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Offshore Sand as a Fine Aggregate for Concrete Production

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Authors' contributions

This work was carried out as a collaboration among all authors. Author DARD reviewed the existing literature and placed the research objectives of the paper in perspective, analysed the data, discussed the results and wrote the draft of the manuscript. The research paper is based on the data obtained from an undergraduate student project undertaken by authors MGSD and CTA where DARD is the academic supervisor. All authors read and approved the final manuscript

Research Article

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ABSTRACT

The aim of this study is to test the relevant properties of offshore sand obtained soon after dredging and to examine the effects on chloride levels of offshore sand when fresh water is drained to simulate average monthly rainfalls. The findings are valid for offshore sand that does not require washing particularly to remove organic matter and other contaminants. As per the results of sieve analysis, grading of the offshore sand is within the limits specified in BS 882:1992. The compressive strength of grade 25 concrete which is the mostly used structural concrete is also within the acceptable limits. The shell content of offshore sand for shells finer than 10 mm and coarser than 5 mm is 6.5 per cent. This is far below the 20 per cent limit specified in BS 882:1992. For grade 25 concrete produced with OPC, an allowable limit of 0.101 per cent by weight of sand was computed for chloride content in offshore sand. The chloride content of offshore sand obtained soon after dredging was 0.04%. Even a rainfall as low as 9.9 mm can reduce the chloride content (range from 0.01 to 0.05) to levels far below the allowable limit (0.101). Rainfalls as high as 581 mm could wash away chlorides almost completely

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(below 0.01). The study revealed that offshore sand obtained from 2 to 7 km away from the western coast, Sri Lanka soon after dredging, could be used as an alternative to river sand.

Keywords: Offshore sand; concrete; fine aggregate; chloride content.

1. INTRODUCTION

1.1 General

Due to the recent growth in the construction industry, the demand for fine aggregate is escalating rapidly. River sand has been the most widely used fine aggregate in Sri Lanka and over-exploitation of river sand to meet the demand has led to various harmful consequences such as increase in the depth of the river bed, lowering of the water table, and salinity intrusion into the rivers. Because of these environmental problems, there is a necessity to restrict river sand mining especially at vulnerable locations. As a remedial measure, the government imposes various restrictions on the extraction of river sand with consequent increases in prices. Not only has this inconvenienced the users directly, but also indirectly impacted on the overall stability of the construction industry owing to concomitant increases in construction prices.

In order to restrict river sand mining and to curb the price volatility in the construction industry, it is necessary to introduce alternatives to river sand. In Sri Lanka, the total demand for sand is about 12 million cubic meters per year, and almost 40 per cent of this volume is used in the Western province. If an alternative source of sand supply can be introduced to Western province, the immediate pressure could be released. There are number of alternatives to river sand, such as offshore sand, shore sand (dune sand), quarry dust and washed soil. Properties of fine aggregate affect those of hardened concrete such as durability, strength, shrinkage, creep, thermal properties, unit weight, modulus of elasticity and surface friction. This complexity has made the exploration for an alternative to river sand still incomplete.

A pilot survey revealed that individuals and state sector clients seldom approve the use of shore sand or offshore sand for concrete let alone reinforced concrete. Further, the initial offshore sand stockpile lying in Muthurajawela is exhausted and fresh offshore stockpiles are being formed, but they require exposure to rain. Therefore, further studies are required looking into the suitability of offshore sand from different perspectives. Since the potential environmental damage due to offshore sand extraction is far less compared to that due to river sand extraction, this concern is not considered in this research.

The objectives of the study are:

a) To determine the grading of offshore sand and compressive strength of concrete produced with offshore sand obtained soon after dredging, before any exposure to rain.
b) To determine the shell content of offshore sand obtained soon after dredging, before any exposure to rain.

c) To determine the chloride content of offshore sand obtained soon after dredging and before any exposure to rain and changes in chloride content when water drains through sand simulating the maximum and the minimum rainfalls.

