EXPERIMENTAL STUDIES OF C& D WASTE AS GEOMATERIAL FOR ROAD CONSTRUCTION

A THESIS SUBMITTED IN FULFILMENT OF
THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

CIVIL ENGINEERING

SUBMITTED BY

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SEPTEMBER – 2016

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Certificate of Originality

The research work embodied in this thesis entitled "Experimental Studies of C& D Waste as a Geo-material for Road Construction" has been carried out by me at the Department of Civil Engineering, Faculty of Technology, University of Delhi, Delhi, India. The manuscript has been subjected to plagiarism check by **TURNITIN** software. The work submitted for consideration of award of Ph.D is original.

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CERTIFICATE

It is certified that the work carried out in the thesis titled "Experimental Studies of C&D Waste as a Geo-material for Road Construction" which is being submitted by Rajiv Goel (Registration No. **10773**)for the fulfilment of the requirement of award of degree of "Doctor of Philosophy" in the Department of Civil Engineering, Faculty of Technology, University of Delhi, Delhi, is original work carried out by the candidate during the period from June- 2010 to Oct 2015 under my supervision and guidance. The matter presented in this thesis has not been submitted for the award of any other degree in any university.

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This work is dedicated to my mother who has been a source of inspiration for hard work and knowledge and her endless love, support and encouragement to me in every walk of life

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ACKNOWLEDGEMENTS

This thesis would not have been possible without the guidance and the help of many individuals who contributed and extended their valuable support in the preparation and completion of this study.

First and foremost, I am heartily thankful to my guide, Prof. Ashutosh Trivedi, Department of Civil Engineering, Delhi Technological University, Delhi (formerly Delhi College of Engineering) for the continuous patient and motivational support during my Ph.D. study and research work and for his constructive suggestion and immense knowledge of the subject. His enormous encouragement, wise guidance and warm support throughout the process, enabled me to develop an understanding of the subject and to finish my research and writing of this thesis successfully. Despite of his tight academic schedule, he used to review my thesis progress, given his valuable suggestions and made corrections and modifications overnight which facilitated me in the completion of the work.

My sincere thanks also goes to all the faculty member of the Delhi Technological University specially Prof. Awdhesh Kumar, Dr. A.K. Srivastava, Prof. R. Mehrotra, Prof. Naresh Kumar, Dr. A. K. Sahu, whose valuable suggestion, encouragement, insightful comments and hard questions during my Pre Ph.D. submission seminar helped me to improve in writing this thesis.

I am indebted to my late father in law Sh. Ram Gopal Garg who continuously enquired about my progress till his last day and whose spiritual blessings have been a constant inspiration in making this thesis a reality. The love and affection showered by my mother and father was the greatest source of energy during the entire period. I am also very touched to my brother in law Shri Ashok Kumar Gupta and Sister Smt. Manju Gupta who gave me inner strength to complete this work.

I would like to express my heartfelt gratitude to my valuable family, especially my wonderful wife Dr. Sarika Goel and my adorable daughters Apoorva and Aanya. Their constant source of love, support and great encouragement helped me to go ahead with my thesis.

This thesis has been completed in time with the support and encouragement of number of people including my well-wishers, friends, colleagues and various institutions. I would like to thank all my well-wishers, friends, colleagues and various institutions whose support made this thesis possible. My special thanks to Mr. Pankaj Agarwal, Director MoRTH, Mr. Rajeev Jain SE/Civil/Department of Post, and Mr Shivom Dwivedi IRSE, DyCE/ Northern Railway for there continuous support during the work. This is an unforgettable experience for me and I feel excited to express my sincere thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for me.

Above all, I express my indebtedness for the blessings of almighty God who inspired me to get this work done.

(Rajiv Goel)

ABSTRACT

The present work proposes a framework for recycling of construction and demolition waste(CDW) as geo-material for construction of sub base and base course of flexible pavement. It was based on the results of experimental studies of physical and engineering properties of recycled CDW aggregates compared to standard requirements as per MoRTH (Ministry of Road Transport & Highways) specification of road and bridge works (2001),which was supported through field testing and performance evaluation of 3 km trial stretch of road constructed using recycled waste.

The physical and engineering properties like specific gravity, grain size distribution, density-moisture relationship by Proctors compaction test, aggregate crushing value, Los angles abrasion value test, and California bearing ratio (CBR) of recycled CDW aggregates have been tested in laboratory and compared with that of new virgin materials as specified in codal specification. It is observed that most of the physical and engineering properties of recycled CDW aggregates fulfil the standard code specification else the effect of variation of property has been analysed and suitable remedial proposals are incorporated in the proposed frame work. The CDW aggregates have variable characteristics as they are extracted from diverse spectrum of materials used in old buildings and structures. This frame work suggests laboratory tests to assess the variation in quality of waste aggregates and suggested the parameters for design of flexible pavements layers using waste materials.

The field investigation and performance evaluation of trial stretch designed as per codal provisions using CDW aggregates, has been carried to investigate the effect of use of this waste as sub-base and base course. Thereafter the performance of sub-base and base course was evaluated through field testing of density of compacted pavement, relative density and relative compaction, plate load test of compacted pavement for assessment of settlement on application of loads and modulus of sub grade reaction. The safe bearing pressure from plate load test at the settlement of 1.25 mm has been found in the range of 450-650 kPaat the top of base course, without the laying of bituminous layers of 130mm thickness. These layers further contribute to the load bearing capacity of pavements. As the permissible axle load in India is 100kN, it can be safely assume that this pavement even with the impact of moving wheel loads may not cause structural failure.

The pavement performance monitoring and evaluation has been carried out for a period of seven years and compared with normal maintenance requirements of typical flexible pavement. The comparison has revealed that the performance of flexible pavement constructed using CDW aggregates is comparable to the natural aggregates.

The present work proposed a frame work for recycling of CDW aggregates in flexible pavements in the form of systematic flow charts and a step by step methodology for utilisation of CDW in field as an economically viable and environmental friendly material with partial or full substitution of standard natural materials in construction of flexible pavements.

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CHAPTER – 1
INTRODUCTION

1.1 Objective and scope

The main objective of the present work is to emphasize and establish construction and demolition waste (CDW) as alternative material in the road construction industry. This work aims for characterisation of recycled construction and demolition waste aggregates in terms of their physical and engineering properties such as specific gravity, Los Angeles abrasion value, aggregate crushing value, flakiness and elongation index, CBR value, particle size distribution and grading requirements, moisture-density relationship strength and compaction. This study proposes the use of crushed CDW aggregates for the construction of road sub base and base course based on results of experimental studies, field trial and performance evaluation.

1.2 Background

The recycling of CDW aggregates as highway material for base course and sub base course of flexible pavements is an opportunity as the cost of new natural materials is increasing due to high demand. The cost of virgin aggregates is on the rise due to their quarrying, crushing and transportation is high energy consuming and energy cost is increasing very fast. Hence in the effort to conserve the natural materials and save energy this work proposes to promote recycling of CDW arising out of demolition waste generated from demolition of old buildings and other structures. The use of recycled CDW is also required to reduce the cost incurred for transportation and disposal of demolition waste to the landfill sites and also to reduce the demand of precious land for disposal sites. The concerns over the environmentally sustainable extraction of aggregates with continuous rise in aggregate requirement for large scale construction of roads and buildings are the major considerations to promote recycling of CDW as aggregates.

The use of concrete and brickwork in building construction was almost a century old. In all the old cities large number of old houses and commercial buildings are under redevelopment to change them in high rise buildings with high floor space index. We have many old buildings and other structures have overcome their limit of use and need to be demolished. (Oikonomou 2005) The average age of these buildings has been estimated within the range of 60-150 years which are living beyond their design life. The large number of these buildings are structurally unsound and are posing threat to the life of inhabitants as such demolition of these old low rise buildings is inevitable. This generates large quantities of concrete and masonry waste that is being disposed in landfill sites or sometimes it is being dumped alongside roads or public land as seen in photograph-1.1.

Photo-1.1 Demolition waste dumped in open area in Delhi

This has created the problem of large landfill sites adjoining to big cities covered with building debris and additional requirement of land. However, demolition waste of these buildings needs to dispose off without causing harm to environment. Demolition waste so generated consists of concrete, bricks, mortars, wood, plastic, stone, steel & glass etc., with brick-mortar-concrete mix debris constituting major portion of this wreckage. This mixture is inert material and on proper gradation by crushing, it can be used for various construction purposes replacing new materials thereby is an effective strategy for disposal of waste which is environment friendly. Recycling of these materials can be planned for better environment of the city. It can fulfil a part of high demand for natural aggregate as high volumes of recyclable demolition wastes are being generated in all metropolitan centres because of concentration of redevelopment works and replacement of old low rise buildings with new high rise buildings. The use of recycled CDW aggregate will reduce the waste storage cost as well as minimize demand of land for disposal near metropolitan cities. Almost all metro cities in India are short of land disposal sites and waste has to be required to be transported for long distances for landfill sites. Municipal Corporation of Delhi has decided to subsidize the recycling of CDW and established a plant for the same as landfill sites are going to be exhausted within next 5-8 years. Our metropolitan cities are already facing shortage of land for dumping sites and this high volume of demolished building debris is taking most of the dumping yards and it is increasing day by day hence the cost of dumping construction and demolition debris is increasing due to long haulage for disposal. This increase in cost of disposal has been can be restricted if we recycle this demolition waste in to useable aggregates. The continued rise in demand of aggregate supports the recycling of CDW in all metropolitan cities especially in National capital region. We have to follow the 4RE concept that is reduction, recycling, reuse, and renewal for management of construction and demolition waste as shown in figure-1.1.

