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THE MAINTENANCE MANAGEMENT FRAMEWORK OF CABLE-STAYED BRIDGE BY BRIDGE INVENTORY DATABASE (BID) MODULE

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ABSTRACT

Bridge Management System (BMS) is as a powerful tool for planning of inspection and maintenance activities and also forecasting the funding requirements to keep the bridge stock in appropriate serviceability level. The maintenance management framework has been proposed for cable-stayed bridges. The Vidyasagar Setu cable-stayed bridge across Hooghly river situated at Kolkata, West Bengal, has been used as a case study for formulation of Bridge Inventory Database (BID) inspection and maintenance systems. This module provides the framework to keep the database of all records, from conception of bridge to its disposal. The bridge has been broken down into 78 sub elements for efficient execution of element-level inspections and for collection of data on patterns of deterioration in elements.

Keywords: Bridge Management System, Bridge Inventory Database, inspection and maintenance etc.

INTRODUCTION

Generally, the Bridge Management System (BMS) is applicable for all types of short and long span bridges. The maintenance management and installation systems of long span bridges of modern technology such as cable-stayed bridges or suspension bridges are complex to meet the functionality level within the limited budget (Sorensen and Berthelesen, 1990).

India has one of the longest cable-stayed bridges - Vidyasagar Setu across Hooghly River situated in Kolkata. There are many cable-stayed bridges that are already in the construction stage e.g. Naini cable-stayed bridge, Goa cable-stayed bridge and few are proposed to be constructed in future at different places in India.

The preservation of these types of bridges are posing serious problems due to (Raghavan and Skettrup, 1999):

- The rapid growth in demand for transportation. Current growth in traffic is 10-12 percent on important corridors.
- Lack of enforcement measures and consequent heavy over-loading.
- The increasing gap between need and availability of funds for maintenance.
- Lack of modern planning and management tools and appropriate maintenance equipment.

LITERATURE REVIEW

The transport network is extremely important and considered a crucial factor for economic and social development for any country. It plays a significant role in the everyday life of the citizens of any nation, by allowing the quick, easy and safe movement of people and goods. The capital investment in the road network is enormous and the bridges are critical elements in preservation program of the network. Most of the bridges in the world have been built during the last 50 years although some are much older. However, the increasing volume of traffic and increased weights of individual vehicles mean that for many structures the loads to which bridges are being subjected are far higher than those envisaged when they were designed (Bevc *et al.*, 2002).

The growth of the bridge stock and the advent of personal computers have led to the development of automated systems for managing the maintenance of bridges. The most appropriate maintenance strategy for a stock of bridges is a complex subject and there are wide ranges of issues that determine the economic approach (Noortwijk and Klatter, 2002). The BMS include the following functions (Raghavan and Skettrup, 1999):

- Provide an inventory of bridges
- Record/predict the historical and future condition of elements and components
- Record/predict the historical and future load carrying capacity of the bridges
- Assess the rate of deterioration
- Evaluate the cost of various maintenance options
- Evaluate traffic management and delayed costs
- Calculate discounted costs to give lifetime costs
- Assess the implications for safety and traffic congestion of deferring maintenance work
- Produce optimal and prioritized maintenance program
- Assist in budget planning

BMS - Present and Future

Management systems in use today are, in large part, maintenance management systems. Some management systems recognize vulnerabilities, including vulnerability to natural hazards as a contributor to priority for remediation (Estes and Frangopol, 1997). Management of design of new bridges and management of obsolescence are not parts of most current BMSs. Explicit evaluation and updation of structural safety are not parts of current management systems, though methods for evaluation of bridge load capacity within maintenance management systems have been proposed (Hearn, 1999c).

Computerized systems for bridge management appeared twenty years ago as databases for storage and simple evaluation of deficiencies. Optimization of maintenance programs became established part of management systems in the late 1980's and early 1990's (Shirolw, 1995). A useful overview of maintenance management systems is provided in Das (1998).

In the 1980's, separate but parallel efforts in the development of BMSs were started by transportation agencies in several countries. Five efforts in USA (in Alabama, Indiana, New York, North Carolina, and Pennsylvania) produced working management systems and significant efforts were made in at least six other US agencies (Illinois, Iowa, Nebraska, New Jersey, Texas and Virginia).

