Information Technology for Concrete Bridges Condition Evaluation and Monitoring

Jan BIEN
Ph.D.
Wroclaw University of Technology
Wroclaw, Poland

Summary

Evaluation of condition of concrete bridges is very often based on a mixture of precise data and fuzzy or uncertain information. Application of computer tools supporting this process requires proper technology for information acquisition, representation and processing. Presented technology of the multi-level hybrid networks integrates symbolic and non-symbolic knowledge representation. The proposed expert tools, based on hybrid networks, utilise both data base and knowledge base of the computer system and confirm usefulness of this information technology.

Keywords: Bridge, concrete, condition, expert system, network, fuzzy logic, hybrid network.

1. Introduction

Development of the bridge infrastructure and growing expectations of the users of transportation network require more and more advanced methods of bridge condition assessment and monitoring by means of the computer-based Bridge Management Systems (BMS) [1], [2], [3], [4]. A large variety of information taken into account in the evaluation of concrete bridge structure requires proper tools for information acquisition, processing and utilisation. Procedure of assessment and monitoring of concrete bridge condition in an advanced data- & knowledge-based BMS is presented in *Fig. 1*. The following main elements of the proposed methodology can be distinguished:

- *model of structure geometry* (non-dimensional representation, one-, two- or three-dimensional models) defined by the applied methods of the computer graphics;
- *model of bridge damages*, including: classification of damages, quantitative and qualitative description of damages, as well as damage location;
- *expert tools* with the ability of learning, recognising and concluding, supporting processes of bridge condition assessment and forecast for the time horizon defined by the system user.

Analysis of information used in the evaluation of the concrete bridge condition confirms that decisions are very often based on fuzzy information and information of various degree of uncertainty [5], [6], [7], [8]. Together with the precisely defined information (e.g. geometrical dimensions) also information of imprecise, fuzzy definition (serviceability, etc.) as well as practically non-defined terms (e.g. visual impression, aesthetics) are used. As measures in the bridge evaluation process can be applied precise numbers and fuzzy linguistic values (e.g. intensive, small, valuable) or fuzzy numbers (about 2, between 4 and 6, etc.). Taking into account two criteria: precision of definitions and precision of measures, classification of the basic types of information [4] is presented in *Table 1*.

Table 1 Types of Information

Measure of Information	**Definition of Information**		
	Precise (P)	Fuzzy (F)	Undefined (U)
Precise (P)	PP	FP	UP
Fuzzy (F)	PF	FF	UF