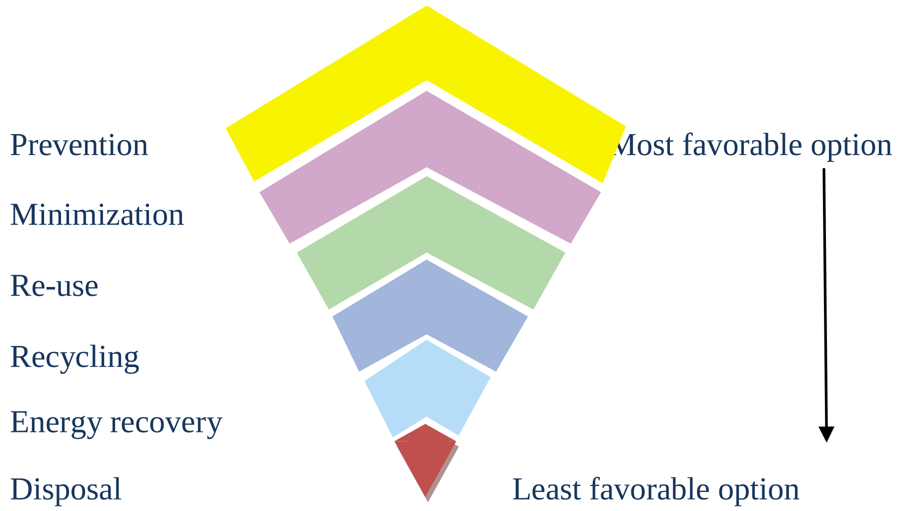


Fig 1.1 Hierarchy of waste management system

1.3 Significance of the present work

This present work is significant as it identifies specific use of recycled construction and demolition waste in sub base and base course of roads and thus establishes recycled CDW as new source of material for road construction on the basis of results of experimental studies, field trials and performance evaluation. Selected crushed concrete rubble can be used as a substitute for natural aggregates in concrete or a base layer of pavements. (Hanson 1992), (Collins 1994), (Mehta and Monteiro 1993) and (Sherwood 1995). The production of recycled CDW aggregates is less energy consuming and less cost of transport as CDW recycling units are within short distance from city hence results in saving of natural materials and energy resources and thereby reduction in construction costs of the roads. The present work provides field test results on a trial stretch constructed with use of recycled CDW in the township roads in the Ghaziabad, NCT of Delhi, India. Recycling of construction and demolition waste as aggregates for flexible pavements is not only useful for environmental protection but also for resources conservation and also very important for sustainable development. (Oikonomou 2005). The present work is an effort to standardise and lay down framework for the CDW aggregates for use in sub base and base course of flexible pavements so that the road construction industry will start using recycled secondary aggregates as major input material and hence we will be able to manage this large amount of waste.

1.4 Recycling of CDW – Impact on Environment

This land fill sites filled up with building waste cannot be developed as greens as no vegetation cover is possible over the concrete and masonry waste. Whenever there is wind flow the fines of the fill spread in the air and create large quantity of suspended particulate matter in the air. The SPM beyond the permissible limits creates problem of human health. Photograph 1.2 shows dumping of construction waste in an open area adjoining to main road. The environmentalists are concerns about the impact of aggregate extraction on environment of surroundings of quarry area. Large-scale extraction of stone from queries also created problem of lowering of water table due to cutting of vegetation over the stone strata. The replacement of recycled concrete and masonry waste will also relax pressure on the queries and the rate of cutting of vegetation will also reduce. This will help in the slow lowering water table and growth of plants in query areas. It is not possible to fulfil the growing demand of aggregates as extraction of new aggregate is not sustainable and hence to fulfil the aggregates demand some alternate source such as recycled CDW aggregates need to be developed.

Photo-1.2 Construction waste consists of dry mortar and brick bats

1.5 Demand for aggregate

The annual aggregate demand of the world will exceed 26 billion ton by the year 2011 China (25%) EU (12%) and USA 11% (Fredonia2007). In the India demand for aggregates has risen steadily since the development activities have increased very rapidly after economic liberalization since 1990. Booms in the construction of commercial and residential complexes and road and highway construction are primary growth driver for the demand of aggregates. NHDP (1998) and PMGSY(2001) have further fuelled the demand of aggregates in India. The crushed rock aggregates and natural sand obtained by quarrying, dredging and crushing of stones, boulders and gravels. The prime users are road construction and maintenance industry which account for about a third of the total aggregate demand every year and new commercial and residential building construction industry which generates nearly half of the total demand. The highway, housing and industrial townships and some other development programs of the government have generated the huge demand of aggregates. It is quite possible to recycle construction and demolition waste in to aggregate and then successful use of these aggregates at least at places of less structural importance. We can fulfil the gap between supply and demand by the use of these secondary recycled CDW aggregates.

1.6 Significance of recycling of CDW in India

In central and southern India we have quarries for gravel and crushed rock suitable for production of aggregates to fulfil the demand of the market in the coming decades but in Northern India especially plains between Ganga and Sutlej that is Punjab, Haryana, Uttar Pradesh, Delhi and Bihar are deficit in availability of aggregate. The transportation of aggregates from far away quarries had increased the cost of aggregate at such a level that it makes more sense to use the recycled aggregates. The construction industry is more acceptable for recycled concrete aggregates in northern India to overcome the problem of shortage of aggregates.

1.7 Thesis outline

This thesis consists of eight chapters.

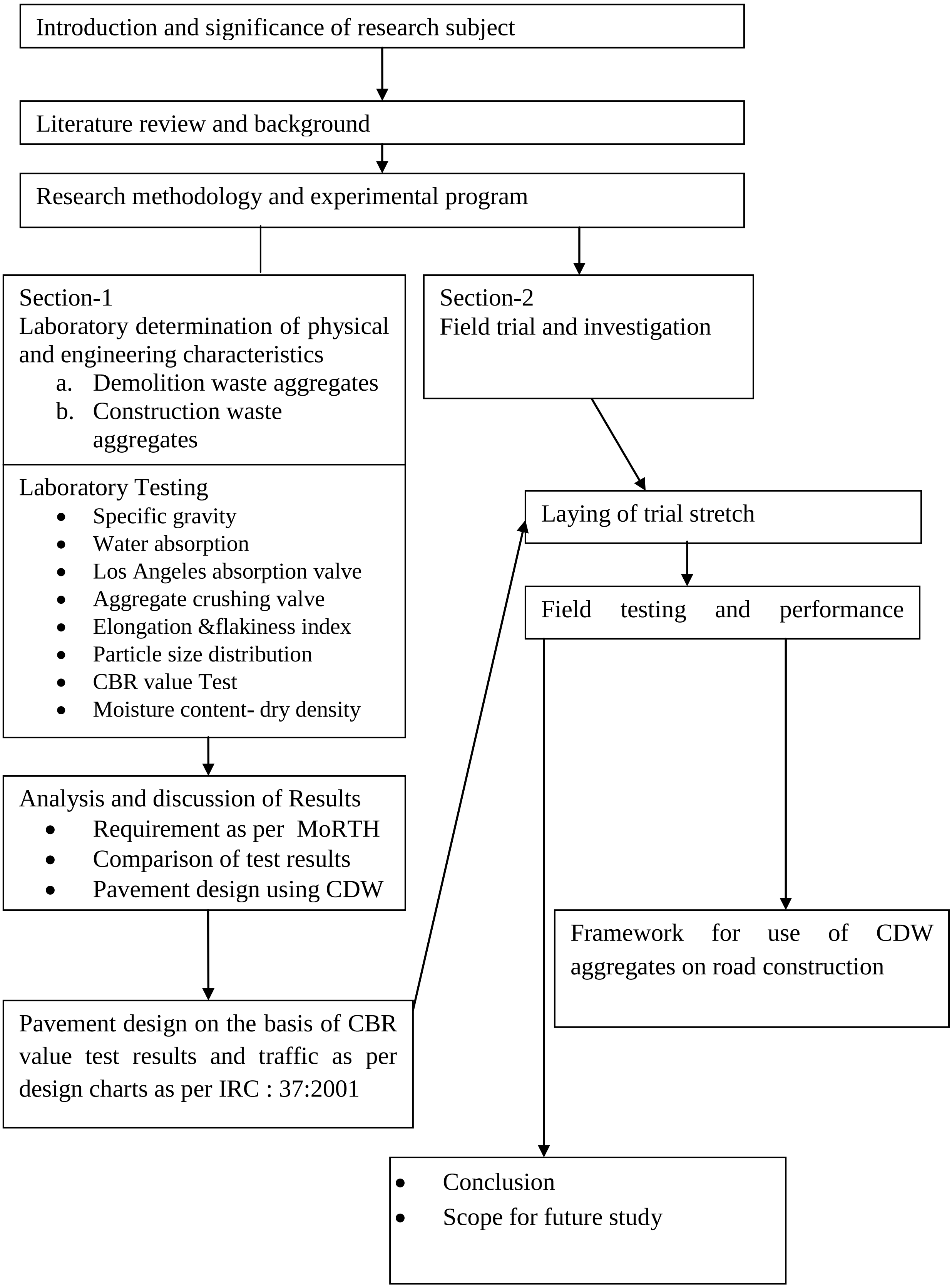
Chapter 1 Consists of an introduction to the entire research study in general and highlights its objectives and scope, background, significance of research subject and thesis organisation.

Chapter 2 Presents literature review and theoretical background relevant to the flexible pavement materials. The review includes the research work performed in flexible pavement planning, design, execution, performance testing. The review also includes the physical and mechanical properties and testing of recycled materials as base course materials in road construction.

Chapter 3 Describes the research methodology and experimental program adopted in the work this includes preparation of sample of recycled construction and demolition waste aggregate materials to be tested and respective testing methods including relevant Indian standard codes.

Chapter 4 Is the analysis and discussion of results of laboratory experimental program and summarises the results of the tests performed on construction and demolition waste materials for determination of characteristics for use as sub base and base course materials in road construction. It also gives detailed design of flexible pavement based on results of experimental program for construction of trial stretch.

Flow Chart-1.1 Layout of Research Work



Chapter 5 presents the construction of trial stretch, field investigation and performance evaluation of the trial stretch of road constructed using CDW for road bases. It also presents the monitoring, maintenance and periodic assessment in systematic manner to prove that the road constructed using CDW

Chapter 6 proposed framework for use of construction and demolition waste aggregates in flexible pavements

Chapter 7 provides a summary of conclusions and makes recommendation for further research.

The thesis ends with references and appendices.

CHAPTER 2
LITERATURE REVIEW AND BACKGROUND

2.1 Literature review

Recycling and reuse are gaining prominence throughout the world as all the countries are facing problems of disposal of waste arising from municipal waste or industrial waste. Specific researches are going on to utilize the waste and important breakthrough were achieved in case of use of fly ash in production of cement, use of slag from iron and steel industry in production of cement as raw materials. Another important area of reuse and recycling is production of manure after decomposition of organic waste from municipal solid waste. The use of fly ash in sandwich embankment construction is another area in which significant progress has been achieved. Coal ash is recognized as an alternative fill material to the conventional natural soils near a coal fired thermal power station where its large deposits are available. The data and the correlations that are pertinent to a wider community of geo-technical and geo-environmental engineers interested in the utilization of coal ash as a structural fill. (Trivedi 2005). As per the US federal highway administration a pattern of use of waste and other industrial by-products is on the rise throughout the world. Stidger (2002) and Inyang (2003) had given the projections of large scale requirement of road construction materials for expected 90% increase of vehicular traffic within the next 20 years. This requires use of large quantity of aggregates and we can replace this with aggregates derived from recycled CDW. We have highest growth of vehicular traffic and fastest development of new roads as road availability in India only 5 meter per capita as compared to per capita road length of 450 meter in the Australia, 280 meter in the United States and 90 meter in the Japan (Gnanendranet al. 2002). We just have around 90,000 Km of National Highways which are targeted to be increased to 1,50,000 Km within next 5-10 years as per MoRTH (2015). Similarly we are upgrading entire road infrastructure to reach at par with the developed countries. Hence the scope of further development of roads in India is much higher than the developed countries.