These efforts created PONTIS BMS for FHWA and BRIDGIT BMS under the National Cooperative Highway Research Program (NCHRP) (Lipkus, 1994). The development of separate systems by state agencies was preempted, ironically, by mandate for management systems in the 1991 Intermodel Surface Transportation Efficiency Act (ISTEA). The Act required management systems, and it imposed deadlines for their implementation. Transportation agencies had either to create management systems of their own or to adopt PONTIS BMS or some other working management system. PONTIS BMS became a dominant choice at USA. There is no longer a Federal requirement for BMSs, but interest in BMS persists. Continuing research in BMSs focuses on better definitions of costs, predictive models for condition ratings, management of design, hazards and obsolescence, and on the use of quantitative measures of condition of elements. The project-level management system has been developed to provide a reliable support tool (QUARDO) in decisions related to fund allocation for maintenance, rehabilitation and replacement options for bridges (Soderqvist and Veijola, 1999).

In Denmark, the Danish Road Directorate developed DANBRO, a web-based BMS. A new management approach has been developed for the reinforced concrete bridges with respect to present and future maintenance system with the need of funds (Lassen, 2003).

A challenge in further development of management systems is the efficient collection of the data needed to make quantitative evaluations of bridges. Existing BMSs in USA use basic data on bridge geometry, material, and design load capacity found in the National Bridge Inventory (NBI) record, together with condition ratings for bridge elements (Klatter *et al.*, 2002).

Condition ratings may be as terse as the three NBI ratings, or may be some expanded set of ratings such as those used in PONTIS. Still, only few, usually less than a dozen, condition ratings are assigned to a bridge. Moreover, condition ratings are qualitative indicators of the visible deterioration of a bridge. Condition ratings are not, at present, useful for assessment of load capacity, structural safety, or other quantitative evaluations.

Existing BMSs rely on condition ratings for information on deterioration in structures. Work to improve information for BMSs includes the examination of deterioration as a latent process, and the creation of quantitative condition ratings defined directly in terms of measurable deterioration (Hearn, 1999b). An overview of data fields in maintenance management systems is provided by Turner and Richardson (1994).

Development of framework for project-level BMS for cable-stayed bridges

MODULE : BRIDGE INVENTORY DATABASE

The BID of any bridge generally presents memoir for the whole bridge, which presents the historical developments, conceptual planning and technical information of the completed bridge. The technical information includes the geometric design, dimensioning of the bridge elements and the design concepts adopted in the design of various structural components and the loads to which it might be subjected. The design and drawings of the elements and the structure as a whole have to be preserved for future references. Hence, proper inventory database management is necessary for each and every bridge.

Conceptual planning of the bridge mainly outlines the concept adopted while selecting best option among the various proposed alternatives, location and other factors. It also includes the historical developments and the various planning stages of bridge projects, which are pre-implementation, implementation and post-implementation activities accordingly.

This section pertaining to the design intent guiding the design and construction of the bridge is based on the extract of the technical specifications as outlined in the tender document issued by the representative of the respective department. Apart from this it includes the final design documents by the consultants and other details that are discussed below.

Relevant Data, Specifications and Codes of Practice

a) **Geometric Design:** The details of geometric design shall be in accordance with the design standard specified as per Indian Standards (including BIS and IRC). In case if some design standard and specification is not available as per Indian Standards then we shall refer the code of practice implemented by American or British Codes, applicable to same conditions.

b) **Structural Design:** The loads, forces and stresses shall be considered generally in accordance with the latest Indian Standard Code of Practice for steel and concrete road bridges respectively. Other than these loading and general features of design shall be in accordance with Indian Roads Congress (IRC) standard specifications and Indian Railway Standard Code of practice for respective steel and concrete works.

