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GUIDELINES FOR USE OF CONSTRUCTION AND DEMOLITION WASTE IN ROAD SECTOR

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3	Secretary General, Indian Roads Congress	Nirmal, Sanjay Kumar

ABBREVIATIONS

AIV	Aggregate Impact Value
BC	Bituminous Concrete
CBR	California Bearing Ratio
C&D	Construction and Demolition
CRRI	CSIR-Central Road Research Institute, New Delhi
CVPD	Commercial Vehicles (Maximum gross weight 12 Tons or more) Per Day
DBM	Dense Bituminous Macadam
DLC	Dry Lean Concrete
DSR	Delhi Schedule of Rates
IEISL	IL&FS Environmental Infrastructure & Services Ltd.
IL&FS	Infrastructure Leasing & Financial Services Ltd.
KRRDA	Karnataka Rural Roads Development Agency
MCD	Municipal Corporation of Delhi
MDD	Maximum Dry Density as determined from Proctor Compaction Test
MDR	Major District Road
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MMGSY	Mukhya Mantri Gram Sadak Yojana
MOEF & CC	Ministry of Environment, Forests & Climate Change, Government of India (Formerly known as MOEF)
MORTH	Ministry of Road Transport & Highways, Government of India
MORD	Ministry of Rural Development, Government of India
MSA	Million Standard Axles
NCCBM	National Council for Cement & Building Materials, Ballabhgarh
NGNRY	Namma Grama Namma Raste Yojane (Rural Road Scheme of Government of Karnataka)
NH	National Highway
NMA	Natural Mineral Aggregate (Coarse aggregates made from crushed stones or crushed gravel)
OMC	Optimum Moisture Content as determined from Proctor Compaction Test
PMC	Pre Mix Carpet (Open Graded Premix Carpet)

PMGSY	Pradhan Mantri Gram Sadak Yojana
PPP	Public Private Partnership
PQC	Pavement Quality Concrete
PWD	Public Works Department
RA	Recycled Aggregate
RAP	Recycled Asphalt Pavement
RCA	Recycled Concrete Aggregate
RCCP	Roller Compacted Concrete Pavement
RILEM	International union of laboratories and experts in construction materials, systems and structures (RILEM is from its name in French)
SH	State Highway
SWM	Solid Waste Management
TPD	Tonnes Per Day
WBM	Water Bound Macadam
WMM	Wet Mix Macadam

GUIDELINES FOR USE OF CONSTRUCTION AND DEMOLITION WASTE IN ROAD SECTOR

1 INTRODUCTION

The draft "Guidelines for Use of Construction and Demolition Waste in Road Sector" was first taken up by the Embankment, Ground Improvement and Drainage Committee (H-4) of previous tenure i.e. 2012-14 and was prepared by the Subgroup comprising Dr. Mahesh Kumar, Shri U.K. Guru Vittal, Shri Satander Kumar and Dr. N.B. Mazumdar. Later, the H-4 Committee was re-constituted for 2015-17 and the draft was deliberated in a series of meetings. The H-4 Committee finally approved the draft document in its meeting held on 30th September, 2015 and decided to send the final draft to IRC for placing before the HSS Committee.

The Composition of H-4 Committee is as given below:

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Director General (Road Development) & Special Secretary to Govt. of India	(Kumar, Manoj), Ministry of Road Transport & Highways
Secretary General, Indian Roads Congress	Nirmal, Sanjay Kumar

The Highways Specifications & Standards Committee (HSS) considered and approved the draft document in its meeting held on 23rd June, 2017. The Executive Committee in its meeting held on 13th July, 2017 considered and approved the same document for placing it before the Council. The Council in its 212th meeting held at Udaipur on 14th and 15th July, 2017 considered and approved the draft "Guidelines for Use of Construction and Demolition Waste in Road Sector" for printing.

Indian construction industry accounts for approximately 50 per cent of the country's capital outlay in successive Five Year Plans' projected investment and continues to show a growing trend. Construction & Demolition (C&D) waste which is generated by the construction industry, makes up about 25 per cent of the Municipal Solid Waste generated annually. The percentage of India's population living in urban areas has increased from 14 per cent at the time of Independence to about 31 per cent at present. Demand for housing and road infrastructure in urban areas is also similarly growing. Legal restrictions on mining in different parts of the country, imposed due to environmental concerns have pushed the construction industry to plan for and promote the use of C&D waste in construction activities including road works.

Construction & Demolition waste constitutes one of the largest waste streams in the world. The amount of C&D waste generated in the country has increased considerably in recent years. Estimates by different agencies regarding quantum of C&D waste generated in our country varies. Management of C&D waste is of major concern due to the shortage of dumping sites and increase in transportation and disposal costs besides pollution and environmental degradation. Dumping of C&D waste across our cities chokes rivers, blocks surface drains, disrupts traffic movement and is an eyesore on the urban landscape.

Re-utilisation and recycling is an important strategy for management of C&D waste and it has important implication on natural resources and environment. Recycling of aggregate material from construction and demolition waste can help to reduce the demand-supply gap for aggregates, conserve depleting sources of good quality stone aggregates and decrease environmental degradation due to quarrying activities. Worldwide many countries are resorting to partial replacement of natural aggregates with C&D Waste to varying degree.

C&D waste can be used in all categories of roads including NH, SH and MDR. Its usage for low traffic volume roads under various schemes like PMGSY, MMGSY, MGNREGA and urban roads carrying low traffic (colony roads) would be greatly beneficial for our country as a whole.

1.1 Terminology

Construction and Demolition (C&D) Waste – Waste generated during construction, demolition or renovation (remodelling) of any structure/buildings (residential/office/ commercial, etc) or associated activities for infrastructure provision.

Construction & Demolition waste as available in dump yards or at its place of generation would comprise of chunks of different sizes. To ensure utilisation of C&D waste, it is important that C&D waste (debris) is not mixed with excavated earth. Also wood pieces, plastic, metal bits if any, should be separated. Additionally such C&D waste (debris of different sizes) would require processing, i.e., crushing and sieving to bring it to proper gradation.

Processed C&D waste/Recycled Aggregates (RA): Processed C&D waste denotes material generated through crushing and sieving to yield a mixture of stone aggregates, brickbats, tile pieces, mortar pieces, etc having a particular size range, i.e., passing and retained sieve sizes, in other words, size graded material conforming to specification limits. Processed C&D waste is also called as Recycled Aggregates.

Recycled Concrete Aggregates (RCA) – Crushed and size graded concrete material produced from discarded or demolished concrete. RCA comprises of the stone aggregates (coarse aggregate) which were used for preparing demolished or discarded cement concrete (source concrete) and it is usually found to be having some amount of cement mortar sticking to stone aggregate particles. It does not contain brickbats, tile pieces, glass, etc.

Natural Mineral Aggregates (NMA) – Aggregate particles which are retained on 4.75 mm sieve, and have been derived from crushing naturally available gravel or hard stone, fulfilling strength property requirements for coarse aggregates as per IS 383, 'Specifications for Coarse and Fine Aggregates for Concrete'.

