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The Ontario Bridge Code: Second Edition

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ABSTRACT

Based on the limit-state design philosophy, the Ontario Highway Bridge Design Code was first published in 1979. A brief account is given of the implementation of the first edition of the code and the problems associated with the implementation. The second edition of the code was published in late 1983. Major changes in the code provisions are identified, and some details of a computer system that is currently being developed to support the code are given.

Despite the diversity of vehicle weight regulations in various jurisdictions, most highway bridges in North America are designed by the same AASHTO specifications (1) or the Canadian Standards Association (CSA) bridge code (2), which is only a slight variation of the former. The Province of Ontario used the AASHTO specifications until 1979, when the first edition of the Ontario Highway Bridge Design Code (OHBDC) (3) was published. The AASHTO specifications were used by choice, because Ontario, like other Canadian provinces, has full jurisdiction over its highways and related matters, which include the formulation and enforcement of vehicle weight laws and the choice of design codes for its highways and bridges. In 1976 the Ministry of Transportation and Communications (MTC) of Ontario decided to write a highway bridge design code of its own, mainly for the following reasons:

1. The lack of conformity between heavy vehicles in Ontario and the AASHTO design vehicles. It is noted that Ontario permits much heavier vehicles on its highways than do most other jurisdictions in North America.
2. The difficulty and tardiness in the incorporation of latest research findings, however significant, in the AASHTO specifications.
3. A belief that the limit-state philosophy would lead to economy of design and uniform, predictable levels of safety in bridges.
4. The need to have a code in SI units in compliance with the government's commitment to metric conversion.

The first edition was written by 17 technical subcommittees under the steering control of an 11-member Code Development Committee in the relatively short time of about 3 years. This first highway bridge design code with a limit-state design format was written by a team of about 80 engineers from both within and without Ontario. Details of its development have been given elsewhere (4).

Soon after the publication of the first edition, work was started on the revision of the code. This work led to the second edition of OHBDC, which was published in late 1983. The purpose of this paper is to give a brief account of the implementation of the first edition and also to identify major changes that have taken place since the first edition.

IMPLEMENTATION OF FIRST EDITION

Following the limit-state format of the code, designers were required to consider both the ultimate and the serviceability limit states. The former limit state corresponds to the maximum load-carrying capacity, and the latter, which includes cracking, vibration, fatigue, and permanent deformations, is associated with loadings for normal use. The resistance and load factors specified in the code were calibrated to a target safety index value of 3.5 (5). The calibration was carried out for reinforced-concrete, prestressed-concrete, and steel structures from relevant available statistical data. Such data were not available for substructures, wood bridges, and soil-steel structures. Because of the lack of prior knowledge of the limit-state methods for these items, the relevant design equations were calibrated less rigorously: The calibration could only be done with respect to designs obtained from other North American codes.

Most problems in implementation of the code related to sections on foundations, wood bridges, and

soil-steel structures. The conservative approach to calibration of these items resulted in designs that, by comparison with designs from other codes, appeared uneconomical. Where possible, relevant code provisions were revised through a series of addenda (6-8). Because of the expectation of extensive revisions, the section on wood bridges was withdrawn, and until the second edition of OHBDC, wood bridges were required to be designed by the AASHTO specifications.

The code provisions did not always appear to result in any significant reduction of materials except for reinforcement in concrete deck slabs. This can be attributed to the design vehicle which, in conformity with heavy trucks in Ontario, is more than twice as heavy as the AASHTO HS-20 truck. The design computation time increased by about 30 percent. However, because there was no change in the drafting time, the net effect on the cost of contract document preparation was an increase of about 10 percent, and this is expected to decline as designers become more familiar with the code and the SI system of units. It should be noted that a 10 percent increase in the cost of contract document preparation corresponds to an increase of less than 1 percent in the total cost of the bridge. This increase appears justifiable on the grounds of more uniform and consistent safety levels, and the use of a more rational design philosophy that has the potential of improvement as more statistical data become available.