General Specifications

a) **Aesthetic Appearance:** To ensure that all parts of the project are of good appearance and aesthetically acceptable. For the bridge project, attention shall be paid to steel work, lighting fixtures etc. in order to preserve cleanliness.

b) **Datum:** The proper datum level should be fixed for measuring the reference levels with respect to the fixed datum. As in Vidyasagar Setu all levels are reduced to the Port Commissioner's datum, which is the level of the Kidderpore Out Dock Sill. This datum is usually referred as KODS.

c) **Tides:** If the bridge is going to be constructed across some a tidal river, the full data of maximum currents and the rise of tides in different seasons should be referred accordingly. The river Hooghly is a tidal river, the mean rise of tides at spring during the dry months is 5.0 m. and during freshets is 5.9 m.

d) **Bore Tides:** When the tidal variation on a particular day exceeds maximum limits the stretch of the river at the bridge site may experience bore tides. Such tides occur at the turn of the tides from low water. In the case of the Hooghly river if the tide exceeds 3.9 m. the stretch at the bridge site its called Bore Tides, these bore tides have been known to break ship mooring and damage jetties, landing stages etc. on the river.

e) **Wind and Weather Conditions:** The data about the maximum wind velocity and direction for various seasons and the rainfall data should be recorded. Where as the maximum wind velocity at Vidyasager Setu is in the order of 129km/hr, the monsoon breaks by about the first week of June when steady rains and moderate south winds prevail for about 3 months. This is followed by the calm cold weather season (HRBC Manual, 2005).

f) **Soil Condition:** This section generally records the strata condition by the number of trial bores to examine the nature and properties of the subsoil. The subsoil testing for Vidyasagar Setu was done by the M/s. Cementation Co., Calcutta, in 1962 (HRBC Manual, 2005). The soil encountered in the boring as divided into the following strata (Table 1):

Table 1: Soil Condition at Vidyasagar Setu Bridge Site

SI. No.	Description	Top level
1.	Soft to firm micaceous inorganic silts	+2.00 m
2.	Medium to poorly graded sand	-8.00 m
3.	Stiff mottled plastic clay with kankar	-22.00 m
4.	Sands and silts possibly lenticular	-33.00 m

g) **Ships and Inland Watercrafts:** If the bridge site is in busy waterway or navigation channel, the maximum tonnage and the width of vessel should be restricted accordingly i.e. the maximum tonnage of IWT vessels is allowed at Hooghly bridge passage is only 1200 tons.

Design Specifications

a) **Geometric Design Criteria:** The geometric design criterion of the bridge shall be based on the future traffic volumes for forthcoming years. The projected average daily traffic (ADT) should be based on the factor of the average peak hour volume. The projected ADT at Vidyasagar Setu for the year 1990 was 85,000. The traffic volume used for design purpose was the average peak hour volume obtained by taking one tenth of the projected average daily traffic volume.

b) **The Bridge:** This section represents the details of bridge elements and other design criteria i.e. main span of the Vidyasagar Setu is 457.5 m c/c of piers, side span 183 m each, river clearance for navigation (33.87m), design speed (80 kilometer per hour), sight distance (OSD 122 m), gradient (Max 1 in 25, Min 1 in 66) and profile, bridge cross section, number and width of lane (three in each direction, width of lane 3.66 m), median (3.05 m), footpath (1.50 m at each side), parapet (1.22 m), cross fall (1 in 60 for concrete, 1 in 48 for bituminous surfacing), roadway clearance (horizontal 0.61 m), surfacing (mastic asphalt 0.038 m thick) drainage system, etc.

c) **Accessibility for Inspection and Maintenance:** The detailed design of all bridge work shall be arranged so that all exposed parts shall be readily accessible for inspection and maintenance. The design shall incorporate permanent maintenance trolleys carried on under slung runway beams and suitably geared for traversing the whole width and length of the steel structure.

Loads and stresses

This section generally keeps the records on various assumptions and deviation made for consideration of loads and other effects i.e. dead load, live loads, footway loading, impact, wind loads, water current, longitudinal forces, earth pressure, temperature, secondary stresses, seismic forces and impact from the passing vessels, etc.

Factor of Safety & Load Factors

This section pertains to the description of the various factors of safety and load factors, which shall be used in the design of the main bridge. The load factors take into account the uncertainties involved in the assessment of specific loads for substructure & foundation and superstructure. From this viewpoint the various load combinations and safety factors have been used for each unit to produce the worst effect at Vidyasgar Setu is shown in Table 2 (HRBC Manual, 2005).