1.2 C&D Waste Disposal and Utilisation Studies and Practices

Industrialised countries have systems in place for recycling of construction and demolition debris. Use of Construction and Demolition (C&D) waste aggregates in road works is a widely accepted practice in countries like Denmark, USA, UK, France, Japan, etc.

In the German construction industry, a 'Closed loop recycling system' operates for the management of C&D wastes resulting in recycling of the order of more than 80 per cent. The closed loop system comprises of steps for (a) avoiding construction wastes (b) recycling methods to allow reuse (c) reducing disposal of C&D wastes to the minimum possible extent and (d) avoiding the disposal of recyclable wastes.

About 95 per cent recycling of concrete rubble has been achieved in Japan. Emphasis in Japan has now shifted from 'quantity-oriented' to 'quality-oriented' recycling, to enable Recycled Concrete Aggregates (RCA) to be used in all types of constructions, including high strength concrete in new construction. Japanese Standards and Regulations have three classes of recycled aggregate: Class H, M and L denoting high, medium and low quality. Special techniques have been developed using mechanical scrubbing using eccentric tubular vertical mill and application of heat to remove mortar sticking to aggregate pieces for producing high quality recycled aggregate.

Many Institutes/PWDs in India have carried out experiments and studies to understand the nature of construction and demolition waste with a view to evolve avenues for utilisation of C&D waste in various construction activities related to buildings, roads and other infrastructure. Some amongst them are:

- CSIR-Central Road Research Institute (CRRI), New Delhi
- National Council for Cement and Building Materials (NCCBM), Ballabhgarh
- Municipal Corporation of Delhi (MCD), presently trifurcated
- Public Works Department, Haryana (Haryana PWD)
- Karnataka Rural Roads Development Agency (KRRDA)
- IL&FS Environmental Infrastructure & Services Ltd (IEISL)

Delhi city can be considered as a typical example for Indian cities with regard to handling of C&D waste. It is estimated that the city of Delhi generates about 3000 tonnes per day (TPD) of C&D waste on an average. Respective Municipal Corporations of Delhi (MCD – North, South and East) are responsible for the transportation and disposal of unclaimed waste (Delhi Municipal Corporation Act, 1957) in their jurisdictional area. However, the total quantity of C&D waste collected and disposed by MCD is estimated to be less than the quantity of C&D waste generated in the city. Moreover, C&D waste is generally disposed of without adequate processing and it gets intermixed with other wastes. In addition to the ad-hoc nature of this system, constraint of space for storage of the C&D waste is the main concern. Keeping this in view, Municipal Corporation of Delhi (before trifurcation) and the environmental subsidiary of Infrastructure Leasing and Financial Services Ltd. (IEISL) carried out various exercises for appropriate management of C&D waste in Delhi. CRRI did a 'Feasibility study on use of Construction & Demolition (C&D) waste in road works' in which they carried out a detailed laboratory investigation on C&D samples collected from Delhi. It was found that processed C&D waste can be used in different forms in road works.

1.3 Sources of C&D Waste Material

The principal source for generation of construction and demolition waste are building construction/renovation/demolition sites. However, no authenticated data is available about

quantum of C&D waste generation in India. TIFAC report (2001) states that estimated waste generation during construction is about 40 to 60 kg per sqm of built-up area. Similarly, waste generation during renovation and repair work is estimated to be about 40 to 50 kg per sqm of built-up area, and 300-500 kg per sqm for demolition of buildings. India added 1 billion sqm of housing in 2013, the C&D waste generated from new construction in the year 2013 would be about 50 million tonnes. As per 2011 census, urban areas in India had about 110 million dwelling units. Considering an average area of 75 sqm per dwelling and that 5 per cent of housing stock is taken up for renovation/demolition every year, C&D waste generation would be about 124 million tonnes per annum (BMTPC Guidelines on C&D waste 2016).

1.4 Brief Details about International Specifications

Many countries around the world have incorporated several provisions to facilitate use of C&D waste for infrastructure building. Developed countries are leading in this regard.

European (CEN) Practice – EN 12620 includes recycled aggregate in the EN Standard for aggregate used in concrete. According to this EN code, aggregates can be of the following types:

- Natural aggregates from mineral resources,
- Manufactured aggregates of mineral origin, involving thermal or other modification, and
- Recycled aggregate, resulting from processing of inorganic material previously used in construction.

UK–BS 8500-2:200628 is the complementary British Standard to BS EN 206-1:200051, it refers to two types of recycled aggregate – Recycled Concrete Aggregate (RCA), and Recycled Aggregate (RA). RCA is obtained by crushing demolished concrete structures, discarded precast elements and unused hardened concrete. BS 8500 stipulates that RCA must be predominantly composed of coarse aggregates and masonry content should be less than 5 per cent. Such aggregate can be used in structural concrete of cube strength upto 50 MPa. In case RCA contains higher percentage of mortar, a maximum of 20 per cent replacement of coarse aggregate can be made in concretes of cube strengths between 25 to 50 MPa. RA may contain masonry up to 100 per cent.

Germany has elaborate regulations for recycling materials in order to utilise them and make them an alternative to fresh materials. Most of them are used in road construction. German guidelines DIN 1045 permits up to 25 per cent of RCA in structural concrete of cube strength 37.5 MPa in dry or low humidity environments. Similar practices are followed in many other countries. Worldwide trends with regard to provisions in specifications for using C&D waste aggregates (RCA as well as RA) in concrete are summarised in the **Table 1**. (A.K. Mullick, 2012)

Table 1 Provisions for Using C&D Waste in Concrete in Different Countries

Country/ Organisation	C&D Type	Maximum Substitution Allowed	Maximum strength of Concrete that can be made using C&D	Other Restrictions
United Kingdom	RCA	20%	20 to 40 MPa	No Chloride Exposure, No Freeze thaw
	RA	Not Specified	16 MPa	Only Mild Exposure
Australia	RCA	30%	40 MPa	
	RA	100%	20 MPa	
RILEM	RA	100%	16 MPa	Masonry Aggregate
	RCA	100%	50 MPa	
Korea	RCA	30%	27 MPa	
Germany	RCA	35%	25 MPa	In dry or low humidity environments
		25%	30 MPa	
Portugal	RCA	25%	35 MPa	
		20%	40 MPa	
Hongkong	RCA	20%	35 MPa	
		100%	20 MPa (Non Structural Concrete)	

2 SCOPE OF GUIDELINES

These guidelines deal with the use of processed C&D waste (RA and RCA) for road works such as embankment, sub-base and base course, for manufacturing kerb stones, paving blocks and for replacing a part of aggregates in different types of cement concrete pavement (PQC, DLC, Roller compacted concrete pavement, etc). C&D wastes can be used in all types of roads including NH provided relevant specification requirements as given in these guidelines are met with. These guidelines on C&D waste usage in road sector have been prepared based on experience gained by different agencies who have worked in this area and practices being followed around the world. Processed C&D waste (RA or RCA) should not be used for constructing reinforced soil walls or for making concrete to be used in structural/load bearing elements (Structures like bridges, culverts, flyovers, etc), pre-stressed concrete and also for bituminous pavement layers. Use of reclaimed bituminous materials from existing black top road pavements is not covered in these guidelines, for which MORTH Specifications section 519 can be referred to.

