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Bridge Management: A Knowledge Based Expert System Approach

Approche d'un système expert pour la gestion des ponts

Ein Expertensystemansatz für die Brückenverwaltung

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SUMMARY

This paper presents a comprehensive microcomputer based bridge analysis and rating system. The system incorporates the grillage analogy method as the analysis medium, the American Association of State Highway and Transportation Officials (AASHTO) load factor of resistance method of bridge rating. The use of expert system technology in Bridge rating has been explored in this paper.

RÉSUMÉ

Cet article présente un système informatique exhaustif destiné aux calculs de vérification et à la classification des ponts. Ce système comporte la méthode analogique en grille servant d'instrument de calcul, les hypothèses de charge d'après les règlements AASHTO et la méthode de résistance pour classer les ponts. Ce système a ainsi servi à vérifier la possibilité d'utiliser un système expert comme principe de classification des ponts.

ZUSAMMENFASSUNG

Der Beitrag stellt ein umfassendes Mikrocomputersystem für die Nachrechnung und Einstufung von Brücken vor. Das System enthält das Trägerrostverfahren als Recheninstrument, die Lastannahmen nach AASHTO-Vorschrift und die Widerstandsmethode zur Brückeneinstufung. Damit konnte die Einsatzmöglichkeit eines Expertensystems in der Brückenklassierung untersucht werden.

1. BRIDGE MANAGEMENT

Of the over half million highway bridges in the United States, 42% are classified as structurally or functionally deficient and 75% are over 50 years design life. Several factors are attributed to this, including increased live loading, conservative design, deferred maintenance and repairs, etc. These factors lead to an increased role of bridge management, which must relate to safety as well as economy. Insuring bridge safety requires a balance between the loads imposed on a bridge and the capacity of its members. The development of bridge evaluation considering the structural safety of the bridge and the safety of its users is an essential component of bridge management involving decisions on new bridge designs, closing or rating of existing bridges.

AASHTO recommends the use of higher levels of analysis (finite elements, finite difference, semicontinuum, grillage, etc.) and rating to reevaluate bridges found to be deficient. The system should take into account the states of deterioration and distress, and effort expended on inspection, evaluation, and maintenance.

The following load and resistance factor equation is used to determine the load carrying capacity:

$$RF = \frac{\phi R_n - \gamma_D D}{\gamma_L L(1+I)}$$

where
- RF = rating factor (the fraction of the rating vehicle loading allowed on the bridge),
- R_n = nominal resistance of the bridge,
- ϕ = capacity reduction factor,
- γ_D = dead load factor,
- D = dead load effect,
- γ_L = live load factor,
- L = live load effect, and
- I = impact factor.

Live load modeling is a complex aspect of the ultimate load capacity evaluation of the bridges. Important parameters in the live load model were identified which included truck configuration (truck type, axle spacing, and axle percentage of weight distribution), gross truck weight, multiple presence of trucks on the bridge, and impact which is dependent on the roadway roughness. Impact factors based on physical tests and weigh-in-motion measurement of bridges under normal traffic were reviewed and then incorporated into the knowledge domain. The maximum live load effect is usually caused by the multiple occurrences of trucks on the bridge, i.e., same lane occupancy effects. Appropriate values of the multiple truck presence factor were incorporated. Improved realistic values of the factors for the resistance, dead load and live load effects were determined based on the constructed representative knowledge domain. The resistance and live load factors also depend on the level of maintenance and inspection, the use of field measurements to estimate the girder distribution factors and the number of lanes of the bridge [1-3].

2. ANALYSIS

The grillage analogy was for analysing the bridges. It is an economical and simple method that can be fully automated using a microcomputer [4-6]. Results from the grillage analysis as applied to bridge structures is well supported by published literature [7-12], among which are Lightfoot [1964], Sowka [1967], West [1973], Hambly [1976], Cope and Clark [1984], and Bakht and Jaeger [1986]. The grillage program used in the development of the system is called BRIDGES [13].

3. EXPERT SYSTEM DEVELOPMENT

Advanced computer applications have made the practice of structural engineering much more efficient in recent years. The use of expert system technology was explored with respect to load factor selection, quantifying the bridge condition, and rating factor interpretation [14]. The *Exsys Professional* [15] shell was used in the development of the expert system ***REX*** **[RatingEXpert]**.

A modular design approach was adopted for the development of the expert system. This method made the appropriation of tasks more lucid and would facilitate further enhancements. Figures 1, 2, and 3 illustrate detailed flow charts of the three system modules showing the interaction between external programs and the knowledge base.

