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Role of Codes in Bridge Durability

Rôle des codes pour assurer la durabilité des ponts

Die Einführung von Normen zur Verbesserung der Dauerhaftigkeit von Brücken

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SUMMARY

If durable bridges are to be produced, reliability and serviceability must be addressed in new design codes. Probabilistic methods enable this to be done by calibrating serviceability conditions to agreed levels. Rehabilitation codes are lacking in reliable data for satisfactory calibration. Tendering methods affect durability levels. Four alternative tendering methods are reviewed. The build/operate/transfer method appears likely to produce the most durable structures.

RÉSUMÉ

Afin d'augmenter la durabilité des ponts, il faut envisager de nouveaux codes de projet. Ce but peut être atteint par des méthodes de probabilité, en calibrant les conditions de service à un niveau acceptable. Les codes de réfection manquent de données valables pour leur calibrage satisfaisant. Le système des soumissions a un effet sur les niveaux de durabilité des ponts. On considère quatre types de soumissions; celle qui semble devoir donner les meilleurs résultats quant à la durabilité des structures, combine la construction, l'opération et le transfert final au propriétaire.

ZUSAMMENFASSUNG

Um bei dem Bau von Brücken einen hohen Grad an Dauerhaftigkeit zu erreichen, müssen in bezug auf Zuverlässigkeit und Instandhaltungsmethoden neue Normen geschaffen werden. Bestimmte Prüfmethoden erlauben es, gewisse Normen für die Brückeninstandhaltung nach bestimmten Richtlinien festzulegen. Reparaturvorschriften geben keine genauen Auskünfte über zuverlässige Instandhaltungsmethoden. Die üblichen Ausschreibungsmethoden beeinträchtigen die Dauerhaftigkeit. Vier verschiedene Methoden werden besprochen. Die Bauen/Betrieb/Übertragungsmethode scheint den höchsten Grad an Dauerhaftigkeit und Zuverlässigkeit beim Brückenbau zu erreichen.

1. INTRODUCTION

Durability is described as the ability of the structure to maintain its level of reliability and serviceability during its lifetime. In the past, durability has been considered mostly in terms of serviceability items, such as cracking and spalling of concrete, corrosion of steel, and limiting maintenance costs. These items were considered as primarily the preserve of construction specifications, site inspection and quality control, rather than that of design codes. Such codes might specify minimum concrete cover, for instance, and other items of good construction practice, but could not adequately address the question of reliability as these older working stress codes were deterministic rather than probability based.

With the introduction of probabilistic limit states bridge codes around 1980, lifetime reliability has become one of the most significant areas for code development. If the required statistical data is available, load and resistance factors can be calibrated to achieve target safety indices at various serviceability limit states as well as the ultimate limit state. Durability has thus become very much an area of interest for design codes.

The 20 year boom in new highway and bridge construction peaked in North America and a number of European countries in the late 1960's. As many of these bridges are now ageing and require extensive maintenance, there has been an increased interest in bridge rehabilitation in the last ten years. This interest initially focussed on repair techniques and materials rather than rehabilitation design, as codes did not address this issue. If rehabilitation is to be cost effective, much work needs to be done on putting rehabilitation design in the same reliability based context as new designs. Much more data is needed on the life expectancy of rehabilitated bridges before this can be completed, but the third edition of the Ontario Highway Bridge Design Code (OHBDC) will have a new section on rehabilitation design when issued late in 1989.

Bridge codes have generally been written to cover frequently built bridge types in the short and medium span range. For long span bridges special design criteria are usually prepared which may not address durability adequately, particularly if probabilistic data is not available which may be the case for a unique design. It is in the long span bridge range that different tendering methods are likely to be used, such as alternative designs, design/build proposals, and more recently build/operate/transfer (BOT). These various methods can produce in themselves wide variations in durability. The latter method, BOT, holds promise for a high level of reliability and serviceability, however, and a current Canadian example is presented.

2. DURABILITY ASPECTS IN DESIGN CODES

Whatever basic code philosophy is used, all bridge design codes should precribe details to ensure ease of maintenance, and specify design details that are considered good practice and likely to produce durable structures. The OHBDC 1983 explicitly addresses maintenance and durability aspects, and some of its provisions will be identified as typifying what can be covered for bridges in a corrosive environment, regularly subject to winter salting.

The components most susceptible to deterioration have been concrete bridge decks, expansion joints and bearings[1]. The minimum slab depth is specified as 225 mm with a minimum cover to the top reinforcing steel of 50 mm. Placing tolerances for reinforcement are given which have to be allowed for in setting the dimensions on the drawings to ensure that the minimum cover is achieved in the field. The OHBDC commentary references the use of epoxy coated reinforcement and membrane waterproofing for decks. Deck drainage and drip detail requirements are given, with downspouts to protrude below soffit level to keep salt water off the superstructure.