1.2 Literature Review

1.2.1 Use of sea sand globally and locally

Sands obtained from seashore or dredged from the sea or river estuaries have been used in the UK over a long period. Currently, in the UK, about 20 per cent of natural gravel and sand requirement is sea dredged with submersible pumps making it possible to win the material from depths up to 50 m [1]. Experimental studies about offshore sand extracted from European and American coasts have shown that these materials are suitable as construction materials for the base and sub base pavements [2]. Also material from marine deposits around the coasts of Great Britain has been used in concrete production for several decades [3].

In China, where coastal areas are rich in sea sand, sea sands are already in wide use in local concrete construction due to convenience in mining and transportation, mature technology, and lower costs; the cost of sea sand is only 50-70 per cent of imported freshwater sand [4]. In recent years, most of the marine aggregate extractions have been carried out in areas of the North Sea, followed by the Baltic Sea, the English Channel, the Irish Sea and the North Atlantic Sea [2]. The main extracting countries are the Netherlands, followed by the United Kingdom, Denmark and France. Also material from marine deposits around the coasts of Great Britain has been used in concrete production for several decades [3]. The dredged marine sediments [DMS] can be used in several applications, such as erosive process control, coastal satabilisation, beach replenishment, productions of construction materials (clay, bricks, a aggregate) or construction works (foundation fill, dikes etc.). Rapid depletion of onshore deposits of construction aggregate has caused Japan to tap sand deposits in coastal waters [5]. Studies show that (DMS) can be successfully used as a fine aggregate for concrete production [2,6].

Having carried out a comprehensive study by Dias et al. [7] using offshore sand samples obtained from a stockpile, dredged in year 2002, just North of Colombo, Sri Lanka concluded that offshore sand is suitable for reinforced concreting work. Sri Lanka Land Reclamation and Development Corporation (SLLRDC) being the custodian of the stockpile took steps to popularize the use of offshore sand as an alternative to river sand for reinforced concrete work but to no avail. Recent surveys conducted revealed despite such steps consumers are apprehensive in using off shore sand for concrete, let alone reinforced concrete. Further, the stockpile just been exhausted, the SLLRDC has started dredging fresh offshore sand. It is planning to expose the dredged sand to rain for a period of three months before making it available to consumers. Therefore, it is opportune and timely to carry out a study to investigate the characteristics of offshore sand.

1.2.2 Advantages and disadvantages of sea sand

Chandrakeerthy [8] comprehensively compared and contrasted the advantages and disadvantages of river sand, offshore sand and crushed fine aggregate. Table 1 displays the advantages and disadvantages of sea sand, over its alternatives, identified in his study. His pioneering study on sea sand cleared the initial inhibitions of use of sea sand on an industrial scale and created a surge in the local consumption.

Table 1. Advantages and disadvantages of sea sand

Advantages	Disadvantages
It is the cheapest form of fine aggregate	It may lead to efflorescence and corrosion of reinforcement
In contrast to crushed fine aggregate, it is more rounded or cubical like river sand and hence, demand for water and cement is low	If washing is necessary, it may be an additional burden
Price fluctuations are small throughout the year	At present sea sand is recommended in Sri Lanka, and even if sea sand is found to be satisfactory there will be considerable user resistance to overcome
As it is found in natural deposits grading of sea sand is generally good	Restrictions on mining sea shore sand, to prevent sea erosion, do not allow full potential of sea sand to be realized
It contains no organic contamination, silt or weak small gravel particles	Offshore sand facility will require a large capital investment
It can be made abundantly available, as Sri Lanka is an island with greater exploitation potential for offshore and seashore sand	
Seashore mining operation is easy while offshore mining is complex. The latter is done on a larger scale with mechanized equipment and, hence, cost can be lowered	
If chloride content is high, it can be reduced to acceptable limits by washing with even sea water	
Grading of sea sand is finer than that of river sand and since local crushed stone coarse aggregate is coarser, it does not show any adverse effects when used in concrete	

Source: Adapted from a study by Chandrakeerthy [8]

1.2.3 Impact of shell content and other impurities

Offshore sand may contain a large content of shells. According to Chapmen and Roeder [9], shell has no adverse effect on strength but the workability is reduced if the concrete is made with aggregate having a large shell content. Although Table 1 of BS 812-1992 stipulates limits on shell content for aggregates coarser than 5 mm, it does not set any limit on shell content of aggregates finer than 5 mm; ie for fine aggregates [10]. With respect to the effect of shell and other impurities, Limeira *et a.l* [2] attest that the presence of small, normally acceptable percentages of coal, chalk or clay is unlikely to affect workability.

