PROJECT BRIDGE MANAGEMENT IN ONTARIO

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SUMMARY

A bridge management system is required to ensure the safety of bridges and to optimize the resources available for maintenance and rehabilitation. This paper describes the bridge management practices in Ontario at the project level and outlines the work in progress toward the development of a comprehensive bridge management system at the network level. The visual inspection condition data collected on bridges are supplemented with data from detailed condition surveys that include nondestructive and destructive sampling and testing. The results of those inspections and surveys are assessed to determine appropriate methods and options for rehabilitation. As an economic evaluation is an important step in the decision making process for work that involves major expenditures, the costs for alternative levels of improvements to a bridge are compared to determine the most economical option for the bridge based on a present value analysis and incremental benefit/cost ratio analysis. One benefit of this approach to bridge rehabilitation is significant improvements in the selection of rehabilitation options through detailed life-cycle analysis to determine optimal cost-effective options.

INTRODUCTION

A bridge management system consists of a logical sequence of events to ensure the safety of structures, to establish priorities for maintenance and rehabilitation, and to optimize the budget for these activities. This paper describes the project level bridge management practices in Ontario and the progress made to integrate these practices into a comprehensive bridge management system (BMS).

The Ministry of Transportation of Ontario owns and maintains approximately 3,200 bridges on the Provincial Highway system. About 50% of these bridges were built before 1960, and require an increasing amount of maintenance and rehabilitation. Approximately 30% of the bridges were built between 1961 and 1970. The distribution of these bridges by type of construction is shown in Figure 1. Figure 2 shows the annual bridge rehabilitation program in the province since 1985. In the mid to late 1980's, over 100 bridges were rehabilitated annually. This figure has decreased recently due the successful efforts of the past and partly due to recent budget constraints. Currently about 80 bridges are rehabilitated annually.

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The provincial highway network in Ontario is considered mature. Consequently, there are few bridges being added to the network, and bridge construction is normally the result of local capacity improvements or the replacement of deficient or deteriorated structures. The changing needs, combined with budget restraints, have resulted in the shift from expansion of the network in the 1960's to the preservation and improvement of the existing network in the 1970's and into the 1990's. Bridge management practices in Ontario, over the past 25 years, have resulted in a bridge population in good condition with few deficient bridges. The BMS developed for the provincial highway bridges is primarily concerned with the preservation and improvement of the existing network.

PROJECT LEVEL BRIDGE MANAGEMENT

Of all the components in a bridge, the bridge deck has exhibited the most rapid deterioration. This is particularly true in North America, where the heavy use of deicing chemicals and frequent freeze-thaw cycles, combined often with exposed concrete surfaces and insufficient concrete cover to the reinforcement, have resulted in rapid deterioration. Most authorities are having to undertake a comprehensive bridge rehabilitation program. This has been the case in Ontario, where in extreme cases, major deck rehabilitation has had to be carried out within 10 years of construction. The need to rehabilitate many bridges with limited resources led to the development of procedures to ensure that the optimum method of rehabilitation is chosen for each structure. Similar deterioration in concrete piers and abutments, beams and slabs are now taking up a larger share of the rehabilitation budget. The bridge project rehabilitation process consists of: data collection, option analysis and selection of the method of rehabilitation, design and preparation of contract documents, and construction.

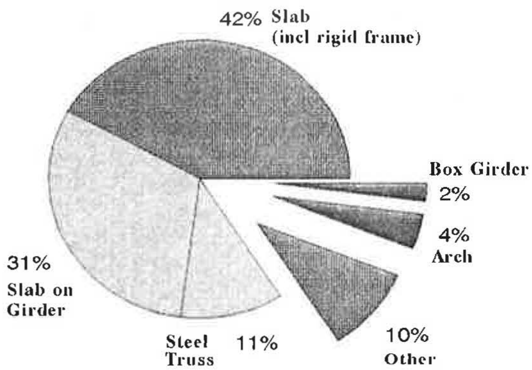

FIGURE 1 Types of bridges in Ontario.