Sealed deck expansion joints are normally used, but as they frequently leak, the use of continuous spans to minimize joints and thus improve durability is encouraged. Seals have to be replaceable, and must be set below the riding surface to reduce wear. If the joints eventually leak, access is needed between the abutment ballast wall and the deck for cleaning, and a minimum gap of 200 mm is called for to enable this to be done. Bridge seats must have a grade of at least 5% so water will drain away from bearings. Bearings have to be accessible for inspection and maintenance and be replaceable without damage to the structure and without removing anchorages permanently attached to the structure.

To facilitate inspection and maintenance of steel or concrete box girders, and enable interior formwork to be removed, access openings have to be provided for each cell, and have closely fitting hinged covers. Such girders shall not contain sewers or water pipes inside them due to the possibility of breakage or leaking, and subsequent girder deterioration or danger of collapse. Gas and oil pipelines are prohibited from all highway bridges on account of fire and explosion hazards.

All these items may appear rudimentary, yet they have to be specified at the design stage, and need to be included in the design code to ensure implementation, otherwise the durability of the built structure may be compromised.

3. RELIABILITY BASED CODES

The move in recent times towards reliability based codes, enables codes to be calibrated to produce relatively consistent safety levels for bridges. This calibration work has generally concentrated on the ultimate limit states [2], but can equally well be applied to serviceability limit states, thereby providing another means of establishing durability levels for structures at the design stage. For the 2nd Edition of the OHBDC in 1983, such calibration was carried out for the serviceability limit states of cracking, vibration, fatigue and permanent deformation [3], as well as ultimate limit states.

The design equation for each specified limit state is:

$$\phi R \geqslant \text{total factored load effect}$$

where ϕ is a resistance factor, R is the nominal resistance, and total factored load effect is the sum of the product of the nominal loads considered multiplied by their corresponding load factor. The calibration process used was the calculation of load and resistance factors, using second moment level-2 reliability analysis [4], to obtain a reliability index close to the preselected target value. The reliability index β is a measure of safety, such that:

$$\beta = \frac{\bar{R} - \bar{Q}}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

where $\bar{R}$ and σ_R = mean resistance and its standard deviation and $\bar{Q}$ and σ_Q = mean load effect and its standard deviation.

The target β selected for ultimate limit states was 3.5. The serviceability limit states can be reached more frequently and lower β values can thus be selected. For example, for cracking of prestressed bridges, a target value of $\beta = 1.0$ was used, which relates to concrete cracking under live load once a week. This frequency of crack opening was considered acceptable, considering the possible fatigue of the prestressing strands and the possible corrosion of strands due to the entry of aggresive salt water. From the durability point of view it should be noted that Ontario practice calls for a full waterproof membrane and asphalt wearing surface over prestressed decks in addition to the serviceability controls on the concrete.

The target reliability values can be selected according to the type of structure and its importance. For instance, for elevated transit structures, where service must be maintained at all times, and no alternative routes are available, higher target β values of 4.0 and 2.5 for ultimate and cracking limit states have been proposed [4].

4. LIFETIME SERVICEABILITY

Based on the history of bridge replacements in North America, a typical design life expectancy would be 50 years. Bridges have become deficient due to functional or geometric inadequacies, serious structural deterioration, or insufficient load carrying capacity due to an increase in vehicle weights. Most bridges over 30 years old have required significant rehabilitation work. With calibrated limit states design codes and a better understanding of the design, construction and operational needs for more durable bridges it is expected that new bridges will show better performance. It is unlikely, however, that any bridge will achieve its 50 year lifetime without some rehabilitation work being needed. If a bridge is to maintain the designed level of reliability and serviceability during its lifetime it is desirable that the code to which it is designed also includes provisions for load capacity evaluation and rehabilitation.

Evaluation and rehabilitation aspects have traditionally not been part of design codes. The first two editions of the OHBDC have covered bridge evaluation, and the third edition will have a new section on rehabilitation. The limit states format is ideally suited to evaluation and rehabilitation, as the actual bridge can be surveyed and the design values of load and resistance factors modified as appropriate. These factors can also be adjusted to suit the anticipated future life of the structure, which is unlikely to be as long as the 50 year life on which the design values were based. By using these methods the load carrying capacity will usually calculate higher than that obtained by applying new design provisions to the evluation process.

When rehabilitation design is required, the new bridge design provisions are not usually suitable, and rehabilitation code sections should again reflect changed loading conditions, structure condition and anticipated future life. The OHBDC will have three rehabilitation categories according to an anticipated future life of greater than 25 years, 10 to 25 years, and up to 10 years. Each category will have its own prescribed load factors. It will be difficult to do a comprehensive calibration of the rehabilitation load and resistance factors at this time, as life expectancy of various rehabilitation techniques is hard to establish. When enough rehabilitation data has been collected, rehabilitation design can be put on the same probabilistic basis as new structures. A code can then consistently address new design, evaluation and rehabilitation to increase the probability of maintaining a uniform level of serviceability throughout the life of a bridge.

5. TENDERING METHODS AND DURABILITY LEVELS

5.1 Background

Most methods of tendering for bridge construction give little incentive to produce the high quality work that will enhance lifetime durability. They usually award to the bidder with the lowest construction cost.