1. 2.4 Limits on chloride content of concrete

Chloride attack is one of the crucial aspects for consideration when the durability of concrete is dealt with. The chloride ions present in sea sand, however, make its application potentially threatening to the durability of concrete structures [4]. The consideration of chloride content has drawn the scholarly attention because it is primarily responsible for chloride induced corrosion of reinforcement. Concrete can get chloride from cement, water, aggregate and sometimes from admixtures [10]. The admixtures presently available in the market either contain negligible amount of chlorides or are completely chloride free.

Although the users are apprehensive about using offshore sand in concrete because of chloride content, Neville [1] attests that sand obtained from the sea bed and washed even in sea water does not contain harmful quantities of salts. BS 8110: Part 1:1995 (Structural use of concrete) [11] specifies a maximum total chloride ion content in the concrete mix. While Euro codes make no mention of sea sand, ICTAD Specification of Building Works prohibits the use of sea sand.

Regarding aggregate, BS 882:1992 [12] sets the limits for chloride content expressed as a percentage by mass of combined aggregate. The code says it is the responsibility of the concrete mix designer to calculate the total chloride content of a concrete mix from the chloride contents of the various constituents and to ensure that an appropriate maximum value is not exceeded. IS 456 of 2000 [13] has its own limits on chloride content of concrete. According to this code, the allowable chloride content in cement is 0.1 per cent.

The most commonly used limit on total chlorides is the 0.4% limit (by weight of cement) specified in BS 5328: Part 1: 1997 for reinforced concrete [14]. As for chloride concentration, the EHE 2008 (Spanish Standard of Structural Concrete) establishes two limits for mass concrete with reinforcement to reduce cracking; the total amount of chloride from the components should not exceed 0.05% in mass of aggregate and/or 0.40% of cement weight [2]. Dias et al. [7] establish acceptable chloride content 0.3% by weight of cement for the total chloride of the concrete mix, based on review of literature.

The presence of chloride in concrete beyond the acceptable limits not only could induce corrosion in steel reinforcement but also cause efflorescence, having absorbed moisture from the air. Efflorescence is caused when salts present in concrete oozes out to the surface forming unsightly while patches. Since efflorescence is more likely in permeable cement-sand mixes than in impermeable concrete, it need not be a consideration when sea sand is used for concreting. Chandrakeerthy's [8] study on use of sea sand in concrete provides no evidence of formation of efflorescence.

2. MATERIALS AND METHODS

An experimental programme was carried out using samples obtained from the offshore sand dredged for the use of Colombo Port Expansion Project. At the time these samples were taken, in 2010, the dredged sand was used to produce 'core loc', which were in turn used to construct the layer in between quarry run and the wave wall of the breakwater structure of the project. In general, the sea around Sri Lanka is not polluted with harmful contaminants. The sand required for the project was extracted from areas 2-7 km offshore of the project and did not contain harmful quantities of organic matter, particularly after sieving. The dredged sand was mechanically sieved using drum sieves to remove organic matter as well as to grade sand into different sizes.

These samples were tested for aggregate properties crucial for local offshore sands which are as follows; grading, shell content chloride ion content.

2.1 Grading of Offshore Sand

In order to determine grading pattern of offshore sand the relevant test was conducted according to BS 812 – 103: 1985 (2000). The sieves used were 5 mm, 4.75 mm, 3.35 mm, 2.00 mm, 1.18 mm, 6 μm, 4.25 μm, 3 μm, 2.12 μm and 1.5 μm.

