Backfilling Manhole Surround Using Recycled Concrete Waste Material

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Abstract

The massive development in the State of Qatar to fulfil the Qatar National 2030 Vision requires efforts to direct the construction sector towards reducing economic, social and environmental impacts through the application of more sustainable construction techniques. The Public Works Authority, Qatar (Ashghal) has acknowledged that using available domestic sources to produce quality aggregate by recycling pavements, construction and demolition waste, and industry by-products is beneficial when natural sources are getting depleted. One of the projects exploring the possibility of utilizing the recycled concrete waste as surround backfill material is Contract C853/1 named the Wakrah-Wukair Drainage Network Branches (WWDNB). This is an ongoing mega drainage project associated with the construction of 67 number of shafts and approximately 17 km of sewer pipes at a maximum depth of 48m below ground level. The proposed material would be replacing the conventionally used materials such as graded limestone, gabbro aggregate and foamed concrete. This paper assesses the feasibility of utilizing recycled concrete aggregate (RCA) for backfilling of permanent shafts whilst satisfying the requirements of the Qatar Construction Specifications (QCS). A number of laboratory tests were therefore conducted, and the proposed material was found to be of acceptable quality. Additionally, mock-up tests are scheduled to confirm the field attributes before implementation on site for shafts in non-traffic areas. Using RCA as shaft backfill is more beneficial from a sustainability perspective as it will decrease the carbon footprint by 70% when compared with using traditional backfill materials. The goal of the study is to introduce an industry-wide application which is both sustainable and economical.

Keywords: Recycled concrete; RCA; Sustainability; Backfilling; Compaction; Construction

1 Introduction

The Wakrah and Wukair Drainage Network Branches (WWDNB) (Contract C853/1) is an ongoing mega drainage project associated with the construction of 67 number of shafts and approximately 17km of sewer pipes at a maximum depth of 48m below ground level. The Public Works Authority (Ashghal) is the designated engineer who is represented by the Engineer's Representative, Parsons International Limited (PIL). PIL provides construction supervision services in the form of site management and engineering review of all designs completed by the Contractor's team. The three-year design-build construction contract was awarded in November 2020 to the Qatar Trading and Contracting Group (QTCG).

The geological strata of the WWDNB project area are comprised of rock formations such as Simsima Limestone, Midra Shale and Rus formation (QTCG, 2022a). The construction includes the excavation of temporary shafts and the installation of drainage pipeline and permanent manholes. Shafts will serve the purpose of launching and retrieval of a Micro Tunnel Boring Machine (MTBM) used for pipe jacking operations. After the completion of pipe jacking and permanent manhole construction, the temporary shafts are backfilled with a selected material which is durable and resistant to settlement (Figure 1).

Fig. 1: Temporary shafts on the WWDNB project used for micro tunneling and manhole installation (left side) and ongoing conventional backfilling works (right side)

The traditional backfilling method in Qatar is to dispose of the excavated material and backfill the shafts using suitable granular fill material. As the suitable material is not naturally available in Qatar, it has to be imported which makes it an unsustainable construction practice. The Qatar National Development Strategy 2018-2022 (NDS-2) acknowledged the existing recycling activities in the construction industry and set a target to increase recycling levels (Hassan et al., 2022). Ashghal has acknowledged that and issued Ashghal Recycling Manual in 2021 to encourage reusing and recycling construction waste in new construction projects.

The project has taken several steps to find innovative approaches and sustainable solutions to be adopted during construction and proposing RCA as a backfill material for deep shaft can be considered as one of them. This initiative can lead similar construction projects in the direction to try out-of-the-box solutions rather than following a conventional approach. Utilising Recycled Concrete Aggregate (RCA) to backfill shafts is an attractive option for Ashghal as it is more sustainable and also more cost-effective. RCA is the resultant of construction and demolition waste which contains relatively clean concrete aggregates which can be crushed and graded into different sizes as required.