The system first queries for information necessary to determine values for the factors, ϕ, γ_D, γ_L, and I in the rating equation. The value of ϕ is dependent on superstructure condition, redundancy, type of maintenance and inspection, and type of steel [1,3]. The value of γ_D takes into account the accuracy of the assumed weight of the structure. The value of γ_L reflects the likelihood of extreme loads side-by-side and following in the same lane and the possibility of overloaded vehicles. The value of the impact factor, I, is calibrated according the roadway surface condition [1,2]. According to AASHTO, γ_D and γ_L, should be selected from categories which were determined from weigh-in-motion studies and structural reliability methods. This information is stored in the knowledge base.

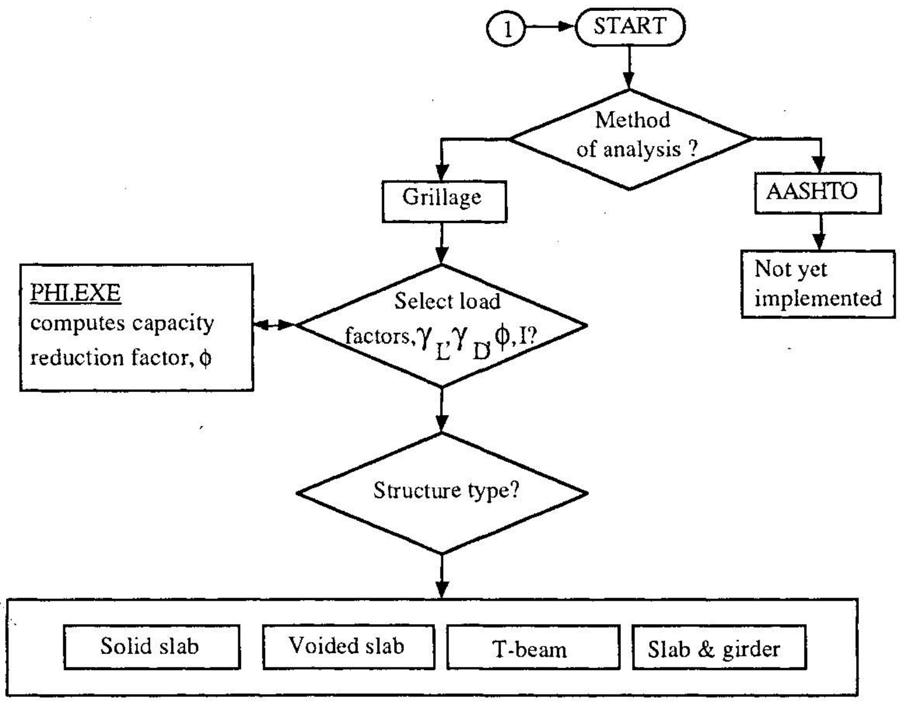

Fig. 1. Load factor selection module

After the load factor selection is complete a series of external programs are executed to generate the input for the grillage program and determine the responses. Depending on the bridge type, the user will be asked questions regarding the geometric properties particular to that bridge cross section type. Cross-sectional properties of standard cross sections are stored in a database. The system creates the grillage mesh and input in a format legible to the grillage program, BRIDGES. The idealization follows the suggestions of Bakht and Jaeger [4-6].