Material Specification

This section gives a brief extract of the material specifications as mentioned in the tender documents issued by the competent authority. In this case, all materials shall confirm to the latest Indian Standard Specifications. In absence of any Indian Standard Specifications the materials shall confirm to the latest American or British Standard Specifications as per the requirement, except where otherwise stated or permitted by the competent engineer. The materials given in Table 3 are mostly used for cable-stayed bridge constructions. There should be a proper database for these materials along with their standard specifications

Table 2 Load Combination and Factors

Load combination case	Worst combination of the loads	Load factors as per codes
1	Dead load, live load, Settlement of foundation, Secondary stresses	1.75
2	Dead load, live load, Settlement of foundation, secondary stresses reduced wind load, temperature variation, and breaking forces	1.40
3	Dead load, settlement of foundation, secondary stresses, full wind load, temperature variations	1.35
4	Dead load, live load, erection loads, settlement of foundation, secondary stresses, temperature variations, breaking forces, seismic load	1.11

Drawings

The general arrangement of drawings of the bridge should be annexed with the help of proper code and title.

Design Assumptions & Deviation Notes

This section pertains to the loading, design and analysis philosophy as considered by the design consultant for the design of the main bridge. The design basis note should be presented in two parts namely the design basis note for the superstructure and design basis note for the substructure and foundation separately. Each section shall consist all the details of analysis, assumption notes, deviations and adopted tolerance limit provisions.

Table 3: Materials Used for Cable-Stayed Bridges

S.No.	Material	S.No.	Material
1	Aggregate for concrete	22	Cement mortar and grout
2	Ballast Stones, Rubble, Hardcore	23	First class bricks
3	Jhama bricks	24	Jhama khoa
4	Cement	25	Water for concrete and mortar
5	Steel	26	Reinforcement
6	Expanded metal	27	Paint

7	Cast iron pipes and specials	28	Concrete pipes and specials
8	Commercially available precast concrete items	29	Asbestos cement pipes and conduits
9	Manhole covers and frames	30	Gully covers and frames
10	Precast concrete gullies	31	Mastic asphalt for carriageway surfacing
11	Bitumen fabric	32	Bitumen damp proof course
12	Compressible jointing materials	33	Water for general purposes
13	Tar and bitumen	34	Salt glazed stoneware pipes and fittings
14	Rubber fenders	35	Malleable iron casting
15	Joint sealing compound	36	Joint Priming compound
16	Asphalt for water proofing	37	Road marking
17	Hot rolled asphalt	38	Hydrated lime
18	Timber	39	Tack coat
19	Bitumen macadam for footway	40	Synthetic polymer bearing material
20	Cables (by manufacturer/supplier)	41	Bearings (by manufacturer/supplier)
21	Expansion joints (by manufacturer/supplier)	42	Others alternative materials as per requirement

ELEMENTS CONSTRUING THE BRIDGE

The main bridge has been divided broadly into certain set of elements that have been further broken down into sub elements (Figure 1). A hierarchial coding structure has been developed upto five levels.

