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Practical implementation of durability index performance-based specifications: current experience

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ABSTRACT

The durability index performance-based approach has been implemented in practice by the South African National Roads Agency Limited (SANRAL) in various infrastructure projects since 2008. This paper provides a comparison of OPI test results from two periods during which data were collected and analysed at the University of Cape Town, Period I (2009- 2010) and Period II (2011 – 2015). The data analysis aimed at evaluating whether variability in test results had decreased over the years with on-going experience of using the approach. It was observed that the OPI limit value was attained for all laboratories, but the variability for these laboratories exceeded the OPI repeatability of 1.80% regarded as a 'norm'. Also, variability in OPI results appears to be increasing, being larger in the later than the earlier period. An overview is also provided of OPI results obtained from five laboratories involved in testing samples from SANRAL projects spanning both periods. Here, it was observed that the limit OPI value was attained on average, with the exception of one laboratory. The variability for these laboratories was also observed to be higher than the test repeatability norm. Finally, observations on DI test reporting and the issues encountered are discussed. A recent adjustment in the calculation spreadsheet, partly to address the problems of capturing information from site, is presented.

1. INTRODUCTION

The durability index (DI) tests developed in South Africa provide measures of the resistance to penetrability of cover concrete. These tests yield transport-related parameters such as oxygen permeability index (OPI (the negative log of the coefficient of permeability k), water sorptivity index (WSI), and chloride conductivity index (CCI) [(1)]. Two of the DI tests (OPI and CCI) have further been developed for use in performance-based design and specification [(2)]. The OPI test has a strong correlation with carbonation depth [(3)] while the CCI, when modified to consider binding effects, has a good correlation with chloride diffusion coefficient [(4)]. Using suitable service life models, and depending on the exposure conditions and given service life, limiting DI values and cover depths used in performance specifications have also been developed [(5)].

1.1 Practical implementation of the durability index performance-based specifications

The South African National Roads Agency Limited (SANRAL) has adopted DI performance-based specifications in their infrastructure projects, with the aim of ensuring construction of durable RC structures [(6)]. In these specifications, concrete structures designated as 'Class W' require measures on strength, DI values and cover depth. The Standard Specifications for Roads and Bridges, issued by the Committee of Transport Officials (COTO), will in the next revision, presently being prepared, also provide for the specification of 'Durability Concrete' and the applicable test methods. However, in future specifications 'Class W' concrete will rather be referred to as 'Class D' concrete. ('Class W' was a prefix introduced previously by the Water Division of the Durban municipality).

For structures in inland environments, limiting DI values of OPI (and WSI) are provided, while for marine structures, a limiting CCI value is provided. Most of the projects undertaken by SANRAL are located in inland environments where the exposure class, according to EN 206 [(7)] is X3, i.e. concrete exposed to moderate humidity, such as inside buildings with moderate or high air humidity, or external concrete sheltered from the rain. The recommended and minimum values for this exposure class in the project specifications are 9.40 and 9.00 (on a log scale) respectively.

Samples for DI testing are obtained from site elements and delivered to laboratories. The test results are then sent to engineers and contractors involved in the SANRAL projects who are required regularly to send results to the University of Cape Town (UCT), mainly for research purposes. Data have now been obtained for a period of ten years (2008 – 2017).

This paper provides a comparison of OPI test values from two periods, i.e. Period I: 2009 - 2010), and Period II: 2011 - 2015, and also for different laboratories involved in SANRAL projects. An overview of DI test reporting and the main observations made in the spreadsheets are also given. The final section of the paper provides an overview on adjustments that were recently made in the DI calculation spreadsheets so as to capture site information.

2. COMPARISON OF SITE-BASED RESULTS

For the purpose of this paper, and to give a general overview of the variability in test results, the data analysed are limited to: i) a sub-project of the GFIP undertaken in the period 2009 - 2010 located in Gauteng Province, from the study reported in [(8)], to be referred to as Period I, and ii) a road rehabilitation project of the N11 undertaken in the period 2011 - 2015 located in Mpumalanga Province, from the study reported in [(9)] and referred to as Period II. The test results from the two periods represent samples from various bridge and culvert elements such as wing walls, apron slabs, beams, bridge decks, etc. The data from these two periods were selected due to the large sample size, 166 and 260 OPI results for Periods I and II respectively.

A summary of the OPI results in terms of average value, coefficient of variation, count, and proportion of defectives from these two periods is summarized in Table 1, with an illustration of the variability provided in Figure 1. [Mukadam [(10)] notes that the transformation of coefficient of permeability (k-values) to OPI (log scale) results in a normal distribution. It is therefore valid to compute the average and CoV on OPI values].