2.2 Concrete Mixture Composition

Mix design for grade 25 concrete was carried out according to BS 5328: Part 1:1989 [14]. The investigation was limited to grade 25 concrete, this being the most commonly used grade in Sri Lanka. The ordinary Portland cement (OPC) was used as the cement type.

The OPC used has the following physical properties:
Bulk Density =180 g/cm^3
Specific gravity = 1.3
Fineness passing 45μ sieve = 96
Specific surface (Blain's) (m^2/kg)=340

The chemical composition of OPC used is LOI (4.33%), SiO_2 (19.56%), Al_2O_3 (4.75%), Fe_2O_3 (3.39%), CaO (63.88%), MgO (1.68%), SO_3 (2.03%), K_2O (0.32%), Na_2 (0.04%) Cl (0.01%).

The most common of all tests on hardened concrete is the compressive strength test, partly because it is an easy test to perform, and partly because many, though not all, of the desirable characteristics of concrete are qualitatively related to its strength; but mainly because of the intrinsic importance of the compressive strength of concrete in structural design [1]. The coarse aggregate, cement and fine aggregate in their specified proportions were initially added to the drum mixer and then water was added. Thereafter, the entire batch of 0.03 m^3 in volume was mixed thoroughly. The specimens are cast in cast-ion moulds of robust construction, generally 150 mm cubes, which should conform within narrow tolerances to the cubical shape, prescribed dimensions and planeness. Before assembling the mould, its mating surfaces were covered with mineral oil to the inside surfaces of the mould in order to prevent any development of bond between the mould and the concrete [1]. Each layer of concrete is compacted by not fewer than 35 strokes with a 25 mm MS rod. The compressive strength was tested at 7 and 28 days, with the average of three test cube results obtained for each age.

2.3 Shell Content in Offshore Sand

The shell content of offshore sand samples was measured separately for the aggregate sizes greater than and less than 5 mm, as per BS 882: 1992 [12]. This was measured from a sample weighing 1000 g. The shell content greater than 5 mm was measured by 'hand-picking' method. The shell content less than 5 mm was measured by dissolving in HCl.

2.4 Chloride Content Test

The chloride ion content of fresh offshore sand was measured before their exposure to rain. Thereafter chloride ion content of offshore sand was measured after two different quantities of water corresponding to the minimum and the maximum monthly rainfalls percolate through the sand simulating the effect of rain. Before using the offshore sand for chloride testing, it was sieved to remove dirt and pebbles.

In order to test offshore under the above two situations, a special container of diameter 457 mm was fabricated to hold a column of sand 2743 mm high. The sand column was supported, at the bottom of the container, on a strainer which facilitated the water to drain into another container. The container had four holes along a vertical line, which could be plugged and made watertight. These holes had been positioned at four levels so that the sand could be sampled at four different levels from A to D; Fig. 1 shows the device used to measure chloride levels in offshore sand.