3 ADVANTAGES AND LIMITATIONS OF USING PROCESSED C&D WASTE PRODUCTS IN ROAD SECTOR

Using processed C&D waste for road construction has the following advantages:

a. Mitigates shortage of raw materials such as coarse aggregates, sand, etc., bridging the demand supply gap.

b. Usually it is available closer to the site, especially for construction within or near a city where C&D waste processing facilities can be set-up, thus saving transportation cost for the aggregates.

c. Conservation of natural resources such as river sand, stone aggregates, etc.

d. Saving land required for dumping of C&D waste by its recycling and usage.

However, strength characteristics of processed C&D waste material may differ from natural mineral aggregates. This aspect should be kept in view for its proper use.

4. TYPICAL PROPERTIES OF PROCESSED C&D WASTE

Construction & Demolition wastes usually comprises of chunks of concrete, broken brick-wall pieces, rubble, tiles, stone pieces, mortar, plaster of paris, etc. Wood and steel (or metallic) components are generally removed for recycling before C&D waste is dumped in the dumping yards. Hence metal and wood are not generally seen in C&D waste. Demolition of 'Pucca' and 'Semi-Pucca' buildings, on an average generates about 500 and 300 kg of waste per sqm of built-up area respectively.

Many times, the C&D waste collected for disposal is heterogeneous in composition and contains considerable amount of excavated soil, making recovery of useful materials more difficult. Saleable material such as pipes, conduits, light sheet material used in ventilation system, wires, pieces of wood and sanitary fittings are removed at source for resale. For effective utilisation of C&D waste, care must be exercised to ensure that C&D waste does not get intermixed with excavated soil. **Table 2** shows the composition of C&D waste as reported by different agencies. Typical physical and engineering properties of processed C&D waste as per CRRI study are given in **Tables 3, 4** and **5**. **Table 6** shows typical properties of processed C&D waste aggregates as per a study conducted by Haryana PWD and **Tables 7** and **8** are based on a study carried out by NCCBM. **Table 9** provides typical range of engineering properties of RCA from different Indian studies (Dr.P. Lakshmy 2015). It should be noted that properties of processed C&D waste shown in these tables are typical values given for information only and properties of any particular C&D waste aggregate intended to be used in road works may vary from these values. C&D waste properties vary depending upon composition of waste (relative percentage of brickbats, stone pieces, concrete, etc), strength properties of original constituents, age of the demolished structure, etc. Hence each sample of processed C&D waste should be tested to determine its physical and engineering strength properties before using it in any road project. Stabilisation techniques (preferably using cement) can be adopted to improve strength properties of C&D waste. The frequency of tests on C&D wastes (number of tests to be conducted) can be kept same as those specified for natural mineral aggregates.

Table 2 Physical composition of C&D waste as per different studies

Item	TIFAC, 2001	MCD, 2004	IL&FS Ecosmart, 2005
Soil, sand, gravel	36.0%	43.0%	31.5%
Metals	5.0%	-	0.4%
Masonry / Mortar	31.0%	15.0%	59.0% (Concrete & Masonry Combined)
Concrete	23.0%	35.0%	
Wood	2.0%	-	1.5%
Others	1.0%	7.0%	7.6%

Table 3 Physical Properties of Processed C&D Waste

Property	Value
Specific Gravity of C&D waste aggregate (More than 6.3 mm size)	2.30
Specific Gravity of C&D waste aggregate (Less than 6.3 mm size)	2.67
Water Absorption, larger aggregates (More than 6.3 mm size)	About 4.5%
Water Absorption, 'Jeera (small)' size (Less than 6.3 mm size)	13 - 14.8%

Source: CRRI Study (Aggregate size determined based on sieve available at crushing plant)

Table 4 Engineering Properties of Processed C&D Waste (20–6.3 mm size)

Property	Test Results
Unit weight (C&D aggregates) – Loose state (kN/m^3)	12.55
Unit weight (C&D aggregates) – Compacted state (kN/m^3)	16.18
Aggregate Crushing Value (%)	37
Aggregate Impact Value (%)	33
Ten per cent fines value – Test conducted on C&D Waste aggregate representative composite sample (RA)	45 kN
Ten per cent fines value – Test conducted on stone chips partially coated with mortar (RCA) in C&D Waste	98 kN
Ten per cent fines value – Test conducted on mortar pieces in C&D Waste	24 kN
Ten per cent fines value – Test conducted on brick bats in C&D Waste	25 kN
Soundness (%) (Using Na_2SO_4)	1.6

Source: CRRI Study (Aggregate size determined based on sieve available at crushing plant)

Table 5 Engineering Properties of C&D Waste Powder (Finer than 6.3 mm size)

Property	Value
Modified Proctor Compaction Test MDD (kN/m^3)	19.3
Optimum Moisture Content (%)	10.5
Standard Proctor Compaction Test MDD (kN/m^3)	17.5
Optimum Moisture Content (%)	12.5
California Bearing Ratio (soaked) %	74
Direct Shear Test – Angle of internal friction ϕ (degree) ***	45°
Cohesion (c) in kN/m^2	6
Liquid Limit (%)	31.0

Property	Value
Plasticity Index	Non Plastic
Permeability (m/second)	1.86×10^{-6}

Source: CRRI Study (Aggregate size determined based on sieve available at crushing plant)

*** ϕ value reported is apparently on the higher side. As reported in literature, ϕ value of C&D waste varies from 38° to 51° (M.R. Madhav, 2015). However, a limiting value of 40° may be considered for angle of internal friction during the design.

Table 6 Comparison of Engineering Properties of RCA and NMA

Property	Recycled Aggregate (RCA)	Natural Mineral Aggregates (NMA)
Aggregate Impact Value (%)	29.9	24.7
Aggregate Crushing Value (%)	35.7	26.5
Los Angeles Abrasion Value (%)	50.2	32.3
Specific Gravity	2.45	2.63
Bulk Density (kN/m^3)	15.00	15.70
Water Absorption after 24 hours (%)	4.7	0.4
Flakiness Index (%)	15.6	-
Elongation Index (%)	17.5	-

@ Source: Haryana PWD (RCA from demolished concrete road near Ambala)

Table 7 Physical & Engineering Properties of RCA

RCA Source	Property	Test Result
Demolished Concrete from Culvert	Specific Gravity	2.17
	Water Absorption (%)	6.7
	Aggregate Crushing Value (%)	36.1
	Aggregate Impact Value (%)	34.9
	Los Angeles Abrasion Value (%)	50.9
	Soundness (%) (Using Na_2SO_4)	4.1
	Elongation Index (%)	21.1
	Flakiness Index (%)	5.6
Demolished Building Concrete	Aggregate Impact Value (%)	31.7
	Specific Gravity	2.19
	Water Absorption (%)	6.9