We are entering in the new phase of development where new industrial townships and new residential townships are under development throughout the India. Similarly we are developing our old earthen roads into all-weather fully paved roads. At the same time we are reconstructing or replacing our old buildings in our old cities like in the old city of Delhi. The waste generation during residential construction projects has been quantified and analyzed and it has been found that approx. 1-10% of material received has been sent back as construction waste (Bossink and Brouwers 1996). In Delhi results of TIFAC (2005) estimation after survey of CDW generation have shown that quantity of CDW varies from 2877 ton per day in pre monsoon period (July) and 446 ton per day in post monsoon period (September). The comparison of composition of CDW given by TIFAC with the composition of waste used in the present study i.e. demolition waste collected from demolition site of Ganga and Yamuna multi-story building of Ghaziabad development authority in Vaishali, Ghazaibad is shown in Chart2.1 The comparison results it may be inferred that the CDW mainly consists of sand, gravel, bricks and concrete.

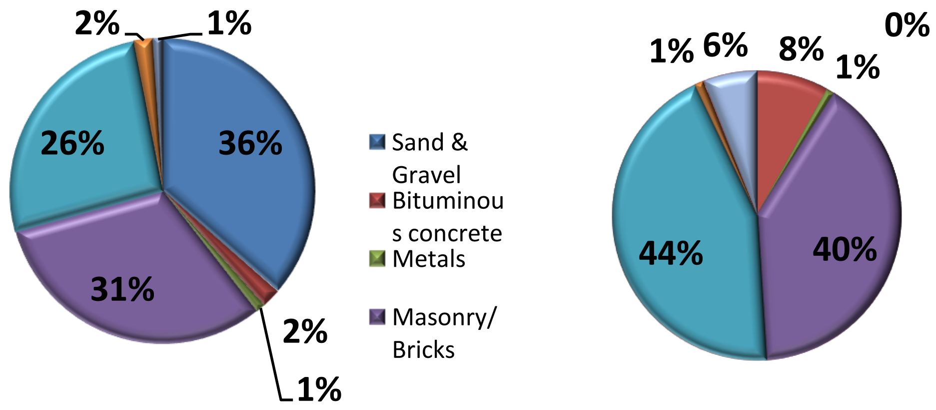


Fig-2.1 Composition of demolition waste TIFAC versus present work

2.2 Current world scenario of recycling of C&D waste

The annual generation of demolition waste in Hong Kong is 58,060 ton of which 45,360 ton is recoverable (Chen et al. 2002). It is estimated by Seik (1997) that the daily solid waste output in Singapore increased from 2075 ton in 1973 to 7329 ton in 1995. The average annual rate of growth of solid waste generation in Singapore was 11.5% up until 1995. The annual quantities of solid wastes disposed rose from 0.74 million ton in 1972 to 2.80 million ton in 2000 (Bai and Sutanto 2002). Singapore's Environmental Pollution Control Act of 1999 contains provisions that support large-scale recycling of wastes.

The composition of CDW waste in EU counties also varies by large extent as given by the EU commission report (2001) given in table -2.1

Table-2.1 Composition of CDW waste in EU countries

Country	Netherlands	Flanders	Denmark	Estonia	Finland	Czech Republic	Ireland	Spain	Germany
Year	2000	2000	2003	2006	2006	2006	1996	2005	2007
Concrete	40%	41%	25%	8%	33%	33%	39%	12%	70%
Masonry	25%	43%	6%			35%		54%	
Other mineral waste	2%	-	22%	53%	-	-	51%	9%	-
Total mineral waste	67%	84%	53%	61%	33%	68%	90%	75%	70%
Asphalt	26%	12%	19%	4%	-	-	2%	5%	27%
Wood	2%	2%	-	-	41%	-	-	4%	-
Metal	1%	0%	-	19%	14%	-	2%	3%	-
Gypsum	-	0%	-	-	-	-	-	0%	0%
Plastics	-	0%	-	-	-	-	-	2%	-
Miscellaneous	7%	2%	28%	16%	12%	32%	6%	12%	3%

Japan requires large scale utilization of recycled materials because of high industrialization rate and consumption patterns. In 1995, Japan discarded about 725.7 million ton of materials out of which 190.5 million ton was recycled (Ishimoto et al. 2000). Each year, the areal waste production of about 650 MT/km^2 (Wei and Huang 2002) creates the need for recycling large volumes in construction.

In Europe, Netherlands took the early lead in the development of national policies and framing/implementation of research to support large-scale utilization of waste in construction. Currently, although some individual countries in Europe still maintain jurisdictions over regional waste management programs, more general policies are now framed within the European Union. The Dutch Building Materials Decree which came into full operation in 1999 following a 3-year trial period, combines soil and groundwater protection standards in establishing performance requirements for construction materials, regardless of whether they are primary or traditional materials. Owing to many years of research on recycling of waste, variable types of waste recycled materials (WRM) produced in the Netherlands. The Dutch have been able to recycle about 90% (Eikelboom et al. 2001) of their waste stream in many applications, primary of which is construction. In Finland, almost all of the solid wastes produced are utilized because of lack of waste storage space and acceptable sources of primary construction materials. For example, in 2001, Helsinki Energy produced 86,183 ton of fly ash, 18,144 ton of bottom ash, and 22,680 tons of FED residues (Havukainen, 2002). About 50% of the ash was used in concrete while the remainder was used in earthwork constructions.

In Taiwan the output of waste concrete from C&D waste will continue to grow unevenly but steadily over the next decade as already annual output in the year 2009 was 8.5 million MT/year, approximately the same quantity generated by the 21st September 1999 earthquake. To reduce pressures on domestic sources of natural aggregates as well as limited landfill capacity Hsiao, T. Y., et al. (2002) proposed the development of a national waste concrete recycling infrastructure. This study suggests that all regions in Taiwan introduce measures to enable better management of waste concrete resources. As management targets, recycling rates of 50% by 2005 and 100% by 2009 are necessary to avoid overloading landfill capacities in all regions of Taiwan.

In Britain, Mulheron and O'Mahony(1988) studied the possibility of using crushed concrete and demolition debris as sub base course aggregates. CBR experiments were conducted and the behavior of recycled material was compared with that of lime stone. Results showed that CBR of crushed concrete was similar to that of natural aggregates. Conversely demolition debris presented a fairly decrease in its CBR. It is also reported that there is little difference between the shear strength of limestone, a standard natural aggregate, and that of the recycled aggregates which includes CDW at high densities. In England and Wales, the construction industry produces 53.5 Mt of construction and demolition waste (C&D waste) annually, of which 51 percent goes to landfill, 40 percent is used for land reclamation and only 9 percent is crushed for future use or directly recovered. (Lawson, Nigel, et al 2001)

Bennart et al. (1997) analyzed the performance of recycled concrete aggregates in base course and sub base course applications. The authors concluded that a blended mixture of 25% of recycled concrete aggregates with 75% of natural aggregate would obtain the same resilient response and permanent deformation properties as a dense graded aggregates base course, currently used in base and sub-base course.

Molenaar and Niekerk (2002) studied the influence of composition, gradation, and degree of compaction on mechanical characteristics of crushed concrete and crushed masonry in Netherlands. The results demonstrated that although the composition and gradation have an influence on their mechanical properties of the recycled materials, the degree of compaction are clearly the most important factor. Motta studied the mechanical behavior of RCDW aggregates from Sao Paulo. The results indicate an increase in the resilient modules over time.

Leite, Fabiana da Conceicao, et al (2011) studied the mechanical properties of recycle waste aggregates from Sao Paulo and the result indicates an increase in the resilient modulus over time. The efforts have been made in the past to find reuse of CDW in pavement and back fill material (Paul and Warwick, 1996). It has also been reported that the well graded RCA may produce a higher resilient modulus under low deviator stresses, as compared with fresh aggregate by the existence of unhydrated cement within the RCA aggregate (Nataamadja and Tan, 2001).

Río Merino et al(2009) cites the percentage in weight of materials forming found C&DW as per Spanish national plan for CDW (2001) are as follows: - bricks, tile or ceramic materials (masonry): 54% - concrete: 12% - stone: 5% - sand, gravel and other aggregate: 4% - wood: 4% - glass: 1.5% - plastic: 1.5% - metals: 2.5% - asphalt: 5% - gypsum: 0.2% - paper: 0.2% - rubbish: 7% - others: 3.1%.

The construction industry in Australia contributes approximately 15%, by volume, of all solid waste disposed in landfills each year. Australian division of a multinational construction company has developed a company policy with the aim of managing waste generated on site and, thereby, reducing the amount deposited in landfill sites. (Mcdonald and Smithers 1998)

In the foregoing discussion, it is evident that many countries have developed materials management policies that support waste recycling in large quantities. The driving factors which translate to economic considerations are material generation rates, lack of waste storage, disposal space and demand for construction materials, and available technical support systems to address engineering and environmental issues. As per the European Commission report (2011) the CDW arising per capita per year are given in Table-2.2

Table-2.2 CDW generation in European Union

Name of country	CDW arising per capita per year ton[a]
Austria	0.46
Belgium	0.955
Bulgaria	4.53
Cyprus	0.545
Czech Republic	4.037
Denmark	0.578
Estonia	4.144
Finland	3.99
France	5.5
Germany	2.33
Greece	0.37
Hungary	0.43
Ireland	2.74
Italy	0.8
Latvia	0.04
Lithuania	0.1
Luxembourg	5.9
Malta	1.95
Netherlands	1.47
Norway	0.7
Poland	0.11
Portugal	1.09
Slovakia	0.26
Spain	0.74
Sweden	1.14
United Kingdom	1.66
EU 27	1.74
India (TIFAC)[b]	0.05

[a] European Commission report (2011) [b] TIFAC report (2001)

2.3 Current scenario of recycling of C&D waste in India

In India we still do not have any organized system of recycling of construction and demolition waste. The understanding of processing the waste and use and sale of products coming out of recycling units is still in its neo natal stage. We still do not have standard government policy and schemes to recycle the construction and demolition waste as shown in table 2.3. In last 3-5 years some isolated experience or trials are being carried out such as recycling of pavement surface by mobile hot mix recycling plant by Public Works Department of Delhi. The western experiences of regional C&D recyclers indicate that successful recycling operations require a minimum of 0.8 ha of clear space for processing equipment, incoming waste stockpiles, recycled materials, and maneuvering room for mobile equipment and operations. A model CDW recycling plant has been established by Municipal Corporation of Delhi as a pilot project at Bawana in Delhi. But this recycled CDW aggregates from this plant are not being used in absence of specification and scientific testing data on this materials. The dumping of demolition waste in landfill sites will exhaust the capacity of dumping yards with in next 5-8 years in Delhi and the situation in other metro cities is no different.