In North America this price is prepared using full design drawings and specifications prepared by the owner or his consultants. Standard design codes are usually applied. On some major projects alternative tendering methods have been used, usually on long span bridges which are beyond the range for which standard design codes apply. Special design provisions have to be prepared, including those addressing durability. The different methods of tendering can have a major impact on the likelihood of obtaining durable bridges, and four methods will be compared from this perspective.

5.2 Single Design Provided by Owner

With this method all contractors bid on the same design, with full drawings and specifications issued, and no provision for changes, except perhaps by applying value engineering after the contract is awarded. The design requirements and construction specifications need to be comprehensive and must be supported by a major quality assurance program by the owner, as the contractor, in order to obtain the job, has to bid providing no more than the minimum specified quality.

The method works reasonably well for large public authorities when building short and medium span bridges on a regular basis. Most highway departments in North America use this method for their bridges, unless the contract value is high enough to warrant going to alternative designs.

5.3 Alternative Designs Provided by Owner

On a large bridge project when it is difficult to select the single most economical design, the owner may provide two or more designs for competitive bidding. The controls needed for durability noted for the single design method are equally necessary under the alternative design method, as the award is still based on the lowest bid, with full documents provided by the owner. There are two further considerations, however, for the alternative design approach. As this method is usually applied to long span bridges, beyond the typical maximum span of about 150 m for which standard design codes apply, special design criteria may need to be prepared covering durability aspects of long spans and possibly unusual types of bridges. The other consideration comes at the design stage, and relates to preparing designs of equal durability, and as far as possible equal maintenance costs over the lifetime of the bridge. As the award is made on lowest construction cost, rather than lowest life cycle cost, the process makes sense only if each alternative is equally acceptable to the owner, which implies equal reliability and serviceability.

5.4 Design/Build with Designs Provided by Contractor

This is the method commonly used in Europe, but has been used only recently in North America. The contractor prepares his own design and bids on this, using overall requirements supplied by the owner. The method is usually applied to large projects or long span bridges, and particular attention again must be paid to design criteria preparation. This may be even more important than under the alternative design approach, as the owner does not know what types of bridge will be designed by the bidders. The specially prepared design criteria thus have to cover a very broad range of structure types and materials to ensure comparable durability. As the award is again based on lowest construction cost, the concerns about equal serviceability and maintenance costs given under the previous method are equally applicable under the design/build approach, but are probably harder to achieve.

The design/build method was used for the retractable roof stadium "Skydome" in Toronto due to open this year. A two phased procedure was followed with approval of technical concept as a first stage producing four finalists. The competing roof types being now known, the final design criteria were prepared before moving up to the second stage of pricing. This stadium roof, with barrel arches spanning up to 200 m is fully exposed to the elements when retracted, and is in many ways more similar to a steel bridge than a building. One interesting aspect of the design criteria, addressing reliability and durability, was the requirement that the roof structure had to stand up after all members within a vertical cylinder of diameter 4.5 m located anywhere in the roof were removed. This requirement produced a highly redundant winning design with a multiplicity of load paths, probably the best way of ensuring a high level of reliability.

5.5. Build/Operate/Transfer (BOT)

The Northumberland Strait Project, a 13 km long bridge linking the Provinces of New Brunswick and Prince Edward Island is the first application of the BOT method in Canada. Developers are required to finance, design and build the toll facility, operate it for 35 years, then transfer it to the Federal Government. The competition has three phases, initial qualification of developers, acceptance of concept proposals, and finally the price proposals. The project is presently held up for a year, following the completion of the second phase, pending a further environmental study.

Design criteria were written by the Federal Government before the second phase, but left many tasks to the developer, such as calibrating the criteria for the ultimate limit states to a target β value of 4.0, carrying out wind tunnel tests, and performing ship collision risk analysis. To the extent possible durability requirements were given for steel and concrete bridges, with the objective of using the best possible techniques. The eventual owner prescribed a 100 year life, in the aggressive environment of an ocean crossing with high winds, wave action, and large ice forces. To increase the chances of achieving this lifetime, and of having a bridge in good condition at the transfer stage, the use of salt as a deicer on the roadway is prohibited. The developer, as the operator, has to use other methods such as urea or CMA.

An important aspect of the BOT method is that the developer is just as interested in durability as the owner. In fact the developer may aim for durability in excess of the prescribed minimum in order to avoid a major rehabilitation cost before the transfer date. The proposals are in effect based on a total 35 year lifetime cost to the developer, as the project will not be awarded on construction cost, but on the basis of the lowest government annual subsidy requirement.

6. CONCLUDING REMARKS

Techniques are now being developed so that design codes for new bridges can properly address lifetime durability. More information on the expected life of repaired components is required before similar progress can be made on rehabilitation design codes.

The level of durability may vary with the contract tendering method adopted. The BOT method on major bridge projects holds the most promise for improved durability as it is the only method that makes long term durability a common goal for both owner and constructor.

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