*Source: NCCBM

Table 8 Properties of Powdered C&D Waste (Fine aggregate)

Aggregate Source	Property	Test Result
Demolished Concrete from Culvert	Specific Gravity	2.12
	Water Absorption (%)	8.2
	Material finer than 75μ (%)	7.7
Demolished Building Concrete	Material finer than 75μ (%)	6.6

*Source: NCCBM

Table 9 Typical Range of Engineering Properties of RCA

Property	Range
Water Absorption (%)	0.9 to 7.0
Bulk Density (kN/m^3)	11.50 to 14.40
Specific Gravity	2.32 to 2.56
Aggregate Crushing Value (%)	17.77 to 36.30
Aggregate Impact Value (%)	9.66 to 38.0

#Compiled from different Indian Studies by: Dr.Lakshmy Parameswaran (2015)

5 EFFECT OF C&D WASTE USAGE IN CEMENT CONCRETE

Cement concrete can be prepared using processed C&D waste aggregates (RA) or by using Recycled Concrete Aggregate (RCA). Many of the studies report usage of RCA rather than RA in concrete. The most significant factor that influences properties of RCA is that it contains hydrated hardened cement paste sticking to natural mineral aggregates. This hardened paste reduces specific gravity and increases porosity leading to higher water absorption. Also coat of weak mortar attached to aggregates results in weaker interfacial transition zone between aggregate phase and mortar, leading to reduction in strength of concrete. **Table 10** shows the effect of replacing Natural Mineral Aggregate (NMA) with RCA in a high strength concrete mix, having cement content of 500 kg/m^3 (PPC), silica fume and water/binder ratio of 0.243, on the physical characteristics of the concrete. The reference mix in **Table 10** (without RCA) was designed for a target slump of 175 mm. The dosage of super plasticizer was maintained constant in all the mixes.

Table 10 Replacing Fresh Aggregate with RCA for High Strength Concrete

High Strength Concrete Using RCA	Replacement by RCA (%)	Slump (mm)	Compressive Strength (MPa) at 28 days	Flexural Strength (MPa) at 28 days	Split Tensile Strength (MPa) at 28 days
R-0	0	180	84.4	14.9	5.8
R-20	20	160	80.5	13.0	4.8
R-40	40	140	75.3	11.5	4.6
R-60	60	130	71.3	10.8	4.5
R-80	80	110	65.4	9.6	4.2
R-100	100	80	62.2	8.0	3.9

#Source: A.K. Mullick (2012)

From **Table 10**, following conclusions can be drawn:

i. As the proportion of RCA replacing NMA is increased, workability (slump) decreases.

ii. Strength of concrete (compressive, flexural and split tensile strength) decreases with increase in RCA. Quantum of decrease in each type of strength varies from one another.

iii. Even with 100 per cent replacement of NMA, compressive strength values of 60 MPa at 28 days with 80 mm slump were obtained.

From a review of published results, following conclusions have been reported with regard to usage of RCA in cement concrete:

i. When NMA was replaced with RCA by 100 per cent, compressive strength of concrete decreased by about 25 per cent at 28 days.

ii. Drying shrinkage and creep of concrete made using RCA, may be higher than concrete made using freshly crushed stone aggregates (natural mineral aggregates - NMA). However, the values seldom fall outside the limit permitted in structural codes, and up to 20 per cent replacement can give comparable results to concrete made using NMA.

iii. Concrete made using RCA tends to be less resistant to those deleterious reactions which are dependent on fluid transport into concrete, mainly as a result of increased permeability. Chloride ingress may be more rapid. Abrasion resistance is lower.

iv. RCA concrete has better resistance to carbonation than concrete made using NMA. However, it tends to be less resistant to fluid transport into concrete, mainly as a result of increased permeability.

CRRI carried out a study on effect of partial replacement of NMA by C&D waste aggregates (RA) on strength properties of Dry Lean Concrete (DLC) and Pavement Quality Concrete (PQC). Replacement was limited to coarse aggregates only. To investigate the effect of C&D waste on the properties of hardened Pavement Quality Concrete, M40 grade of concrete was designed using Portland pozzolana cement (IS 1489 – Part 1), coarse aggregates comprised of Delhi Quartzite (Natural mineral aggregates) and sand from Badarpur (near Delhi) was used as fine aggregate. In case of PQC, cement content was kept as 420 kg/m^3 and water/cement ratio was kept equal to 0.44 in all the mixes tested. For evaluating compressive and tensile strength, concrete mixtures containing 20, 40 and 60 per cent of NMA (Delhi Quartzite) replaced by processed C&D waste aggregates (RA) were prepared. Compressive strength results of PQC mixtures at 7 and 28 days are given in **Table 11**. It can be seen that, using RA in PQC led to decrease in 28 days compressive strength by about 12 per cent when 60 per cent of NMA had been replaced by C&D waste aggregates (RA).

Table 11 Compressive Strength of PQC with C&D Aggregates (RA)

Mix Designation	C&D Aggregate Percentage	Compressive Strength (MPa)	
		7 Days	28 Days
Conventional concrete	Nil	28.2	39.5
C&D 20	20	26.3	36.2
C&D 40	40	25.9	35.6
C&D 60	60	24.6	34.7

Flexural strength of PQC mixes was obtained by testing concrete beam specimens of size 100 mm x 100 mm x 500 mm. Beam specimens were tested under third point loading system in Universal Testing Machine. Results of these tests are given in **Table 12**. These results also show marginal decrease in flexural strength, due to usage of RA.

Table 12 Flexural Strength of PQC with C&D Aggregates (RA)

Mix Designation	C&D Aggregate Percentage	Flexural Strength (MPa)	
		7 Days	28 Days
Conventional concrete	Nil	3.5	4.4
C&D 20	20	3.3	4.3
C&D 40	40	3.0	4.0
C&D 60	60	2.9	3.8

In case of Dry Lean Concrete, DLC mix of 10 MPa strength at 7 days was adopted. Cement content in DLC was kept at 150 kg/m^3 of concrete. Compressive strength results of DLC

mixes with different C&D content are given in **Table 13**. Recently, CRRI carried out another study using RCA and reported very nominal decrease in strength of concrete made with RCA+NMA mix in comparison with concrete made using NMA alone (**Table 14**). This was attributed to 'rough texture of RCA which provides better bonding and interlocking between the cement mortar and the RCA'. Fly ash was also used as an admixture in these studies (Dr. Lakshmy Parameswaran, 2015).