Inventories, Data Collection and Databases

The basis of Ontario bridge information system is an extensive computerized *Ontario Structural Inventory System* (OSIS) (*1*). This inventory includes all structures in the province, and contains general design information. It is being extensively changed to meet current requirements as part of the Ministry's bridge management needs. A separate inventory, Ontario's *Bridge Clearance and Loads Information System* (BCLIS) (*2*), is maintained for clearances and load limits on the provincial highway system.

Besides the inventory data, every bridge on the provincial highway system is subject to a biennial routine detailed visual inspection. The extent and severity of any defects as well as an assessment of their effect on the performance or proper functioning of the component are recorded following the procedures given in the *Ontario Structure Inspection Manual* (OSIM) (*3*). Condition ratings are assigned and recorded on an individual span basis for each span in the structure and for all components. Components are rated on a scale of one to six with six being excellent condition. Separate condition rating systems are used to assess the material and performance conditions of individual components of a structure, and the performance condition rating of the entire structure. General guidelines for assigning appropriate material and performance condition ratings are given in Figure 3 and Table I, respectively. The rating of the performance defect is not necessarily the same as that of the material defect; therefore, the same component may have different material and performance condition ratings. The *Ontario Structure Inspection Management System* (OSIMS) (*4*), is the computerized system for managing the inspection data collected, and for obtaining reports. These reports are used to help in the prioritizing of repairs and rehabilitation. The retrieval of data and reporting from data in OSIS and OSIMS is very flexible and can be tailored to the end use. The condition of bridges along with the recommendations for additional investigations or repairs and rehabilitations also can be extracted from OSIMS.

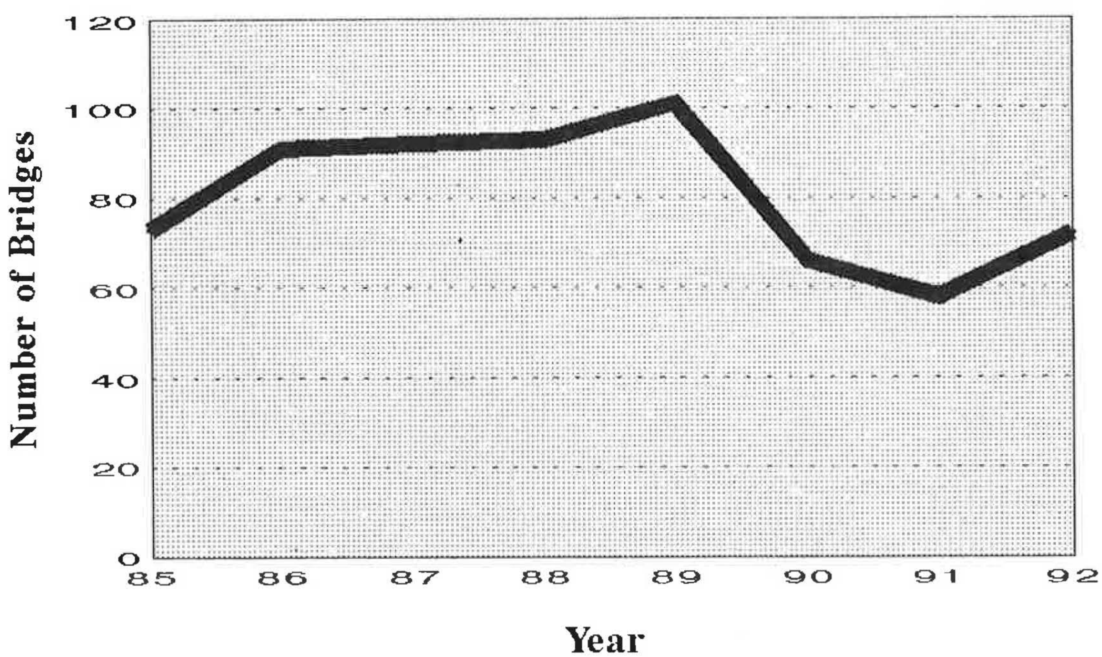

FIGURE 2 Bridge rehabilitation in Ontario.