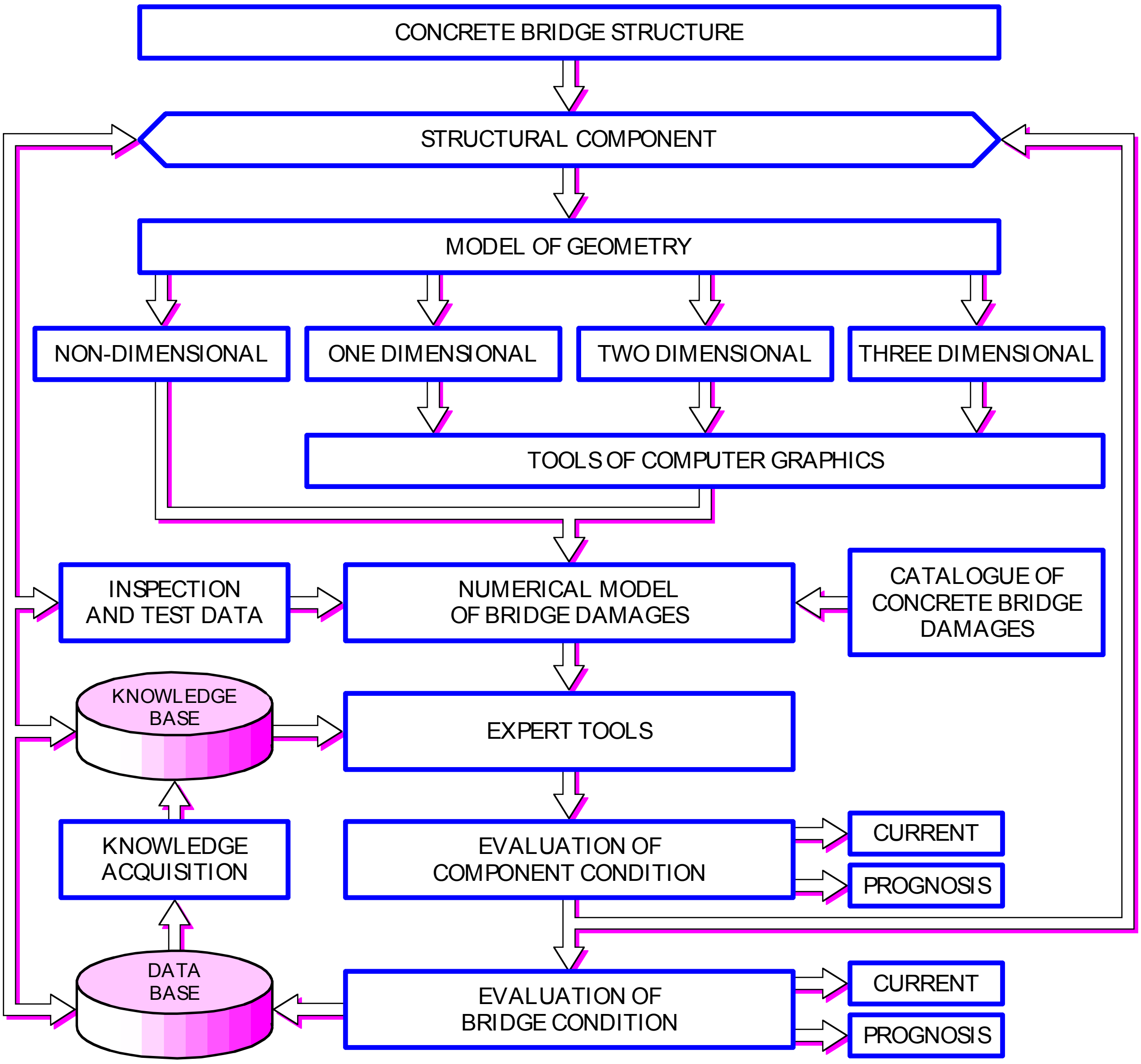

Fig. 1 Procedure of assessment and monitoring of concrete bridge condition in knowledge-based BMS

2. Technology of multi-level hybrid networks

For integration of all types of available information in one computer tool a multi-level hybrid network technology can be applied [4], [9], [10]. Procedure of the expert tool creation is presented in *Fig. 2*. The main steps in the process are as follows:

- on the information level - knowledge acquisition and analysis for selection of the representation method: symbolic or non-symbolic;
- on the component level – decomposition of the modelled problem and selection of the type of component representing each sub-problem, creation of the component, testing and evaluation;
- on the hybrid network level – design of architecture of the hybrid network, defining connections between individual components, testing and evaluation of the final expert tool.

Process of component creation and hybrid network design can be supported by the computer system NEURITIS [4] developed at the Wroclaw University of Technology. In this system the hybrid network - according to the problem that should be solved and to the type of available information - can be built of the following components:

- neural component, based on the non-linear multi-layer neural networks trained by means of the supervised back propagation method;

