Results of Questionnaire on the Effect of Cracks on Durability of Reinforced Concrete Structures

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Report: Results of Questionnaire on the Effect of Cracks on Durability of Reinforced Concrete Structures

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1. Introduction

This short report presents the results of a questionnaire entitled "Effect of Cracks on Durability of Reinforced Concrete Structures," which was sent to specialists involved in concrete durability throughout Europe and North America. The purpose of the questionnaire was to assist in the focusing of research on the durability, monitoring, and service life modeling of reinforced concrete structures. The results of the questionnaire were used to shape the Ph.D. study entitled "Transport and Corrosion Initiation in Cracked Reinforced Concrete," being performed at the Technical University of Denmark by Brad Pease. Additionally, the results will be utilized by other researchers at the Technical University of Denmark and Purdue University involved in the following projects:

- *Non-destructive Electrochemical Methods for Monitoring of Reinforcement Corrosion*, Peter Vagn Nygaard, FORCE Institute and DTU
- *Management of Reinforcement Corrosion*, André Küter, DTU
- *Using In-situ Monitoring to Predict the Life Cycle Performance of Concrete Structures*, Farshad Rajabipour, Purdue University
- *Water Transport in Cracked Concrete*, Jason Weiss, Purdue University

2. Demographics of Respondents

A total of 15 responses have been received from participants in Denmark, The United States of America, Germany, The Netherlands, and Canada with a range of 10 to 40 years experience. A total of eleven responses came from European nations and four from North America. Respondents' position descriptions included owners, designers, researchers, inspectors, repair contractors, materials engineers, producers, and consultants. Those surveyed had approximately 24 years of experience on average and came from a wide range of job descriptions and geographic locations, providing information from varying perspectives and leading to a more accurate view of the concrete society's opinions on current needs in research.

3. Results of Questionnaire

In this section the responses to the individual questions are presented as an average reply of all respondents. Additionally, the average response from North America and Europe has been provided to assess any trends based on geographic location. In this section, the questions are given followed by the response.

General / Question 0:
When and how often, in your experience, do inspections for cracks in reinforced concrete structures take place?

The results for this question can be seen below in the Table 1. The case of never inspecting for cracks was not indicated by any participant (i.e. 0%).

Table 1: Frequency of Crack Inspection

During Construction			Regularly with Maintenance			Once Problems Arise		
Overall	North America	Europe	Overall	North America	Europe	Overall	North America	Europe
73%	75%	73%	60%	75%	45%	33%	0%	45%

Question 1 and 2 within the Questionnaire section required the participant to rate the importance of various factors, where a 1 would be of little importance and 5 would be of great importance.

Question 1:
Rate the importance of the following factors affecting the durability of reinforced concrete structures exposed to harsh environments.

Table 2 shows the average rating for question 1 including the overall, European, and North American outlook. Additional factors were suggested (and ranked) by individuals including moisture (5), type of structure (4), drying and wetting cycles (5), availability of moisture and oxygen (5), and exposure conditions (5).

Table 2: Ranking of Factors Effecting Durability of Reinforced Concrete Structures

	Overall	North America	Europe
Quality of Concrete	4.5	4.3	4.6
Location of Reinforcing Steel	4.2	4.3	4.1
Cracking of Concrete	3.6	4.0	3.4
Chloride Loading	3.4	2.8	3.8

Question 2:
Rate the importance of the following factors on the durability of cracked concrete.

Table 3 provides the overall, European, and North American rankings for question 2. An additional crack type was suggested to be chloride induced cracking and was assigned a rank of 3 out of 5. Other suggested factors on the durability of cracked concrete were the type of loading, location and depth of cracks, cover depth, water-to-cement ratio, and reinforcement type.