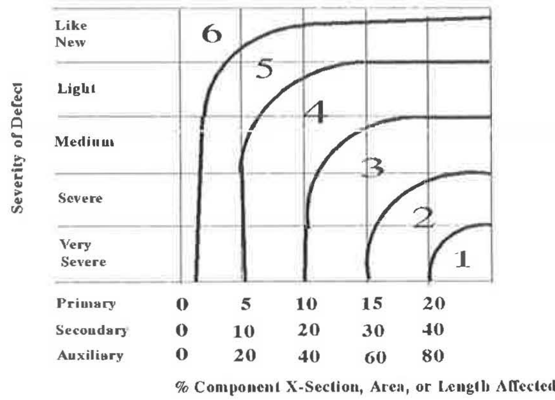

FIGURE 3 Material condition rating system.

TABLE I PERFORMANCE CONDITION RATING SYSTEM

Rating	Performance Condition of Components	Guidelines for the Approximate Reduction in the Capacity of the Component to Perform its Intended Function, %		
		Primary Components	Secondary Components	Auxiliary Components
6	Very Good	0 to 1	0 to 2	0 to 5
5	Good	1 to 5	2 to 10	5 to 20
4	Fair	5 to 10	10 to 20	20 to 40
3	Poor	10 to 15	20 to 30	40 to 60
2	Urgent	15 to 20	30 to 40	60 to 80
1	Critical	over 20	over 40	over 80

Detailed Condition Surveys

Approximately two years before a scheduled rehabilitation, a detailed condition survey is carried out. The purpose of the detailed condition survey is to determine the extent and severity of defects and deficiencies in the structure components. The data collected are used to determine and assess viable methods for rehabilitation. Both destructive and nondestructive testing and sampling methods are used. The procedures for carrying out detailed condition surveys, the description of the rehabilitation methods used by the Ministry, and criteria for the selection of technically viable methods are detailed in Ontario's *Structure Rehabilitation Manual* (5). A detailed condition survey involves a significant amount of work and cost, and is not carried out unless there is a need to rehabilitate the structure and the structure has been identified for rehabilitation. Some factors considered include: extent of defects and deterioration observed by routine detailed biennial inspections, age of the bridge, poor design or construction details, and repair history of the bridge. In addition, where the bridge is within the limits of a road or other rehabilitation contract, it is also considered for rehabilitation and a survey carried out.

For exposed concrete surfaces, the survey usually consists of:

- a thorough visual survey to record the extent and severity of cracks, scaling and spalling and patched areas;
- measurement of corrosion potentials (taken on a 1.5 m x 1.5 m grid);
- measurement of concrete cover (taken on a 1.5 m x 1.5 m grid);
- taking cores from sound and deteriorated areas of the concrete; and
- photographing significant deterioration.

On decks with a bituminous wearing surface, one must drill through the wearing surface to measure corrosion potentials; and, it is not possible to measure concrete cover and delamination. It is also more difficult to determine the condition of the deck slab, more cores may be taken. Further, sections of the bituminous wearing surfacing (approximately 250 mm x 250 mm) known as a sawn samples are removed to examine the condition of the underlying concrete deck surface.

All the cores are sketched, photographed, and subjected to a visual examination, and some are selected for testing for compressive strength, chloride content, and air-void system. A report is prepared for each structure and includes a description and analysis of all the on-site and laboratory testing. A summary of the sampling and testing requirements for concrete cores, and for the sampling requirements for asphalt sawn samples is given in Table II.

The other components of the structure are inspected visually. Where deterioration is found in the other substructure or substructure components, one must decide whether to include the work in the deck rehabilitation contract or by separate contract. Often, steel beams and girders will exhibit deterioration of the coating system, requiring recoating. This work is often carried out in a later contract for several reasons, such as: to prevent possibly damaging the new coating during concrete rehabilitation; to limit the extent of road rerouting and public inconvenience; and to facilitate contract administration as this work is usually carried out by specialized contractors. However, where later coating work will be necessary, those areas that will be exposed during concrete removals, which would be inaccessible after the rehabilitation are included as part of the work. These areas are typically under and around the expansion joints. Requirements for condition surveys and nondestructive and destructive sampling and testing are currently being developed for steel and wood components.