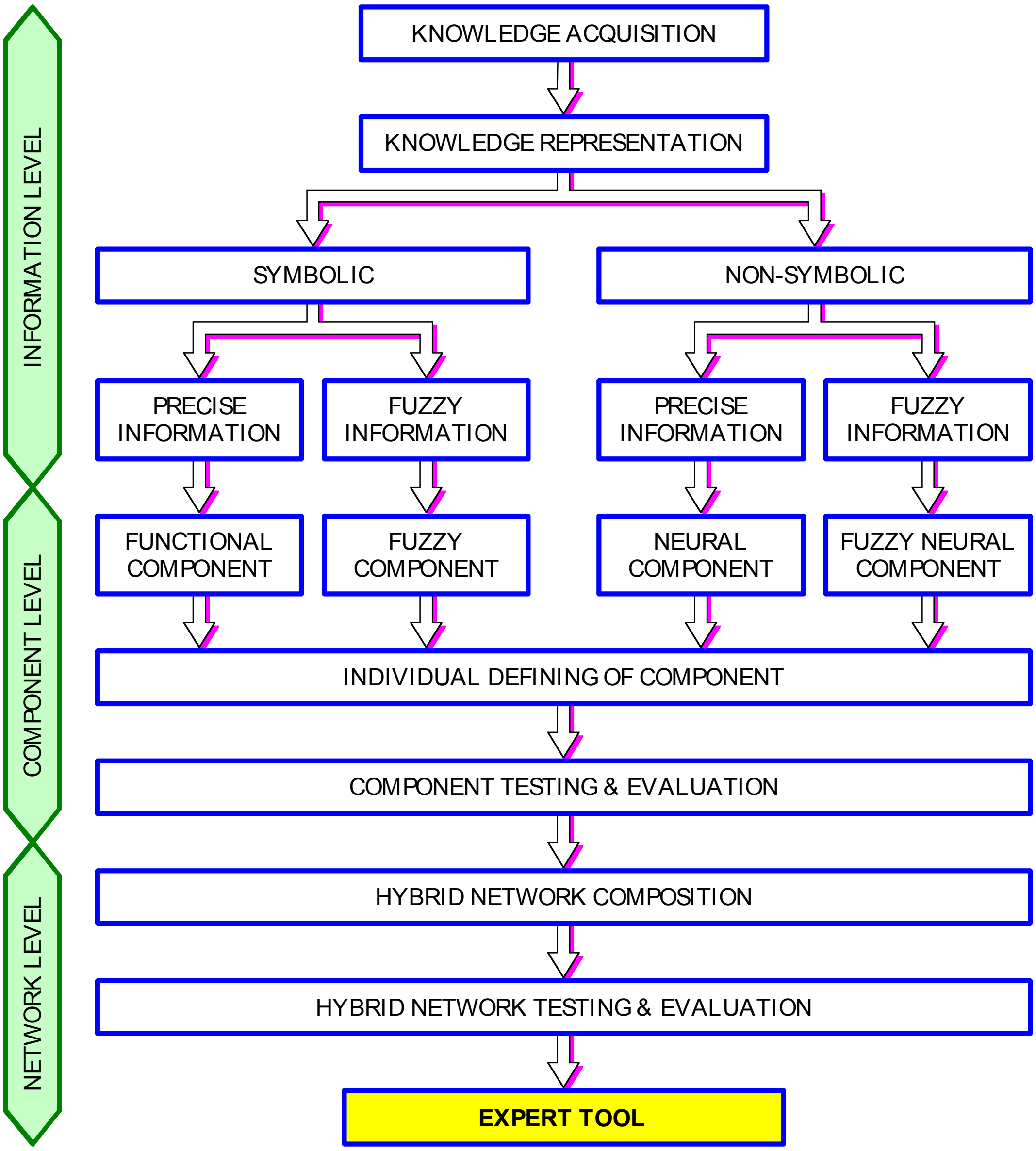

Fig. 2 Creation of expert tools based on the technology of multi-level hybrid networks

- fuzzy component, based on the fuzzy logic with the possibility of fuzzy inference;
- fuzzy-neural component, integrating fuzzy logic and neural network technique;
- functional component that enables implementation of the analytical functions.

Components of all types can be used in one network of the multi-level architecture. Number of the components as well as number of the network levels is not limited and depends on the specific application needs.

3. Expert tools supporting evaluation of bridge condition

Described information technologies are applied in Poland for few years in the Railway Bridge Management System "SMOK" [11] developed for the Polish State Railways (PKP). Two expert tools are implemented in the system: the Bridge Evaluation Expert Function (BEEF) and the Prognosis Expert Function (PEF). Procedure of evaluation of the concrete bridge condition based on results of the visual inspections is presented in *Fig.3*. Technical data of each component (support, main girder, deck, etc.) of the concrete bridge are stored in the system data base and are used for identification of the component construction (plate girder, box girder, etc.) as well as for recognizing material (plain concrete, reinforced concrete, prestressed concrete). Damages detected during inspections are identified by means of the "Catalogue of Concrete Bridge Damages" (*Fig. 4*) and parameters of each imperfection (intensity, extent, location) are defined. Numerical model of the bridge damages is saved in the data base. Both technical and inspection data are used by the BEEF for evaluation of the current technical condition (*Fig. 5*). The Bridge Condition Index (BCI) with the value between 5.0 (like-new condition) and 0.0 (failure) is used for condition rating. Dedicated hybrid network is used for assessment of each combination of the bridge element type, construction and material.