The RCA (Figure 2) analysed in this study has been supplied by Qatar Primary Material Company (QPMC), an agency processing and supplying aggregates and other construction materials in the State of Qatar. This paper presents an assessment of the locally available material and pursues various studies conducted on this subject to understand if the material's properties are fit-for-use.

Fig. 2: RCA material stockpile and sampling at QPMC

2 Properties of the Proposed Material

2.1 Gradation

The requirements for backfilling material as per QCS (2014), Section 08 [Drainage Works], Part 02 [Earthworks], Sub-clause 2.3.4 [Backfilling Excavation] specify the use of a suitable selected fill material with no specific requirements related to the material gradation, except that "the uniformity coefficient should be more than 10 and the maximum stone size shall be 75mm with less than 15% of material passing through 0.063mm sieve". The material gradation adopted for the study complies with QCS (2014), Section 08, Part 02, Table 2.2 [Gradation Requirements for Pipe Bedding, Rigid Pipes], which specifies gradation for pipes above a Nominal Diameter (DN) 800 mm. The QCS requirements against the laboratory test results for the RCA are presented in Table-1. The bedding material gradation provides a high load-bearing capacity and a stable base below the pipes. Thus, using such a graded material for backfilling lowers the risk of settlements and creep (QTCG, 2022b).

Table 1: Gradation requirements as per QCS and RCA test results (QTCG, 2022b)

Sieve Size (mm)	Acceptance Limits (% by Mass Passing)	RCA Test Value (% by Mass Passing)
25	100	99.5
20	90-100	94
14	50-80	68
10	40-70	54
5	25-60	40
2.36	10-40	24
0.5	0-15	8

It has been demonstrated that systematic processing of the material through crushing and screening can achieve the required gradation for the purpose of application. The sieve analysis results of RCA sample have fulfilled the gradation criteria as per the desired property requirements.

The RCA is not expected to exhibit any alarming settlement, since as presented above, the material is well graded which will reduce the void ratio of the compacted material.

2.2 Physical and Chemical properties

The proposed RCA material has been tested to assess the physical and chemical properties listed in Table-2 against the requirements of QCS (2014), Section 08 [Drainage Works], Part 02 [Earthworks] and applicable requirements of Section 05 [Concrete], Part 02 [Aggregate] and Section 06 [Roadworks] Part 03 [Earthworks] along with proposed target engineering properties by the contractor's designer.

Table 2: Required properties of the RCA material and test results (QTCG, 2022b)

Property	Requirement Reference	QCS Reqd. value	Targeted value	Test Result
Organic content	QCS (2014), Section 08, Part 02, clause 2.3.4 3(f)	2% max	Free of organic impurities	No impurities
Clay Lumps and Friable Particles	QCS (2014), Section 05, Part 02, Table 2.1	2% max	Free of content	0.16%
Minimum Index Density	For reference only	None	1.8 g/cm^3	1.840 g/cm^3
Maximum Index Density	For reference only	None	2.0 g/cm^3	2.045 g/cm^3
Shell content	QCS (2014), Section 05, Part 02, Table 2.1	3% max	None	Nil
Resistance to fragmentation: Los Angeles abrasion	QCS (2014), Section 05, Part 02, Table 2.1	30% max	None	14 %
Flakiness Index	QCS (2014), Section 05, Part 02, Table 2.1	35% max	None	4%
Water Absorption	QCS (2014), Section 05, Part 02, Table 2.1	2% max	None	4.36% & 5.92 % when retested
Soaked Compacted California Bearing Ratio at 95%	QCS (2014), Section 08, Part 02, clause 2.3.4 3(g) QCS 2014, Section 06, Part 03, Table 3.1	15% min	15% min	55%
Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)	For reference only	None	None	2.14 g/cm^3 at 7.1% OMC
Swelling	QCS (2014), Section 06, Part 03, Table 3.1	2% max	2% max	0.28%
Angle of Internal Friction	For reference only	None	30˚ min	32˚
Cohesion	For reference only	None	None	2.5kN/m^2
Aggregate 10% fines value (Dry Condition),	QCS (2010), Section 05, Part 02, Table 2.1	150kN min for 20mm and 100kN min for 10mm	125kN min for graded RCA[1]	130kN
Aggregate 10% fines value (Soaked Condition)	For reference only	None	For wet/dry TFV ratio	99kN
Aggregate 10% fines value - Ratio (Wet/Dry)	(Stålheim, 2014)	None	75 min	76.2
Fines content (Material passing #200 sieve[2])	QCS (2014), Section 08, Part 02, clause 2.3.4 3(b)	15% max	10% max	0.6%
Plasticity Index	QCS (2014), Section 08, Part 02, clause 2.3.4 3(c)	6% max	6% max	Non-plastic

