1-9:Fatigue*, 2005 CEN,
3. CULEK B. ml. *Analýza přesnosti predikce únavové životnosti ocelových železničních mostů*, Diploma thesis, Pardubice 1998,
4. VOJTÍŠEK J. *Výpočty a ověřování životnosti strojních částí namáhaných proměnlivými kmitavými silami*, Ústřední výzkumný ústav Škoda 1976,
5. SCIA Group nv: SCIA.ESA PT – user manual, 2007,

Resumé

STANOVENÍ ÚNAVOVÝCH KŘIVEK MOSTŮ S PRVKOVÝMI MOSTOVKAMI

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Únavová životnost ocelových mostních konstrukcí závisí na materiálových charakteristikách. V případě teorie kumulace únavového poškození jsou materiálové charakteristiky dané únavovou Wöhlerovou křivkou. Únavová životnost konstrukce jako celku (např. mostů) závisí na únavě kritického detailu (konstrukční detail s nejnižším poměrem únavové pevnosti a napětím od zatížení). Stanovení únavových křivek kritických detailů je možné pomocí norem (tabelizace), empirických vztahů nebo experimentálně.

V článku je popsán experimentální přístup stanovení únavové křivky daného konstrukčního detailu (spojení podélníku a příčníku – prvková mostovka ocelového mostu). Experiment byl prováděn na ocelových vzorcích v měřítku 1:2.

Summary

DETERMINATION OF FATIGUE CURVES OF THE BRIDGES WITH MEMBER DECKS

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Fatigue lifetime evaluation of a steel bridge structure depends on material characteristics. In the case of fatigue cumulative damage theory are the material characteristics given by fatigue Wöhler's curve. Fatigue lifetime of complex structures such as steel bridges depends on their fatigue critical details (structural details with the lowest ratio of fatigue strength and load stress). Determination of fatigue curves of critical details is possible through codes, empirical equations or experimentally.

In the paper is described experimental approach of fatigue curve determination of given structural detail (connection of longitudinal and cross beams – member deck of steel bridge). Experiment was performed on steel specimens in given scale 1:2.

Zusammenfassung

DIE BESTIMMUNG DER ERMÜDUNGSKURVEN DER BRÜCKEN MIT DEN FAHRBAHNROSTEN

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Die Ermüdungslebensdauer der Stahlbrücken hängt von den Materialbezeichnungen ab. Im Fall der Teorie von der Kumulation der Ermüdungbeschädigung sind die Materialzeichnungen durch die Wöhlerskurve gegeben. Die Ermüdungslebensdauer der ganzen Konstruktion (z. B. der Brücke) hängt von der Ermüdung des kritischen Details (das Konstruktionsdetail mit dem niedersten Verhältniss der Ermüdungfestigkeit und der Spannung von der Belastung). Es ist möglich die Ermüdungskurven der kritischen Details mittels der Normen, der empirischen Bezügen oder der Experimentalversuche festzulegen.

Im Beitrag ist der Experimentalansatz von der Bestimmung der Ermüdungskurven des bestimmten Konstruktionsdetails (die Längsträger- und Querträgerverbindung) beschrieben. Das Experiment wurde auf den Stahlprüflingen im Maßstab 1:2 durchgeführt.