

## **Insights about Concrete Spalling in a South African Region**

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### **Abstract**

Cosmetic and structural damages due to concrete spalling could manifest as a result of poor concrete pouring, harsh chemical actions, and in extreme cases, exposure to freezing temperatures. Given the impact that this anomaly could have on project performance in terms of the frequency of defects and rework, a study was embarked upon so as to examine the issue from a regional perspective in South Africa. The overall objective of the study was to identify the causes of concrete spalling among the general contractors (GCs) interviewed so that remedial measures suitable for the region can be put forward. The findings based on the semi structured interview instrument used for the study indicates that indeed concrete spalling could be a major problem in the regional industry. It was discovered that concrete usually suffer from damages arising from acid attacks (sulphates and carbonation) that cumulates in corroded reinforcements. The respondents perceived that a combination of inadequate concrete cover and workmanship perpetrate the malaise, especially at Port Elizabeth. In order to circumvent concrete spalling induced rework in the industry, it can be argued that improved specification writing and craft workmanship should be engendered.

### **Keywords**

Concrete, Construction, Corrosion, Spalling, South Africa

### **1. Introduction**

Concrete spalling is concrete that flake, break or become pitted (Woodsen, 2009). These phenomena can be the effect of a number of different factors such as poor insulation and environmental factors that may have stressed the concrete to the point of deterioration (Woodsen, 2009). In South Africa, concrete

spalling is mainly attributed to reinforcement corrosion as major developments could be situated near coastal regions that are exposed to marine environments, which poses a threat to the durability and service life of reinforced concrete structures (Muigai, 2008). The reason for this is that the marine environment carries harmful substances such as chlorides and sulphur dioxides, which could induce reinforcement corrosion with the aid of oxygen, carbon dioxide and water ingress (Wilmot, 2007). Thus, different environments bring forth deteriorative elements in varying degrees and therefore highlight the importance of proper environmental investigation and design prior to the construction of reinforced concrete structures (Wilmot, 2007).

Spalling concrete is defined as the bulk of concrete which detaches itself 'from the main body of concrete' (Woodsen, 2009). When this spalling is small in nature, then this is referred to as disintegration. When there is a significantly large mass of concrete that detaches itself from the rest of the concrete body, this is then classified as 'spalling' (Woodsen, 2009). According to the literature, the difficulty of spalling has been encountered for many years (Woodsen, 2009). Past findings acknowledged that it has a colossal financial effect, not even to mention the health and safety (H&S) hazard that it imposes to the occupants of buildings. This research is thus aimed at identifying the causes of concrete spalling, the remedial techniques used for spalled concrete and the precautionary measures that can be taken to prevent its occurrence. This is based on the premise that 'cosmetic and structural damage due to concrete spalling occurs because the pouring of concrete on site may be poorly done or it may be due to exposure to harsh chemical attack and / or freezing temperatures.'

In addition, it has been observed that concrete can deteriorate in more than one specific way (Addis, 2009). Deterioration can be caused by chemical attack, physical attack, mechanical attack and reactions between the properties of the materials in the concrete mix itself. Improper placement, curing and compaction techniques can cause concrete to deteriorate much faster than initially anticipated. These reactions can all cause concrete to crack, flake and spall. Perhaps, there is sufficient evidence that proves that spalling concrete is a serious problem and that there are numerous reasons for spalling to take place. One can quite often see the physical and aesthetical damage on structures when driving past concrete structures such as bridges, especially close to the coastal regions. One of the commonest causes of spalling concrete is corroding reinforcement (Day, 2006).

'Reinforcement is the Achilles heel of concrete' as the one is dependent on the other as steel plays an integral part in the resistance of tensile stresses accumulated in concrete members (Day, 2006). It is known that reinforcement corrosion in reinforced concrete structures is the main factor contributing to the reduced service life of reinforced concrete structures (Batis *et al.*, 2004) as spalling occurs due to the expansive forces (see Figure 1 for an example) that are being exerted within the concrete as a result of the corroding reinforcement (Li *et al.*, 2005). These corroding reinforcements then wedges out concrete (Day, 2006). Cracks give access to more moisture and aggressive agents, which catalyze the whole deterioration process (Muigai, 2008). Thus to protect the reinforcement embedded within the concrete, one has to design the desired quality and concrete cover thickness taking into consideration the environment in which the concrete member will find itself (Muigai, 2008). Cover of concrete is very much prone to be neglected due to improper curing and compaction techniques and this could lead to the penetration of undesired moisture and other 'aggressive agents' (Muigai, 2008).