Notes:
[1] Average of the required values in QCS 2010 taken.
[2] 0.075mm sieve was used while QCS states 0.063mm, however, since the fines content is very low, therefore this is acceptable.

The test results in Table-2 have been studied in order to assess the suitability of the material, and the following has been concluded:

Organic content, Clay Lumps and Friable Particles: RCA is expected to be free of organic impurities, clay lumps and friable particles unlike naturally excavated material. The proportionate settlement by permitting 2% of organic content, clay lumps and friable particles is eliminated by using an impurity-free material. The tested samples are observed to practically be impurity free with a negligible 0.16% content of clay lumps and friable particles.

Minimum and Maximum Index Density: Although the limits of index density test are not defined, the minimum and maximum index density tests were conducted to get relative results in order to compare the material with the properties of the existing ground and conventional backfill materials. The test results which range between 1.840 g/cm^3 and 2.045 g/cm^3 can be compared against the density of the in-situ rock mass (approx. 2200 kg/m^3 for Simsima limestone) and general backfill material (2000 to 2100 kg/m^3).

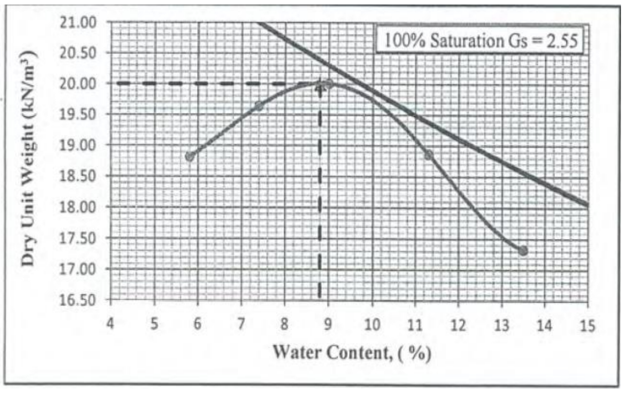
Shell content: Although the inclusion of shell content has no impact on the proposed application, the tests were conducted to ensure no external contamination. The tests indicated no presence of shell content in the RCA material.

Resistance to fragmentation/Los Angeles (LA) abrasion: The result of the LA test, which in this case is 14% and within the stipulated maximum 30%, satisfies the criteria for resistance to fragmentation or abrasion.

Flakiness Index: The test provides an indication of the level of achievable compaction, as flaky material tends to break down and lose strength during compaction which may cause further settlement. The flakiness index of the RCA material is only 4%, which is far below the max 35% limit.

Water Absorption: Crushed concrete typically has a higher water absorption since the crushed mortar has higher absorption than natural aggregates (Aminur et al., 2014), and this can be observed from the performed tests (4.36% and 5.92% when retested). Despite the relatively porous nature of the RCA as reflected by the absorption results, the RCA is typically relatively strong with good resistance to weathering and aggressive environment (Hassan et al., 2022). Furthermore, the water absorption property is usually specified and necessary for aggregates intended for use in bound layers, such as structural concrete or asphalt. Therefore, since the RCA exhibited higher strength (LA abrasion) and resistance to weathering (soundness) complying with QCS 2014, the recorded higher water absorption values are not considered detrimental for the backfilling application and will have no impact on the bearing capacity and/or performance of the unbound/backfill layers.

