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New Building Designs Incorporating Lessons from Failures

Conception de bâtiments en tenant compte des leçons tirées de dommages

Bauwerksentwürfe unter Berücksichtigung der Lehren aus Schadenfällen

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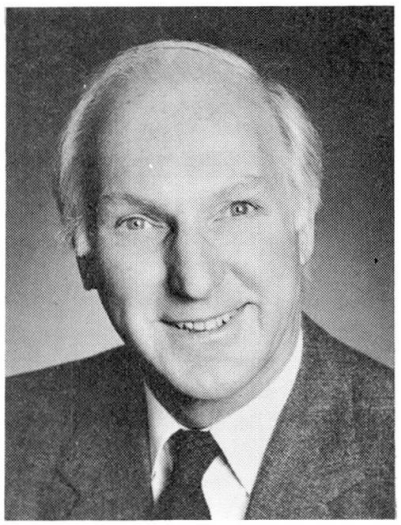

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SUMMARY

The presentation discusses some of the factors which lead to deterioration of buildings, and, in particular, parking structures. Examples are given to illustrate designs and details which have performed poorly in service, and other designs and details which perform well. Some figures are given for the apparent 'savings' made in construction costs and the real costs incurred subsequently for restoration. The general inadequacy of feedback to designers, from buildings in service, is discussed, along with some reflections on the roles of Codes and Standards.

RÉSUMÉ

Cet artcile traite de quelques facteurs contribuant à la détérioration de bâtiments, plus particulièrement de parkings. Des exemples, bons et mauvais, de conceptions et de détails constructifs sont donnés. Des comparaisons entre les économies lors de la construction et les frais de réparations sont faites. Les projeteurs sont trop peu informés du comportement en service de leurs structures. Le rôle des normes est discuté.

ZUSAMMENFASSUNG

Der Beitrag behandelt einige Einflussfaktoren auf die Schädigung von Gebäuden, speziell von Parkgaragen. Es werden Beispiele gegeben, welche ein unbefriedigendes Verhalten zeigen und andere, welche sich bewährt haben. Zahlen über die vermeintlichen Einsparungen beim Bau werden mit den Instandstellungskosten verglichen. Die mangelnde Rückkoppelung zwischen Konstruktion und Bauschäden wird diskutiert, zusammen mit einigen Gedanken zur Rolle von Normen.

1. INTRODUCTION

There has been a phenomenal boom in building construction in North America during the past 30 years. During the past 5 years there has developed a phenomenal boom in the business of repairing and restoring buildings.

Our firm now undertakes about 300 new design projects a year, and over 100 projects on the investigations and restoration of existing buildings. Some buildings suffer premature deterioration due to loading or environmental conditions that could not reasonably have been forseen at the time of design.

Most of the problems, however, could have been avoided, at very little extra cost, by better attention to design, details, specifications and construction practice.

In most cases that we have investigated, problems have resulted from a lack of judgement or care.

Many areas of Canada and the northern United States suffer extremes of climate, and significant atmospheric pollution. Salt is used extensively throughout long winters. These conditions provide very rapid tests for structural systems and materials. We hope that some of the lessons we have learned may help those practicing in other regions.

Problems occur in buildings of all categories, but parking garages, as a category of buildings, show the most widespread, conspicuous and generally costly troubles. We have designed about 400,000 square metres of parking decks, and investigated and repaired about 1,200,000 square metres of parking decks.

This paper will discuss three types of parking structures as examples. Many of the lessons from these most vulnerable structures, however, can be applied to other structures which have less severe exposure in service. The paper will deal with precast concrete, post-tensioned concrete and conventional reinforced concrete construction.

During the preparation of this paper a tragedy occurred in Vancouver, British Columbia, when the roof of a shopping centre, which was designed as a parking deck, collapsed within a few weeks of its completion. The cause of this failure has been identified by a public enquiry, as being a basic design error. The design engineer failed to consider lateral stability of the unrestrained bottom flange of a steel girder which was continuous over the supporting columns. The error was not caught by checking within the design office, by the building officials in reviewing the drawings, by the steel fabricator who produced fabricating details, nor by a second firm of consulting engineers who were called in to check the structure during construction, before the failure. The enquiry panel recommended, among other things, that structural engineers be subjected to more stringent examination before being allowed to practice. The extremely low fees negotiated for the consulting structural engineers, in this case, were criticised. It was recommended that a fee scale should be enforced with a minimum level that was sufficient to allow consultants to provide adequate time and effort to the design of building structures.

It will be interesting to see how that recommendation fares, as it is out-of-step with the present march towards deregulation. Fortunately, basic design errors which lead to tragic failure are very rare.

This paper is intended to address deficiencies which are very common.

2. THE SCOPE OF THE PARKING STRUCTURE PROBLEM IN CANADA

Various estimates have been made regarding the scope of the problem of premature deterioration of parking structures in Canada, and the approximate cost of rehabilitation and replacement.

It is believed that there are about 5,000 framed parking structures, including parking levels beneath buildings. Most of these have been constructed in the past 30 years.

As an order of magnitude indication, one study in 1987 estimated that the costs to deal with premature deterioration, as distinct from normal maintenance, may be around $3 billion in Canada alone. Even when these garages are "dealt with", they can rarely be put into a really sound condition. Some contamination remains. Although the subsequent useful life expectancy may be increased, on-going maintenance and repairs are likely to be higher than for a structure which was well built in the first place.

Table I gives data on 3 structures investigated by the author to indicate the costs involved for repair and protection on a per square metre basis.