Table 3: Ranking of Factors Effecting Durability of Cracked, Reinforced Concrete

	Overall	North America	Europe
Harsh Environments	4.5	4.8	4.4
Maximum Crack Width	4.0	3.8	4.0
Crack Orientation			
Longitudinal	3.8	3.3	4.1
Transverse	3.1	2.8	3.3
Crack Type			
Plastic Cracking	3.6	2.7	4.0
Shrinkage Cracking	3.7	3.0	4.0
Load Induced Cracking	3.6	3.3	3.7

Question 3:
For each structural application, crack orientation, and crack depth please indicate a crack width that would be of concern as related to the durability of the given structure.

Question 3 was a survey of crack widths concerning the durability of reinforced concrete structures. Various structural applications including marine structures in the submerged and splash zones, bridge decks, and a beam in a building were listed along with varying crack depth to cover ratios. The ranges of values given for crack widths are shown in Table 4.

Table 4: Results of Question 3 for (a) Transverse Cracking (Perpendicular to rebar) and (b) Longitudinal Cracking (Parallel to rebar)

(a)

	Crack Width (mm)	
Structural Application	**Depth/Cover ≥ 1.0**	**Depth/Cover = 0.5**
Submerged Marine Structure	0.2 - 0.5	0.3 - 1.0
Marine Structure in Splash Zone	0.1 - 0.3	0.1 - 0.5
Bridge Deck	0.15 - 0.3	0.15 - 0.3
Beam in Building	0.15 - 0.5	0.15 - 0.5

(b)

	Crack Width (mm)	
Structural Application	**Depth/Cover ≥ 1.0**	**Depth/Cover = 0.5**
Submerged Marine Structure	0.1 - 0.5	0.2 - 1.0
Marine Structure in Splash Zone	0.0 - 0.2	0.1 - 0.5
Bridge Deck	0.0 - 0.2	0.0 - 0.5
Beam in Building	0.1 - 0.5	0.2 - 0.5

Question 4:
Are you familiar with service life models and if so indicate the applications you have used various models for.

Of the 15 responses, 12 had experience with service life models. Duracrete, Life-365, HETEK, Stadium, and an in-house program were reported upon. Service life models have been used to compare and evaluate various mixtures and as a design tool, however on average these models were rated to be accurate only 45% of the time. It should be noted that several respondents indicated that too little information is available to assess the accuracy of these models currently.

Question 5:
Based on your experience with service life models, please rank which improvements are most needed to improve service life estimations provided by current service life models for reinforced concrete structures.

Table 5 provides the results on what is perceived as the most needed improvements to current service life models. Additional improvements suggested by participants included considerations of traffic loading, other factors affecting durability (i.e. alkali-silica reaction, sulfate attack, and freeze-thaw), and other variables such as workmanship and as-built material properties.

Table 5: Ranking of Possible Improvements to Current Life Cycle Models

	Overall	North America	Europe
Improved Environmental Condition Information	3.3	3.0	3.4
Improved Material Parameters	3.8	3.3	4.0
Treating Concrete as a Heterogeneous Material	2.3	2.5	2.3
Including Effect of Cracks on Life Cycle Estimation	4.3	4.7	4.1
Considering Moisture State of Concrete	4.0	3.7	4.1

4. Summary

Through a questionnaire on the effect of cracking on durability of reinforced concrete structures, the general opinions of professionals involved in design, execution, and operation has been examined. Based upon the results of the survey the following conclusions have been made.

- Longitudinal cracks were viewed as slightly more detrimental to the durability of reinforced concrete when compared to transverse cracks. Longitudinal cracks were ranked 3.8, compared to transverse cracks which were ranked 3.0.
- The varying causes of the cracking were considered to be less influential on the durability of concrete.

- Control of longitudinal crack width was considered more important than transverse crack width. The occurrence of any cracking, longitudinal to the reinforcement, caused concern; however, a less strict minimum crack width of 0.1 mm caused concern for transverse cracking.
- General opinion concluded that including the effect of cracking on durability of reinforced concrete structures is the most needed improvement to current service life models.

5. Acknowledgements

The authors would like to thank each person who participated in the questionnaire for their time and effort. Your contributions are appreciated and the results of this survey have been utilized in the refinement of a Ph.D. study entitled “Transport and Corrosion in Cracked Reinforced Concrete.”