Table 1 indicates that the average value of OPI for both periods complies with the recommended value in the project specifications of 9.40 (log scale) (although in

Table 1: Comparison of OPI test values from the two periods

Statistical measure	Period I (2009 – 2010)	Period II (2011 – 2015)
Average OPI (log scale)	9.78	9.67
CoV (%)	2.53	2.93
Defectives (% < 9.40)	5	16
Count (n)	166	260

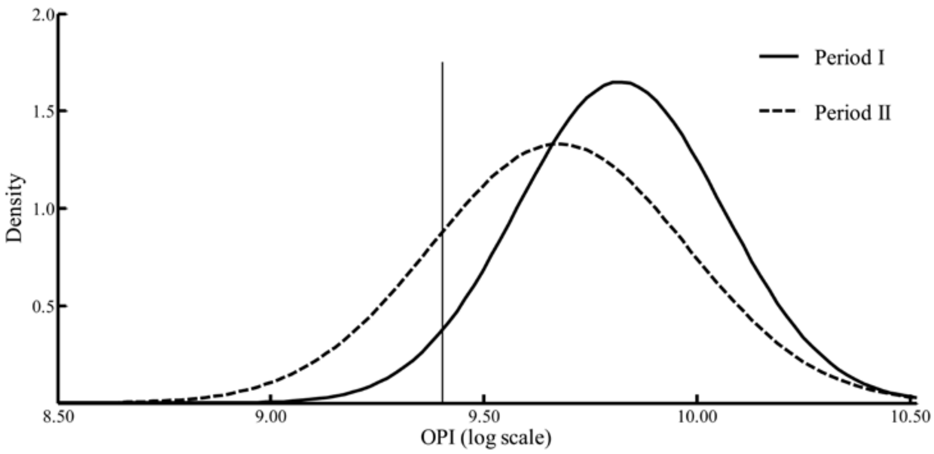

Figure 1: Comparison of variability of OPI values from the two periods considered (the vertical line indicates limit value of 9.40)

Table 2: Summary of variability (1s% coefficient of variation) in OPI results for various studies

Source	Variability in OPI test results (%)	
	Laboratory	Site
Gouws et al. (12)	1.00	
Gouws et al. (12)		
Wet cured ready mixed concrete		1.00
Wet cured site mixed concrete		2.00
Actual structure		3.00
Stanish et al. (11)	1.80	
Nganga et al. (8)		1.75 - 4.60

Table 3: Comparison of statistical summaries of five laboratories: OPI testing

Statistical measure	Laboratory				
	1##	2##	3##	4#	5#
Average (log scale)	10.24	9.96	10.33	9.31	9.91
Standard deviation (log scale)	0.29	0.31	0.33	0.19	0.20
CoV (%) (Repeatability)	2.83	3.11	3.19	2.04	2.02
Count (n)	25	44	21	20	47
Defectives (% <9.40)	0	6.82	0	65.0	0

- Period I; ## - Period II

Period I, the limit value was actually 9.70 at that time). For both periods, there were no values below the allowed minimum value of 9.00 (log scale). The variability (in terms of reproducibility) in both periods was higher than that obtained from an inter-laboratory exercise [11], which can be expected for site-based results. The proportion of values that fails to comply with the limit value is relatively low in Period I, but considerably higher in Period II, with three times more the number of defectives being obtained.

The variability was however within the range of a previous study by Nganga [8] on site-based results, as summarized in Table 2. This table also gives other variability data from Gouws [12], which were obtained at an early stage in the development of the DI approach.

From the illustration of variability and proportion of defectives provided in Table 1 and Figure 1, it is observed that Period II has a wider range of variability when compared to Period I. Even with continued implementation of the DI-based performance specifications in practice, the extent of variability in test results appears not to be decreasing. This indicates that limitations are present in execution of the approach, both on site where test specimens are obtained, and in the laboratories where they are tested. Therefore, a consideration of variability in test results of different laboratories involved in undertaking the tests is provided in the next section.

3. COMPARISON OF LABORATORY RESULTS

A comparison was made of OPI test results from five laboratories involved in SANRAL projects. These results are from different projects and the time period ranged from 2008 – 2015. The laboratory results are from both Periods I and II above, and are limited in number since only a few of the SANRAL projects indicated which laboratory was involved in the testing. The sample size differs in each case; a summary of statistical measures on these data and the Period from which the data were obtained are provided in Table 3.

Table 3 shows that the laboratories recorded acceptable average OPI values that comfortably met the recommended limit value of 9.40 (log scale), with the notable exception of Lab 4. The variability in test results for all the laboratories was higher than the repeatability of 1.80% established in an inter-laboratory exercise [11]. The number of defectives was generally low for the laboratories considered, with the exception of Lab 4, which was exceptionally high at 65%. This indicates that in addition to the average value, variability and proportion of defectives in test results should be considered.

This variability in the different laboratories could arise from several reasons such as different sources of samples tested which vary in the concrete mix used, genuinely high scatter in concrete quality for a specific project, different laboratory operators undertaking the tests, difficulties in undertaking the OPI tests e.g. misinterpretation of test procedures or unsuitable laboratory conditions. It is difficult to verify the cause of such high variability in different laboratories, but an assessment of the DI test reporting, which should be done on a standardized MS Excel spreadsheet, may provide an indication of where some of the problem may lie. This is addressed next.