Selection of Rehabilitation Treatment and Option Analysis

The selection of the rehabilitation method is the crucial step in bridge rehabilitation. It includes consideration of many factors, some of which are technical, some economic, and some purely practical. The following factors most influence the selection of the rehabilitation method:

- life cycle costs of the different rehabilitation options compared to the cost of replacement;
- nature and extent of the deterioration;
- anticipated remaining life of the structure;
- location of the structure and its importance in the highway network;
- AADT at the site and the impact of lane closures on traffic flow;
- load-carrying capacity of the structure;
- history of deterioration and previous repairs;
- future reconstruction program near the structure; and
- the type of structure, its size and geometry.

Any rehabilitation option must ensure that the completed structure will be structurally adequate to carry all applied service loads. It is therefore necessary to establish that the component can be repaired, rather than replaced, and that all the components of the structure will support any additional loading resulting from the rehabilitation. These may be additional permanent loads, i.e., overlays, or may be construction loads in coating contracts, where work platforms and environmental protection may be suspended from the structure. This evaluation is carried out according to the *Ontario Highway Bridge Design Code* (OHBDC) (*6*).

Further, rehabilitation options considered are those that will prolong the life of the component by 10 years or more. Consequently, temporary repairs, such as patching or epoxy injection, are considered routine maintenance items rather than rehabilitation. Consideration is also limited to work which will be done by contract awarded through a competitive tender process. The choice of which method to use on any particular bridge deck or component depends on its condition, as determined from detailed condition surveys. Where rehabilitation is delayed more than four years from the date of the condition survey, then a new condition survey is normally carried out and the method of rehabilitation reassessed and contract documents updated as needed.

TABLE II REQUIREMENTS FOR SAMPLING AND TESTING BRIDGE DECKS

REQUIREMENTS FOR CORE SAMPLES

Percentage of deck area with corrosion potential more negative than -0.35V and with delaminated concrete	Number of Cores Required				Minimum Number of Cores	
	First Survey		Update Surveys		First Survey	Update Surveys
	Asphalt Covered Deck	Exposed Concrete Deck	Asphalt Covered Deck	Exposed Concrete Deck		
0 to 10%	1 core per 100 m^2	1 core per 200 m^2	1 core per 500 m^2	1 core per 500 m^2	6	3
10 to 25%	2 cores per 100 m^2	1 core per 150 m^2	2 core per 500 m^2	1 core per 500 m^2	6	3
more than 25%	3 cores per 100 m^2	1 core per 100 m^2	3 core per 500 m^2	1 core per 500 m^2	6	3

REQUIREMENTS FOR TESTING OF CORES

Test	Deck Area	Number of Cores		
		First Survey		Update Surveys
		Min	Max	
Compressive Strength	< 500 m^2	1	2	1 optional
	500 to 2000 m^2	2	4	
	> 2000 m^2	4	6	
Chloride Content	< 500 m^2	1	2	1
	500 to 2000 m^2	2	3	
	> 2000 m^2	3	4	
Air Void System	< 250 m^2	1	1	1 optional
	250 to 1000 m^2	2	2	
	> 1000 m^2	3	3	

REQUIREMENTS FOR SAWN SAMPLES

Percentage of deck area with corrosion potential more negative than -0.35V and with scaled or delaminated concrete	Number of Sawn Samples Required			Minimum Number of Samples	
	First Survey	Update Surveys			
		Deck Waterproofed	Deck not Waterproofed	First Survey	Update Survey
0 to 10%	1 per 200 m^2	1 per 500 m^2	1 per 200 m^2	6	3
10 to 25%	1 per 200 m^2	1 per 500 m^2	1 per 150 m^2	6	3
more than 25%	1 per 200 m^2	1 per 500 m_2	1 per 100 m^2	6	3

The technical consideration in selecting the method of rehabilitation can conveniently be dealt with by examining the relative advantages and disadvantages of the different options. Decision matrix tables and flow charts to assist in the selection of the rehabilitation methods for concrete decks and other components are given in the *Structure Rehabilitation Manual* (*5*). These are used with the results of the condition survey, other relevant available data and sound engineering judgement to select appropriate methods and strategies for rehabilitation. A typical decision matrix for a bridge deck in poor condition is illustrated in Figure 4.