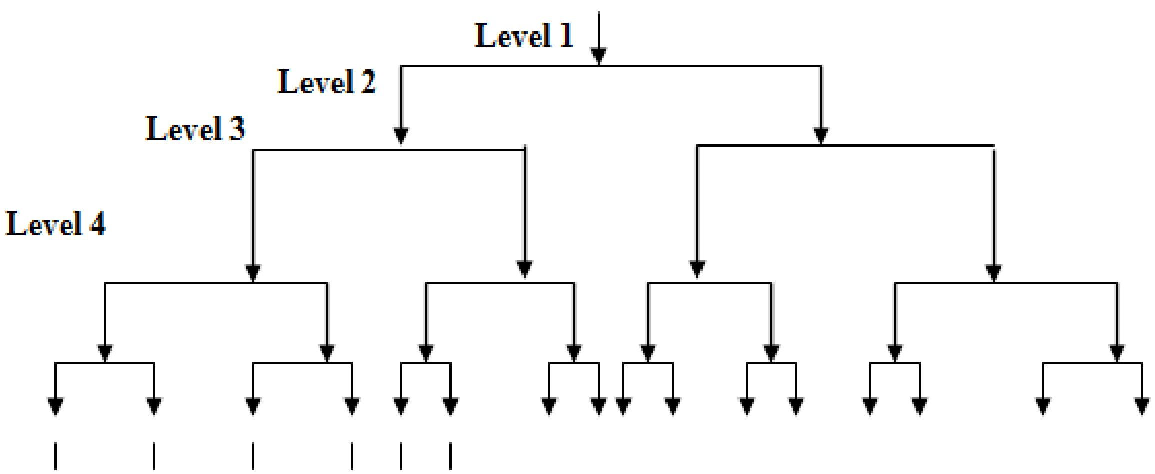

Figure 1: Element Breakdown Hierarchy

The element hierarchy is based on breaking down the main elements into smaller elements. The purpose of this hierarchy system is to establish a logical break down of the structure into smaller elements identified for inspection (Henriksen, 1999). Each element has comparable technical properties with respect to materials and maintenance and also identical administrative interfaces. The element hierarchy is used to create a complete list of all the different elements forming the cable-stayed bridge. This list is used to organize all the maintenance related data systematically by relating the information to the element numbers. The element hierarchy also describes the location of each element by using a set of codes referred as the 'Element Location Codes'. The element hierarchy breakdown and coding structure that has been developed is shown in Table 4.

Table 4 Element Hierarchical Breakdown and Codification

Element No.					Description	Element Location Codes					
L1	L2	L3	L4	L5	Hierarchy Element	Code 1	Code 2	Code 3	Code 4	Code 5	Code 6
ID	ID	ID	ID	ID		Start St.	End St.	Elem- -ent No.	Orienta-- tion of face	Level	Positi- -on on face
10					Left Interchange						
20					Right Interchange						
30					Main Bridge						
	10				Super Structure						
		10			Concrete Deck						
			10		Deck Slab						
			20		Cantilever Slab						
			30		Nosing Element						
		20			Steel Grid System						
			10		Main Longitudinal Girder						
			20		Middle Longitudinal Girder						
			30		Intermediate Cross Girder						
			40		End Cross Girder						
			50		Pylon Cross Girder						
		30			Cable System						
			10		Stay Cables						
				10	Cables						
				20	Upper Anchorage						
				30	Lower Anchorage						
			20		Holding Down Cable						
				10	Cables						
				20	Upper Anchorage						
				30	Lower Anchorage						
		40			Pylon						
			10		Pylon Head						
			20		Top Portal						
			30		Bottom Portal						
			40		Pylon Leg-Upstream						
			50		Pylon Leg-Downstream						
			60		Pylon Base						
	20				Substructure						
		10			Anchor Pier						
			10		Pier Cap						
			20		Pier						
		20			Pylon Piers						
			10		Pier Cap						
			20		Pier						
	30				Foundation						
		10			Anchor Pier Foundation						

			10		Top Slab						
			20		Holding Down Cable Arrangement						
			30		Infill Materials						
			40		Steining						
			50		Bottom Plug						
		20			Pylon Piers Foundation						
			10		Well Cap						
			20		Steining						
			30		Bottom Slab						
			40		Fendering System						
	40				Bridge Appurtenances						
		10			Wearing Surface						
			10		Carriage way						
			20		Walk way						
		20			Crash Barrier						
			10		Vehicular Crash Barrier - Inner						
			20		Vehicular Crash Barrier - Outer						
			30		Pedestrian Railing						
		30			Drainage System						
			10		Drainage Spouts						
			20		Down take Pipes						
		40			Bearings						
			10		Vertical Bearings						
			20		Horizontal Bearings						
		50			Expansion Joint						
			10		Exomet Expansion Joint						
			20		Maruer Swivel Expansion Joint						
	50				Access Facilities						
		10			Gantry						
			10		Gantry						
			20		Rails						
		20			Lifts						
		30			Ladder Systems						
			10		Stairs						
			20		Ladders						
			30		Platforms						
	60				Electrical Installations						
	70				Mechanical Installations						
	80				Toll Collection Building						

The element hierarchy for the structures is based on a break down into maximum six element levels with individual properties. The location of an element and the exact position on a face of the element can be indicated using maximum six location codes, 1 to 6 as described below:

Code 1: Stationing at start (or at centre of element, e.g. at piers) of the element

Code 2: Stationing at end of the element

Code 3: Number of the element

Code 4: Orientation of face, e.g. inner/outer (for piers) etc.