Table 13 Compressive Strength of DLC with C&D Waste Aggregates (RA)

Mix Designation	C&D Aggregate Percentage	Compressive Strength (MPa)	
		7 Days	28 Days
Conventional concrete	Nil	13.5	18.2
C&D 10	10	13.0	17.3
C&D 30	30	11.1	16.3
C&D 50	50	9.9	13.1

Table 14 Strength Properties of Concrete Using RCA and Fly ash

Mix Designation	Percentage Replacement of NMA with RCA	Slump (mm)	28 Days Compressive strength in MPa	56 Days Compressive strength in MPa	56 Days Split Tensile strength in MPa
NAC*	Nil	65	46	53	3.96
NAF**	Nil	61	47	58	4.15
R50***	50	63	47	54	3.53
R75	75	62	47	54	3.63
R100	100	68	49	57	4.15

* M45 grade concrete using Natural Mineral Aggregates (NMA) - Cement used 410 kg/m^3

** M45 grade concrete using NMA and fly ash (82 kg/m^3 of fly ash was admixed in addition to 410 kg/m^3 of cement)

*** In the NAF Concrete given above, 50 per cent of NMA was replaced using RCA

Table 15 provides comparative test results of concrete using Recycled Concrete Aggregates (RCA) vis-a-vis concrete using NMA as reported by Haryana PWD. RCA was used for 100 per cent replacement of coarse aggregates. **Table 16** provides highlights of a study by NCCBM on concrete mix. From these tables, it can be observed that at lower percentages of replacement of natural fresh aggregates by RCA, decrease in strength of concrete is nominal.

Table 15 Comparative Test Results of concrete with RCA and NMA

Property	Concrete using NMA	Concrete using RCA
Compressive Strength, MPa	16.0 at 3 days	13.2 at 3 days
	26.9 at 28 days	24.5 at 28 days
	38.5 at 90 days	37.1 at 90 days
Flexural Strength, MPa	3.4	2.95
Tensile Strength, MPa	2.66	2.20
Bond Strength with steel, MPa	4.0	3.6
E value in compression, MPa	28000	20000
E value in tension, MPa	32000	27000
Shear Strength, MPa	1.95	2.30
Drying shrinkage (%)	0.04	0.067
Loss on abrasion (%)	0.13	0.16

Table 16 Concrete mixes incorporating OPC 1, silica fume, NMA, Recycled Concrete Aggregates (RCA) of size 10–20 mm and chemical admixture (Super plasticiser)

Binder Designation	% Dosage of Admixture	% Replacement of 10-20 mm size NMA by RCA	Compressive Strength (MPa)			Slump (mm)
			3 Days	28 Days	90 Days	
Binder 1	0.25	0	28	41	46	80
Binder 1	0.25	25	27	41	47	90
Binder 1	0.25	50	34	41	44	80
Binder 1	0.25	75	30	37	41	90
Binder 1	0.25	100	11	29	34	100
Binder 2	0.25	50	17	36	38	95
Binder 2	0.25	75	19	36	40	95
Binder 2	0.25	100	16	35	40	90

* Coarse aggregate (NMA) ratio of 20 mm:10 mm was 60:40

** Percentage of sand in the whole mix was about 42 per cent of the aggregate mass

6 C&D WASTE PROCESSING PLANT IN DELHI

In collaboration with Municipal Corporation of Delhi (formerly under MCD, presently under North Delhi Municipal Corporation), a pilot project has been implemented by IL&FS Environmental Infrastructure & Services Limited (IEISL) to demonstrate the potential of a scientifically managed process for utilisation of C&D waste in Delhi. Salient features of this plant are given in this section. The activities carried out include collection, transportation to the designated processing site and processing of the waste to produce value added products. The plant was set up in the year 2009 on PPP basis at Jahangirpuri (Burari) in North Delhi in a seven acres plot provided by MCD (**Photo 1**). In this plant, C&D waste received at this plant (**Photo 2**) is processed to prepare value-added products like paver blocks, kerb stones, etc.

Being the first such project of organised management of C&D waste in the country, it has set an example, which can be replicated by other cities in India.

Photo 1 C&D Processing Plant at Burari in Delhi

Photo 2 (a) and 2 (b) C&D Waste brought at Burari Plant in Delhi

The design and technology for processing was evolved from scratch, modifying and fine tuning the design a number of times. The initial capacity of 500 tonnes per day (TPD) of C&D waste has been expanded to 2000 TPD at present. The operations include crushing, sieving and sizing the C&D waste, separating 'fines' (particles less than 75 micron size) from the crushed C&D waste and using C&D waste aggregates to prepare value added products. The operational units in the plant include:

- Inspection and weighing of C&D waste using computerised weigh bridge
- Mechanical and manual segregation and resizing (crushing)
- 'Dry' and 'Wet' processing for separating different size fractions
- Preparation of C&D waste products like coarse aggregates, manufactured sand, paving blocks, kerb stones, concrete blocks, etc.

Photo 3 Dry Processing of C&D Waste

The operations start with C&D waste being brought from designated dumping sites to the plant in trucks. The waste is unloaded on the tipping floor where undamaged whole bricks are removed manually for further use. C&D waste received at this plant is generally devoid of any wood or plastic or metal. Any such waste if present, is also manually removed. C&D waste is then crushed manually and/or mechanically to 200 mm to 400 mm size range for further processing, using dry process or wet process. In the dry process, concrete pieces are segregated manually and are fed to the crusher for size reduction (**Photo 3**). The dry processing unit handles and processes concrete blocks and stones to produce Recycled Concrete Aggregate (RCA).

Wet process has been developed to improve the recovery ratio from the C&D waste received at the plant (**Photo 4**). Moreover, wet process is less noisy, creates less air pollution and the end products are cleaner. The biggest advantage of wet processing facility is extraction of sand from the processed C&D waste. This helps in generating more amount of useful output from the facility and lesser amount of process residues. The wet processing line consists of different units like Grizzly crusher(s), Prograde for separating very fine sized particles (less than 75μ size), Vibro screens, Evo-wash (washing plant) and Sedimentation tank (called 'Thickner'). The Wet Processing system at Burari has been designed to handle about 60 tonnes of C&D waste per hour. Water is recycled after sand washing so that only about 10 to 15 per cent of fresh water is required. As reported by IEISL, products made in this plant have been tested in various laboratories and found to be suitable. Market has been developed for these products (**Photo 5 to 8**). The products made in this plant have been priced at a lower cost than Delhi Schedule of Rates (DSR) as shown in **Table 17**. The approach road to this plant has been paved with concrete made using C&D Waste (**Photo 9**)

Table 17 Comparison of Price of Products (year 2015) made using C&D with DSR

DSR Code No	Item	Unit	DSR Rate in ₹	Price of equivalent item made using C&D (₹)
983	Fine aggregate (sand)	m^3	700	665
1159	Stone dust	m^3	1100	950
287	Brick mix aggregate	m^3	600	465
295	Stone aggregate 20 mm	m^3	1175	900
297	Stone aggregate 10 mm	m^3	1175	900
1182	Surkhi	m^3	700	635
8686	Precast Kerb stone, M20 Grade	m^3	4100	3950
7070	Precast CC Paver block, M30 Grade	m^2	360	340
7237	Precast Paver tile (22 mm thick)	m^2	540	475

Photo 4 C&D Wet Processing Plant

Photo 5 Value added products

Photo 6 Coarse Aggregates Prepared from C&D Waste

Photo 7 Sand Prepared from C&D Waste

Photo 8 (a) and 8 (b) Preparing Value Added Products from C&D Waste

Photo 9 PQC Pavement Constructed Near the Plant Using C&D Waste (RA)

7 SPECIFICATIONS AND METHODOLOGY FOR USING PROCESSED C&D WASTE IN ROAD SECTOR

In this section, salient aspects of specifications and methodology for usage of C&D waste in road works are given. Processed C&D waste can be either Recycled Aggregates (RA) or Recycled Concrete Aggregates (RCA). Construction of road embankment, sub-base and base layers of road pavement can be taken up using RA or RCA. For concrete applications, RCA is preferred, however RA can also be used in concrete applications as explained in section 7.7.