- The methods considered for the rehabilitation of decks are:
  - Concrete patching with waterproofing and bituminous paving;
  - Normal concrete overlay with waterproofing and bituminous paving;
  - Latex modified concrete overlay;
  - Latex modified concrete overlay with waterproofing and bituminous paving;
  - Silica Fume concrete overlay;
  - Cathodic protection using coke mix and bituminous paving;
  - Cathodic protection using coke mix with a concrete overlay and bituminous paving;
  - Cathodic protection using anode mesh in concrete overlay, waterproofing and bituminous paving; and
  - Full depth replacement.
- The methods for rehabilitation considered for other concrete components are:
  - Concrete patching;
  - Concrete re-facing or encasement;
  - Latex modified shotcrete;
  - Silica Fume shotcrete;
  - Full depth replacement; and
  - Cathodic protection.
- The methods for rehabilitation considered for structural steel components are:
  - Strengthening or replacement of components;
  - Adding shear studs to make the beams composite with the deck; and
  - Applying a protective coating system.

The criteria for the selection of coating systems for coating structural steel components are given in the *Structural Steel Coating Manual* (*7*), and illustrated in Table III. Most of the methods used have been in place since 1978 and have been working well. However, modifications in the policy on concrete removal have been made in some areas to improve the durability of the repair or rehabilitation. Currently, concrete is removed in all deteriorated areas and all areas where half-cell readings are more negative than -0.35 volts, even if the concrete is otherwise sound. This has improved both the estimates of concrete removal and the product. Concrete is removed to sound concrete or to at least a minimum specified uniform depth of 25 mm below the first or top layer of reinforcement, and for an additional depth of 25 mm just around the bars in the next layer of steel. These practices have improved the durability of patches, overlays and shotcrete repairs. The policy for removal of high half-cell areas does not apply to rehabilitation by cathodic protection as it is not necessary in that case.

Financial Analysis

The criteria for the selection of the rehabilitation method or coating system deal with the technical and practical considerations, exclusive of cost. While costs are important, the cost of the rehabilitation method is only part of the total cost of a contract. This occurs because items such as traffic control, and mobilization can be a considerable portion of the total cost. This is particularly true if the extent of the rehabilitation or components needing rehabilitation is limited. Where many rehabilitation methods are feasible, or where the choice between rehabilitation and replacement is not obvious, then a life cycle costing between competing options is carried out to help make the choice. The methodology of carrying out life cycle financial analysis is given in the *Structural Financial Analysis Manual* (SFAM) (*8*). Analyses are carried out on a computer using Lotus, 1-2-3™. Guidelines are given in the SFAM on the life cycles of various rehabilitations based on the experience on major freeways in Ontario. They can be modified for local conditions and experiences. Considerable research is needed to refine these but as long as consistent data are used the analysis leads to valid choices.

Present Value Analysis Using PRVAL Program

PRVAL is a template overlay developed to perform financial analysis for bridge rehabilitation projects. The life cycle costs of viable rehabilitation options and strategy are carried out. These are compared to replacement costs, and/or may include replacement of part or all of the bridge at some time. The present value of estimated expenditures over the remaining life of the structure for each of the rehabilitation strategies is then calculated, and that option with the least present value is chosen as the preferred option and strategy to