4. DI TEST REPORTING

A standard DI test reporting template in the form of an Excel calculation spreadsheet has been developed, mainly to undertake two aspects: i) to capture needed information on the test sample such as source of sample (structural element represented); date of casting, coring and testing (to provide the age of a sample); mix design details, construction methods used (curing, compaction) and any anomalies in a test sample; ii) to calculate the OPI and k-value, WSI and porosity, and CCI and porosity (as relevant). The average test results, extent of variability and a variability check is made. Output graphs of the OPI and sorptivity test results are also given in this spreadsheet.

4.1 Observations on reporting in the DI spreadsheets

From considering the spreadsheets of several laboratories, some issues that arose in almost all of the laboratories were:

i. Missing information: On the source of samples, the structural element from which the sample was obtained or the geographical location was not always indicated. Details on mix designs used, construction methods and the condition of the samples on receipt from the site was in most cases also not provided.

ii. Age of test samples: the age of casting of a structural element or date of receipt of samples in the lab was in most cases not provided, which makes it difficult to determine the age at the time of testing. For some laboratories, however, the age of the samples at testing was provided and in most cases, it was more than the recommended maximum age in the specification of 35 days.

iii. Missing results: there was a predominance of missing results for the WSI test. In some cases, no results were given at all; in other cases, only two test determinations were provided, which however does not yield a valid test result since at least three test determinations are required. The missing test results indicate that there was difficulty in undertaking the sorptivity test, or alternatively, that this test was not regarded as important.

iv. Outlying values: On evaluating the variability in test determinations to obtain a test result, it was observed that in some cases one determination appeared to be significantly different from the others ('outlier'). Such a value will influence the average and variability of a test result. Table 4 illustrates several cases, where one of the four determinations shows a large difference from the other three test values. The consequence is a high value for the coefficient of variation (see Table 4), which should alert the test operator to possible problems.

Table 4: Illustration of variability in test determinations due to 'outlier' results (highlighted in bold)

Example	OPI (log scale)				Average	CoV (%)
	1	2	3	4		
A	9.71	9.16	9.15	**10.00**	9.50	4.43
B	10.32	10.22	10.00	**9.36**	9.98	4.32
C	9.04	9.82	**8.83**	9.58	9.32	4.94
D	10.00	10.25	9.70	**9.26**	9.80	4.34
E	9.94	10.14	**8.68**	9.94	9.68	6.93
F	**8.57**	9.30	9.20	8.76	8.96	3.90
G	**8.64**	9.55	9.64	9.48	9.33	4.96

The OPI test method allows re-testing of a specimen if a value appears unusual, and recommends inspecting the specimen to see if there are any unusual physical features such as a large piece of aggregate, cracks and the like. However, the data in Table 4 indicate that a robust statistical method for identifying outliers needs to be adopted.

4.2 Adjustment in the DI test spreadsheets to incorporate site information

Several alterations in the DI spreadsheets have been made over the years, and the latest spreadsheet that was amended in November 2015 is available to the public on the Concrete Institute (TCI) website [13]. This latest version of the spreadsheet is largely similar to previous ones (no alterations were made on the computation sections) but an additional worksheet was made that aims at capturing information that can be obtained only from site. Such information from site includes mix design details, age of casting, source of sample, date of receipt of samples in the laboratories, and condition of these samples when received.

This addition to the spreadsheet aims at ensuring that the person delivering test samples from site provides sufficient information on such samples and signs for this, before the samples are received in a laboratory. This should help to eliminate the recurring problem of missing information on samples, as is often the case. Provision of this site information would also make it easier to determine where the cause of a problem may lie when invalid test results are obtained i.e. whether it is due to the condition of the samples received from site elements or poor testing in the laboratory.

5. CONCLUSION

The durability index performance-based approach has been implemented in practice since 2008 for various SANRAL infrastructure projects. From a comparison of test results from two time periods (2009-2010, and 2011-2015), it was observed that the variability in OPI results appeared to be increasing in the later period. A further comparison of OPI test results for five different laboratories was made. From this evaluation it was observed that the limit OPI value was attained on average with the exception of one laboratory. The variability for these laboratories was also observed to be higher than the test repeatability norm.

From the analysis of test results for the two periods and the different laboratories, it is observed that in addition to the average test result, the variability and proportion of defectives should also be considered. It would be helpful for the industry and the specifying authorities to reflect on what might be considered as acceptable variabilities and percentage of defectives allowed. It is also recommended that a suitable Outlier test be developed for OPI results, and in general for all the durability index test results.

From a review of the DI test reporting spreadsheet, various issues were observed. One main issue was missing information which can only be obtained from those delivering samples from site to the laboratories. To address this recurring issue, an adjustment in the spreadsheet has been made which will capture such information.

From the overview of OPI test results, it is observed that the DI performance-based approach has been successfully implemented in practice. Various issues that may arise will continue to be identified with on-going experience of using the approach, and will be addressed to ensure this approach continues to be useful in the construction industry.

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References and Author's details on page 22.

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