Table-2.3 Policies and rules for CDW management in India

Year	Authority	Document	Description
2000	Ministry of urban development	Manual of solid waste management	includes a chapter on construction and demolition waste, with basic guideline on its handling
2000	Ministry of environment and forest	Municipal solid waste (management and handling) rules	Directs civic bodies to follow them management procedure
2005	Ministry of urban development	Status of water supply, sanitation and solid waste management in urban areas	Notes problem with transport of C&D waste
2010	Ministry of environment and forest	Report of the committee to evolve road map on management of wastes in India	Recommends amendment to MSWM rules 2000 to address the C&D waste for its collection, utilization and safe disposal
2013	Ministry of environment and forest	Draft municipal solid waste (management and handling) rules 2013	Draft stage

The details analysis of reasons of slow progress in recycling of CDW in India, Negative impacts of non-introduction of CDW management systems in India, Advantages of introducing CDW management systems and suggestions for recycling management of CDW in India are described in detail in following paragraphs.

2.4 Reasons of slow progress in recycling of CDW in India

a. Poor awareness of general public about recycling: The general public is not aware about the problems of uncontrolled disposal of waste. We consider that waste need to be disposed in dumping yards without thinking the negative impact of this waste on our health and economics. We treat it as something that is not fit for use must be dumped or used as landfill material. The impact on environment, impact on health and impact on economy due to non-recycling of CDW are not well documented and published and thus public awareness is very poor about this problem. The officials of local bodies involved in solid waste management are mostly ignorant of these problems and hence quite often their reaction to such information is indifferent and this attitude became counterproductive.

b. Ignorance of business community: Indian business houses are not aware of the fact that wastes is a valuable resources and recycling is good business opportunity. We have to remove the notion that C&D wastes have no value. The idea of separation of demolition waste into different usable fractions at demolition site for its reuse and recycling is now acceptable up to certain extent in the general public. It is a long and step-by-step process of learning and it will take long time to change the psychology of the public in India.

c. Unhealthy conditions: Most of the people are reluctant in dealing in the waste as handling of construction and demolition waste can be dangerous for health in terms of inhaling of fine particulate matter, cuts and burns during handling, presence of toxic unhealthy substances like broken glass and metal scrap. The common public does not understand the concept of reuse and recycling of CDW and they do not want to take the risk of effects of poor quality due to use of secondary material received from recycling of CDW.

d. Scope of illegal disposal: We have an easy and free of cost option of illegal disposal of solid waste on any government land or along the road. There is no legal framework to stop such practice or punish a person who disposes their waste wherever they found possible. Recently National Green Tribunal had taken some steps to prevent such practice but due to non-coordinated efforts of different government agencies it is still to show any effect on ground. Now we have to frame legislation against such practice which should have severe penalties for non-compliance. In addition to this we should start charging the fees for disposal in landfills to create awareness for waste minimization, separation and recycling.

e. Absence of CDW disposal policy: In India we have a solid waste disposal policy which includes the management of CDW but it is lacking clarity of management. Many state governments and local bodies still do not have any rules, regulations and guidelines for disposal management of CDW. Due to this reason most of the CDW becomes the part of municipal solid waste and also dumped with it in dumping yard. It does not treated taking care of the special requirements of demolition, separation at source, decontamination, recycling into consideration.

f. Lack of technology: Non availability of technology and standards of recycled CDW is another reason of slow absorption of recycling of CDW. The slow acceptance of recycled CDW aggregate as these materials do not provide the high strength but still these materials can be used as substitute to the new material where its low price makes them acceptable. We need technical characteristics of the materials with standards to reused or recycled CDW. The standard specifications for methods of processing of CDW, testing methods, quality control parameters and certification of products must be developed for use of CDW but this is rarely the case in India. Some research institutes like CRRI and BMTPC are in the process of development of methods for testing of aggregates and standards of quality of materials obtained from CDW but this will be a long process.

g. Lack of market research data: The non-availability of adequate data regarding its feasibility and market for reusable or recycled CDW also creates fear in the entrepreneur interested in recycling venture as new business. This same situation exists in most countries but markets for recycled products can be developed for acceptable quality at competitive prices. We need to have the legal, technical, institutional and economic prerequisites for development of markets for recycled aggregates and products.

h. Competition in market: The competition within the new building material sector is also a factor in non-development of recyclers of CDW aggregate as they are afraid of competition with new material operators and traders. These All recycled CDW commercial products have to overcome market related problems before generation of demand in the market of materials. The tendency of charging of higher prices some recyclers for by-product as a useful building material kills the advantages of using cheap recycled materials.

i. Shortage of funds: The shortage of funds required to establish a recycling industrial unit, which requires land near big cities and a variety of costly technical equipment also affecting the development of recycling systems for C&D waste. The initial funds for establishment and purchase of equipment for a recycling plant need to be first invested by the government agencies in developing country like India. We have to make funds available for the purchases of equipment machines etc and we should give a higher priority to CDW recycling.

j. Poor Infrastructure: The shortage or non-availability of infrastructure like land for storage of recovered materials, facility for transport of recycled CDW aggregates, roads from recycling plant to center of city, reliable and skilled human resources, system of control of flow of materials and processes are also affecting the introduction of a functioning CDW management system. This system needs time for establishment and required to be tested under field conditions.

k. Lack of Information network: In India we do not have any national waste information systems which is also require for functioning of CDW management system. This national waste information system should be based on actual and reliable data of quality and quantity of waste materials producing along with locations and information about the demand of various types of recycled products and quantities of these materials. Normally large quantity of CDW is available at numerous decentralized places, thus makes it extremely difficult to collect and transport to one single location hence it is necessary to develop a network of CDW recycling units of waste industry within the country or region. We have very initial information on good practices in the field of recycling of CDW. Our country has just intended to develop CDW management system. We need to learn from others developed countries that have already developed well-functioning

CDW management systems. The information of good practices is very important for the introduction of recycling of CDW waste in India. We need to search for good practices in other countries and needs a certain amount of adaptation as it may not be totally transferable to India due to different conditions.

l. Poor thrust on recycling by Government: Non availability of political patronage for a functioning CDW management is also affecting growth of recycling in India. Any such new system requires support and stability of political system for its implementation. There must be a continuous thrust and push from political system which controls the local authorities for implementation of CDW management system in the building and road construction.

2.5 Negative impacts of non-introduction of CDW management systems in India

The Indian government bodies have been failed till date to introduce CDW management systems and hence already causing facing huge economic and environmental losses throughout the country. The negative impacts of non-implementation of CDW management systems are:

a. Irreparable damage to environment: Natural landscape gets permanent destruction with presence of landfill sites. We are suffering from irreparable environmental losses happening due to air pollution from the bed smells of decaying organic waste, development of toxic fumes due to incineration, water and soil pollution from decaying and leakages toxic substances.

b. Health hazards: The uncontrolled incineration and disposal of waste in dumping yards gives free proliferation and fast reproduction of insects, rats and other creatures affecting the human health. The air, water and soil get polluted near the landfill sites and the cause of a variety of health problems for the people living in the adjoining area. Man power involved in rag picking of reusable and recyclable materials from the waste are prone to get cuts and burns by sharp and heavy objects like glasses and metal wires and cuttings. Their life is in danger due to landslides of landfill sites and many people have been killed due to these health hazards.

c. New landfills sites require new land due to rapidly increasing solid waste: The rapid population growth and urbanization near big cities in India is generating large amount of solid waste and thus landfills are growing at an incredible pace. Old C&D landfills are quickly being filled, and space for new ones is growing scarce (Gavilan and Leonhard 1994). This requires additional land on already congested cities that are already short of land for development of greens and recreational facilities. Normally CDW constitute around 35- 40% of municipal solid waste, if got separated and recycled, we can reduce the rate of growth of landfills by half. Although we need to reduce the quantum of municipal solid waste to zero or to least possible to check this negative impact of landfills.

d. Social and economic factors: The high demand of land for dumping yards will results in increase in land prices and it also affects the areas adjoining to landfills as it rapidly loses the value and become colony of poor people of the area. The high and medium business enterprise and small and medium industries, recreational facilities tend to move to area away from landfill sites. The more dumping in dumping yards without extracting recyclable materials reduces the number of jobs in the area and thus leading to social decline.

e. Excessive use of natural resources: Non-recycling of CDW causes non reduction in demand of new materials for construction. Now new materials have to be excavated and manufactured and hence extract more natural resources. The result is increased demand of natural resources which will be met by increased extraction from new quarries and thus deforestation. This will further increase the environmental degradation and results into more financial and economic losses, which could have been easily compensated by reuse and recycling of CDW. The saving of resources by the use of recycled aggregates in construction is based on the assumption that the usable aggregates can be extracted from the construction and demolition waste. (Weil et al 2006)

2.6 Advantages of introducing CDW management systems

In India we are facing large number of difficulties in establishment of reuse and recycling and CDW management system. We need to find solution of these difficulties as the introduction of CDW management system always gives more advantages as compared to problems encountered. The advantages of introduction of sustainable CDW management system are:

a. Improvement in environment: A fully operational CDW management system will require less space for landfills and hence less air pollution, less degradation of soil, less pollution in water and we will have low unsightly conditions. A operational CDW management system will convert CDW in to usable aggregates and hence reduce need of virgin materials, so there will be reduction in extraction of natural resources from quarries and hence less deforestation to leave natural environment in its original state. This will results in less requirement of energy to manufacture new raw materials and new products. This will release less carbon dioxide and so many other harmful items into the air, soil and water.