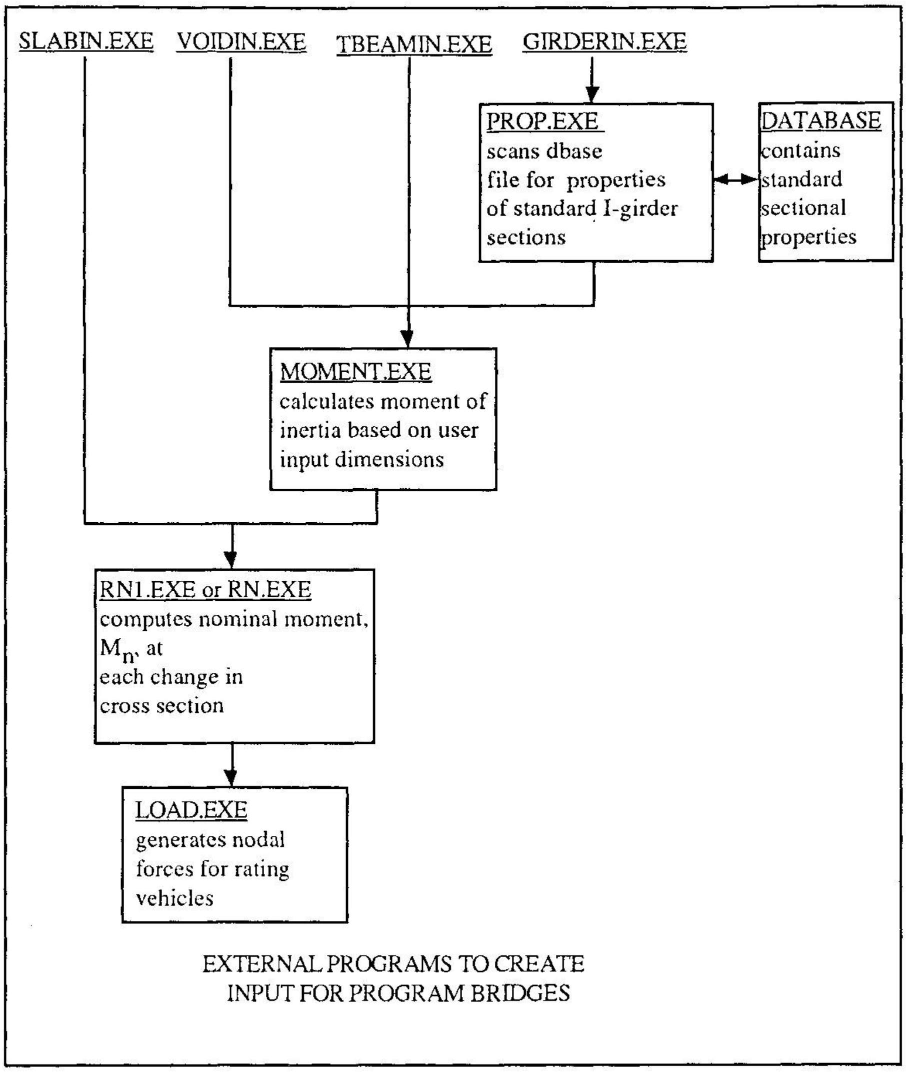

Fig. 2 Input generation module

The knowledge base has 24 built in live load configurations plus a custom load creation option. The built-in loadings include traditional AASHTO truck and lane loading configurations, current AASHTO truck configurations, and Florida truck configurations.

The program BRIDGES is executed and the maximum value of L and corresponding value of D are obtained for each span to span beam. At each variation in the transverse cross section (i.e. edge beams, sidewalks, etc.) the user is asked to provide the steel properties and the system computes the values of the resisting moment, R_n, based on AASHTO/ACI provisions [16-19]. The system then computes the rating factor for each group of grillage beams corresponding to a span to span beam on the bridge and the governing critical rating is then determined from among the rating factors.

The output of the system consists of two parts: the *Exsys Professional* output and the detailed output file. The *Exsys Professional* output contains the resistance and load factors used, the maximum moments, the governing rating factor, and an interpretation of the result. The detailed output file is more comprehensive and contains an echo of the input, a plot of the mesh, deflections at each node, the rating factors for each beam, and the governing rating factor.

4. SCOPE

The current system is capable of analyzing and evaluating simply supported solid and voided slabs, AASHTO girder and slab, and T-beam bridges [Figure 4]. The system also accommodates the presence of edge-stiffening such as sidewalks, edge beams, and parapets and additional overlays such as asphalt and concrete.