Mainly because of the new design philosophy, there were a number of problems in the implementation of the code. The code writers had to provide an interpretation service for clauses that they were either responsible for or familiar with. A Code Implementation Committee was set up to gather feedback from users so that the problems could be identified and addressed in the second edition of the code. Results of the feedback can be summarized as follows:

1. There was a general reluctance to use refined methods of analysis, and an extension of the range of application of simplified methods was sought.
2. There was a resistance to the complexity of the simplified method of analysis, which, for the cases analyzed, gave answers similar to those given by the AASHTO method.
3. The introduction of the new provisions for the dynamic load allowance (DLA), which required the calculation of the natural frequency of the bridge, did not appear to pose any problem.
4. The empirical method for design of deck slabs, which results in a considerable reduction of reinforcement, was widely used.
5. The serviceability limit state of cracking appeared to govern the design of concrete bridges.
6. The limit state of fatigue governed the design of steel bridges more frequently than is the case when AASHTO specifications are followed.
7. Earthquake loading substantially increased the footing sizes and the number of piles and generally governed the design of fixed piers.
8. There was a general concern that the code provisions relating to shear resistance of concrete beams were overly conservative.

Although called the design code, the OHBDC also covers explicitly the evaluation of the load-carrying capacity of existing bridges. The code has now been applied to the evaluation of more than 60 bridges. The multiple-level posting, which can be established through the code provisions, is now used for posting of some bridges in Ontario.

As discussed earlier, the level of safety in a bridge was measured by a quantity called the safety index and denoted by β (9). To compare the values of β as obtained for OHBDC design with those obtained by the AASHTO specifications a large number of steel and concrete bridges were designed by the two codes, and values of β were calculated (9). As shown in Figure 1, β for AASHTO designs varied from about 1.5 to 14, illustrating the nonuniformity of safety levels. β-values for OHBDC designs remained close together.

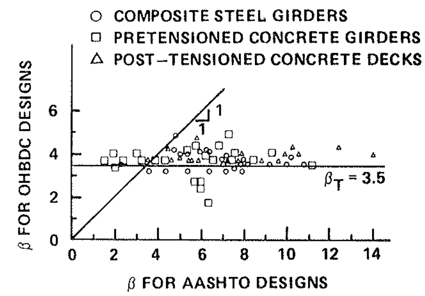

FIGURE 1 Comparison of safety index values.

THE SECOND EDITION

After the publication of the first edition of OHBDC, the technical committees were formed again, with a slight reduction in numbers, to start updating the code. The committee structure was generally the same as that for the first edition. The distribution of the affiliations of code writers remained unchanged, and professional fees were paid to consultants as before. The process of technical committee drafts and Code Development Committee reviews followed by public comments, as adopted for the first edition, was followed for the second edition.

The number of code sections was reduced from 17 to 14 by consolidating several sections dealing with loads.

In the following, major changes in specific code sections with respect to the provisions of the first edition of the code are identified and discussed.

Loads

The major change in the section on loads relates to the consolidation of the following three sections from the first edition:

1. Live and Dead Loads and Load Factors,
2. Dynamic Load and Vibration, and
3. Miscellaneous Loads and Movements.

The committee structure dealing with the three topics was the same as before. However, provisions under the three preceding headings were placed in a logical sequence under one heading. All clauses dealing with loads and load effects, which in the first edition were found in a number of locations, were consolidated under one heading.

A limited vehicle weight survey conducted in 1979 (10) indicated that the Ontario design vehicle still represented the vehicle population in Ontario quite closely. Consequently no change in the design-vehicle and live-load factors was sought.

As shown in Table 1 different values of modification factors for multilane loading were specified in the first edition for static loads and for DLA. Because of this, the governing multilane loading could not be established beforehand, and even when simplified methods of analysis were used, a designer had

TABLE 1 Modification Factors for Multilane Loading

No. of Loaded Design Lanes	Modification Factors in First Edition of OHBDC		Combined Modification Factors
	Static Load	DLA	
1	1.00	1.0	1.00
2	0.95	0.70	0.90
3	0.85	0.60	0.80
4	0.75	0.50	0.70
5	0.67	0.50	0.60
6+	0.60	0.50	0.55

Note: DLA = dynamic load allowance.

to investigate all the loaded-lane conditions separately. It was decided to amalgamate the modification factors for static and dynamic loads into one value in such a way that the resulting load effects were not substantially different. The amalgamated values of the modification factors as they appear in the second edition of the code are also given in Table 1.