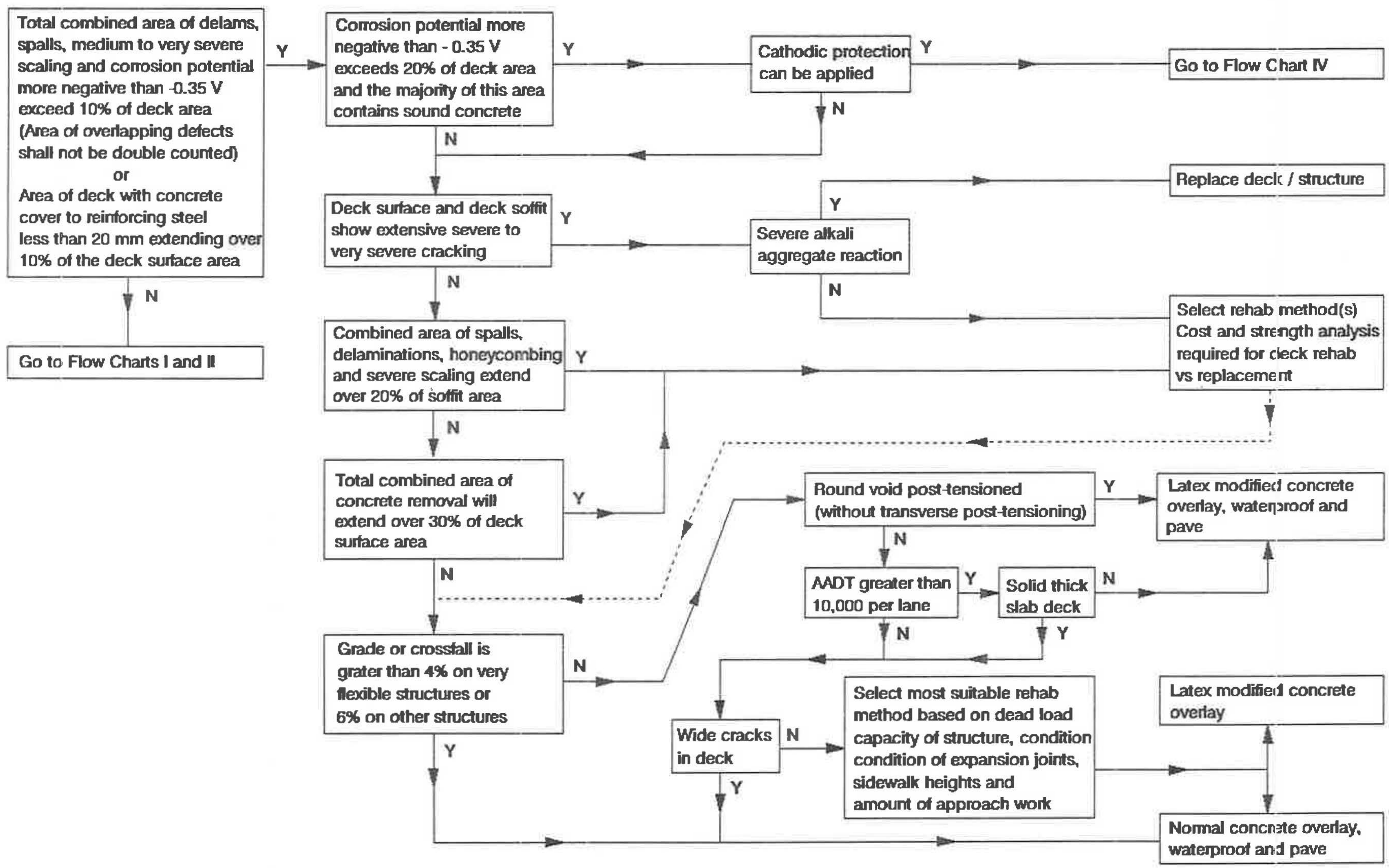

FIGURE 4 Selection of deck rehabilitation method (for deck in poor condition).