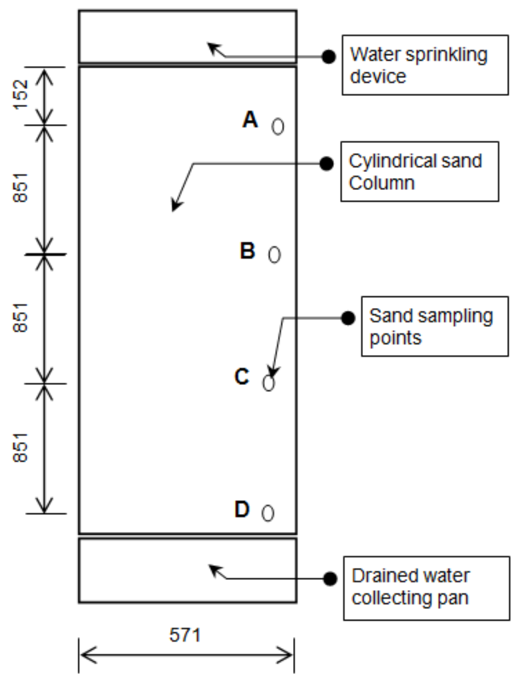

Fig. 1. Container used to measure chloride levels in offshore sand

A sample taken directly from the offshore sand was checked for its chloride content. Then the container was filled with offshore sand and a volume of fresh water corresponding to a height of 10 mm (the lowest average monthly rainfall for the last 03 years in Colombo being 9.9 mm) was sprinkled evenly from the top surface of container. Four samples were taken after 5 days of drainage through the holes made for sampling. This sprinkling was repeated with a further 571 mm height of water (the highest average monthly rainfall in Colombo being 581 mm), and another set of samples were taken after 5 days of drainage. The samples had to be oven dried prior to Chloride testing as per BS 1377: Part 3 (1990) [7].

Each sand sample weighing 100 g was oven dried at 110ºC overnight; moisture content was measured after oven drying the sand samples for 24 hrs. A sample of 50 g sand (dried) was placed in a conical flask and a volume of 100 ml distilled water was added to it and thereafter the mixture was shaken overnight with a shaker. Filtered (the chloride contain water) by using a No. 01 filter paper. Silver Nitrate 25 ml (V_1), Nitric acid 5 ml, Ferric Alum indicator solution 5 ml was added to the extracted sample (then chloride has been precipitated). Thiocyanate solution (*Concentration of C)* drops were added from a burette until the first permanent colour change occurs (NH_4SCN or KSCN). When the colour changed to brick-red, the volume of Thiocyanate (V_2 in ml) was measured; the Chloride ion content is given by 0.007092 (V_1 -10CV_2).

Testing the concentration of Thiocyanate

- Transferred 25 ml of the Silver Nitrate (concentration 0.1 mol/l) solution into a 250 ml conical flask, using a pipette, and added 5 ml of the Nitric acid (concentration 6 mol/l) solution and 1 ml of Ferric Alum (concentration 100 g/l) indicator solution
- Added Thiocyanate (concentration 0.1 mol/l) solution from a burette until the first permanent colour change occurred, that is from colourless to pink.
- Recorded the volume of Thiocyanate solution (V) $C = \frac{2.5}{V}$

2.5 Market Survey

A market survey was carried out to find the prices of offshore sand, confining it to the western province as 40 per cent of country's sand requirement is used in this area.

3. RESULTS AND DISCUSSION

3.1 Grading of Offshore Sand

Table 2 displays the result of sieve analysis of the offshore sand sample which weighed 1438 g. Fig. 2 represents the sieve analysis results of the offshore sand graphically, and by interpolation the D_{50} value of the sample was computed to be around 0.9 mm. The offshore sand sample obtained from Muthurajawela stockpile had a D_{50} value of around 0.6 mm which according to the authors is very appropriate for concrete production [7]. The higher D_{50} value indicates the coarseness of the sand and thereby the need for less mortar paste and water content.

Table 2. Sieve analysis of the offshore sand

Sieve size mm	Weight retained g	Retained %	Cumulative % weight retained	% passing	Specified limits (%)	
					Lower	Upper
5.000	0.00	0.00	0.00	100.00	89	100
4.750	0.80	0.06	0.06	99.94	85	100
3.350	13.80	0.96	1.02	98.98	74	100
2.000	114.70	7.97	8.99	91.01	53	100
1.180	424.70	29.53	38.52	61.48	30	100
0.600	439.20	30.54	69.05	30.95	15	100
0.425	212.60	14.78	83.84	16.16	11	85
0.300	108.70	7.56	91.39	8.61	5	70
0.212	82.50	5.74	97.13	2.87	3	40
0.150	41.30	2.87	100.00	0.00	0	15
Total	1438.30					