In conformity with the usual practice, in the first edition of OHBDC it was specified that for the limit state of fatigue the single design vehicle should be placed in the most eccentric position. The fatigue response of a bridge component should depend on the normal transverse positions of traveling vehicles rather than some imaginary positions that may result in the worst load effects. With this in mind, it is now specified in the second edition that for the limit state of fatigue, the single design vehicle should be placed at the center of a traveled lane. It is anticipated that because of this change, economy will be justifiably affected, especially in bridges with wide shoulders.

After the publication of the first edition, an extensive and thorough dynamic testing program was undertaken. In this program 27 bridges of different types, span lengths, and so on, were tested. Details of bridges tested together with some relevant results have been given elsewhere (11). From test results the premise of the DLA provisions of OHBDC that DLA depends mainly on the first natural frequency of the bridge was validated. It was also found that the DLA values as given in the first edition of the code can be slightly reduced. Figure 2 shows the first- and second-edition DLA values corresponding to various values of the first natural frequency of the bridge. It is noted that the frequency of multispan bridges can be conveniently calculated by the simplified method given by Billing (12).

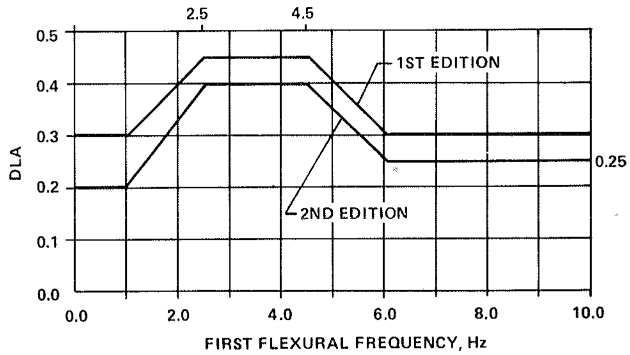

FIGURE 2 DLA values.

Deflection limitation criteria, which are concerned with human response to vibrations, have also been slightly relaxed in the second edition. These criteria are shown in Figure 3 together with the corresponding criteria given in the first edition.

The rather large number of load combinations specified in the first edition has been considerably reduced, and load combination factors have been eliminated by modifying the load-factor values.

Analysis of Bridge Superstructures

Provisions of the section on analysis of bridge superstructures have been the most controversial ones, mainly because of the reluctance of designers to be subjected to methods of analysis that are not so simple as the AASHTO load-distribution criterion (1). Because of the specification of different multilane modification factors for static load and DLA, the specified simplified methods became tedious, if not complex. The amalgamation of the two modifica-

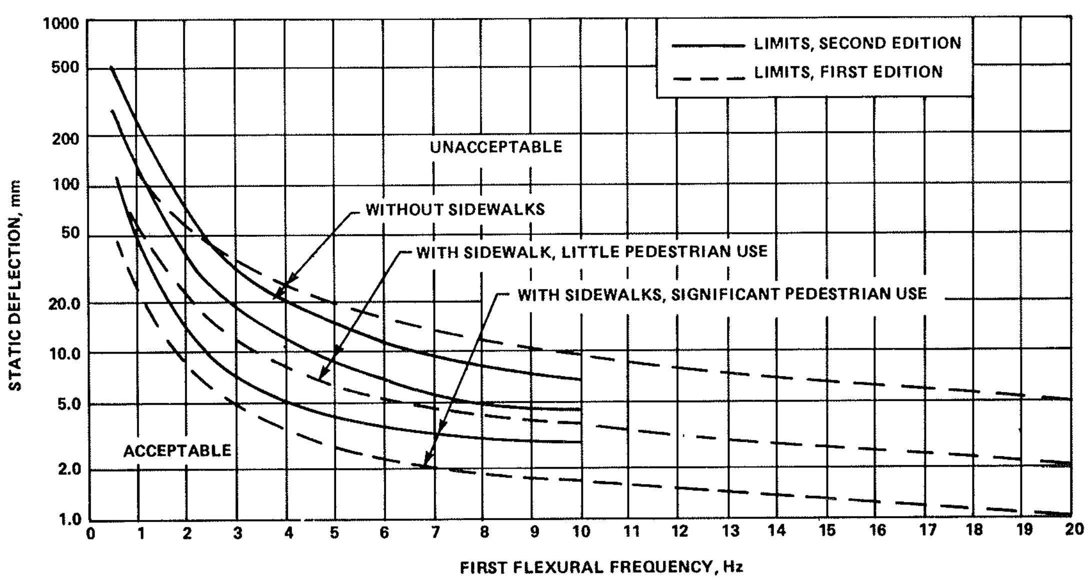

FIGURE 3 Deflection limitations.

tion factors into one, as discussed earlier, meant that the governing load cases could be established beforehand and the simplified methods made even simpler.