Proposed general classification of the typical damages of the concrete bridges is presented in *Table 2*. For unification of the damage identification in the presented evaluation system the damage catalogue [12] has been elaborated (*Fig. 4*).

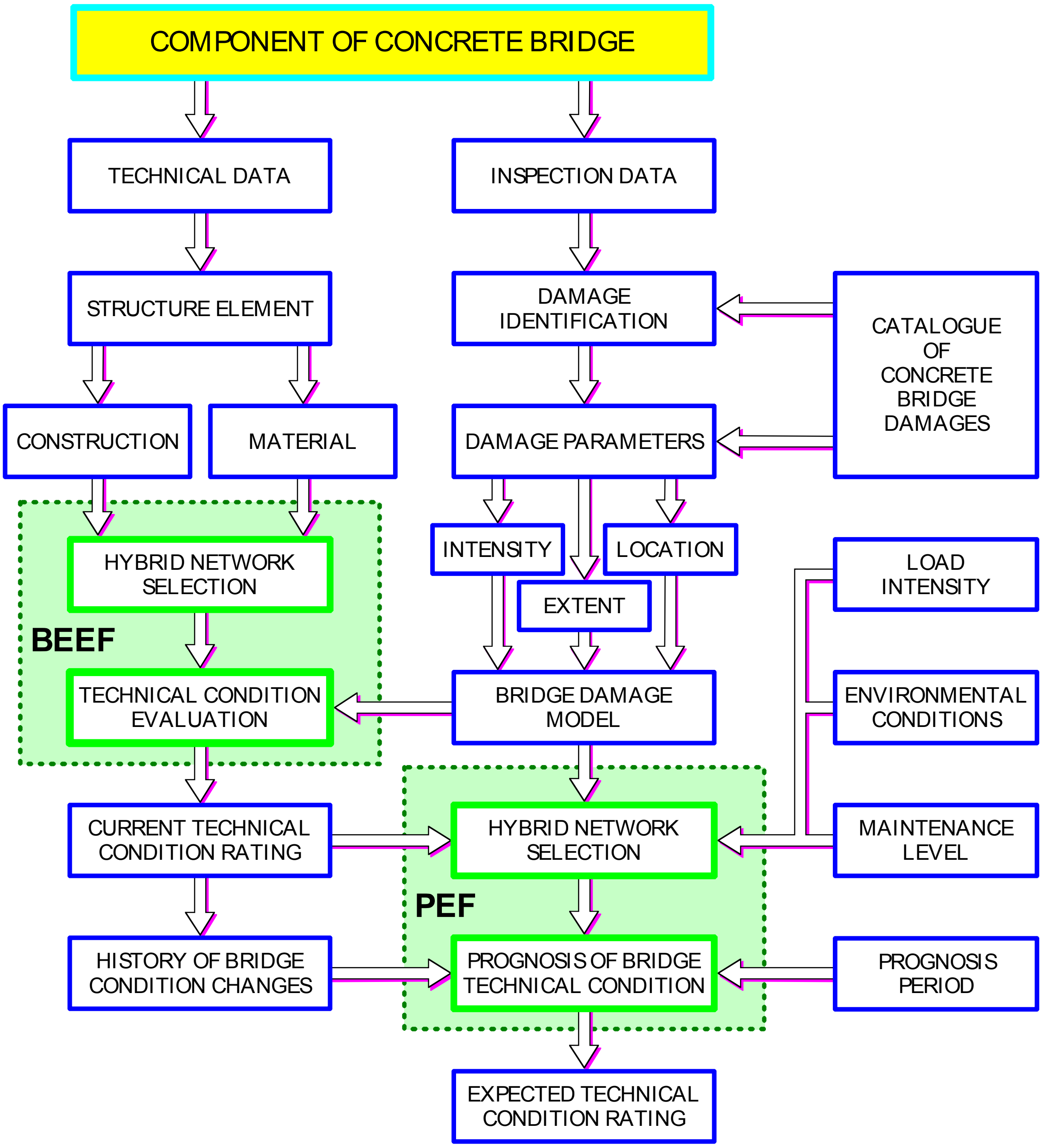

Fig. 3 Evaluation and forecast of concrete bridge condition by means of expert tools: the Bridge Evaluation Expert Function and the Prognosis Expert Function in the RBMS "SMOK"

Table 2 Typical Damages of Concrete Bridge Structures

Damage Type	Damage Kind
1. Deformation	permanent
	temporary
2. Material destruction	change of physical properties
	change of chemical properties
3. Material discontinuity	crack
	fracture
4 Losses of material	loss of concrete
