

Six Axioms for Building Durable Concrete Structures

by Noel P. Mailvaganam and G.G. Litvan

Durable concrete structures can be achieved only through careful attention to many details. This Update discusses the key determinants of durability for both new construction and repair.

The durability of concrete structures can be defined as their ability to sustain the serviceability for which they were designed. Basic to the concept of durability is a commitment to quality and its assurance. With respect to concrete, quality assurance is a matter of testing and inspecting to ensure the proper selection, proportioning, mixing, handling, placing, and curing of the materials, as well as the appropriate design of the structure itself.

The following axioms should be taken into account for both the construction of new concrete structures and the repair of deteriorated structures.

1. Match the materials to the environment

Durability becomes an issue when a material's resistance to deterioration is less than that required to withstand the aggressiveness of the environment in which it is to function. For example, steel will not corrode in a dry and salt-free environment, but it will do so in the presence of moisture and chloride ions. Similarly, concrete made with Type-10 cement will not resist sulphate attack, and will therefore be unsuitable for use in sulphate-rich soils.

To ensure the choice of an appropriate material, the environmental conditions to which the material will

be exposed must be known so that its behaviour under these conditions can be predicted and addressed in the design. When a designer contemplates using a new material, problems may arise if there has not been sufficient experience with the material to adequately understand its behaviour or to allow for the development of standards.

In the absence of standards, several factors should be critically evaluated, among them the relevance of the test data provided in product literature, and the limitations and requirements associated with the environmental conditions of the project.

2. Combine only materials with similar properties

Concrete is a solidified mixture of diverse materials. When these materials are incompatible with one another, the concrete cracks and spalls, resulting in unsightly surfaces and the need for expensive rehabilitation work. Materials are considered to be incompatible when the differences in their physical or chemical properties create a state of instability.

For example, galvanic corrosion is promoted when two metals with different electrochemical properties are combined in a building assembly. When moisture is present, a galvanic cell is set up, causing the less noble metal (see list of metals in galvanic series, Table 1) to corrode.

This galvanic corrosion phenomenon is common, for example, in copper/aluminum roof assemblies and is related to the relative positions of the two materials in the

The designer must have an awareness of environmental conditions including:

- minimum and maximum temperatures
- temperature cycles
- exposure to ultraviolet radiation
- amount of moisture
- wet/dry cycles
- presence of aggressive chemicals

Table 1. Arrangement of metals in galvanic series

Cathodic or more noble metals (least electrically active)	
Metal	Relative nobility
Gold	1
Mercury	2
Silver	3
Copper	4
Lead	5
Nickel	6
Cobalt	7
Iron	8
Tin	9
Zinc	10
Chromium	11
Aluminum	12
Anodic or less noble metals (most electrically active)	
Metals are listed here in decreasing order of electrical activity. Metals that are less active (more noble) are protected by those that are more active (less noble). The anodic (less noble) material will corrode whereas the cathodic (more noble) material will not.	

electrochemical series. The copper (the more noble material) flashing on roofs literally destroys the aluminum (the less noble material) gutters and downspouts.

It is therefore prudent to embed in concrete only those metals that are electrochemically similar, or to interpose some sort of barrier — for example, a coated cathode — to prevent the formation of a galvanic cell.

The use of materials with different thermal coefficients or different moduli of elasticity should also be avoided (see Figure 1) since they expand and contract at different rates, and their deformation

characteristics are significantly different. In both instances, the incompatibility of the selected materials will lead to deterioration of the concrete. When the load is perpendicular to the bond line, the difference in

modulus does not cause problems; however, when it is parallel to the bond line, deformation of the material with the lower modulus transfers load to the material with the higher modulus, which may then fracture.