To extend the scope of the simplified methods and to make the analysis provisions easier to comply with, the following revisions have been incorporated:

1. The code clauses have been rearranged entirely to follow a logical sequence of operations.
2. Provisions for analysis of dead loads and live loads and the respective limitations for the use of relevant simplified methods have been separated.
3. Limitations on the applicability of simplified methods have been relaxed. It is now explicitly permitted to exercise engineering judgment in deciding whether a bridge is within the prescribed limits sufficiently closely for a simplified method to be applicable.
4. Unlike the first edition, the second edition contains simplified methods for both external and internal girders.
5. The simplified method for longitudinal shears has been revised and further simplified.
6. Based on recent research (13), a simplified method is provided for the calculation of transverse shear intensity in multibeam bridges.
7. An additional simplified method is provided for the analysis of multicell box girders.
8. A simplified method is provided to incorporate the effects of increased vehicle edge distance on longitudinal moments. This method is expected to prove useful for the analysis of bridges for the limit state of fatigue in which a vehicle is placed at the center of a traveling lane, thus increasing the vehicle edge distance considerably in many cases.
9. A simplified method of analysis is also provided to account for the presence of edge stiffening, for example, as provided by barrier walls.

Most of the simplified methods given in the code are derived from computer-based refined methods; they are presented in such a way that a designer, using methods similar to that of the familiar AASHTO load distribution criterion, can use the results of refined analyses, reduced to a graphical or tabular form, without having to perform the refined analysis computation.

Deck Slabs

One of the more compelling reasons for a bridge design code written for Ontario was a belief that concrete deck slabs of slab-on-girder bridges were usually overdesigned by a large margin. The basis of this belief was a large number of laboratory and full-scale tests showing that the failure mode for these components was that of punching shear and not flexure, for which the deck slabs are usually designed. From the studies it was concluded that a deck slab can safely sustain modern heavy vehicle traffic if it has a ratio of span to thickness of 15 and two meshes of orthotropic reinforcement with a minimum area of reinforcement in each direction and each mesh of 0.3 percent of the concrete area. Details of the basis of this empirical approach have been given elsewhere (14).

In the first edition of OHBDC, the deck slab thickness for new designs was required to be at least 190 mm. This limit has been increased to 225 mm in the second edition. The requirement for minimum slab thickness is not related to the strength of the slab but to considerations of durability. It is believed that slabs exposed to deicing salts should have reinforcement with a minimum cover of 50 mm from the salt-exposed surface. A recent survey of depths of cover conducted in Ontario showed that the standard deviation of the depth of cover is about 10 mm. Hence to ensure that in 97.5 percent of cases the actual depth of cover would be at least 50 mm, a depth of cover of 70 mm has been specified. This requirement, together with the requirement of a minimum spacing of 25 mm between two layers of reinforcement, results in an overall minimum deck slab thickness of 225 mm.

There was some ambiguity about the applicability of the empirical method in concrete slab-on-girder bridges without intermediate diaphragms. This ambiguity has been removed by clearly stating that the empirical method can be applied to concrete slab-on-girder bridges without diaphragms.

The empirical method for deck slabs was only an alternative permitted in the first edition if certain conditions, for example, a certain deck slab overhang width, were met. Confidence in the empirical method has grown since 1979. In Ontario several deck slabs have been designed by the empirical method and are performing well, and independent tests done in New York (15) have also confirmed the validity of the basis of the method. With the growing confidence in the empirical method it was decided to make the method mandatory rather than permissible in the second edition for all deck slabs that conform to conditions necessary for the application of the method.

The empirical method as given in the first edition was not applicable to bridges having skew angles larger than 20 degrees. Since the first edition, several tests have been conducted by MTC on deck slabs of bridges with large skew angles. From tests results it was concluded that away from the skew supports the deck slab behavior is similar to that of deck slabs in right bridges. Consequently, in the second edition it is specified that 0.3 percent isotropic reinforcement be provided in the middle regions of the decks and 0.6 percent in the end regions. The two regions are identified in Figure 4.