TABLE III COATING SYSTEM SELECTION CRITERIA

Coating System (total dry film thickness)	Optimum Utilization	Remarks
Inorganic Zinc/Vinyl (200 - 215 um)	Girder type structures. Use on Class A highways justified by its service life.	Not compatible with other paints. Will not tolerate inadequately cleaned surfaces that may occur on truss structures.
Epoxy Zinc/Vinyl (225 um)	Truss type Structures Use on Class A highways justified by its service life.	The epoxy-zinc will tolerate less than ideal surface cleanliness as may be encountered on a truss type structure.
Coal Tar Epoxy (400um)	Steel Piling.	Black in color.
Aluminum Epoxy Mastic (225 um)	All structure types.	Only to be used for spot cleaning/coating by Bridge crews.
Metallizing (200 um)	Steel posts or attachment brackets on concrete posts.	Suitable for all components including girders. Zn/Al alloy wire is used. Must be "seal" coated, usually with vinyl top coat.
Hot Dip Galvanizing (87 um)	Standard steel handrails.	Has also been used successfully on Ministry bridge girders.

follow for that bridge. There are four levels of sophistication for carrying out the financial analysis. These are analyses that consider: only capital costs; capital costs and residual values; capital costs, residual values and maintenance costs; and, analyses that incorporate given percentages or probabilities for uncertainty in costs.

Incremental Benefit/Cost Ratio Analysis Using COSBEN Program

COSBEN is a program developed to perform incremental benefit-cost analysis for bridge rehabilitation projects. The analysis can be carried out with or without user costs. Here, the option with the highest benefit/cost ratio greater than one is chosen.

Theory of Present Value Analysis

The present value analysis involves the calculation of the cost of alternative options in present day monetary terms, i.e., the amount required in today's value to obtain goods and services at any future date. It allows for the comparison of alternative options on an equitable basis. The present value *PV* of expenditure *C* in year *n* at a discount rate *r* is given by the expression:

$$PV=\frac{C}{(1+r)^n}$$

The present value of several expenditures C_n over *n* years is similarly given by:

$$PV=\sum_{n=1}^{n} \frac{C_n}{(1+r)^n}$$

The incremental benefit/cost ratio, *IB/IC*, is the ratio of the additional benefits realized in moving from one improvement option to another, divided by the corresponding difference in costs. This method not only optimizes the selection of options efficiently but also ranks the projects beginning with the most net benefit. It is used both at the project and network levels. Figure 5 shows the total benefit and first cost curves plotted for the various options for a bridge. Initially, the increment of benefit, *IB*, is higher than the increment of cost, *IC*;

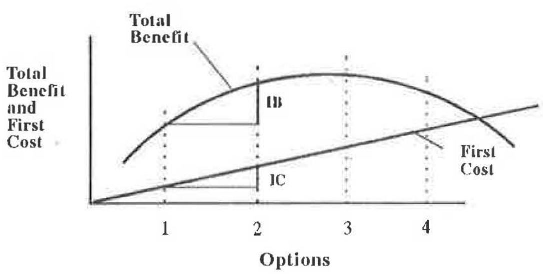

FIGURE 5 Total benefit and first cost.

however, as costs increase the incremental benefits typically decline and are less than the incremental costs. The slopes of these benefits and first cost curves support the theory of diminishing returns. For a particular level of improvement there exist points on the benefit and cost curves, where the slopes of the two curves are equal, i.e., *IB* = *IC*. At this level of improvement the net benefit is a maximum. This is illustrated in Figure 6. Any option below this level where *IB/IC* > 1 is a

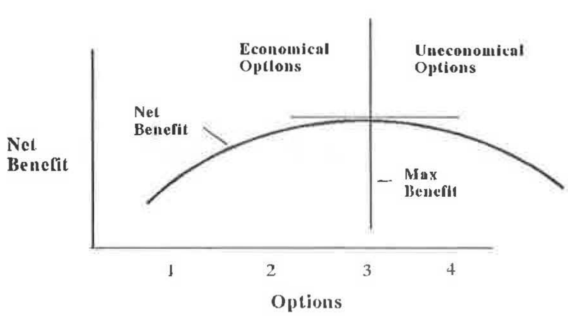

FIGURE 6 Net benefits.

desirable option. The procedure is to list rehabilitation options in order of increasing costs and calculate the *IB/IC* ratio for each option. Options for which *IB/IC* ratio is less than 1.0 are discarded. The options are then sorted in descending order of *IB/IC*. For a limited budget, the order of preference is the order from the highest to the lowest *IB/IC* ratio. The following should be estimated for each option in constant monetary terms:

- Engineering design cost;
- Construction cost;
- Miscellaneous costs such as, demolition, traffic control, work on approaches, utilities, stream-diversion, detours, etc.; and
- Maintenance and future rehabilitation costs.

