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A Review Study on Geotechnical Applications of Construction and Demolition (C&D) Waste

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Abstract. Due to rapid urbanization, there is marginal increment in generation of construction and demolition (C&D) waste. The sustainable development of modern society demands the proper utilization of C&D waste as the replacement of natural resources. Many of studies have done in the field of utilization of C&D waste in various engineering applications. This paper reviews the studies related to the Geotechnical Engineering applications of C&D. This study includes Geotechnical and Geo-environmental assessment of C&D waste materials like:- reclaimed asphalt pavement (RAP), recycled concrete aggregate (RCA), fine recycled glass (FRG), waste rock (WR), crushed brick (CB). The C&D waste material characterization studies show that laboratory and field tests results of most of the C&D waste materials gives satisfactory fulfillment of the standard specifications of material which should be used as sub-base/base layer of roadway pavement or the backfill material of geosynthetics reinforced structures. This is also reported that to enhance the engineering properties of C&D waste, some additives like:- cement, clay, fly ash, geosynthetics are useful. This review study concludes that Construction and demolition wastes have good performance in Geotechnical applications all over the world and also promote the more utilization of C&D waste.

Keywords: C&D Waste; Earth Structure; Soil Stabilization; Geotechnical Characterization.

1 Introduction

In most of the developing countries, sustainable management of construction and demolition (C&D) waste becomes as an emerging issue to deal with. Construction field generates larger part of solid wastes. This waste may include:- wood, concrete, metals, asphalt, paper, gypsum wallboard, glass, roofing, drywall and plastic. Consumption of concrete is at second number after water, so recycling or reuse of C&D waste becomes necessary to protect environment and sometimes economy. The reuse of C&D waste also leads to the reduction in demands of natural construction materials due to which natural resources will also conserve.

The conventional way of dealing with this waste is landfilling but in last few decades various researchers comes out with their studies regarding effective reuse of C&D waste. The C&D wastes are outcomes of the civil engineering works so most of the studies were investigated the Civil Engineering applications of this waste. This present study mostly deals with the utilization of C&D waste in several Geotechnical applications.

The most common Geotechnical applications of the C&D waste materials are in pavement base material, geosynthetics reinforced structures, backfill material in retaining walls etc. The present review study mainly focus on soil stabilization using C&D waste materials.

2 Reuse of C&D Waste Material in Soil Stabilization

Stabilization of soil is the alteration or modification in soil to improve its physical and engineering properties. The idea of C&D waste material to be used as soil stabilizer takes place as there is large amount of chances of the improvement in the soil properties with its insertion.

Feng et al. (2014) investigated the utilization of C&D waste material for dynamic compaction in collapsible soils. This study proposed the use of C&D waste material in the down-hole dynamic compaction as pile filler. The efficiency and feasibility of this proposal were validated in detail on the basis of four practical case studies in different locations in China. On the basis of the discussion and case studies of this research, it is concluded that this proposal is broadly applicable efficiently and environmental friendly at the same time.

Sharma et al. (2016) performed an experimental program to determine the effect of fly ash, C&D waste and lime on geotechnical characteristics of clay. This experimental study included the tests like: California bearing ratio (CBR), compaction, differential free swell, unconfined compressive strength (UCS) and pH. The test results indicated that soaked CBR, UCS and pH value increase whereas maximum dry density and differential free swell index decrease with addition of fly ash, lime and C&D waste in clay. This study also reported that the reuse of C&D waste in clay is economical than the lime.

Mohammadinia et al. (2016) determined the behavior of C&D waste material with addition of geopolymers as stabilizers. Two pozzolanic binders, ground granulated blast furnace slage (S) and fly ash (FA) were used. Resilient modulus, elastic modulus and compressive strength were tested for three different combinations of binder materials: 4% S, 2%S + 2% FA, 4% FA. The test results were indicated that both resilient modulus and compressive strength were increase with geopolymer stabilization. The C&D waste materials tested in this study, are reclaimed asphalt pavement (RAP), crushed brick (CB) and recycled concrete aggregate (RCA). It was reported in this research that geopolymer stabilized RAP and RCA were found to be feasible options as future pavement sub-base or base material. The test results also indicated that the slag based stabilized material provide higher compressive strength than the fly ash based stabilization.

Saravanan et al. (2016) investigated the utilization of C&D waste material in building and strength enhancement of rural roads. In this research the base or sub-base layer of rural roads were partially replaced by powdered brick and prolonged cement. The standard proctor, UCS, direct shear and CBR tests were conducted on the samples with partial replacement (5%, 10%, 15%, 20% and 25%) for both powdered brick and prolonged cement. The optimum percentage of replacement is found 15% at which the stabilized samples provided the best results. It was concluded in this study that the partial replacement by prolonged cement provides good results as compared to powdered brick. Due to utilization of C&D waste material in sub-base layer the need of conventional laterite reduces which finds to be economical for rural road construction projects.