3. Assess the limitations of a particular material in its functional context

Since every job has unique conditions and special requirements, the selection of materials, particularly those used in repairs, must be based on knowledge of their function and of the environment in which the materials have to function. Their physical and chemical properties as well as their limitations with respect to installation and performance must also be considered. In particular, the designer should anticipate the degree of abrasion or wear to which a surface will be subjected. For example, parking garage ramps have to be constructed with a special cast concrete and an applied polymeric coating impregnated with an abrasion-resistant material such as emery or corundum to resist abrasion caused by turning wheels.

In choosing a material, the designer should be aware not only of the properties that seem to best address the intended function and location of the structure but also the auxiliary properties that did not constitute the basis for selecting the material. In fact, these properties often have a significant influence on durability. For example, air entrainment is used chiefly to provide durability with respect to freeze/thaw cycles but it also enhances workability.

4. Protect materials from general deterioration

Most concrete deterioration can be attributed to water penetration. Since concrete absorbs moisture until it becomes saturated, preventing water from collecting on surfaces is of prime importance. Moisture fosters deterioration not only because it promotes chemical reactions but also because it carries dissolved chemicals that can react with the steel, lime and other components in the concrete. It also plays a major role in concrete deterioration through freeze/thaw cycling (see Figure 2). By providing sufficient slopes and effective drainage

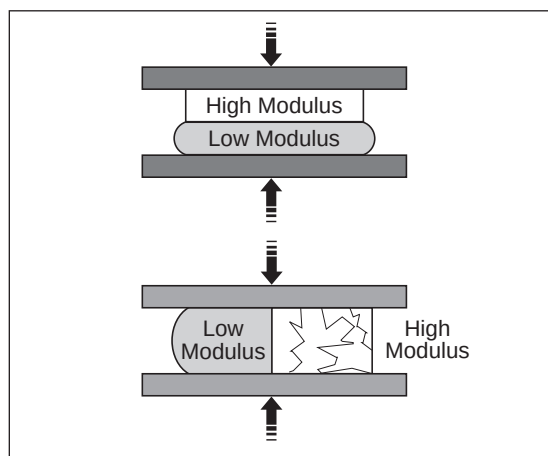


Figure 1. Materials with differing moduli of elasticity.

When materials with widely differing moduli of elasticity (a measure of stiffness) are in contact with one another, the significant difference in their deformation characteristics may cause problems.



Figure 2. Example of freeze/thaw damage

An example of a change in use that would have an impact on a structure would be the addition of a roof garden to a parking garage at a later date. In this case, the base concrete would have to be protected from ponded water and saturated soil; proper soil drainage and an adequate concrete coating would have to be provided.

hardware, it is possible to prevent water from ponding and thus from being absorbed. Concrete design should accentuate water-shedding characteristics for vertical elements — for example, the proper design detailing of window ledges can prevent the wall from wetting — and incorporate slopes and drain holes for

such horizontal elements as decks.

Steel in reinforced concrete is prone to chemical attack in certain corrosive environments. But without water, an electrolyte (which is required to support any corrosion cell) cannot form. Furthermore, without water, freeze/thaw cycling cannot take place.

Sealing the surface with a penetrating concrete sealer or a waterproof deck-coating system helps to prevent the ingress of water and water-borne salts. However, one of the most effective means of protecting reinforcing steel against corrosion is a durable, 50-mm-thick reinforcement cover. Such a high-quality concrete cover is made from a low water/cement ratio (< 0.5), air-entrained ($6\% \pm 1\%$) concrete and is characterized by

- low permeability to moisture, carbon dioxide, chlorides and other atmospheric sulphurous gases, and
- the presence of an adequate air void system to resist damage caused by freeze/thaw action.

Tiny bubbles of air purposely introduced into the concrete serve as pressure-release vessels for water in an environment where freezing takes place. The presence of air in hardened concrete is a critical factor governing freeze/thaw durability.

5. Allow for change in use in the design

During the service life of a structure, its environment and occupancy may change (see box). As a result, the structure will have to withstand stresses different from those for which it was originally intended. For this reason, it is important to allow for change by providing protective and strengthening measures and hence a margin of safety with respect to the inherent resistance of the selected materials.