3. ILLUSTRATIONS OF DESIGNS AND DETAILS WHICH HAVE LED TO FAILURE AND CORRESPONDING DESIGNS AND DETAILS WHICH PERFORM MORE SATISFACTORILY

Slides will be shown to illustrate each of these structures, showing details of failures or premature deterioration.

Failures illustrated include:

Corrosion of reinforcement due to:

- Inadequate concrete cover, depth and quality.
- Failure or omission of surface protection systems.
- Inadequate protection of post-tensioning tendons, unbonded, in plastic sheaths or paper wrappings.
- Inadequate protection of anchorages for post-tensioning tendons.
- Inadequate sealing systems at joints.
- Poor details leading to entrapment and concentration of contaminants.

Structural distress due to:

- Excessive deflection and displacement. e.g. creep deflection, thermal movement.
- Inadequate provision of expansion and control joints.
- Movement due to earth pressure or ice formation.
- Impact.
- Corrosion of embedded electrical conduits.

Corresponding slides will be shown to illustrate equivalent structures in which details and protection have been better engineered to provide durability in service.

4. FEEDBACK

In Canada, the construction of large numbers of parking structures began in the late 1950's, mostly for apartment buildings and office buildings. Large parking decks for shopping centres began to appear in the 1960's. Some of these were designed and built with care and consideration for exposure conditions, but many were not.

By the late 1970's serious problems were obvious in many of these structures. Effort was quickly put into investigation and rehabilitation techniques by a few firms.

In hindsight, it is both remarkable and distressing that so much new construction was completed throughout this period, and into the 1980's, without recognition of the lessons that these failures should have taught.

Developers were generally unable or unwilling to appreciate that lowest initial cost did not always mean lowest life-cycle costs. Projects were often built and sold off, so that the original developers did not have to face the subsequent repair costs.

There was fierce competition between the proponents of various systems to increase their market share by lowering initial costs. Bonded post-tensioning tendons gave way to unbonded tendons because they were $2.00/square metre less expensive. Failures in parking decks with unbonded tendons are widespread. The author is not aware of any significant failures of decks reinforced with bonded tendons.

Many precast parking structures for shopping centres were designed and built by contractors who had no experience of conventional cast-in-place structures, and were not aware of the hazards that arise in service. When leaking and corrosion did develop in precast decks, we find that owners and operations managers called in other contractors to apply sealants and to try to treat the symptoms. The original designers were rarely made aware of the service failures, and they repeated past details, or devised even less expensive ones, genuinely in ignorance of their deficiencies.

5. CODES AND STANDARDS

Until 1987, we have had very little guidance from National Codes or Standards on the design and protection of structures exposed to severe environments.

Our 1970 National Building Code stipulated that "Special attention shall be given to the spacing of expansion joints, the details of construction joints, the amount of shrinkage steel provided and the amount of protection afforded the reinforcing steel in structures in which danger of steel corrosion is increased due to the presence of salt or acid solutions or vapours."

Concrete cover requirements were stipulated for only two situations - surfaces exposed to "the weather or to be in contact with the ground", or "surfaces not exposed to the ground or weather". Parking decks, especially below-grade, were most commonly categorised as if they were not exposed to the weather - despite their severe exposure to salty water and slush brought in by vehicles.

In 1987, the Canadian Standards Association published their first Standard on Parking Structures, CAN/CSA-S413-87.

This is a landmark publication. It sets out specific recommendations for design, detailing and construction of parking garages, over and above the general requirements of the national Standards for reinforced and prestressed concrete construction. It includes particular guidance on concrete toppings, tendon protection, epoxy-coated reinforcement, protective surface membranes, construction and expansion joints, slopes and drainage. Minimum protection systems are given for light use and heavy use areas on different structural systems.

This Standard was published over ten years after serious deficiencies in general practice had become apparent. The "industry" was very slow to formalise the lessons that should have been learned from inadequate performance in practice.

This Standard has now been incorporated into the mandatory Building Code of the Province of Ontario, and all new parking structures are required to comply with its requirements.

To meet these requirements, a parking deck probably costs about $30.00/square metre more than the cost in today's dollars of the poorest practices which were commonly followed by developers two or three years ago. There have been strong complaints from suppliers of some systems which were not incorporated into the Standard. We feel there is a justifiable fear that an exclusive Standard may inhibit the introduction of new and possibly improved materials and methods. But better mouse-traps do eventually force their way onto the market.

A new Standard is a great help towards the assurance of durable structures, but diligence and sound judgment by the design engineer is needed in the application of all Codes and Standards. There is no substitute for the experience, and the opportunities taken to learn from failures, problems and successes of previous building designs.

TABLE I

GARAGE	A	B	C
STRUCTURE TYPE	Concrete flat slab, normal reinforcing, nominal 20 mm cover, no surface protection, nominally flat	Precast concrete TT units on precast columns and prestressed girders, in-situ topping, no surface protection	Post-tensioned cast-in-place slabs on normally reinforced columns and beams
Framed area	60,000 m^2	18,000 m^2	22,000 m^2
Year completed	1975	1975	1972
Year major repair work begun	1980	1987	1982
Direct costs to date for repairs and protection	\$80.00/m^2	\$64.00/m^2	\$374.00/m^2 (Plus approximately \$400.00/m^2 indirect costs)
Estimated "avoided" costs to provide better details and protection in accordance with knowledge available at the time of construction	Less than \$10.00/m^2	Less than \$10.00/m^2	Less than \$12.00/m^2