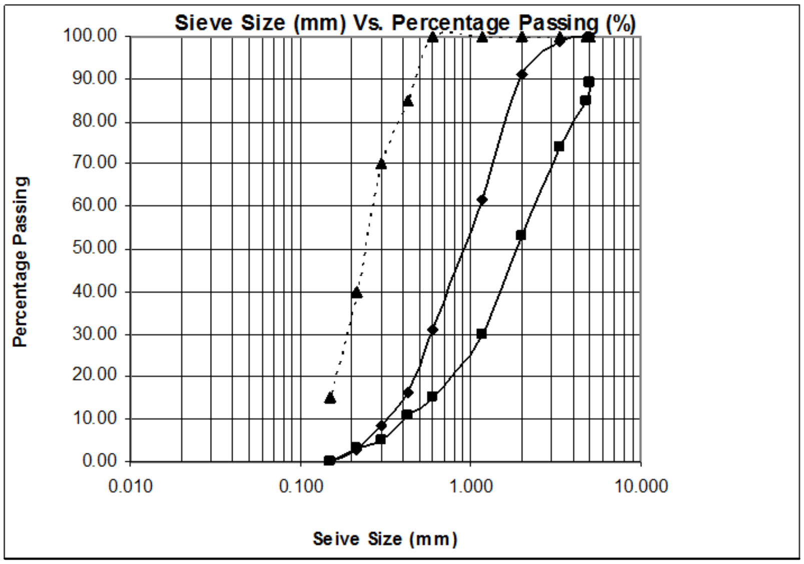

Fig. 2. Sieve analysis of offshore sand

As per the results of the sieve analysis, the offshore sand complies with the overall limits specified in the BS 882: 1992 [12]. Therefore, the grading of the offshore sand used in the test is suitable for concrete production. The specific gravities of offshore sand and the coarse aggregate are 2.65 and 2.63 respectively.

3.2 Concrete Mix Properties

Table 3 presents the concrete mix design results, together with strength results, for concretes made with offshore sand for grade 25 concrete being the most widely used structural concrete. The fresh offshore sand, without being washed and cleaned, was used for the concrete mix design specified above.

In this study, freshly dredged offshore sand brought to the site, was used to check the strength of concrete. From the results obtained for grade 25 concrete it can be seen that the strength of concrete is within the specified limits. According to literature review, the study done on offshore sand stockpiled at Muthurajawela [7] shows that the compressive strength is within the required level.

Table 3. Test results of mix design (grade 25)

Attribute	Value
Target mean strength (N/mm^2)	35
Cement (kg/m^3)	339
Coarse aggregate (kg/m^3)	1027
Fine aggregate (kg/m^3)	837
Water (kg/m^3)	200
7 day strength (N/mm^2)	28
28 day strength (N/mm^2)	34

3.3 Shell Content in Offshore Sand

Table 4 gives the shell content as a percentage of the total weight sample offshore sand. It also gives the limits on shell content as per BS 882: 1992 [12].

Table 4. Shell content of offshore sand

Grading	Shell content	Limits as a percentage
> 5mm	6.35%	Finer than 10 mm and coarser than 5 mm- 20 % Coarser than 10 mm- 8 %
< 5 mm	5.5%	No Requirement

From the results obtained for shell content of off shore sand it can be said that the shell content is within the specified limits.

3.4 Chloride Levels in Offshore Sand

The limits stipulated in BS 882:1992 on the chloride ion content by mass, expressed as a percentage of the mass of the combined aggregate, are as follows[12]:

Prestressed concrete and heat cured concrete -0.01
Concrete containing embedded metal with cement complying with BS 4027 -0.03
Concrete containing embedded metal with other cement-0.05
Other concrete – No limit

Dias et al. [7] define an acceptable level for chloride ions in offshore sand, which is 0.086 per cent of by weight of sand for grade 25 concrete used for reinforced concrete. This is to be produced with Portland cement when w/c=0.59, cement=300, sand=875, sand/cement 2.9.