**Figure 1: Spalling due to expansive forces of corroding reinforcement (Photo: H.J Duminy)**

## **2. Method of Investigation**

Purposive sampling selection was used in the generation of the primary data for the study. Purposive sampling is the process of selecting members of a chosen population based on the researcher's informal knowledge of representativeness (Leedy and Ormrod, 2010). In this case, the fact that the respondents were based in Port Elizabeth and that they are known to be involved in concrete works informed the decision to approach them. Although, 25 civil engineering contractors were purposely selected from the Eastern Cape Master Builders Association (ECMBA) members, only 8 agreed to participate in the study. The interview questionnaire consisted of both open and close ended questions pertaining to concrete spalling and repair. While some of the questions were based on 5 point Likert scale, some required only a yes or no answer.

With exception of 2 site engineers, the other 6 respondents were all directors in their firms. The types of construction that the respondents routinely undertake include alterations, specialist concrete works, and civil works. It is notable that on the average, the respondents can be considered to have over 22 years of concrete repair experience. One respondent have being involved in concrete works for 50 years, while 6 of them have between 18 and 27 years. 4 of the respondents have undertaken concrete repair related in house trainings in the past; 1 of them undertook an on-site training provided by PCI; and 3 of them relied on their civil engineering university education. It is however notable that one of the respondent contends that they only make use of the advice from specialist in their firm. Although, on the average the concrete repair works that have been done by the respondents amounted to R14, 308, 750.00 ( $\pm$  \$1.6m), some of the informants have undertaken projects in excess of R100m ( $\pm$  \$11.15m) in project value.

## **3. Results**

Four of the respondents observed that they usually undertake repair on spalled concrete due to corroded reinforcement between 25 and 30 months post construction period. Three of them however contend that it could be as much as 36 months after the completion of construction, while only 1 respondent suggests

that it could happen between 13 and 18 months. In other words, concrete spalling occurs before concrete elements attain their design lifespan. Based on the perceptions of the respondents, Table 1 indicates the frequency of concrete spalling due to external factors. The responses are tabulated in terms of percentage responses within a range of 1 (never) to 5 (always) and a mean score ranging between 1 and 5.

Impact and salt crystallization ranked first and second among thirteen other external factors. The difference in the ranking was based on standard deviation ‘ranking differentiation.’ Six of the respondents (75.0%) contend that impact often lead to concrete spalling, while four of them observed that salt crystallization may sometimes result in concrete spalling. In addition, the majority of the respondents suggest that water, sulphates and movement could also lead to concrete spalling. When asked if their firms have a testing and monitoring system related to concrete, five of the respondents replied in the affirmative and when asked if their firms revisit repair jobs for checking purposes, six of them responded in the affirmative. Some of them visit such sites twice or thrice during the defect warranty year and thereafter, at the fifth year occasionally. It is notable that six of the respondents observed that the structural member most susceptible to concrete spalling is the beam, two of them mentioned the column and three of the respondents mentioned suspended slab.

In addition, only five of the respondents endeavor to issue guarantees for repair works carried out by their firms. Whenever cracks and de-bonding were observed on repaired concrete works, a number of causes were postulated by the respondents. Five of them were of the opinion that poor workmanship often / or always leads to cracking, while five of them also said shrinkage could be responsible. Even six of the respondents mentioned that sometime / often times insufficient curing could result in cracking. Given the importance of workmanship to the quality assurance and control process, the education and training of the workforce in construction is very vital. In this context, the average level of education of the work force working with concrete repair materials in the companies surveyed show that Grade 1-7 and Grade 8-12 predominate, although a limited percentage of national diploma and BTech holders could be found among them.