Costs associated with maintenance are the routine maintenance costs. These would include minor repairs, maintenance, touch up painting, etc., carried out on a regular basis.

The life cycles for the rehabilitation methods, is the time between two successive rehabilitations or replacements, and have to be determined. Preferably, these should be based upon data collected in the field; however, as this type and volume of data may be limited, these may be estimated based upon available data and experience. The bridge may also have useful remaining life at the end of the period for any particular option. This is called the residual life. There are no specific methods of assessing this; therefore, a thorough knowledge of the performance of past rehabilitations, experience and sound engineering judgement are probably the best way of assessing the useful residual life. From the residual life, the residual value of the structure for the particular option can be determined. There are several methods available for determining the residual value. The method used here is the second cycle replacement method.

The discount rate depends on several factors (*9*), such as the magnitude of investment return, inflation and capital market conditions, preferences for current and future consumption, etc. A discount rate of 6% is recommended for government projects, which may be different for other agencies. Sensitivity analysis may be carried out by varying these rates.

For the incremental benefit/cost analysis, the following additional parameters are required: agency costs and benefits, and user costs and benefits. Agency costs are the same as for the present value analysis. Agency benefits are given in terms of the cost savings between rehabilitation and replacement, and of the cost of the rehabilitation. Maintenance and various types of rehabilitations extend the useful life of the bridge. These expenditures would postpone major expenditures for replacement. The difference between the discounted future cost of a rehabilitation option and that of a replacement option is the agency net benefit. The agency net benefit plus the cost of the rehabilitation is the agency total benefit. User costs are costs incurred by the user due to deficiencies or substandard conditions at the bridge. The following are the user costs:

- Accident Costs—costs resulting from accidents at bridges due to width restrictions, poor approach alignment, etc.; and
- Functional restriction costs—costs due to load restrictions and detours for certain classes of vehicles increase travel time and, therefore, operating costs. These vary for different locations and countries.

User benefits of a bridge rehabilitation option are the reduction in costs to the users due to the rehabilitation. In determining user benefits it is assumed that deficiencies will be eliminated when the bridge is repaired or replaced. The reduction in the number of accidents due to a certain type of improvement is used as a measure of user benefit for that type of improvement. The dollar value placed on different types of accidents is crucial in estimating user benefits. These may vary for different countries. The change in accident rate is measured by the difference in the number of accidents per million vehicles. The accident cost depends on the severity of the accident. Two methods for assessing accident costs considered are the Human Capital Approach and the Willingness to Pay Approach. The Human Capital Approach considers the direct and indirect costs, but does not consider the intangibles offered to the society and the loss in the quality of life. The Willingness to Pay approach includes the value of life in the estimates. As such, the latter approach is more conservative.

FUTURE WORK, IMPROVEMENTS AND ENHANCEMENTS

The rehabilitation policies and procedures in Ontario have developed over many years to the point that they are well documented in Ministry's manuals. The number of bridges rehabilitated each year and the funds spent on them are such that most of the needs on the provincial network are being met without undue inconvenience to the public. The project bridge management system that is currently in place is satisfying immediate needs but is continuing to be developed. Work is currently underway in the following areas to address future needs and enhancements to the system:

- merge all information on bridges under a single database management system;
- continue research and investigations to determine the life cycles of the various rehabilitation methods;
- identify, develop and implement other modules needed for a complete bridge management system of the provincial bridges at the network level;
- develop and incorporate expert systems for selection of rehabilitation methods and options analysis for project level bridge management; and
- develop and incorporate expert systems for network bridge management.

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