Kanniyappan et al. (2019) investigated the reuse of C&D waste material as soil stabilizer under the pavement construction. In this study the red soil stabilization by using recycled coarse aggregates (RCA) were explored. The RCA mixed with red soil in different proportions as:- 5%, 10%, 15%, 20%. As the test results presented in Table 1, it is reported that the CBR value increases with increase in RCA percentage in red soil. The pavement thickness was also designed as per IRC: 37-2001 and it is indicated in Table 2 that thickness of pavement reduces with increase in CBR value. Due to this the economy of the construction project also reduces as pavement thickness reduces.

Table 1. CBR values of RCA and red soil blends after Kanniyappan et al. (2019).

Sr. No.	Sample Name	Proportion of Sample Replaced	CBR Value
1	Normal red soil	-	6.56 %
2	RS + P-1	5% RCA	6.81 %
3	RS + P-2	10% RCA	9.93 %
4	RS + P-3	15% RCA	20.63 %
5	RS + P-4	20% RCA	28.95 %

Table 2. Designed pavement thickness for various CBR values after Kanniyappan et al. (2019).

CBR value	Pavement thickness
6.56 %	480 mm
6.81 %	451 mm
9.93 %	380 mm
20.63%	250 mm
28.95%	195 mm

Kianimehr et al. (2019) performed the experimental study to stabilize the clay soil using recycled concrete aggregates (RCA). In this research the experiments like: compaction, direct shear and uni-axial compression tests were performed on various blends of RCA and clay (Fig. 1). On the basis of test results it was concluded that with addition of RCA in clay, the optimum moisture content increases and maximum

dry density decreases. The higher percentage of RCA in clay leads to the higher shear strength and lower settlement. It was also reported in this study that 15% RCA in clay blend, provided the best geotechnical properties when used as base or sub-base material of rigid pavements.

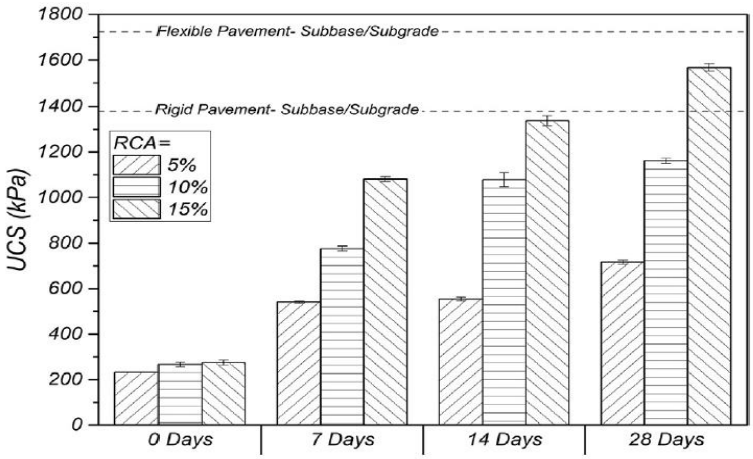

Fig. 1. UCS test results for different RCA-Clay blends for various curing times after Kianimehr et al. (2019).

Hidalgo et al. (2019) evaluated the efficiency of finely milled brick debris (BD) as soil stabilizer. The two types of soil stabilized in this study by alkali activated brick dust were:- sandy textured residual soil (S1) and silty textured residual soil (S3). The particle size of brick waste used as stabilizer is less than 0.035mm. The UCS test was performed both type of soil with different concentration of brick dust at different moisture content and curing temperature. Alkaline activation was done by two materials: - (i) Hydrated lime residue in the city of Medellin here referred as RC, (ii) Commercial sodium hydroxide (NaOH). A combination matrix was generated of percentage of soil stabilizer (7%, 14% & 21%), curing temperature (20 ℃-30 ℃ & 40 ℃-50 ℃), alkaline activator (RC & NaOH), curing age (7day & 14days), curing humidity (59% - environment & 95% - moist room). It was concluded in this research on the basis of test results that the soil strength increases up to 1.7-2.3 times with respect to non-stabilize soil. It was also concluded in this study that RC is more efficient activator than NaOH and effective percentage of BD in soil stabilization is lower than 14%.

3 Other Geotechnical Applications of C&D Waste Materials

The focus of this present review study is on application of C&D waste materials in soil stabilization. There are many of other geotechnical applications of C&D waste, some of them are as follows:-

- As pavement base or sub-base material
- As backfill material in retaining walls
- As fill material in geosynthetics reinforced structures etc.

The use of C&D waste materials in the mentioned applications has been summarized as given in Table 3.