7.1 Processing of C&D Waste

Before using C&D waste in road works, it requires processing (mainly crushing and grading). Adequate care should be exercised when C&D waste is produced during construction or demolition activities to ensure that, it is not intermixed with soil or wood (or any other organic material like leaves, plant braches, etc) or plastic (waste plastic bags, pipes, etc). Glass and ceramic tiles are not generally separated from C&D waste. However, adequate precautions should be exercised to protect workers (use of gloves and gum boots) from such sharp edged pieces. Metallic parts (reinforcement steel, wires and cables, etc) are usually removed before or during demolition as they have high scrap value. Even then, if some metallic parts are still left behind, they should be removed before crushing the C&D waste.

The next step would be crushing C&D waste in stone crushers (Jaw type crushers) of suitable capacity to convert the big chunks of debris to desired gradation (re-sizing). For using C&D waste in rural roads or for small works, Engineer may allow manual crushing of C&D waste, instead of mechanical crushers. C&D waste after crushing should be checked for its gradation and if it meets the specification requirement for the application for which it is intended to be used, no further processing would be required. Otherwise, crushed C&D waste would have to be sieved using mechanical sieves available at stone crushing plants to bring C&D waste aggregates to required gradation. Additionally, mechanical stabilisation (intermixing particles of different gradation using tractor towed rotavators in the field) may also be adopted. After processing C&D waste in this manner, it can be used in road works in following ways:

a. Embankments
b. Flexible pavements – In granular sub-base layer, for bound/cement stabilised base and sub-base course and for granular base courses
c. Concrete pavements – Dry lean concrete, Roller Compacted Concrete, Plain cement concrete pavement
d. Paving blocks and Kerb stones

7.2 Processed C&D Waste for Embankment Construction

Crushed C&D waste (RA) can be used as fill material for embankment construction since it fulfils MORTH and MORD Specifications with regard to density and plasticity. However, in case of earth embankments, maximum size of coarse material should not exceed 75 mm. In case of rockfill embankments, MORTH Specifications limit the maximum size of coarse particles to be 300 mm. C&D waste in unprocessed form normally contain particles of different sizes. Hence it would be necessary to crush C&D waste, so that maximum size of the particle is less than 75 mm. If it is not economically feasible to crush C&D waste to 75 mm and below size, the Engineer may allow particles of bigger size (upto 300 mm size) subject to field demonstration of satisfactory compaction. Compacted C&D waste, per se, may not support growth of vegetation and may be having surface voids. It is also a non-plastic material, and hence, embankments constructed using C&D waste would be prone to erosion and subsequent failure. Hence it is suggested that side slopes of embankments constructed using C&D waste should be protected by providing a good earth cover, in a manner similar to fly ash embankments (**Fig 1**). The side cover thickness can be about 0.5 m for embankment height less than 1 m. For embankments of height varying from 1 to 3 m, cover thickness can be kept as 1 m. Cover thickness of 1.5 to 2 m would be required for embankments of height exceeding 3 m. The design of the embankment (stability analysis) is mandatory for high embankments (embankments of height 6 m and above), and design should be carried out as per IRC:75, 'Guidelines for the Design of High Embankments'. Crushed C&D waste may have a very high value of angle of internal friction (ϕ). However, it is recommended that actual ϕ value should be determined using laboratory tests on representative samples and in any case, a maximum limiting value of 400 be considered for ϕ value during stability analysis. Further, C&D waste usage for reinforced soil wall construction (reinforced earth embankment or mechanically stabilised earth wall) is not recommended.

Before undertaking construction of road embankment using C&D waste, clearing and grubbing activities should be carried out at the proposed site. After clearing and grubbing operation, the existing ground needs to be compacted as per specification requirements. Embankment construction activities can then be started by laying loose layer of crushed C&D waste. The material shall be tipped, spread and levelled in layers extending to required dimensions by a suitable dozer. Side earth cover shall also be spread simultaneously to provide confinement to C&D waste. Water should be sprinkled above this loose layer by using water tankers. Quantity of water required can be based on field trials or compaction test carried out on crushed and powdered C&D waste in the laboratory. After sprinkling water, mixing should be carried out by using a tractor towed disc harrow or rotavator. The tolerance limits of variation from the specified moisture content (OMC) are normally +1 per cent to –2 per cent. However, due to porous nature of C&D waste particles, slightly higher quantity of water may sometimes be required. Compaction can then be carried out using vibratory rollers to the specified degree. The compacted thickness of each layer should not be more than 250 mm. For constructing embankments for rural roads having height less than 1.5 m, the Engineer may permit use of static rollers, but thickness of compacted layers shall be restricted to 150 mm. After compaction of each layer, the surface voids shall be filled with broken fragments of C&D waste or good earth. Next layer, where required, shall be placed in the same manner, above the earlier compacted layer. The top of the embankment shall be provided with subgrade constructed using good earth to act as a sealing layer over C&D waste embankment. The quality control operations can be carried out as per MORTH or MORD specifications depending upon category of the road in a manner similar to earthen embankments.

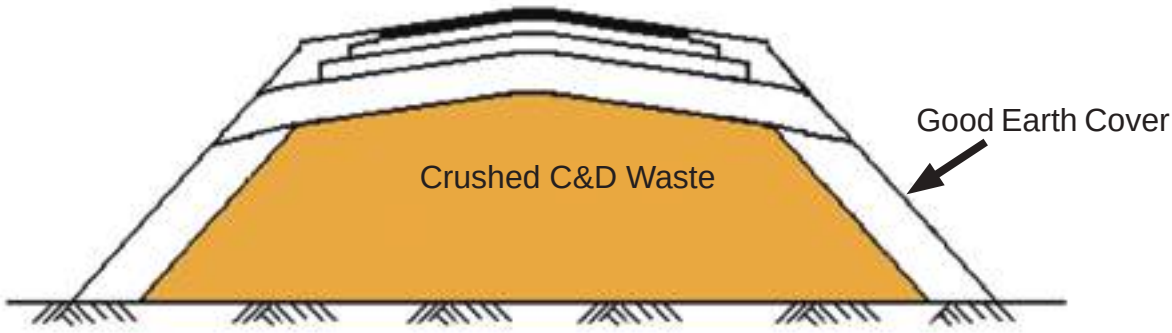

Fig. 1 Typical Cross Section of Embankment Using C&D Waste

7.3 Granular Sub-base Construction Using RCA

MORTH Specifications Section 405 provides Guidelines for 'Crushed Cement Concrete Sub-base' which consists of breaking and crushing the damaged cement concrete slabs (i.e., RCA) and re-compacting it as sub-base in one or more layers. This clause restricts use of 'Cement concrete' only. Cement concrete should be crushed to conform to WBM aggregate gradations given in **Table 18**. Crushed material can be compacted using tandem or vibratory rollers with light sprinkling of water. Thickness of each compacted layer shall not be more than 75 mm. For details, MORTH Specifications (Section 405) can be referred.

