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Offshore sand for reinforced concrete

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Abstract

A figure of 0.075% by weight of sand was arrived at as a safe limit for allowable Cl^- ion content in offshore sand for OPC based reinforced concrete. A 2 m high sand column was fabricated for checking the effects of natural drainage and simulated rain on the chloride levels in offshore sand, and the action of even 80 mm of rain was found to reduce Cl^- contents to below acceptable levels. The accelerated corrosion performance of grade 20 concrete (i.e. the most critical structural grade) with the allowable Cl^- content in the sand was satisfactory and similar to a chloride free control mix; on the other hand, a mix with seawater saturated sand (0.3% Cl^-) showed clear evidence of high corrosion.
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Keywords: Offshore sand; Chloride content; Accelerated corrosion; Half cell potential; Shell content; Sand grading

1. Introduction

The over-exploitation of river sand for construction purposes in Sri Lanka has led to various harmful consequences [1,2]. Suggestions for various river sand alternatives, such as offshore sand, dune sand, quarry dust and washed soil have also been made [2,3].

The research reported here is on offshore sand, which was considered the most viable of the alternatives for river sand, with respect to availability, ease of extraction, environmental impact and cost [1,2]. It should be noted that offshore sand extracted from below around 15 m of ocean depth (i.e. beyond the surf zone) would not affect the coastal sediment budget. It has been found that the dredging and pumping costs would be around 90% of the stockpiled sand cost; transport costs from the stockpile would not be excessive as the sand is meant to service the construction boom in the commercial capital of Colombo, which is just 15 km away [3]. Harvesting of beach sand is clearly unacceptable, not only because it would directly contribute to coastal erosion, but also because the aggregate may have high chloride contents due to repeated wetting and drying cycles.

2. Objectives and strategy

The following are the broad objectives of the research reported in this paper.

1. To review the literature on using offshore sand in construction, focusing especially on the use of lower grade concretes in warm climates, with particular reference to the effect of chlorides on reinforced concrete.
2. To measure the relevant properties of offshore sand, namely grading, shell content and chloride content, examining also the effects of draining and simulated rain on the chloride content.
3. To study the corrosion properties of reinforced concrete containing offshore sand with various chloride contents, using accelerated corrosion testing.

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3. Literature review

3.1. Use of offshore sand in concrete

Although offshore sand is reportedly used in many countries such as the UK, Continental Europe, India, Seychelles and Singapore, most of the documentation regarding its use was found mainly regarding UK practice, and to a lesser extent regarding European practice [4]. A distinction must also be made between offshore sand and sand deposits in dry coastal areas. The latter would tend to have very high chloride contents resulting from salt spray and evaporation over long periods of time. In particular, the use of such deposits for concrete construction in the Middle East has led to very early onset of corrosion [5,6]. A study done on Sri Lankan beach sands has also shown fairly high chloride levels in some samples [7]. The use of sea water for batching or for curing [6,8] would also promote corrosion; such practices should not be resorted to.

In the UK around 11% of its aggregate extraction is from offshore sources. In South East England and South Wales, this figure is as high as 30% and 90%, respectively [9]. While much of this aggregate is processed (inclusive of washing), it is largely unprocessed sand (together with land based coarse aggregate) that is used on the West Coast and along the Bristol Channel [10]. The use of such aggregate in concrete has not caused any major durability problems in the UK during the past 60 or more years of its use. In fact, chloride related durability problems in the UK have largely been due to the use of Calcium chloride as an accelerator (up to a dosage of 0.15% by weight of cement), a practice [10] that had been permitted up to 1977. The use of de-icing salts also causes chloride related durability problems in many countries.

3.2. Permeability, strength and efflorescence

Research carried out by Chapman and Roeder [11] has established that hollow shells in offshore sand get filled with cement paste or mortar, and that their hollowness does not impair either concrete strength or impermeability; their flakiness, which may reduce workability, has also been found to be offset by their smoothness, and also the greater roundedness of the offshore sand itself. BS 882 (1992) did set some limits on the shell content in coarse aggregate, but none whatsoever on that in fine aggregate [12]; this is fortuitous because there would not be any easy way of removing shells from marine dredged fine aggregate [13]. Chandrakeerthy's results do not indicate any adverse effects on strength or absorption for concretes made with beach sand [7].

The literature also indicates that efflorescence from soluble salts is rare in concrete [14]; in any case it will be less than that from the free lime present in the concrete or mortar. Chandrakeerthy [7] also did not find any efflorescence in concretes made with large chloride ion concentrations of up to 4.44% by weight of cement.

3.3. Acceptable chloride levels

By far the greatest concern with respect to offshore sand is its chloride level, with respect to the enhancement of corrosion. Most codes of practice specify allowable chloride limits as percentages by weight of cement. The easiest to measure is the total chlorides in the concrete mix, and here it must be remembered that Portland cement itself [10] can have 0.01–0.05% Cl^-.

The most commonly used limit for total chlorides is the 0.4% limit (by weight of cement) specified in BS 5328: Part 1: 1997 for reinforced concrete [15]. It should be noted that the limit for prestressed concrete is 0.1% and that for reinforced concrete made with sulphate-resisting Portland cement (SRPC) is 0.2%. BS 882: 1992 used these limits [12], together with the allowance for chlorides in the cement, to suggest guidelines for maximum Cl^- contents in the total aggregate of 0.01% (by weight of total aggregate) for prestressed concrete and 0.05% for reinforced concrete. We shall hereafter focus mainly on (non SRPC) reinforced concrete, since it is by far the most widely used concrete material.

It may be prudent however to reduce the above 0.4% to say 0.3% Cl^- ion content (by weight of cement), because even in the UK, there is apparently some evidence that levels as low as 0.4% Cl^- can still promote corrosion, albeit in highly carbonated concrete [10]. Furthermore, a study from Iraq [8], which has a hot environment like in Sri Lanka, has indicated that corrosion could occur at Cl^- levels of even 0.3%.

A better index of potential for corrosion is probably the free or water soluble chloride content. ACI 201-2001 gives limits of 0.06% and 0.08% (once again by weight of cement) for reinforced concrete in moist environments with and without exposure to external chlorides, respectively [16]; this limit is raised to 0.15% for concrete in dry, above ground conditions. The relationship between total and free chlorides has been found to depend on binder type, except at total chloride contents below 0.3%, where concretes with many binder types [17] have yielded very low free chloride contents of below 0.024%. This can be seen as another argument for restricting the total chloride content to 0.3% by weight of cement. It has also been found that the threshold free chloride content to initiate corrosion is around 0.1% by weight of binder for various binder types [18].

An even better index of corrosion would be the Cl^-/OH^- ratio, although this would be difficult to specify. The threshold value for this ratio has been found to decrease as the pore solution pH is increased [19]; it is also lower for an internal chloride source compared to an external one [17]. It must also be appreciated that the threshold Cl^- levels to initiate corrosion will be higher in cements with higher C_3A contents [18,19], as they have the capacity to bind chlorides into chloroaluminates.

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