b. Good health for all: A reduction in landfill areas means reduction in pollution, fewer diseases, injuries and accidents. This has a direct beneficial impact on the public health around the landfill sites and their productivity results in significant economic progress. Both national and international investors will be attracted in a better environment and healthy conditions having high productivity and good health of people. This will help in the growth of the local economy.

c. Increase in working life of landfill sites: We have to fix a target of zero waste but the landfill sites for management of MSW we will have to continue with landfills in coming years. If we divert CDW for reuse and recycling, the life of the landfill sites can be increased to more than double as biodegradable solid waste gets reduces after decomposition. This will improve the economic and social condition of area and provide more land for productive uses.

d. Saving of natural and financial resources: Reuse and recycling of CDW replaces new materials and products. This reduces the need of new natural materials. This will save and conserve natural materials and also saves cost of excavation, transport and manufacturing. Sometimes it also saves the funds required for the import of materials and products which are recovered during recycling of CDW. Once the common public and government agencies realize the value of reuse and recycling of CDW then no one chooses the illegal dumping of such waste. In order to examine the eco-efficiency of C&D waste systems at the local level in a city, we have to estimate future waste projections for the city (Bohne et al 2008).

e. Saving of high energy cost: The production of new natural materials require energy in every step i.e. in excavation, transportation and manufacturing. The replacement of new natural materials with recycled materials saves the high energy costs and hence makes this a case of significant financial gain. The less energy uses means reduction in CO_2 emissions and other pollutants and hence a positive impact on the environment.

f. Reduction of costs of constructions: A fully operational CDW management system produces recycled materials at lower cost than those of new products. These materials give competition to new materials in the market and become marketable. This will reduce the costs of new constructions due to availability of cheaper materials. This is the most effective incentive to contractors and builders to educate them about the reduction in cost of construction just by recycling the construction waste. (Dolan et al 1999)

g. Creation of new jobs: The development of recycling industry will create many new jobs in the field of sorting of waste, Drivers for transportation of construction and demolition waste, peoples for running collection yards, operation and maintenance of machines of recycling plants, operation of material delivery yards, people involve in sales and marketing of recycle products and many other related works. This will be a special field in the building construction and demolition industry. This will develop demolition contractors as new profit centres creating revenue from salvaged building products like secondary bricks etc. We already have some manpower which is earning their livelihood from rag picking from landfills. This category of people belongs to very poorly managed recycling sector and do not have any fix income. They live their life without job security, with no work place safety measures and very poor and non-acceptable social status. Employment of these human resources in the recycling industry will help them to raise their social status and hence their self-esteem and standard of living.

2.7 Suggestions for recycling management of CDW in India.

While the disadvantages and advantages of operational CDW management system have been discussed in detail as above, still we need number of other essential tools, which are necessary for a good CDW management system. These are already developed in good shape in some developed countries which are near the goal of zero waste but in India ultimate goal of zero waste will be a long drawn process as the CDW management system is just starting. The main issues in creation of CDW management system are outlined below.

a. Research and development of technology for recycling: India is lacking in research in the field of viable technology for recycling of construction and demolition waste.(Tam, Vivian WY 2008). We need to initiate research and develop new technologies in cooperation with foreign research institutes and experts. We need to carry out surveys for assessment of types of construction and demolition waste and their approximate quantity being generated in the different regions of India. This survey and generation of record is essential for development of a sustainable system of management of construction and demolition waste. We need to develop Indian standard codes and specifications to generate demand for recycled products in new construction. In India many universities and central research institutes in coordination of private companies studying the characteristics of construction and demolition waste to determine their potential use in construction. A number of methods of recycling CDW are being tested in the construction industry. A trial of use of crushed asphalt and concrete waste in road construction is being carried out by NDMC along with CRRI in Delhi.

b. New law for regulation of CDW management: We have to enact a new legislation that creates suitable conditions for construction and demolition waste management system to function. This law should provide a framework for the recycling plant and allied industry operation, system of collection and transportation for management of CDW waste, licensing of recyclers, permissions for waste collection and transportation, etc. to be carried out as single window system to achieve the final objective of construction and demolition waste management. We have to have an enforcement mechanism to enforce the levy on landfill, impose penalty on unauthorized dumping of waste and to ensure that the law should be followed and all fees and fines are collected. Local authorities and municipalities must create a special wing or department to monitor and ensure 100% recycling of CDW. We need strict and enforceable safety standards to ensure the safety of human resources involved in recycling and for the safety of people living around recycling units. The responsibility of producer should be incorporated in the proposed law for CDW management system.

c. Government incentives in form of subsidies or no taxation for growth of recycling industry: Government must encourage reuse and recycling of CDW by giving tax breaks and subsidies to recycling industry and should have high landfill charges to discourage waste disposal in landfills. The tax exemptions on use of recycled products, high levy on aggregates extracted from quarrying, high custom duties on imported raw materials and products will create a market for recycled materials and products. The taxes and duties should be fixed so that secondary goods and recycled materials become economical than the new materials and products. Special markets for recycled product must be established.

d. Creation of new associations of user and recyclers: We should establish an association of professionals involved in demolition activities and recycling industry, and also the users of such materials. It will provide positive support and representation to recyclers, users and other people involved in recycling industry. This will be helpful for drafting of new legislation and rules for the recycling and CDW management system. This will be further helpful in the development of recycling business as industry. It will facilitate communication between the recyclers, users and government authorities. This can also be used to spread knowledge about advancement or development of new technology in the field of recycling and guide recyclers in regards of required knowledge on all aspects of the recycling business.

e. Quality standards and Certification: Standardization of specification for quality of recycled products and their certification by some government agency is mandatory for development of recycling industry for the construction and demolition waste sector. We have to create international organizations to develop standards and criteria for evaluating green products. Certification to the green products must be issued after testing on quality standards. ISO 14001 standards is the best known international certification, which is verified by specialized certification bodies. The national certifications such as the ARV quality seal in Switzerland, the LEED green building rating system of USA, the BREEAM green leaf rating system of UK and the RAL quality seal of Germany are many such certifications available in developed countries.

f. Training programs and workshops for exchange of information: The training and workshops for the workers and managers of recycling industry is required for sustainable system of construction and demolition waste management. The transfer of information is the first step towards learning about good practices in the field of recycling from other countries. This can be done through workshops and seminars, professional journals and newsletters of recyclers associations. We can also conduct training programs for new manpower in the field of recycling in our educational institutions. The industry and professional associations can share the knowledge through conferences and workshops. This has to be developed as joint action of all including government agencies, local authorities, research institutes, recycling industry and users of recycled products.

g. Promotion of reuse and recycled CDW products: All the above initiative must be supported by advertisements in professional and commercial journals involved in the business of construction materials. Green labeling on such products along with energy credits to users of such products will be a big booster in the promotion of CDW products. It will have strong effects to promote sales and demand of recycled construction and demolition waste. Similarly it should be emphasized that public buildings should be built with secondary products from demolition sites and recycled construction and demolition waste products. We need legislation to make it compulsory that the public and community buildings need to be built with materials having certain portion of recycled content. The specifications having a provision for recycled materials in construction of some public buildings or structures will drive market and will be a powerful tool in development of CDW management system.

h. Infrastructure development: Separate CDW collection systems should be developed first by municipalities and then privatization of such facilities should be considered to make CDW management efficient and economical. We have to give recyclers sufficient time, funds, and market and giving new enterprise a chance to participate. We should develop and run collection yards and facilities for recycling of CDW.

2.8 Road pavement and its function – can this be achieved using CDW in construction of roads

Pavement or road surface is the bonded durable surface laid down on a strip to carry vehicular traffic loads through wheels pavement interaction.

The road pavement is a structure that support vehicular traffic load without permanent deformation and cracking during its design life. Furthermore, the pavement surface need to be smooth enough to provide ride comfort and to drain out water from rainfall or snowfall without permitting seepage into base course and sub base course of the road.

The ancient Indian roads were built using slabs laid over plain surfaces with unbounded joints or from gravels to make the surface hard. The Grand Trunk Road was constructed throughout as an embanked, thoroughly well-drained and well-metaled highway of the first class. It is raised in every part well above the height of known floods or inundations. The top width of the earthwork was 40 feet, with side slopes of 4 to 1 with metaled central portion of 16 feet width constructed using either broken stone or gravel of compacted thickness of 150mm. This was the first road in the world having aggregates bonded with bonding materials and an example of flexible pavement. In Europe at around the beginning of the 19th century, binding agents began to be used to assist aggregate cohesion and improve the durability of roads. By the end beginning of the 20th century road construction also started with rigid pavement, the other principal pavement types were started throughout world.

Pavements are designed on the basis of various factors like traffic conditions, loading conditions and environmental conditions of the surrounding area using different materials of various sizes. There are two types of pavements based on the manner in which the loads are distributed to the sub grade flexible pavement and rigid pavement. Details of these two are given below,

2.8.1 Flexible pavements

The pavement in which loads are distributed to the sub grade through inter particle interaction are defined as flexible pavements. Flexible pavement can also be defined as the one consisting of a mixture of asphaltic or bituminous material and aggregates placed on a bed of compacted granular material of appropriate quality in layers over the sub grade. Water bound macadam roads and stabilized soil roads with or without asphaltic toppings are also examples of flexible pavements. The flexible pavement are designed on the basic principle that for a load of any magnitude, the intensity of a load diminishes as the load is transmitted downwards from the surface by virtue of spreading over an increasingly larger area, by carrying it deep enough into the ground through successive layers of granular material. Thus for flexible pavement, there can be grading in the quality of materials used, the materials with high degree of strength is used at or near the surface. Thus the strength of sub grade primarily influences the thickness of the flexible pavement. The CDW aggregate are having similar physical and engineering properties and can be easily used in sub base and base course of these pavements without affecting the quality of final structure.