Table 18 Grading Requirement for using Crushed Concrete as Sub-Base

Grading No	Size range	Sieve Designation	Per cent by weight passing
1	63 mm to 45 mm	75 mm	100
		63 mm	90 - 100
		53 mm	25 - 75
		45 mm	0 - 15
		22.4 mm	0 - 5
2	53 mm to 22.4 mm	63 mm	100
		53 mm	95 - 100
		45 mm	65 - 90
		22.4 mm	0 - 10
		11.2 mm	0 - 5

7.4 RA Usage in GSB Layer

Crushed C&D waste (RA) is a heterogeneous material and contains brick bats, mortar, tile pieces apart from concrete chunks. However, crushed C&D waste is a free draining material, possessing good CBR value. If adequate care is taken to ensure that C&D waste is not mixed with clayey soil, crushed C&D waste would be a non-plastic material. However, the gradation of crushed C&D waste may or may not satisfy the MORTH or MORD Specifications for sub-base layer. By suitably modifying the crushing process and by adopting mechanical stabilisation technique (by mixing gravel/moorum/sand and crushed C&D waste in suitable proportions as per IRC:SP:89 'Guidelines for Soil and Granular Material Stabilization Using Cement Lime and Fly Ash'), it would be possible to obtain desired gradation for using it in sub-base layer. Such mechanically stabilised processed C&D waste should be tested to ensure that its gradation, plasticity and strength requirements meet MORTH or MORD Specifications for GSB materials, depending upon type of the road in which it is intended to be used.

7.5 C&D Waste for Bound/Cement Stabilised Sub-Base/Base Course

The base course of flexible pavements normally consists of granular layers like WBM or WMM. Presently IRC:37 'Tentative Guidelines for Design of Flexible Pavements' as well as IRC:SP:72 'Guidelines for the Design of Flexible Pavements for Low Volume Rural Roads' provide templates for design of flexible pavements by adopting bound/cement stabilised base and sub-base layers. C&D waste aggregates (RA) usually contain brick bats and hence they may not satisfy strength criteria (AIV or Los Angeles abrasion value) for aggregates to be used in granular base courses like WBM or WMM. However, processed C&D waste (RA as well as RCA) can be stabilised using admixtures like cement or a mixture of cement+fly ash or cement+slag or a combination of such cementitious materials. After stabilising C&D waste, it can be used for bound sub-base or base course construction. When C&D waste

is crushed, both coarse aggregate sized particles and powdered C&D waste are produced. Both these components can be stabilised using cement and used in sub-base or base course construction.

MORTH or MORD Specifications as well as IRC:SP:89 and IRC:SP:72 can be referred to for gradation and strength requirements of admixture stabilised (bound) C&D waste. In case of rural roads, minimum 7 days compressive strength of 1.70 MPa is required for cement stabilised C&D waste for its use in sub-base course. IRC:SP:72 (which is applicable to rural roads) stipulates minimum 7 days compressive strength of 3.0 MPa for cement stabilised base course layer. IRC:SP:89 specifies 7 days unconfined compressive strength varying from 1.5 MPa to 12 MPa for cement stabilised base/sub-base course depending upon gradation of the material. Mix design of cement stabilised C&D waste should be carried out as per IRC:SP:89 to decide percentage of cement to be added to C&D waste for use in cement stabilised layer. Further, the design mix should satisfy the durability test requirements also as per IRC:SP:89.

7.6 C&D Waste for Granular Base Course

RCA can be used as a component for construction of granular base courses like WBM, WMM, etc in case, it fulfils aggregate requirements like gradation, strength, water absorption, etc as per MORTH Specifications in case design traffic is more than 2 msa or MORD Specifications in case design traffic is less than 2 msa. Strength properties of RA are generally inferior to RCA. RA can also be used in lower base course of rural roads if it meets aggregate requirements like gradation, strength, water absorption, soundness, etc.

7.7 RA and RCA Usage for Cement Concrete Pavement/Paving Blocks/Kerb Stones

As per MORTH and MORD Specifications, aggregates conforming to IS:383 can be used for constructing plain cement concrete pavement, dry lean cement concrete sub-base, roller compacted concrete, paver blocks, kerb stones, etc. C&D waste aggregates (RA or RCA) after processing (crushing and sieving) may not exactly meet strength requirements specified for aggregates to be used in cement concrete as per MORTH or MORD Guidelines. RCA may contain coating of cement mortar sticking to it, which may cause reduction in strength properties of concrete and such concrete may have higher shrinkage. Hence, following points are suggested for using C&D waste aggregates (RCA and RA) for cement concrete pavement, paving blocks and kerb stones:

(a) Studies have shown that when natural sand is used, up to 30 per cent of natural crushed coarse aggregate (natural mineral aggregates - NMA) can be replaced with Recycled Concrete Aggregate (RCA) without significantly affecting strength properties of the concrete for grades upto M40. Hence, Recycled Concrete Aggregates (RCA) of size more than 4.75 mm can be used for partial replacement of NMA for rigid pavement construction (PQC and RCCP) for rural roads and urban colony roads having average daily traffic less than 200 vehicles per day. Further such replacements shall be restricted to concretes of grade M30 and below. Replacement of NMA by

processed C&D waste aggregates can be restricted to about 20 to 30 per cent depending upon laboratory test results. Combined gradation of RCA and NMA shall meet the specified gradation of coarse aggregates to be used for PQC. This combined gradation shall be used during the mix design. Replacement of NMA by RCA is not advocated in case of PQC used for highways (M40 and above).

(b) Replacement of NMA by RCA in dry lean concrete base course can be 30 per cent. Combined gradation of RCA and NMA shall meet the specified gradation of coarse aggregates to be used for DLC or RCCP as the case may be. Mix design has to be carried out after incorporating RCA.

(c) In case of kerb stones and paving blocks used for footpaths and light traffic (cycle and two wheeler track, parking areas and rural roads carrying average daily traffic upto 200 vehicles per day) RCA can be used to replace upto 100 per cent of NMA provided specified compressive strength is achieved at 28 days. Combined gradation of RCA and NMA shall meet the specified gradation for coarse aggregates to be used for paving blocks/kerb stones.

(d) During processing, some amount of powdered C&D waste is also produced apart from coarse aggregate particles. Powdered C&D waste can be used to replace about 20 to 25 per cent of natural sand in DLC and RCCP using concrete of M20 grade or less. Usage of powdered C&D waste to replace sand can be in addition to usage of RCA or RA which are used to replace coarse aggregates (NMA). Use of such powdered C&D waste as manufactured sand to replace natural sand in higher grades of concrete (more than M20) is not advocated. Instead, as indicated in Section 7.5, such powdered C&D waste can be used in stabilised pavement layers.