A fresh sample was tested for chloride ion and it contained 0.04 per cent of water soluble chloride. This value is almost same as that (0.044) obtained by Dias et al. [7]. The acceptable level of the chloride ion for grade 25 concrete can be computed as below:

Allowable chloride in concrete is 0.3 per cent by weight of cement
Cement too has chloride up to 0.05 per cent
So, off shore sand can afford to have chloride up to 0.25 per cent
According to Table 3, concrete mixture has 1 m^3 of concrete which contains 339 kg of cement and 837 kg of sand. Hence, sand can afford to have chloride up to 0.101 per cent (0.25 x 339/837). The chloride in fresh offshore sand (0.04 per cent) is far below the acceptable level of 0.101 per cent.

As can be seen from Table 5, offshore sand can be used without any washing for concreting purposes. Nevertheless, it is prudent to know to what extent exposure to minimum or maximum rainfall, could wash away chlorides ions from offshore sand, which is a cost effective procedure. This enables to achieve lower chloride ion levels and making it usable under different circumstances.

According to the rainfall data for Colombo for the period 2007 through 2009, the minimum rainfall is reported in February 2007, which is 9.9 mm (approximated to 10 mm). Table 5 displays chloride ion levels of samples extracted at given levels when a rain water height equivalent to the minimum rainfall was sprinkled evenly from the top of the sand container. Even a very low rainfall can reduce the chloride content significantly (from 0.4 to 0.1). However, due to capillary action moisture content of sand placed at the bottom of the container is high; as a result chloride content of sand has increased.

The table also displays chloride ion levels of samples extracted at given levels when a rain water height equivalent to the maximum rainfall was evenly sprinkled from the top of the sand container. The water percolation through the sand column is so high that it has been able to wash away chloride almost completely (<0.01).

Table 5. Chloride levels of samples of sand column test

Sample description	Location of sample extraction		Chloride (water soluable) (as Cl^{-}, w/w%)
	Position	Level (measured from the top)	
9.9 mm rainwater to simulate minimum rainfall; after 5 days of drainage	A	0.152	0.01
	B	1.003	0.02
	C	1.854	0.03
	D	2.705	0.05
581 mm rainwater to simulate maximum rainfall; after 5 days of drainage	A	0.152	<0.01
	B	1.003	<0.01
	C	1.854	<0.01
	D	2.705	<0.01

In the second set of readings taken after a water height of 10 mm is made to percolate through the sand, simulating exposure to the minimum monthly rainfall of 10 mm. The chloride ion content varied from 0.01% - 0.05%, the highest concentration being at the bottom of the sand column. At the bottom of the sand column, the chloride ion content is higher because of the higher moisture content due to the capillary action.

In the third set of readings when a water height corresponding to the maximum monthly rainfall made to percolate the chloride ion content reduced to levels < 0.01, which is far below the acceptable limit. Therefore, by exposing offshore sand to rain the chloride ion content can be reduced drastically. Therefore, by keeping offshore sand exposed to rain, the chloride ion in offshore sand can be washed away making it more suitable to be used in concrete.

3.5 Market Survey

A breakdown of type, location, supplier and price of sand supplied to Colombo are depicted in Table 6, as at February 2013.

Table 6. Breakdown of sand supplied to Colombo

Type	Location (Extraction)	Supplier	Price per cube at site(in Sri Lankan rupees
Offshore sand (exposed to rain	Muthurajawela	SLLRDC	7,400
Offshore sand	Kirinda	Individual	8,500
River sand	Manampitiya	Individual	11,500

According to the market prices in Table 6, the offshore sand comes from Muthurajawela is much cheaper than any other sand available in the market. Further, since this sand is sold by a statuary body, the reliability of quality with respect to chloride content is guaranteed. However, since this sand is only available at two sites; Muthurajawela and Nawala, the consumers have been inconvenienced and required to pay additional transport charges. On the other hand, Kirinda sand is not only available at many outlets around Colombo but also finer than Muthurajawela making it more suitable for specific uses. This explains why Kirinda sand despite being priced 15 per cent higher still has a market share. Since the price of river sand is 55 per cent higher than Muthurajawela sand, there is a potential for increased market share for offshore sand.