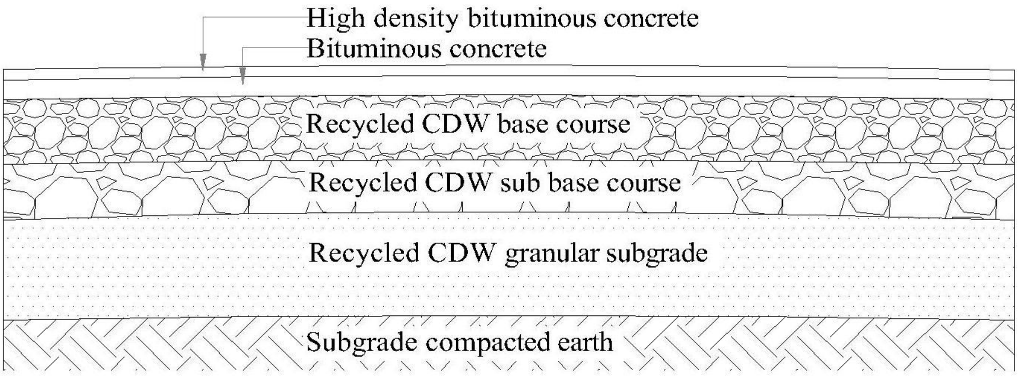


Fig 2.2 Typical layers of flexible pavements using CDW aggregates

2.8.2 Rigid pavements

The pavement in which loads are distributed to the sub grade through structural action of top hard slab surface is called rigid pavement. A rigid pavement is constructed from cement concrete or reinforced cement concrete slabs. Grouted concrete roads are in the category of semi-rigid pavements. The design of rigid pavement is based on providing a structural cement concrete slab of sufficient strength to resists the loads from traffic. The rigid pavement has rigidity and high modulus of elasticity to distribute the load over a relatively wide area of soil.

In case of rigid pavement the minor variations in sub grade strength have little influence on the load carrying capacity of pavement. Rigid pavement design is based on the flexural strength of concrete as major factor and not the strength of sub grade. Due to this flexural strength of pavement it acts like a slab and does not affected sub grade deflection beneath the pavement. The concrete slab pavement bridges the localized failures and areas of inadequate support from sub grade because of slab action. In case of rigid pavement structure deflection is lower than that of flexible pavements due to high modulus of surface elasticity. The sub base layers of this pavement can be constructed using CDW aggregates as these layers are of unbounded materials.

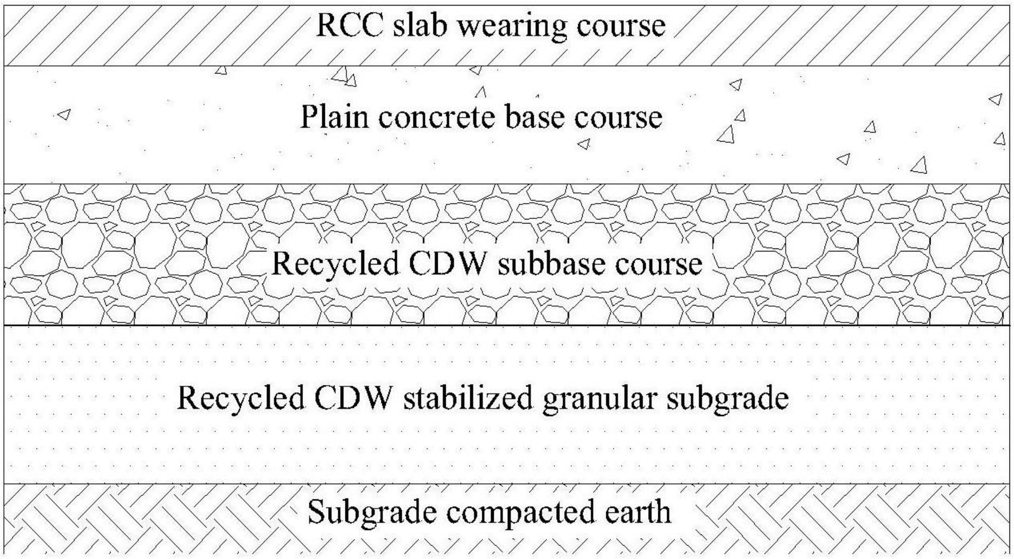


Fig 2.3 Typical layers of rigid pavements using CDW aggregates

According to Flaherty (1974), rigid pavement structure is a two or three layer system as can be seen in Figure 2.1. It consists of a Reinforced or plain Cement Concrete (PCC) surface course of the thickness of 150mm to 300mm depending on traffic, over a cementitious base course, sub base course and earthen sub grade. Rigid pavement are mainly characterized with the strength, less surface friction, smoothness, less noise, impervious and better drainage properties. The sub-base layer is optional in the rigid pavement structure. If the condition of the sub-grade soil found to be poor and have very low strength then only the sub base layer is laid down above the sub grade. A sub-base in a rigid pavement does not have much influence in its load carrying capacity but is important to provide permanent support for the concrete slab and to maintain stability under poor drainage, mud-pumping, frost, swell, shrinkage of high-volume change soils conditions (Flaherty 1974). The sub base layer of this pavement is not prone to ingress of water hence recycled CSW aggregate having water absorption limit more than the permissible can easily be used in these pavements.

2.9 Scope of utilization of construction and demolition waste in India

India is a very large country and already has a large network of roads crisscrossing east to west and north to south, throughout the country. We have large number of agencies involved in construction of roads. The standard making agency for all the roads in the country is Indian Road Congress (IRC), under the MoRTH. The design and construction of roads is being carried out as per the standard and specifications given by the IRC.

The National Highways and Expressways in India are less than 3% of total road network and they carry more than 70% of heavy commercial traffic in India. State Highways and major district roads are 15-18% of total road network and this carries approx. 20-25% of heavy commercial traffic. Rest all the roads i.e. 80 % of the total roads carries hardly 5% of heavy commercial traffic. These roads which carries only local traffic of medium and light commercial vehicles, buses and other small traffic, especially urban street roads etc. can be easily constructed by using recycled C&D waste. Even if we utilize all the waste generated by construction and demolition industry we will not be able to meet the 5% of requirements of materials for the construction of these roads. On the bases of use of roads we can classify roads as under.

Table-2.4 Classification of roads as per location and use of material (proposed)

Non-urban highways carrying major portion of heavy commercial vehicles.	Urban roads	Rural roads
International highway[a]	Arterial street[a]	Border road[a]
Expressway[a]	Sub arterial street[b]	Forest road[a]
National highway[a]	Collector street[b]	Through village road[b]
State highway[a]	Local street[b]	Link village road[b]
Major district road[a]		

[a] Continue to use conventional materials as they carry HCV and away from production centers of RCDW aggregate.
[b]Present work proposals for use of CDW aggregate in urban roads and rural roads which carries least number of commercial vehicles.

2.9.1 Classification and lengths of roads in India based on surfacing i.e. surfaced or non-surface (earthen road). The total road length as per https://data.gov.in/resources/all-india-and-state-wise-total-and-surfaced-road-length-31st-march-2011/download is divided state wise as follows in the year 2011 given in the table 2.5.

Table-2.5 State wise classification of surface and non-surfaced urban roads - Scope for use of CDW aggregates

State/U.T	Urban roads - total[a]	Urban roads - surfaced[a]	Urban non - surfaced roads - Scope for use of CDW aggregates[b]
Andhra Pradesh	13843	10994	2849
Arunachal Pradesh	53	53	0
Assam	6664	4693	1971
Bihar	9975	4596	5379
Chhattisgarh	8031	6075	1956
Goa	479	415	64
Gujarat	21687	16765	4922
Haryana	9930	6497	3433
Himachal Pradesh	2213	1767	446
Jammu & Kashmir	1762	1752	10
Jharkhand	514	472	42
Karnataka	24090	15438	8652
Kerala	13305	10883	2422
Madhya Pradesh	14144	9919	4225
Maharashtra	20407	15207	5200
Manipur	211	155	56
Meghalaya	110	106	4
Mizoram	324	283	41
Nagaland	98	96	2
Odisha	18618	11340	7278
Punjab	8085	6517	1568
Rajasthan	12564	10528	2036
Sikkim	162	160	2
Tamil Nadu	17582	14810	2772
Tripura	280	211	69
Uttar Pradesh	76475	50244	26231
Uttrakhand	4465	3172	1293
West Bengal	94179	65874	28305
A. & N. Islands	56	56	0
Chandigarh	1613	1613	0
D. & N. Haveli	NA	NA	0
Daman and Diu	38	38	0
Delhi	29087	20402	8685
Lakshadweep	1	1	0
Puducherry	794	762	32
	411839	291894	119945

[a]MoRTH[b] Present work

These urban non surfaced 119245 km roads can be constructed using CDW aggregates and this can consume all our demolition waste within urban area where it is generated.

2.9.2 In addition to the above we can quantify the length of urban roads in which we can use CDW aggregates for sub base and base course in urban areas in India.

Table 2.6 Total road length by in urban area in India[a] which can use CDW aggregates

Sl No.	Category	2008 (Km)
1	Urban Roads	304327
2	Municipal Roads	277264
3	MES Roads	14143
4	Railway Roads	11749
	All Categories	607483
Source : Ministry of Road Transport & Highways		

[a]MoRTH[b] Present work

As per the data collected from various sources we can easily understand that still we have more than 25% earthen roads. We have more than 70% roads comes under category of urban streets and village roads. From all of the above we may not like to utilize CDW materials in national highway, expressways or state highways but at least we can use these materials in urban roads and village roads which are more than 70% of total road network of India. The present work is the work carried out for the testing of the CDW material on a trial stretch of the urban township road and consumed around 50,000 m^3 of waste generated from the demolition of multi-story towers in NCR of Delhi

CHAPTER – 3
RESEARCH METHODOLOGY AND EXPERIMENTAL PROGRAM

3.1 General

This chapter detailed out the research methodology and experimental programs used in this research work. First part of this work is for establishing the suitability of CDW as geo-material for use in sub base and base course of flexible pavements after characterization of physical and engineering properties of materials. This has been established through the experimental investigations for physical and engineering properties like specific gravity, grain size distribution, density-moisture relationship by Proctors compaction test, aggregate crushing value, Los angles abrasion value test, and California bearing ratio (CBR). The tests as per relevant IS codes were carried out to characterize CDW aggregate in order to evaluate the physical and mechanical properties that affects the behaviour of CDW aggregate for use as base and sub-base course.

The research methodology and experimental programs has been divided into two segments in regards to achieve objective of this work. In the first segment of this work laboratory determination of physical and engineering properties of demolition waste aggregates, construction waste of concrete and construction waste of mortar and brickwork has been carried out and comparison of these physical and engineering properties have been made with the requirements of Indian standard codes. Then the pavement has been designed as per the IRC:37. The second segment of this work consists of construction of trial stretch of road using CDW aggregates and then field investigations and performance monitoring of sub base and base course of pavements.

This chapter is all about the methodology and experimental program adopted in laboratory and field for testing of CDW aggregates. Laboratory tests were carried out for analysis of test results for further utilization in the design and construction of sub base and base course of flexible pavements. This chapter describes the methods, apparatus and test procedures as per relevant Indian standard codes for testing of materials. Details of samples and their source are also presented in this chapter. All tests were conducted as per the procedure laid down in relevant IS codes and results obtained are then compared to the results of pavement made of standard new materials.