Code 5: Level, height in meters or number of lifts of the scaffold above individual defined levels

Code 6: Co-ordinates on the face characterized by individual co-ordinate systems applied to the different elements and whether the co-ordinates shall be used for horizontal, vertical or circular face

The location codes may be used for different purposes of inspection and repair. The location codes are used to record positions of individual elements with identical or almost identical properties except for the location. Only the three first location codes are used in the BID. The last three location codes may be used for purposes of inspection to pinpoint exact positions of on an element, e.g. damage records from inspections or repairs carried by standard maintenance.

Condition Rating System

The condition rating system assigns a Condition Rating Number (CRN) to represent the physical condition of the inspected bridge elements. The lower CRN represents more serious deterioration of the bridge. The system thus helps in identifying progressive deterioration in the condition of the bridge. The CRN is used to monitor the deterioration and fix priorities for repairs and rehabilitation works. The CRN scale has been taken from the Railways Manual (Railway Bridge Manual, 1998) and modified. The description of the rating scale is given in Table 5.

Table 5: Condition Rating Numbers

Condition Rating No. (CRN)	Condition of Bridge Component
1	Being heavily and critically damaged and possibly affecting the safety of traffic, it is necessary to implement emergency temporary repair work immediately or rehabilitation work without delay after the provision of a load limitation sign.
2	Damage detected is critical and thus it is necessary to implement repair work or to carry out a special inspection to determine whether any rehabilitation works are required.
3	Damage detected is slightly critical and thus it is necessary to implement maintenance or repair work.
4	A condition which requires routine maintenance.
5	No damage found and no maintenance required as a result of the inspection
#	Not inspected

When any component in a bridge is more than one in number, CRN assigned to each of them and the lowest observed CRN should be considered for the record. When observed condition rate is '3' or lower, the special inspections or reduced interval of principal inspection must be considered to determine the damage cause or damage extent to select the repair strategies. The condition rate '1' and '2' must be avoided by initiating necessary inspection and maintenance/repair works in due time.

Damage Description: **All damages should be described preferably by reporting as indicated below:**

- Type of damage
- Extent of damage
- Characteristic of damage
- Development of damage

The inspector should always indicate the cause of damage in the inspection records. If he is uncertain about the cause of damage, he will recommend for a special inspection.

Preservation of Design & Drawings

a) ***General procedure:*** The relevant design notes and drawings pertaining to the bridge should be available with the concerned department. The full maintenance system manual should be converted into electronic copy and stored in compact discs (CDs) enclosed with BID. Compact discs shall be used for storing the design documents and drawings, as it will protect the original materials from excessive handling.

b) ***Preservation of compact discs:*** CDs are complex laminate structures vulnerable to damage by light, humidity, temperature, mishandling, and pressure. CDs can be destroyed in few minutes by poor handling or damaged in a few hours of being stored outside their cases. The causes for failures of Compact Discs include (Care for CDs, 2005):

- Physical stress leading to delaminating, warping, and/or improper tracking
- Dirt or grit scratching media and leading to loss of information
- Yellowing of the plastic or light recording layer
- Low reflectivity due to oxidation of the aluminum layer (laser rot)
- Natural aging

Hence, the methods of preserving CDs are also very important for keeping the bridge inventory data for long time. Mainly it depends on the storage environment, housing, storing, handling and cleaning of CDs.

CONCLUSIONS

This module provides the framework to keep the database of all records, from conception of bridge to its disposal. The bridge has been broken down into 78 sub elements for efficient execution of element-level inspections and for collection of data on patterns of deterioration in elements. Element hierarchical system have been developed for specific bridge elements which offers rapid field inspection, reproducible determination of quantities, and simple, direct check of accuracy and completeness of inspections. Condition rating system is used for identifying the elements or bridge which need either repair and rehabilitation or reconstruction measures.