Wood Structures

A major change in the section on wood structures was the introduction of a set of design provisions for prestressed wood decks. As discussed in various publications (16,17), this new structural system consists of laminated decks that are transversely posttensioned. The purpose of prestressing in this case is to hold the laminates together so that the interlaminate slip is avoided. The system has been successfully applied to rehabilitate existing nail-laminated decks and also has been incorporated into the design of a new bridge (18).

The second edition of the code contains design

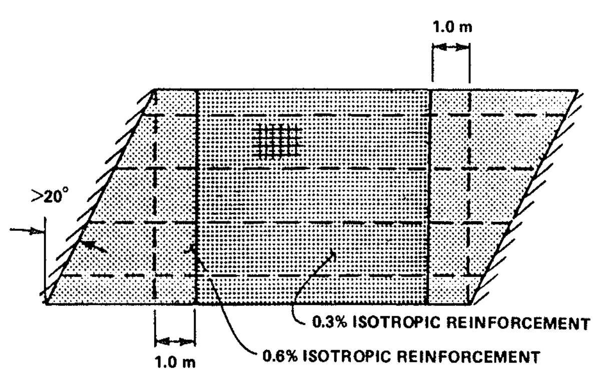

FIGURE 4 Reinforcement in deck slabs of skew bridges.

provisions for prestressed wood decks and details of approved prestressing systems. The code also has provisions for the design of wood-concrete composite bridges and gives approved details of the wood-concrete interface.

An extensive study was undertaken to compare the designs of wood bridges resulting from the AASHTO and OHBDC provisions. Details of the study have been reported elsewhere (19). A summary of the results of the study for sawn stringer bridges with transverse-laminated decks is shown in Figure 5. It can be seen that the AASHTO specifications result in deeper stringers when the stringer spacing is less than about 900 mm, but the situation reverses for larger stringer spacings; that is, the OHBDC provisions lead to deeper stringers.

COMPUTER SUPPORT SYSTEM

When a new code is implemented quickly, it is unlikely that there will be existing computer programs immediately available for use with it. In anticipation of the code, the MTC library of bridge programs had been metricated and converted to a load-factor format so that they could be used, at least in a limited way, with the new code. A new live-load routine was developed, but there was still a good deal of manual transfer and combining of required data. The level of sophistication of these converted programs was below that for programs that were available for calculations with the AASHTO specifications.

The current MTC library of bridge programs has been developed over the past 20 years and has undergone extensive modifications. The rapid change of programming techniques over the years has resulted in substantial nonuniformity between the various programs, making maintenance and modifications quite difficult. For the library of programs to be able to support the new code, two alternatives were considered: updating existing programs individually or developing a new modular system. The latter alternative, although incorporating a high initial cost, was chosen because of its long-term benefits. Because the system was modular in nature, it could easily accommodate changes and would be easy to maintain.

The computer system chosen to be developed is called the Ontario Modular Bridge Analysis System (OMBAS). Although called the analysis system, it also incorporates routines for design. The system includes a number of large modules, a data base, and a number of utilities. Each large module will perform a separate and unique function that is recognizable to the designer and constitutes a normal design step. Broadly speaking, the application subsystem includes 11 large modules carrying out the following functions:

1. Control,
2. Input,
3. Geometry-related calculations,
4. Idealization,
5. Generation of dead-load-related data,
6. Solution,
7. Generation of live-load-related data,
8. Generation of load combinations,
9. Calculation of resistances,
10. Detailing, and
11. Output.

The utilities system contains modular units that facilitate system development, operation, and maintenance. Details of OMBAS are given elsewhere (20).

The work on OMBAS is planned in two phases; phase 1 is scheduled for completion soon after the publication of the second edition of the code. It is expected that at the end of this phase the system would be suitable for code testing. The second phase is expected to take another 3 years.

The projected cost of the development of OMBAS is $840,000. The work on the project is being carried out by an MTC project team. An established project management system is being followed that calls for regular reviews by a user review group and a quality review group; the membership of the former includes consulting engineers and MTC staff. The latter group includes an external computer systems adviser. All Ontario users will have access to OMBAS, as they now do to the existing library of programs.

IMPLEMENTATION PLANS

A new commentary volume has been issued with the second edition of the code. This commentary explains the derivation of code clauses and cites references. With this commentary available, implementation by designers already familiar with the first edition should not be a problem. Seminars are planned, however, to ensure that users understand the new provisions and have a chance to discuss them with the authors.