Maximum Dry Density (MDD) and Optimum Moisture Content (OMC): The MDD value is measured for the RCA backfill material to determine the optimum moisture content required for the material to attain maximum compaction. The MDD value of 2.14g/cm^3 at 7.1% OMC obtained during testing as per Figure 3.



Uncorrected:	
Optimum water Content, (%)	**8.8**
Maximum Dry Density, (g/cm^3)	**2.04**
Maximum Dry Unit Weight, (kN/m3)	**20.01**
Corrected:	
Optimum water Content, (%)	**7.1**
Maximum Dry Density, (g/cm3)	**2.14**
Maximum Dry Unit Weight, (kN/m3)	**20.96**

Fig. 3: Compaction curve and RCA test results for MDD and OMC

Soaked Compacted California Bearing Ratio (CBR) and Swell Potential: The obtained results for the soaked compacted CBR (55%) and swell potential (0.28%) at 95% MDD were found to be within the required limits of min 15% CBR and max 2% swell, which indicates that there is a low probability of settlement due to volume change.

Angle of Internal Friction: Although there are no specific shear and deformation parameter requirements for backfill materials, the strength of the RCA material was tested by carrying out a direct shear test as a potential comparison against similarly graded natural aggregate. An angle of 32° was obtained with a cohesion value of $2.5kN/m^2$, where the angle of friction is greater than the stipulated minimum 30°.

Aggregate 10% fines value (TFV): Test conducted on the RCA provided a value of 130kN in dry condition which is more than the desired 125kN min. Tests were also carried out in soaked conditions to drive a soaked/dry TFV ratio, with an obtained value of 76.2. Considering the results of the soaked/dry TFV ratio, a value of min. 75 indicates a better-quality material in terms of durability (Stålheim, 2014). The TFV test is planned to be repeated post-compaction on site to reassure the results are within the required limits.

Fines content: A result of 0.6% using the 0.075mm (Sieve No. 200) separating sieve indicates very low fines, which suggests a low potential for settlement.

Plasticity Index (PI): Although the requirement allows max 6%, the RCA is found to be free from any clay content and similar materials.

3 Planned Mock-Up and Field Tests

Following the laboratory tests and evaluation of results, and to confirm how the RCA would behave in practice after compaction, a mock-up with pre-construction field testing as per Table 3 is planned to be performed in a shallow excavation replicating the actual site conditions.

The method of backfilling is proposed to be conducted as follows: The RCA will be evenly spread in layers not exceeding 300mm in height and compacted to achieve a minimum of 95% compaction of the standard MDD. It is expected that larger layer thicknesses are required due to the coarser grain composition of the RCA when compared to traditional backfill. During the compaction trial, the target will be to establish the maximum possible loose layer thickness at the achieved target compaction level. The achieved compaction will then be checked for verification on site through Nuclear Dry Density (NDD) testing. Further samples will be collected from the compacted layer and tested for gradation properties to ensure that any increase in the percentage of fines (Sieve No. 200) does not exceed 10% post compaction. This will be compared to the gradation results for uncompacted material, a sample which will be taken prior to compaction.

Additionally, settlement monitoring will be conducted to study the long-term behaviour of the backfill to properly assess the behaviour of the reinstated ground. Since cyclic load-bearing capabilities due to vehicle traffic need to be considered for the application in traffic areas, shafts backfilled with RCA will initially only be approved for use in non-traffic areas.

Upon successful mock-up results, testing in accordance with Table 4 will be performed for quality control (QC) purposes as well as settlement monitoring.