3.2 Collection of test samples of demolition waste aggregates

This research work is based on the demolition waste obtained from Ganga and Yamuna multi-storey towers in Vaishali, Ghaziabad, NCT of Delhi. This demolition waste was brought at the construction site namely Crossing Republic Township at Ghaziabad and the material was then hand broken and crushed to required size and used for construction of trial stretch of 3.0 km length. The water bound macadam roads were constructed over a compacted sub-grade of good earth having CBR value 8-10 and the road crust was designed as per IRC: 37: 2001 and constructed as per MoRTH specification. However, the base course and sub-base course material was replaced by CDW material fulfilling the criteria of physical properties. The road was overlaid and finished with bituminous layer. A general description of recycling steps is illustrated in following photographs. These photo graphs were taken during the construction of trial stretch of township roads in Crossings Republic, NH-24 Ghaziabad.

The samples of demolition waste aggregates were collected in three stages. First set of sample has been collected for testing of physical properties from the demolition waste arrived at site of construction of trial stretch from demolition site. The photograph 3.1 shows the sample collection of first set of sample of demolition waste site Ganga & Yamuna towers in Vaishali to road construction site Crossings Republik. The second sets of samples were collected during the hand crushing operation. The third set of samples were collected after dry rolling of base course to determine the grading availability of aggregates as we were not having mechanical means of grading of different size of aggregates and this was being done manually based on experience of the engineers and staff working at site.

Photo-3.1 Collection of demolition waste

Photo-3.2 Manual screening

Photo-3.3 Manual crushing of demolition waste

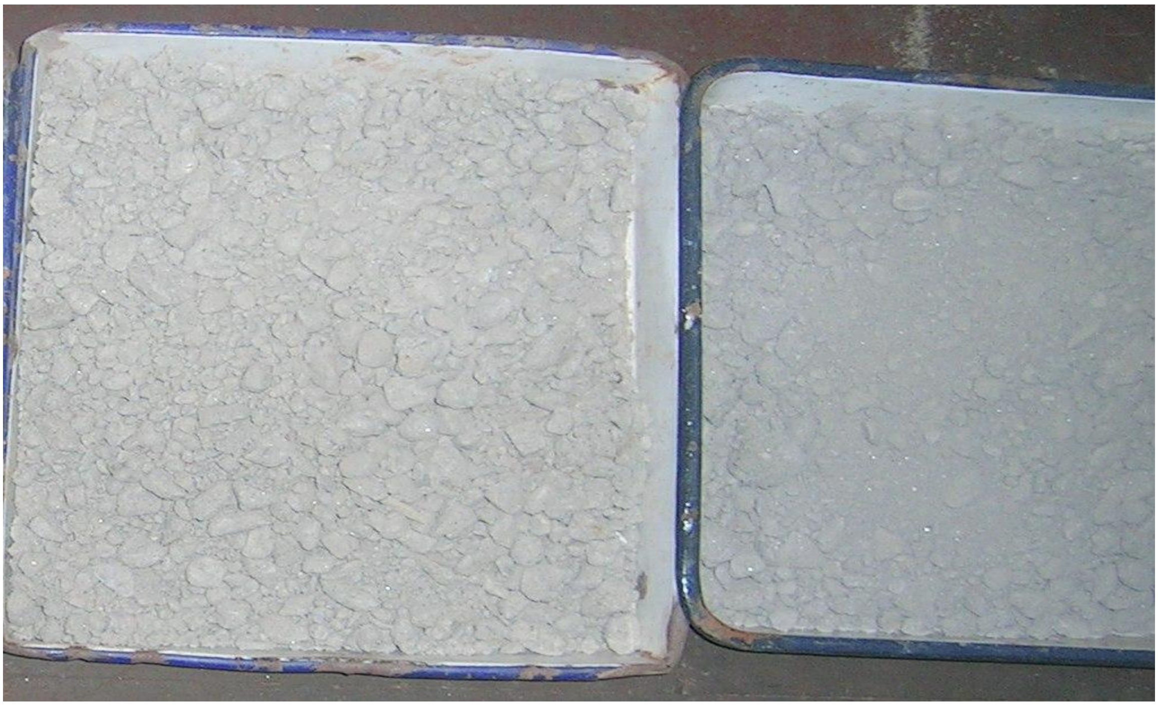


Photo-3.4 Collection of concrete waste sample

Photo-3.5 Collection of mortar and masonry waste sample

Photo-3.6 Sampling of mortar and masonry waste of a construction site

3.3 Collection of test samples of construction waste of concrete

Concrete construction is most common in the present era of construction and during the various construction operations wastage of concrete is a standard in spite of the best management of concrete production and placement. We have collected the samples of waste concrete from the high rise construction site at Crossings Republik, Ghaziabad and crushed it to the requirements of testing.

3.4 Collection of test samples of Construction waste of mortar and brickwork

The waste from brickworks and plaster is the largest portion of the construction waste in the high rise framed buildings. The cut brick pieces, brick bats and mortar from brickwork and plaster which are not fallen on the ground while working or excess mortar at the day working has been thrown as waste. We have tested samples of this waste as the third material for testing and collected this also from the housing project Panchsheel Wellington site at Crossings Republik, NH-24, Ghaziabad.

3.5 Laboratory testing for characterization of CDW aggregates

This section describes about various test that have been carried out to characterize the construction and demolition waste aggregates in terms of physical and engineering properties as required by MoRTH specification for materials to be used in sub base and base course of flexible pavements. The results of the test conducted for specific gravity, flakiness and elongation Index, particle size distribution and grading, moisture-density relationship, water absorption; Los Angeles abrasion value, aggregate crushing value and CBR value are elaborated and discussed in detail.

3.5.1 Test for Specific Gravity

Tests for specific gravity is performed as per IS : 2386 (Part III) - 1963 Methods of test for aggregates for concrete – Test for specific Gravity, density, water absorption and bulking and values obtained were compared with that of natural aggregates used in construction of WBM and WMM roads as recommended by MoRTH specifications. Specific gravity is defined as the ratio of the weight of an equal volume of distilled waters at that temperature both weights taken in air.

Three sets of test samples of crushed CDW aggregates were prepared to find out specific gravity. Each set consists of three samples, one of course particles of size more than 11.2 mm and other set consists of fine grain particles of size less than 11.2 mm.

The specification of grading i.e. particle size less than 11.2mm is taken as the same is used in MoRTH specifications (2001). The results of specific gravity of samples of CDW as determined in laboratory are shown in the Table-3.1.

Table-3.1 Specific gravity test of various CDW aggregate and MoRTH requirements

Demolition waste aggregates	Mortar and brickwork waste	Concrete waste aggregates	Standard code requirement[a]
2.61	2.58	2.68	2.55-2.75

[a]MoRTH specification (2001)

The above test results indicate that the range of specific gravity of CDW waste is almost same as that of natural materials and the uses of it in earlier construction and then demolition and crushing has not affected it any way.

3.5.2 Tests for Water absorption of waste aggregates

The porosity of the aggregate affects the water absorption and permeability and hence is very important factor. These properties also affect the stability of pavement in wet condition. The specific gravity of the aggregate depends on its porosity. The water absorption test of an aggregate after one hour and twenty-four hour of soaking give important inferences in regards of stability of pavement in wet condition. (Fouad M. Khalaf and Alan S. DeVenny 2004)The values of the test results for 24 hour soaking are higher water absorption owing to presence of lumps of cement mortar, brick bats which are inert and have low plasticity index.The aggregate may contain variable size pores within its structure. The large pores can be seen by microscope or even with the naked eye. The smallest pores are usually larger than the size of the gel pores contained in the cement paste. The pore size affects the penetration of water inside the aggregates and loss of shear strength due to presence of water.

According to Murdock and Brook (1979) it is often useful to determine the absorption of an aggregate after only a few minutes of soaking as this rate of absorption of water provides an indication of the reduction in workability between mixing and placing when used in concrete. The results of the test results for 24 hour soaking are as per Table-2. As per code IS: 2386 (Part III) - 1963 Methods of test for aggregates for concrete – Test for specific gravity, density, water absorption and bulking.The values of higher water absorption of recycled CDW aggregates are owing to presence of cement mortar, brick bats which are inert and porous.

Table-3.2 Water absorption test of CDW aggregates and standard code requirements

Demolition waste aggregates	Mortar and brickwork waste	Concrete waste aggregates	Standard code requirement[a]
3.38%	2.69%	5.5%	2 %

[a]MoRTH specification (2001)

3.5.3 Los Angeles abrasion value test

The Los Angeles abrasion value tests on the coarse fraction was carried out as per Indian Standard code IS: 2386 (Part IV) - 1963 Methods of test for aggregates for concrete Part-IV - mechanical Properties. The test conducted using a Los Angeles Abrasion testing machine to determine abrasion loss of the aggregate particles. The test material prepared from CDW contained a combination of the aggregate fractions which remained in sieves. The fractions measured from 19.0mm to 13.2 mm, 13.2mm to 9.5mm, and 9.5mm to 4.7mm. The desired mass for the first two fractions cited was 2500g and for the last fraction 5000g. Fractions were prepared via the following steps: sieving to obtain the appropriate fractions, washing to remove clay particles and dust, drying and cooling, loading the material and allocating abrasion balls in the Los Angeles abrasion testing machine.

According to the standard, fractions from 19.0mm - 13.2mm and 13.2mm - 9.5mm need 11 steel balls with a 5000g mass. For 9.5mm - 4.75mm, 7 steel balls with a 5000g mass are needed. After the material and the balls were put into the machine, the revolution counter was set to 500. On completion, the material and balls were removed from the drum and the material split from the steel balls. After separation, the material was put through a 1.70mm sieve and weighed and the material that passed through was retained. The material that was coarser than 1.70mm was washed and oven-dried at 105^{0}C to 110^{0}C for minimum period of 16 hours.

This test has been performed only for demolition waste and concrete waste aggregates. The waste material of mortar and brick work waste consists of either mortar or the brick bats.