4. CONCLUSION

1. As per the results of sieve analysis, grading of the offshore sand is within the limits specified in BS 882:1992. D_{50} value is around 0.9 mm which is much higher than the same obtained for Muthurajawela sand (0.6 mm). The characteristic compressive strength (25 N/mm^2) is also within the limits and therefore offshore sand obtained soon after dredging, before any exposure to rain, is suitable for producing concrete with respect to gradation.
2. The shell content of offshore sand for shells finer than 10 mm and coarser than 5 mm is 6.5 %. This is far below 20 %, the limit specified in BS 882:1992.
3. For grade 25 concrete produced with OPC, an allowable limit of 0.101% by weight of the sand was worked out for chloride content in offshore sand. The chloride content of offshore sand obtained soon after dredging was 0.04%. Even a rainfall as low as 9.9 mm can reduce chloride content (range from 0.01 to 0.05) to levels far below the allowable limit (0.101). Rainfalls as high as 581 mm could wash away chlorides almost completely (below 0.01).
4. Since the offshore sand dredged from places about 2- 7 km away from the shore is having a chloride content well below the allowable limits, it is not necessary to expose stockpiles to rain. However, when stockpiled to heights more than 1 m, the sand lying below this level tend to contain higher chloride contents (in the region of 0.03). The high D_{50} also affords a greater drainage capacity to offshore sand. Hence to make the maximum benefit of stockpiling, the draining has to be done to moderate heights.
5. The study revealed that offshore sand obtained from 2 to 7 km away from the Western coast, soon after dredging, can be used as an alternative to river sand, which is considered the most viable of all alternatives, in terms of availability, ease of extraction, environmental impact and cost. However, some offshore sand may require washing in order to remove organic matter that could not be physically separated by sieving, and other contaminants.
6. It is required to conduct further research to determine the suitability of offshore sand extracted from other areas around the country along the coastal belt particularly in the Northern and Eastern provinces where construction industry has increased after civil war was over.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Neville AM, Properties of Concrete, 4th ed. India: Pearson; 1995.
2. Limeira J, Etxeberria M, Agullo L, Molina D. Mechanical and durability properties of concrete made with dredged marine sand. Journal of Construction and Building Materials. 2011;25:4165-4174.
3. Newman K. Aspects of workability, strength, shrinkage and creep, sea dredged aggregates for concrete, Proceedings of a Symposium, Sand and Gravel Association of Great Britain, Buckinghamshire; 1968.
4. Huiguang Y, Yan L, Henglin L, Quan G. Durability of sea sand containing concrete: Effects of chloride ion penetration, Mining Science and Technology (China), 2011;21:123-127.
5. Padan JW. Offshore Sand and Gravel Mining Offshore Technology Conference, 2-5 May 1983, Houston, Texas
6. Limeira J, Etxeberria M. Dredged marine sand in concrete: An experimental section of a harbour pavement. Journal of Construction and Building Materials.2010;24:863-870.
7. Dias WPS, Seneviratne GAPSN, Nanayakkara SMA. Offshore sand for reinforced concrete, Journal of Construction and Building Materials. 2008;22:1377-1384. .
8. Chandrakeerthy SRDeS. Suitability of sea sand as a fine aggregate for concrete production, Transactions, Institution of Engineers, Sri Lanka. 1994:93-114.
9. Chapmen GP. Roeder AR, The effect of sea shells in concrete aggregates, Concrete Transactions. July 1969;251-63.
10. Shetty MS. Concrete Technology, India; S. Chand & Company Ltd.; 2009.
11. BS 8110: Part 1:1997, Structural use of concrete, British Standards Institute, London; 1997.
12. BS 882:1992. Specification for aggregate from natural sources for concrete, British Standards Institute, London; 1997.
13. IS 456 of 2000. Code of practice for plain and reinforced concrete, Indian Standards Bureau, New Delhi; 2000.
14. BS 5328: Part 1:1997. Guide to specifying concrete, British Standards Institute, London; 1997.

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