(e) When C&D waste aggregates (RA or RCA or manufactured sand) is used in PQC/DLC/RCCP or for Paver blocks, concrete mix design has to be carried out as per IRC specifications using C&D waste aggregates and optimum quantities of different materials (natural as well as C&D waste aggregates, binder, water and super plasticisers if any) shall be determined. Same mix proportions shall be adopted during execution of road works.

(f) When C&D waste aggregates are used, mixing of ingredients for concrete can be carried out by adopting 'Two Stage Mixing Process'. In this process, first, the required amount of NMA, fine aggregate and RCA or RA as the case may be, are mixed for about 60 seconds. About half of the required quantity of water is added to this aggregate mix and mixing continued for another 60 seconds. Cement is added to this mix and mixed for 30 seconds. Remaining half of the required quantity of water is then added and mixing is continued for 120 seconds to yield the concrete mix ready for placement and compaction.

(g) Processed C&D waste aggregates (RA, RCA or manufactured sand) should not be used for pre-stressed concrete or in structural concrete (bridges, culverts, flyovers, etc).

8. Quality Management

Quality management is essential for achieving the goal of constructing durable and good quality roads. Processed C&D waste (RA and RCA) shall be free from deleterious material such as, organic content, vegetable matter, coal, clay lumps, external substances such as plastics, carry bags, paper etc. RA shall also be free from chemicals, known to be detrimental for the strength or durability of concrete such as, chlorides, sulphates, etc. beyond the threshold value. Quality checks (including frequency and type of quality control tests) for embankment or pavement layer construction using C&D waste aggregates shall be carried out in the same manner as per provisions of MORTH or MORD Specifications for relevant components of work using naturally available materials. Application of provisions of MORTH or MORD Specifications shall be decided depending upon category of the road. Further, standards from BIS regarding aggregates and concrete (IS 383, 456 etc.) need to be kept in view in this regard.

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Annexure - I

SUCCESSFUL CASE STUDIES

Several state governments as well as union government have taken up several initiatives to promote usage of C&D waste. India's first plant for recycling of C&D waste was established in 2009 at Burari in North Delhi by IL&FS under an agreement with North Delhi Municipal Corporation. Brief details of this plant have already been given under Section 6. Based on the success of this venture, another C&D waste processing plant was established by IL&FS at Shastri Park, New Delhi in association with East Delhi Municipal Corporation. Details of other initiatives/successful case studies are given below:

CONSTRUCTION OF RURAL ROAD USING C&D WASTE BY KRRDA

Karnataka Rural Roads Development Agency (KRRDA) constructed a rural road near Bengaluru City in Nov 2012 by using processed C&D waste (RA). Pavement cross section adopted by them is shown in **Fig 1**. This rural road constructed under NGNRY scheme of Karnataka Government, provides connectivity to Sydamipalya village, a rural habitation having population less than 500. C&D waste for constructing this road was collected from Bengaluru City. Collected C&D waste was crushed to bring it to gradation specified for conventional GSB/Soil-Aggregate materials and used in road construction. The Control Section consisted of GSB, Soil-Aggregate and WBM Base layers and PMC with seal coat as wearing course. In the first test section, crushed C&D waste was used to replace GSB. In the second test section C&D waste was used to replace both GSB as well as Soil-aggregate base course. The performance of all the sections has been good (**Photo 1 and 2**).

Fig 1: Typical Cross Section of Rural Road Made Using C&D Waste by KRRDA

Photo 1 Rural Road Constructed Using C&D Waste by KRRDA Near Bengaluru

Photo 2 Another View of Rural Road Constructed Using C&D Waste

PAVEMENT WIDENING WORK USING C&D WASTE IN DELHI

Demonstration test road construction of about 150 m length involving usage of stabilised C&D waste in both bound as well as granular (unbound) form for base and sub-base course respectively, was taken up jointly by CRRI, IEISL and MCD in 2009 at Delhi. The work involved widening existing road pavement on both sides of the road. For sub-base, crushed C&D waste conforming to GSB gradation specified by MORTH was adopted. Over the granular sub-base, 150 mm cement stabilised base course (5 per cent cement admixture) was laid. For mixing cement with crushed C&D waste, tractor towed disc harrow was used (**Photo 3, 4** and **5**). The pavement cross adopted is shown in Fig 2. Performance of this stretch monitored over a period of two years was very good.

Photo 3 C&D Waste Being Manually Crushed for Test Road Construction in Delhi

Photo 4 Cement Stabilisation of C&D Waste for Test Road Construction

Photo 5 Cement Stabilised Base Course of C&D Waste Test Road

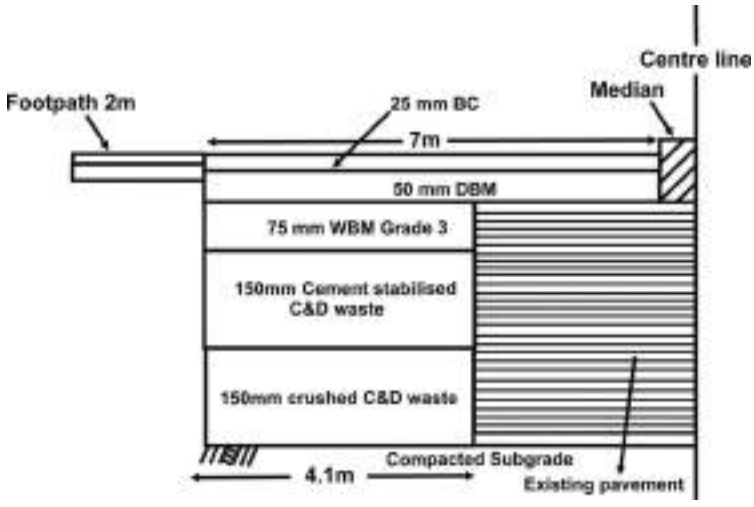

Fig 2 Typical Cross Section of C&D Waste Test Road (Widening Portion) in Delhi

EAST KIDWAI NAGAR, NEW DELHI

M/s Enzyme India Pvt Ltd has set up C&D waste recycling plant with the support of M/s NBCC in 2014 to use C&D waste generated during 'Re-development of East Kidwai Nagar, New Delhi'. The project involves demolition of 2444 existing houses and allied structures. The plan is to produce bricks/kerb stones using C&D waste generated in an eco friendly manner.

AHMEDABAD, GUJARAT

Ahmedabad Enviro Peojects Pvt Ltd has commenced a 100 tonne per hour capacity plant for recycling C&D waste since June 2014. Ahmedabad Municipal Corporation (AMC) has designated 16 spots around city where citizens can dump C&D waste. The agency then collects C&D waste from these designated spots in their own vehicles. The C&D waste thus collected is being used to produce RCA, bricks, blocks and other precast concrete products.