REFERENCES

1. **Augusti, G., M. Ciampoli, and D. M. Frangopol** (1998) Optimal Planning of Retrofitting Interventions on Bridges in a Highway Network. *Journal of Engineering Structures,* Elseviser, Vol. 20 (11), 933-939.
2. **Bevc, L., B. Mahut, and K. Grefstad** (2002) Bridge Management Systems (BMS): extended review of existing systems and outline framework for a European system, *European Commission DG 7, 4th framework programme, Deliverable D2, BRIME* PL97-2220, D (2), 1-58.
3. **Care for CDs** (2005) <http://www.itl.nist.gov/div895/carefordisc/> (March 15, 2005).
4. **DANBROweb Demo-version** (2002) <http://www.rambro.dk/users_guide.htm> (May 12, 2004)
5. **Degarmo, E. P., W. G. Sullivan and J. R. Canada** (1984) *Engineering Economy*. Macmillan Publishing Company (USA) and Collier Macmillan Publishers (UK).
6. **Estes, A. C. and D. M. Frangopol** (1997) Lifetime Bridge Maintenance Strategies Based on System Reliability. *Structural Engineering International, (IABMAS)* Vol. 7(3), 193-198.
7. **Flaig, K. D., and R. J. Lark** (1999) Integration of Reliability-Based Assessment Techniques into an Advanced BMS. Proceedings of *TRB Transportation Research Circular 498,* G (3), 1-11.
8. **HRBC Manual** (2005) *Hooghly River Bridge Commissioners manual for Vidyasagar Setu cable-stayed bridge*. Ravindra Publishers, Kolkata, India.

9. **IRC - SP 35,** (1990) *Guidelines for Inspection and Maintenance of Bridges*. Sagar Printers & Publishers, New Delhi.

10. **Johnson, M. B.** (2003) Condition – Based Bridge Asset Valuation. Proceedings of the *9th International Bridge Management Conference, Florida*, April, 149-153.

11. **Klatter, H. E., J. M. V. Noortwijk, and N. V. V. Eck** (2002) Bridge Management in the Netherlands; Prioritization Based on Network Performance. Proceedings of *1st International Conference on Bridge Maintenance, Safety and Management (IABMAS), Barcelona*, July, 112-119.

12. **Lassen, B.** (2003) Bridge Management Through the Internet with DANBROweb. Proceedings of 9*th International Bridge Management Conference, Florida,* April, 244-251.

13. **Miyamoto, A., K. Kawamura, and H. Nakamura** (2001) Development of Bridge Management System for Existing Bridges. *Advances in Engineering Software,* Elseviser, vol. 32, 821-833.

14. **Noortwijk, J. M. V. and H. E. Klatter** (2002) The Use of Lifetime Distributions in Bridge Replacement Modelling. Proceedings of *1st International Conference on Bridge Maintenance, Safety and Management (IABMAS), Barcelona*, July, 1-8.

15. **Road Signs & Traffic Control Equipment** (2005) <http://www.ubd.co.nz/ company- profiles /191624943 > (July 8, 2005).

16. **Scherschligt, D. and R. B. Kulkarni** (2003) PONTIS – Based Health Indexes for Bridge Priority Evaluation. Proceedings of the *9th International Bridge Management Conference (FLORIDA)*, April, 29-47.

17. **Thompson, P. D., A. Marshall, W. Robert, J. Aldayuz and K. Hurst** (2003) Integration of AASHTO's BRIDGEWare products**.** Proceedings of the *9th International Bridge Management Conference, Florida*, April, 85-95.

18. **Web Based Bridge Reporting and Mapping Systems** (2005) Bridge Portal, <http://www.camsys.com/csbri03.htm> (May 17, 2005).

19. **Woodward, R. J.** (2001) Bridge Management Systems (BMS): extended review of existing systems and outline framework for a European system. *European Commission DG 7, 4th framework programme, Deliverable D13, BRIME* PL97-2220, D (13) 1-67.

20. **Xanthakos, P. P.** (1995) *Bridge Superstructure Repair and Maintenance Analysis*. Prentice –Hall, Englewood Cliffs, N.J. USA.

21. **Yanev, B., R. B. Testa and M. Gravin** (2003) Maintenance Strategy to Minimize bridge Life Cycle Costs Proceedings of the *9th International Bridge Management Conference, Florida*, April, 189-199.

22. **Yield Curve** (2005) <http://www.stcionline.com/tbill_yieldcurve.html> (March 10, 2005).