**Table 1: External factors contributing to concrete spalling**

Factor	N/A	Unsure	Never..... Always					MS	Rank
			1	2	3	4	5		
Impact	0.0	0.0	12.5	0.0	12.5	75.0	0.0	3.50	1
Salt crystallization	0.0	25.0	0.0	0.0	50.0	12.5	12.5	3.50	2
Water	0.0	12.5	0.0	12.5	37.5	25.0	12.5	3.43	3
Sulphates	0.0	0.0	0.0	12.5	50.0	37.5	0.0	3.25	4
Movement	0.0	0.0	25.0	0.0	12.5	50.0	12.5	3.25	5
Acids	0.0	12.5	0.0	25.0	50.0	12.5	0.0	2.86	6
Erosion	12.5	37.5	0.0	12.5	12.5	12.5	12.5	2.80	7
Wear	12.5	0.0	12.5	37.5	12.5	25.0	0.0	2.25	8
Vibration	12.5	0.0	25.0	25.0	25.0	12.5	0.0	2.00	9
Biological	0.0	62.5	0.0	37.5	0.0	0.0	0.0	2.00	10
Overload	0.0	0.0	37.5	50.0	12.5	0.0	0.0	1.75	11
Explosion	0.0	12.5	75.0	0.0	0.0	12.5	0.0	1.43	12
Freeze / thaw	25.0	12.5	37.5	12.5	12.5	0.0	0.0	1.14	13

Regardless of the educational background of the workforce, the respondents mentioned four methods that were often used in concrete repair works. They suggest that restoring members with 'repair concrete', hand filling of mortar and spray on concrete were often / always used for such works. The repair works were carried out after determining the state of the concrete either through visual or non-destructive methods. In this sense, epoxy systems, polymer-bound concrete and mortar and polymer-modified concrete and cement mortar were rated high in term of performance of materials used for repairs.

The respondents also observed that inadequate concrete cover often lead to the corrosion of reinforcement. They contend that during severe conditions of exposure, corrosive fumes / salt laden air and mildly aggressive water could lead to corrosion of reinforcement; and in very severe / extreme conditions of exposure, highly corrosive fumes, aggressive water, and other wet conditions general contribute to the corrosion of reinforcement. In general, the eight respondents cited 'lack of quality control and insufficient concrete cover' as major causes of concrete spalling, especially in coastal regions of South Africa that include Port Elizabeth. One respondent cited such concrete spalling on the city beach front / harbor and freeways as a case in point.

#### **4. Discussion**

For most structures in the interior of the country, good detailing, good construction and adequate cover will control the rate of carbonation due to a variety of agents that are aggressive to concrete and the reinforcement inside of it (Perrie, 2008). By keeping the absolute capillary pressure value below the value at which air entry takes place, crack initiation may also be prevented in concrete (Slowik and Schmidt, 2010). In effect, it is possible to reduce or eliminate concrete spalling if the abovementioned guidelines are observed by concerned parties. It can be argued that contractors and the design team should:

- Ensure adequate communicate of instructions when pouring concrete;
- Implement a good testing system to assure consistent quality of concrete;
- Train the workforce that generally work with concrete, and
- Ensure adequate concrete cover is specified when building in coastal regions.

#### **5. Concluding Remarks**

The study indicates that cosmetic and structural damage does occur in the South Africa region due to corroding reinforcement. The designed lifespan of concrete elements were thus significantly affected by the corroded reinforcement. As suggested in the literature, concrete and reinforced concrete suffers from concrete carbonation attack by absorbing carbon dioxide from the atmosphere, which then initiate corrosion of reinforcement. Sulphates and other salt laden environments are prone to attack concrete due to concrete's high alkaline properties. It is notable that the eight respondents to the study cited poor workmanship and a lack of adequate quality control on site when pouring concrete as the root cause of most defects in concrete. Such defects include honeycombing and premature shrinkage that in turn cause cracking which can allow moisture and / or other harmful substances to penetrate and damage the reinforcement and then result in spalled concrete. It was therefore concluded that due to the low level of educated workforce working with these materials, improper compaction and curing techniques could lead to the premature degradation of the design lifespan of concrete elements

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