	loss of reinforcement
	loss of prestressing tendons
5. Damages of protection	structural damages
	change of physical properties
	change of chemical properties
6. Displacement defects	dislocation
	displacement limitation
7. Contamination	dirtiness
	vegetation

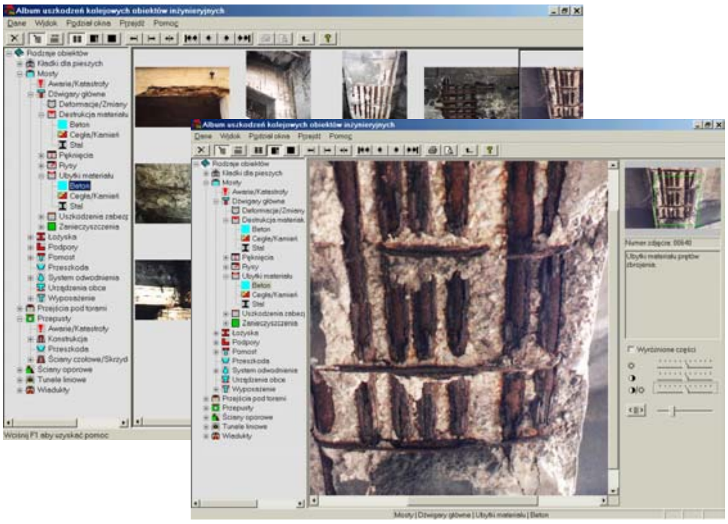

Fig.4 Catalogue of bridge damages

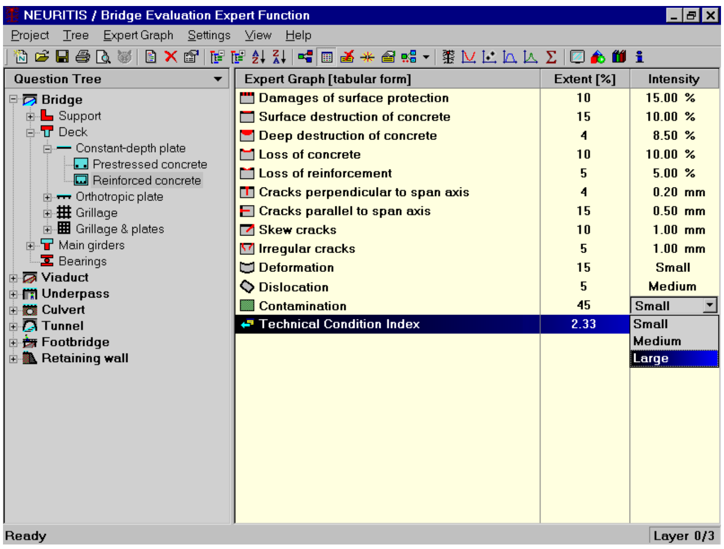

Fig. 5 Expert tool BEEF in the system "SMOK"

The catalogue presents few hundreds of the examples of the concrete bridge damages sorted by the bridge components (supports, main girders, decks, etc.), component construction and material. Each example consists of the photo (photos) and short description of the damage as well as explanation of the damage classification.