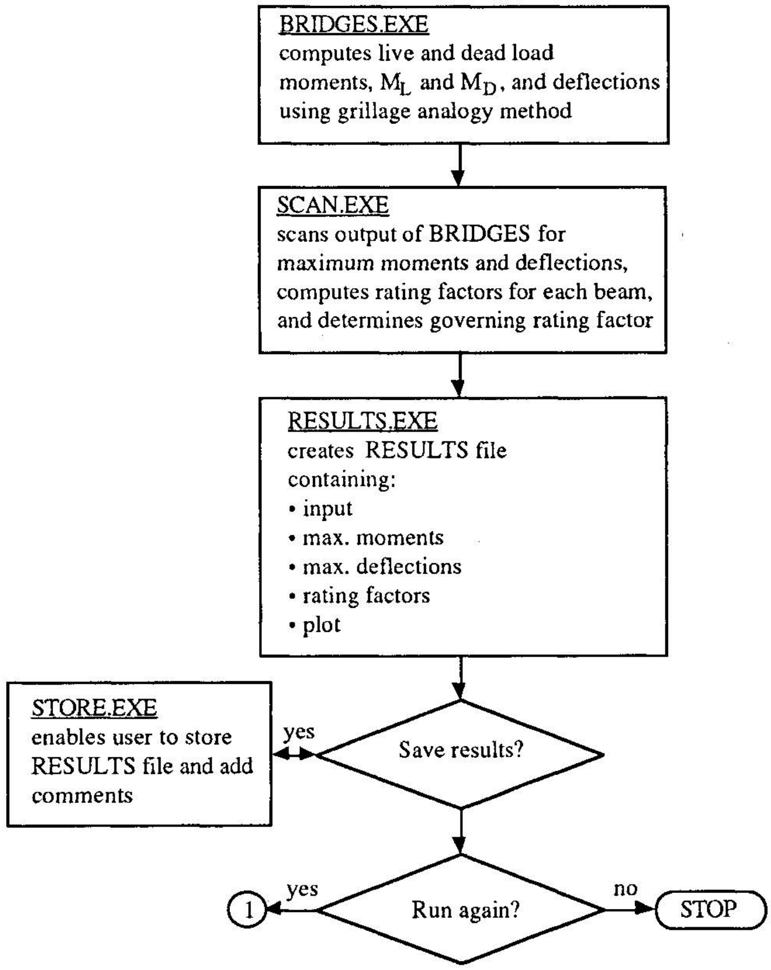

Fig. 3 Computation and results module

5. APPLICATION TO ACTUAL BRIDGE [20]

The rating results of the expert system were compared to actual field tests conducted on bridges maintained by FDOT to determine the effectiveness of the system. Figure 5 shows a portion of the output file produced by the expert system for bridge # 780021 in St. Johns County, Florida. The bridge is a solid slab bridge with edge beams and has a width of 34 feet (10.36m) and a span of 20 feet (6.10m).

The rating factor for an SU2 (34 kips; 151.24kN) rating vehicle is determined to be 2.45. This was established by the FDOT on February 26, 1992 based on incremental loading and strain measurements. The operating rating factor determined using the expert system is 2.32.

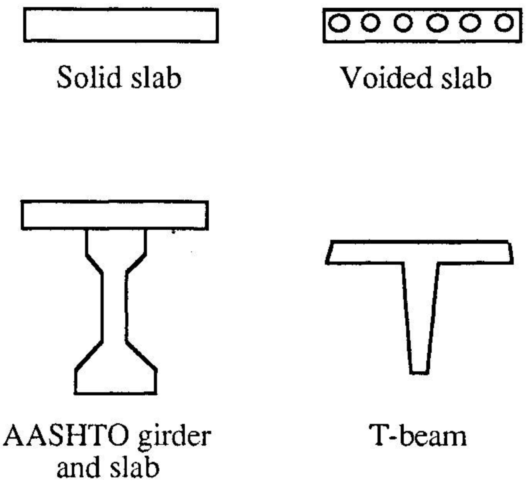

Fig. 4 Types of bridge cross-sections that are incorporated in the expert system

CRITICAL RATING FACTOR

RATING FACTOR	= 2.32	1 kip-ft = 1.356 kN-m
NOMINAL MOMENT, Rn(kip-ft)	= 61.59	
DEAD LOAD MOMENT, MD, (kip-ft)	= 6.63	
LIVE LOAD MOMENT, ML, (kip-ft)	= 8.08	

LOAD AND RESISTANCE FACTORS

Φ = 0.80
γ_L = 1.67
γ_D = 1.3
Impact Factor, I = 1.3

	RATING FACTOR	Rn (kip-ft)	ML (kip-ft)	MD (kip-ft)
BEAM 1	3.40	177.89	14.05	29.66
BEAM 2	5.38	61.59	3.58	5.76
BEAM 3	4.16	61.59	4.59	5.99
BEAM 4	3.04	61.59	6.23	6.28
BEAM 5	2.70	61.59	6.97	6.51
BEAM 6	2.32	61.59	8.08	6.63
BEAM 7	2.32	61.59	8.08	6.63
BEAM 8	2.70	61.59	6.97	6.51
BEAM 9	3.04	61.59	6.23	6.28
BEAM 10	4.16	61.59	4.59	5.99
BEAM 11	5.38	61.59	3.58	5.76
BEAM 12	3.40	177.89	14.05	29.65

Fig. 5. Partial output listing showing rating results

6. RESULTS AND CONCLUSIONS

The expert system developed in this project succeeded in providing a prototype model [21]. It provides an interface between the user and complex computer analysis programs via an expert system shell and various other conventional programs. The system is designed to be user-friendly and requires minimal computer knowledge; it is entirely menu driven and easily operable. It enables the novice, with little knowledge of bridge engineering, to analyze and evaluate the load carrying capacity of a highway bridge successfully. The tedious and mistake prone task of bridge idealization and calculation of the corresponding section properties has been automated. Mundane tasks such as the processing of large outputs and calculation of the rating factors are now performed by the computer.