6. Provide regular maintenance through routine repair

Even though designers allow a large margin of safety in their designs (that is, they build in redundancy), once deterioration reaches a certain critical limit, immediate repair or rehabilitation is needed to restore the level of performance to its intended (design) level of service (see Figure 3).

The timing of rehabilitation with respect to the rate of deterioration is of paramount importance. In practice, a structure is in need of repair when its performance is unacceptable to the users. Many owners hold the mistaken belief that a major rehabilitation corrects deficiencies and that the structure's performance thereafter will remain trouble-free for a long time.

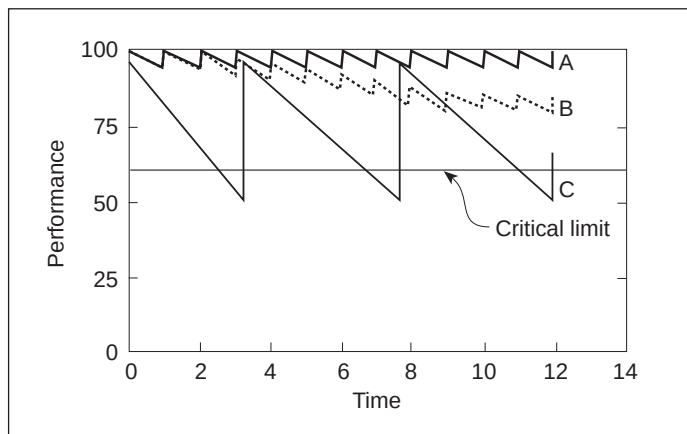


Figure 3. The effects of different types of repairs on a parking garage

Curve A represents performance over time with repairs carried out to full restoration at frequent intervals.
 Curve B also represents repairs carried out at frequent intervals but without full restoration.
 Curve C represents infrequent major repairs.

In fact, if the rehabilitation work is not carried out in time, the structure may not be repairable to the required level of service.

Even if full restoration eventually becomes difficult or impractical (curve B), ongoing rehabilitation can achieve high performance at a fraction of the cost of occasional major renovations (curve C).

Summary

Significant advances are being made in correctly matching new materials with traditional ones, ensuring that the selected combination provides acceptable long-term service in concrete structures. To assure predictable performance, designers must have a good understanding of:

- the properties of the materials that they intend to use;
- the ways in which the materials will interact with the environment;
- the ways in which the materials will interact as a composite material;
- the proper timing and type of maintenance required for a particular structure.

References

1. Concrete Manual: A Water Resources Technical Publication, 8th edition, U.S. Department of Interior, Washington DC, pp. 211-214, 1979.
2. Fulton, F.S., 1977. *Concrete Technology*, Portland Cement Institute, Johannesburg, South Africa, pp. 307-310.
3. Mailvaganam, N.P., 1992. Repair and Protection of Concrete Structures, CRC Press, Boca Raton, FL.
4. Feld, J., 1967. Lessons From Failures of Concrete Structures, American Concrete Institute, ACI Monograph No. 1, pp. 23-39.
5. Emmons, P.H. and A.M. Vaysburd, 1995. "Performance Criteria for Concrete Repair Materials Phase 1," Technical Report REMR-CS-47, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Noel P. Mailvaganam is the manager of Evaluation and Repair in the Building Envelope and Structure Program at the National Research Council's Institute for Research in Construction.

Gerard G. Litvan is a materials consultant.

© 1997
 National Research Council of Canada
 September 1997
 ISSN 1206-1220



Canada

"Construction Technology Updates" is a series of technical articles containing practical information distilled from recent construction research.

For more information, contact Institute for Research in Construction,
 National Research Council of Canada, Ottawa K1A 0R6
 Telephone: (613) 993-2607; Facsimile: (613) 952-7673; Internet: <http://irc.nrc-cnrc.gc.ca>