Implementation of the new OMBAS computer system will represent a larger change, and special sessions of instruction will be held. The changeover from the current system to OMBAS will be a gradual one,

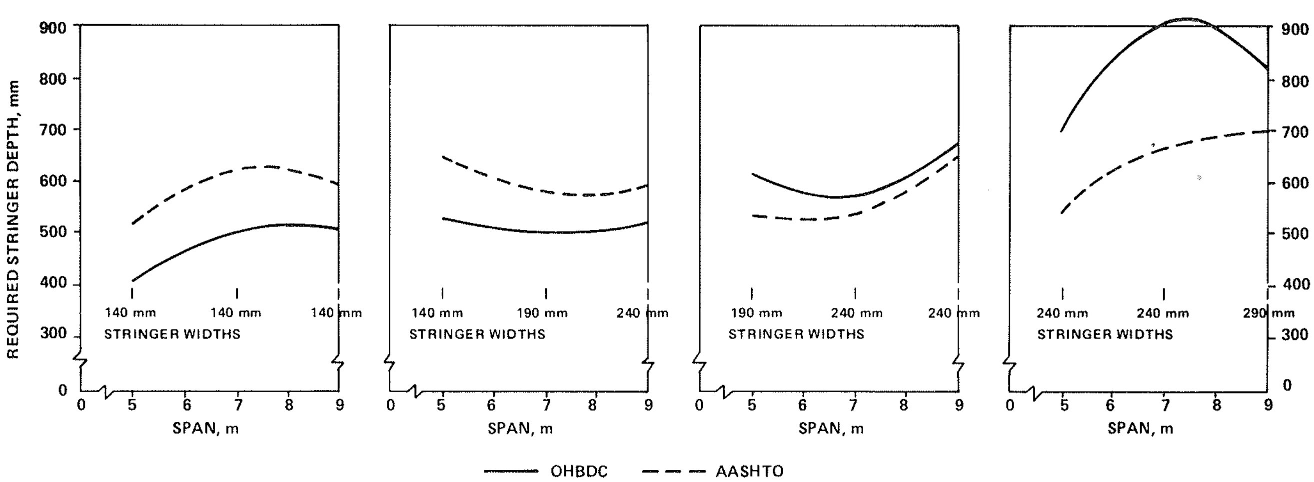

FIGURE 5 Comparison of AASHTO and OHBDC designs for bridges with sawn stringers and transverse-laminated decks.

and the existing programs will not be dropped until the full capability of OMBAS has been tested in the production mode.

The OHBDC first edition has been used on all MTC bridges for several years but has been optional in application to municipally owned bridges in Ontario. By the end of 1984, when OMBAS is fully operational, the second edition will become mandatory for the design and evaluation of all bridges in the province. All drawings will then require the seal of two professional engineers, one the designer and the other the checker, thus assuring that all designs have been carried out and checked in conformity with the code.

CONCLUDING REMARKS

The code has had wide acceptance in Ontario with no more problems in implementation than anticipated. The simultaneous issuing of a commentary and a reasonable lead time for familiarization are key items to ease the introduction of a new code. The code provisions, where appropriate, have recently been incorporated into the design criteria for elevated structures for a light rail transit system in the Toronto region, and the same limit-state format and calibration process has been followed. Within Canada the CSA Highway Bridge Committee is considering adoption of a number of OHBDC provisions and is also producing a limit-state design specification for the next edition. The AASHTO Bridge Committee has shown interest in some clauses, such as the deck slab empirical design method, as have code writers elsewhere, particularly those in Australia, New Zealand, and Japan.

Although introduction of the OHBDC has not brought about large changes in material quantities or costs, it does provide for the heavy Ontario truck loads in a more rational manner and with more consistent safety levels than before. The limit-state format appears to be the best to accommodate future changes as more statistical data become available and improvements are made in probabilistic design techniques.

In most jurisdictions there is an increasing emphasis on maintenance and rehabilitation, which will continue in years to come. Although the OHBDC covers the evaluation of existing bridges, the code provisions for bridge rehabilitation need to be expanded. This will be a major topic of study in preparation for the third edition, as will the provisions of design methods for partially prestressed concrete. Most future structural research and development projects in MTC will be generated by code needs. This continued development and the active participation of the code writers and users should ensure that the OHBDC remains in the forefront of available bridge codes.

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