Table 3. A brief introduction about some of the studies related to Gotechnical applications of C&D waste. (RCA= Recycled concrete aggregate; MRA= Mixed recycled aggregates; WR= Waste rock; CB= Crushed brick; RAP= Reclaimed asphalt pavement)

Sr. No.	Reference	Application	Country	Type of C&D waste	Main observation
1	ETN (2000)	Unbound base	Finland	RCA	The load carrying capacity of motorways increases due to self-cementitious property of RCA
2	Fernandes et al. (2009)	Unbound sub-base	Portugal	RCA	The test results indicated that RCA layers provided the higher elastic moduli (450MPa) than the conventional aggregates (150 MPa)
3	Ainchil et al. (2009)	Cement treated Sub-base layer	Spain	RCA	The mechanical properties enhanced due to replacement of soil by RCA
4	Choi and Won (2009)	Rigid concrete pavement	USA	RCA	The difference in performance between 100% RCA replacement pavement and conventional concrete pavement is not very significant
5	Disfani et al. (2011)	Road works	Australia	Waste glasses	fine and medium recycled glass material provided the satisfactory geotechnical behavior for application mainly in road works, whereas the coarse recycled glass material was found to be unsuitable
6	Arulrajah et al. (2011)	Rigid concrete pavement	Australia	CB	Performance of CB is satisfactory only upto 65% moisture content and it is effective only under light loading conditions

7	Arulrajah et al. (2012)	Pavement sub-base	Australia	WR	WR provided the satisfactory geotechnical and geo-environmental properties as pavement sub-base material
8	Agrela et al. (2012)	Cement treated Sub-base layer	Spain	MRA	Cement treated MRA provided the good mechanical performance and low deflection under impact loading but it requires higher water content for optimum compaction
9	Sommer (2012)	Rigid concrete pavement	Austria	RCA	The 100% replacement by RCA provided the adequate mechanical performance and 5% cheaper than the conventional pavements
10	Irali et al. (2013)	Rigid concrete pavement	Canada	RCA	The 50% replacement by RCA provided the comparable engineering properties and there was no negative affects
11	Santos et al. (2013)	Backfill	Brazil	MRA	C&D waste material showed the satisfactory performance as backfill material in geosynthetic reinforced model structure
12	Saride et al. (2015)	Pavement base/sub-base applications	India	RAP	The design mix 20:80 proportion of natural aggregates and RAP respectively with fly ash 40% by weight, fulfills the Indian road congress (IRC) specifications of base/sub-base material for low volume roads
13	Sadati and Khayat (2016)	Rigid concrete pavement	USA	RCA	12% lower compressive strength and 25% higher shrinkage provided by the 40% replacement by RCA
14	Vieira et al. (2016)	Backfill	Portugal	RCA	The large scale direct shear test results indicated that the C&D waste materials are efficient alternatives as backfill material in geosynthetic reinforced structures
15	Uceda (2017)	Rigid concrete pavement	Spain	MRA	The difference between strength provided by conventional pavements and pavements of 100 % replacement by MRA, is higher initially but it decreases with time going

16	Singh et al. (2018)	Rigid concrete pavement	India	RAP	This study concluded that only upto 50% fine RAP can be used for major highways whereas 100% fine RAP can used for less utility roads
17	Bhushan et al. (2019)	Backfill	India	RCA	The geotechnical and geoenvironmental characterization of RCA indicates that this waste aggregates fulfills the required standard specification of the backfill material for mechanically stabilized earth walls
18	Saride et al. (2019)	Pavement base applications	India	RAP	The experimental studies indicates that the RAP and natural aggregate mix provide the durable performance as a pavement base material
19	Singh et al. (2019)	Rigid concrete pavement	India	RAP	The addition of RAP in concrete mix, improve the workability but reduce the properties of hardened concrete.

4 Study Outcomes and Conclusions

The present literature study mainly focuses on application of C&D waste in soil stabilization. The reviewed literature indicated that there in significantly less quantity of studies are available related to the soil stabilization using C&D waste. So, there is good scope of research to explore in this field. Most of the studies are based on utilization of Recycled Concrete Aggregates (RCA) and Crushed Brick (CB) as soil stabilizers. On the basis of the literature study, following scope of research are available:

1. The investigation about the reuse of other types of C&D waste materials like: - Recycled asphalt pavement (RAP), waste excavated rocks, glass waste etc. is less explored.
2. The experimental testing on various C&D waste blends as soil stabilizer can be done.
3. The physio-chemical bonding between C&D waste and soil mass can be investigated in detail.
4. The modified large scale tests can be performed on C&D waste and soil mixture to validate the feasibility of application. The large scale tests can help to better relate the practical conditions.
5. The most of the studies are failing to find out that the stabilization of soil by using C&D waste materials leads to be economical or not. So, economy factor for this application of C&D wastes can be investigated in detail.

6. The slope stability check is missing in the studies related to the embankment filled with soil stabilized by using C&D waste.
7. There are many possibilities of good analytical and software related work on the basis of experiment results of soil stabilized by C&D waste materials.
8. The environmental impact of C&D waste material used in soil stabilization can be deeply investigated by doing geo-environmental characterization of C&D waste blends with soil mass.

The literature review study concluded that most of the C&D waste materials provided the satisfactory results as soil stabilizers. So, for sustainability development and for reduction in demand of natural resources as soil stabilizer, the utilization of C&D waste materials provides the better solution.

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