The rating factors provided by the system for the four bridge types have been validated with rating factors obtained by actual field tests conducted by the FDOT.

The database containing a wide array of data pertaining to six standard cross sections is being updated with additional cross sections such as standard T-beams, cellular decks, etc. The knowledge base can be readily accessed and modified as bridge codes and expertise change and as more bridge types are added to the system. Selection of load and resistance factors based on structural reliability methods eliminated the need to evaluate a bridge based on two rating levels, inventory and operating [1]. Furthermore, utilizing the grillage analogy method eliminated the need for distribution factors in determining the live load effect.

Current work to create a more comprehensive system include: a rating for shear, a graphical input, a complete library of standard cross sections stored in the database and more emphasis on the bridge condition and load factor selection through the use of fuzzy logic is being explored [22].

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REFERENCES

1. Transportation Research Board, Load Capacity Evaluation of Existing Bridges, NCHRP Report No. 301, Washington, D.C., December, 1987.

2. Transportation Research Board, Strength Evaluation of Existing Reinforced Concrete Bridges, NCHRP Report No. 292, Washington, D.C., June, 1987.

3. AASHTO, Guide Specifications for Strength Evaluation of Existing Steel Concrete Bridges, Washington, D.C., 1989.

4. BAKHT, B., JAEGER, L. G., Bridge Analysis Simplified, McGraw-Hill Book Company, 1985.

5. JAEGER, L.G., BAKHT, B., Bridge Analysis by Microcomputer, McGraw Hill Book Company, 1989.

6. JAEGER, L.G. , BAKHT, B., The Grillage Analogy in Bridge Analysis, Canadian Journal of Civil Engineering, 9(2), 1982 pp 224-235.

7. LIGHTFOOT,E., "A Grid Framework Analogy of Laterally Loaded Plates", International Journal of Mechanical Sciences, Pergamon Press, Oxford, England, Vol.6, June, 1964.

8. SAWKO, F, "Computer Analysis of Grillage Curved in Plan", Publ. IABSE, Vol. 27, Inst. Association of Bridge and Structural Engineers, Zurich, 1967.

9. WEST, R., Recommendations on the Use of Grillage Analysis for Slabs and Pseudo-slab Bridge Decks, Report 46.017, Cement and Concrete Association, and Construction Industry Research and Information Association, London, 1973.

10. HAMBLY, E.C., Bridge Deck Behavior, Chapman and Hill, London, 1976.

11. COPE, R.J., CLARK, L.A., Concrete Slabs : Analysis and Design, Elsevier Applied Science Publishers, 1984.

12. BAKHT, B., JAEGER, L.G., Analysis of Bridges with Intermediate Supports by the Semi-continuum Method, Proc. Annual Conference of the Canadian Society for Civil Engineering, Toronto, 1986.

13. SEN, R., Bridges: A Computer Program for the Grillage Analysis of Bridge Decks According to AASHTO Loading, December, 1987.

14. AROCKIASAMY, M., Expert System Applications to Structural, Transportation, and Environmental Engineering, CRC Press, 1992.

15. Exsys Professional, EXSYS System Development Package, 1988.

16. AASHTO, Standard Specifications for Highway Bridges, 14th edition. Washington, D.C. (1989).

17. ACI, Building Code Requirements for Reinforced Concrete (ACI 318-89), Detroit, Michigan, November, 1989.

18. NAWY, E.G., Prestressed Concrete: A Fundamental Approach, Prentice-Hall Inc., 1989.

19. NAWY, E.G., Reinforced Concrete: A Fundamental Approach, Second Edition, Prentice-Hall Inc., 1990.

20. SAWKA, M., Knowledge Based Expert System for the Analysis and Rating of Florida Bridges, Masters Thesis, Florida Atlantic University, 1992.

21. AROCKIASAMY, M., SAWKA, M.J., SINHA, V., SHAHAWY, M. A., Knowledge Based Expert System Approach for Analysis and Rating of Florida Bridges, Proc. Second International Conference on Bridge Management, University of Surrey, U.K., April 18-21, 1993.

22. SINHA, V., Knowledge and Fuzzy Logic Based Bridge Management Decision System, Unpublished Doctoral Dissertation Proposal, Florida Atlantic University, 1992.