Two-level classification presented in *Table 2* was used for defining of the "List of Typical Damages" for each combination of the following parameters: type of structural element, construction and material. As an example the list for plate deck made of the reinforced concrete is shown in *Fig. 5*. Methodology of defining of the damage intensity and extent is presented in the damage catalogue for each damage distinguished in the classification.

On the basis of the history of the condition changes and taking into account conditions of the bridge operation (loads, environment, maintenance quality) the Prognosis Expert Function (*Fig. 3*) can be used for forecast of the expected condition after the prognosis period, defined by the system user [10].

4. Conclusions

Presented technology of the multi-level hybrid networks seems to be a powerful and effective tool supporting evaluation and monitoring of the concrete bridge condition. The main advantages of the presented methodology can be listed as follows:

- integration of the diverse types of information on various levels of uncertainty in one expert tool;
- effective composition of the data and knowledge in the process of bridge structure evaluation;

- possibility of modification or replacement of the hybrid network components without decomposition of the whole network;
- possibility of development of new types of the components as well as implementation of the mechanisms of self-modification (machine learning).

As difficulties of the technology can be noticed:
- time-consuming process of the knowledge acquisition from experts, data bases, etc.;
- long time necessary for preparation of the components and for creation of the networks;
- required cooperation of large group of specialists (bridge experts, knowledge engineers, computer scientists, etc.).

Practical applications of the proposed procedure of the bridge condition evaluation confirm usefulness of the method, but the technology needs continuation of the research to create more advanced and effective expert tools.

References

[1] BRITO DE J., BRANCO F., "Concrete Bridges Management Using Knowledge-Based Systems", *Conference on Maintenance of Bridges and Civil Structures*, Paris, France, 1994, pp. 383-392.

[2] DAS P.C., "New Developments in Bridge Management Methodology", *Structural Engineering International*, Vol. 8, No. 4, 1998, pp. 299-302.

[3] ENRIGHT M. P., FRANGOPOL D. M., "Survey and Evaluation of Damaged Concrete Bridges", *Journal of Bridge Engineering*, Vol. 5, No. 1, 2000, pp. 31-38.

[4] BIEN J., *Modelling of Bridge Structures During Operation* (in Polish), Wroclaw University of Technology, Wroclaw, 2002, 348 pp.

[5] ZADEH L. A., "Fuzzy Sets and Information Granularity", *Advances in Fuzzy Set Theory and Applications*, North-Holland, Amsterdam, 1979, pp. 3-18.

[6] MELHEM H.G., ATURALIYA S., "Bridge Condition Rating Using Fuzzy Sets and an Eigenvector of Priority Settings", *Computing in Civil Engineering*, ASCE, No. 2, 1994, pp. 1908-1915.

[7] BIEN J., "Expert Functions in Bridge Management Systems", *Transportation Research Circular*, No 498, 2000, pp. H-3/1-15.

[8] BIEN J., "Neural Networks in Bridge Management Systems", *Structures Congress of the American Society of Civil Engineers „Advanced Technology in Structural Engineering"*, Philadelphia, USA, 2000, pp. 1-8.

[9] BIEN J., "Multi-Level Hybrid Networks in Bridge Management Systems", *World Multiconference on Systemics, Cybernetics and Informatics*, Orlando, 2001, Vol. II, Information Systems, pp. 316-321.

[10] BIEN J., "Hybrid Networks in Bridge Condition Evaluation and Prediction", *First International Conference on Bridge Maintenance, Safety and Management*, IABMAS, Barcelona, 2002, pp. 451-452 + CD.

[11] BIEN J., "SMOK – Integrated Railway Bridge Management System" (in Polish), *Inzynieria i Budownictwo*, Vol. 53, No. 3, 1996, pp. 180-184.

[12] BIEN J., "Scientific and Technical Basis of the RBMS SMOK. Part V" (in Polish), Wroclaw University of Technology, Institute of Civil Engineering: *Bridge Damage Classification and Identification*, Report SPR-120, 231 pp.; *Bridge Damage Catalogue*, Report SPR-119, 130 pp., Wroclaw, 1999.