Table 3: Recommended pre-construction tests during the mock-up

Stage	Tests	Frequency
Before compaction	Gradation Proctor – MDD Abrasion Ten Per cent Fines	Once
During compaction	Compaction level (nuclear gauge)	Each layer (95 %)
After compaction	Gradation Ten Per cent Fines	Once (selected layer that has reached 95 %)

Table 4: Recommended tests during site execution for QC purposes

Stage	Tests	Frequency
Before compaction	Gradation Proctor – MDD Abrasion Ten Per cent Fines	Once
During compaction	Compaction level (nuclear gauge)	Each layer (95 %)

4 Sustainability Benefits

Utilising concrete waste material is an excellent example of how to implement and follow the 'Reduce, Reuse and Recycle' philosophy. It will also reduce the usage of equipment & accessories, manpower and overall cost of a project.

The NDS-2 has estimated construction waste to constitute approximately 80% of the solid waste generation across Qatar, with estimated stockpiles of 80 to 100 million tonnes (Mt) accumulated in landfill sites (Hassan et al., 2022). The weighted average carbon footprint for various recycled materials is 3.0 kg CO_2e/t, compared to that of local limestone, which is 8.2 kg CO_2e/t and imported material that is 10.3 kg CO_2e/t (Hassan et al., 2022).

On this project, the usage of waste concrete is estimated to replace approximately 83,000 tons of quarried rock aggregate. Therefore, an approximate estimation indicates that a 60-70% reduction of the total carbon footprint can be achieved when the conventional backfill materials such as limestone, gabbro or foamed concrete are replaced by RCA.

It is also worth mentioning that significant cost savings can be achieved by adopting RCA for the proposed application which is a motivating factor from a project perspective. An approximate estimation of the cost of RCA is expected to be half that of limestone or gabbro aggregate and one-third of the foamed concrete. Once regularised, further cost reductions could be achieved from mass producing RCA with the added advantage of environmental benefits.

Furthermore, using a recycled material for construction will also raise the project's score on contractually mandated participation in the Civil Engineering Environmental Quality Assessment & Award Scheme (CEEQUAL).

5 Discussion

Assessment of the laboratory test results indicated a positive sign to proceed further to use this material as backfill, however, the planned mock-up tests and long-term settlement monitoring are still required to properly assess the behaviour of the reinstated ground.

The authors would also like to highlight some viewpoints and recommendations for further research and studies to be conducted for the following:

- While in contact with water, RCA material may precipitate calcium carbonate contained in the leachate from the crushed concrete, also known as tufa, which is formed through a series of chemical reactions. To control tufa precipitation, washing the RCA is required by some agencies to remove the dust, which typically contains free lime and calcium hydroxide (Ellen et al., 2001).
- The recycled concrete may react with groundwater which may result in a change of material properties. This is subject to further studies by others.

6 Conclusions

Based on the performed suitability testing on the recycled concrete aggregate, the tested material is found to be of acceptable quality and is adequately satisfying the minimum requirements specified under QCS for suitable backfill. Additional tests were also carried out to analyse the durability and strength of the aggregate under dry and soaked conditions.

RCA is not expected to exhibit alarming settlement, since the material is well graded which will reduce the void ratio of the compacted material. Also, the material has low crushing and abrasiveness potential, high soaked CBR values and a satisfactory TFV value, which reduces the risk of disintegration. Furthermore, the post compaction settlement behaviour of the RCA aggregates will be evaluated during the mock-up testing. If the requirement will be achievable in the field for compaction criteria of minimum 95% of the laboratory established MDD value, the material would be proven to have no adverse impacts in performance when compared to the conventional backfill material produced from excavated rock.

Since the long-term behaviour of the material is yet to be evaluated in terms of settlement, as cyclic load-bearing capabilities are still unknown, shafts backfilled with RCA on the project will initially only be approved for use in non-traffic areas.

Using RCA as shaft backfill is more beneficial from a sustainability perspective as it will decrease the carbon footprint by 70% when compared with using traditional backfill materials such as limestone, gabbro or foamed concrete.

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