Table-3.3 Los Angeles abrasion value of CDW aggregates and standard code requirement

Demolition waste aggregates	Mortar and brickwork waste[b]	Concrete waste aggregates	Standard code requirement[a]
39.66%	-	36.46%	40%

[a]MoRTH specification (2001)
[b]Used as granular sub base hence not performed

The Los Angeles abrasion value tests on the coarse fraction were carried out and the results of tests are presented in the table below. It may be noted from the table that these values are within permissible limits of 40% prescribed for natural aggregate for construction of base and sub-base course. The reason of higher value of abrasion test is due to the fact that waste aggregate consisted of stone aggregate, small pieces of brick, mortar pebbles and mortar adhered with the stone aggregates. These particles of mortar are comparatively weak in strength. Bachir Melbouci (2010) carried out the hardness test on crushed concrete aggregates and found that Los Angeles abrasion value as 31 under standard test conditions.

3.5.4 Test for aggregate crushing value

The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. Crushing value is a measure of the strength of the aggregate. The aggregates should therefore have minimum crushing value. The test has been performed as per Indian standard code IS: 2386 (PartIV) - 1963 Methods of test for aggregates for concrete Part-IV Mechanical Properties.

The strength of CDW to be used in sub-base and base course was obtained by aggregate crushing value test. The test sample consists comprises the test material of aggregates sized 12.5 mm - 10.0 mm, should be dried by heating at 100-110^{o}C for a period of 4 hours and cooled. The crushed material was sieved through the 2.36mm sieve and aggregate crushing value was calculated as given in the table. The aggregate crushing value of the CDW aggregate is higher than the crushed stone aggregates as there is mortar adhered around the particles and brick bats which get crushed easily during the testing. The test results for crushing values are as under:

Table-3.4 Aggregate crushing value of demolition waste aggregates and standard code requirements

Demolition waste aggregates	Mortar and brickwork waste[b]	Concrete waste aggregates	Standard code requirement[a]
16.89%	---	14.53%	30%

[a]MoRTH specification (2001)
[b]Used as granular sub base hence not performed

Aggregate crushing value test were not conducted on the mortar and brickwork waste as the material was almost in the shape of fine particles and brick bats and there was no material in the range of 10mm to 12.36mm as required for the test.

3.5.5 Test for Flakiness and Elongation Index

Flakiness index is defined as the ratio of particles having thickness less than the 60% of mean size of the particle i.e. if a one side dimension of the particle is less than 0.6 times the mean dimension it is called as flaky aggregate and percentage of such aggregate is called flakiness index. It is tested with the help of specially designed standard flakiness test sieve.

Elongation Index is defined as the ratio of particles having length more than the 180% of mean size of the particle i.e. if length of the particle is more than 1.8 times of the mean dimension it is called as elongated aggregate and percentage of such aggregate is called Elongation Index. It is tested with the help of specially designed standard elongation flakiness test sieve.

The test for Flakiness index and Elongation index needs to be carried out to analyse the capability of material for interlocking and packing of aggregates to achieve highest possible density of pavement. These flaky and elongated particles are undesirable in the aggregates as they may brake on application of heavy loads during compaction. Still all the aggregates have some portion of flaky and elongated aggregates. The test for Flakiness index and Elongation index has been carried out as per Indian standard code IS:2386-Part-1:1963 – Methods of test for aggregates Part-I-Particle size and shape on three sets of sample collected from the crushed construction and demolition waste. The sample has been sieved from a set of sieve so as to separate out the particle from 63mm to 10mm and test was carried out only on the aggregates. Following test results were obtained.

Table-3.5 Flakiness and elongation index of demolition waste aggregates and standard code requirements

Description of materials	Flakiness index	Elongation index	Combined flakiness and elongation index
Demolition waste aggregates	14.5	11.47	26.00
Mortar and brickwork waste[b]	-	-	-
Concrete waste aggregates	12.45	8.76	21.21
Standard code requirement[a]	-	-	30

[a]MoRTH specification (2001)
[b]Used as granular sub base hence not performed

From the above results we found that the combined flakiness and elongation index of demolition waste is 26.0% and that of concrete waste is 21.21% which is within permissible limits given for the materials for construction of water bound macadam roads by MoRTH specifications for roads and bridge works.

3.5.6 Standard CBR Value Tests

Laboratory CBR tests were conducted as per Indian standard code IS 2720: Part 16: 1987 Methods of test on Soils (Part-16) Laboratory determination of CBR, on the samples collected from the CDW aggregates. This is penetration test developed by the California Division of Highway as a method for evaluating the stability of soil sub-grade and other flexible pavements material. The test results are correlated with flexible pavements thickness required for highway and air fields.

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The following table gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%. The C.B.R. values are usually calculated for penetration of 2.5 mm and 5 mm. Generally the C.B.R. value at 2.5 mm will be greater that at 5 mm and in such a case/the former shall be taken as C.B.R. for design purpose. If C.B.R. for 5 mm exceeds that for 2.5 mm, the test should be repeated. If identical results follow, the C.B.R. corresponding to 5 mm penetration should be taken for design.

The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

Table-3.6 Results of soaked and un-soaked CBR test of CDW aggregates

Sample type	OMC (%)	CBR at OMC	CBR soaked
Demolition waste aggregates	10	72.5	68.6
Concrete waste aggregates	8	87.4	79.8
Mortar and brickwork waste aggregates	12	40.4	34.8

3.5.7 Test for particle size distribution and grading of CDW aggregates

Test for particle size distribution and grading of CDW aggregates were conducted as per IS 2720: Part 4: 1985, Methods of test for soils - part 4: grain size analysis and as per IS:2386-Part-1:1963 – Methods of test for aggregates Part-I- Particle size and shape. These curves are obtained for various types of waste materials which can be used as replacement of natural materials and then compared with the standard requirements as per MoRTH specifications of WBM and WMM for highways. The grading requirement was fulfilled in the trial case by combining the CDW particles, manually separated finer aggregates were used as screening and binder and coarser aggregates after manual crushing were used as course aggregates for the construction of water bound macadam base course.

The aggregates are is generally divided into different parts based on particle size the fraction of aggregates of size more than 100 mm are big boulders and needs to be crushed again, particles of size 11.2mm to 100mm are used in WBM layers along with screening and a graded mix of 0.6mm to 63 mm has been used as WMM. The grading requirement was fulfilled in the trial case by combining the CDW particles of size more than 11.2 mm and particles of size less than 11.2 mm were used as screening and binder while making the water bound macadam base course and base course.

The results of particle size distribution of demolition waste aggregate, concrete waste aggregate and mortar and brick work waste are given in table 3.6 and particle size distribution curve has been plotted in Fig - 3.1.

3.5.8 Determination of moisture content – dry density relation using standard Procter compaction test

Procter compaction test for determination of maximum dry density of CDW (i.e. particle size < 11.2 mm) Compaction characteristics i.e. optimum moisture content and maximum dry density of CDW is determined by standard Proctor test as per IS2720:part-7.This method covers the determination of the relationship between the moisture content and density of soils compacted in a mould of standard size with a 2.5 kg rammer dropped from a height of 30 cm.

Table-3.7 Particlesize distribution of various CDW materials

IS Sieve (mm)	Demolition waste	Mortar and brick work waste	Concrete waste	50:50 Mix of mortar waste & concrete waste
100	98.92	100.00	100.00	100.00
90	98.59	99.40	99.48	99.50
63	71.42	96.30	92.35	94.91
45	49.01	89.30	76.11	85.81
22.5	21.65	79.20	50.42	76.54
11.2	13.53	67.20	15.84	54.09
4.75	8.01	52.30	6.71	31.62
2.36	2.92	28.30	2.31	14.86
0.425	1.19	12.25	1.36	5.29
0.075	0.87	1.80	1.15	1.10
0	0.00	0.00	0.00	0.00

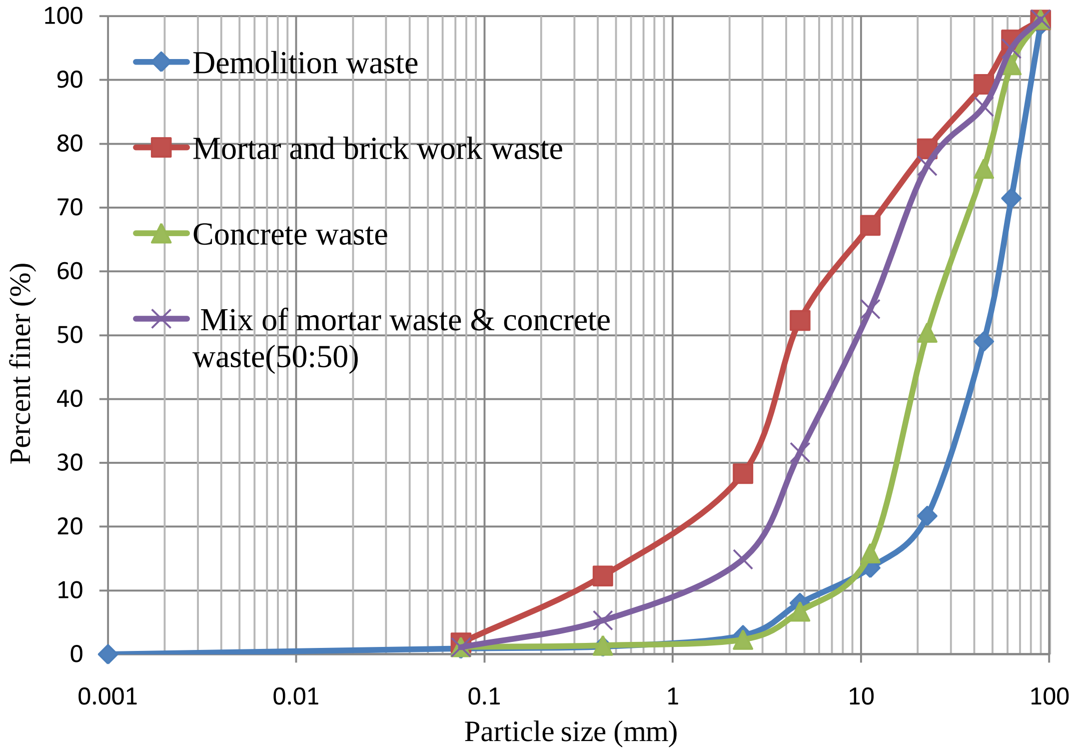


Fig - 3.1 Gradation of various recycled aggregates

The compaction of soil by rolling etc. is best performed if we add certain amount of water during compaction less than or more than that quantity of water will not help us to achieve maximum compaction or maximum dry densityof compacted soil. The most beneficial water content is known as optimum moisture Content.

Table-3.8 Results of standard Procter density test

Water content	Demolition waste aggregates	Concrete waste aggregate	Mortar and brickwork waste
%	kN/m^3	kN/m^3	kN/m^3
6	18.5	19.6	15.1
8	19.1	21.2	15.3
10	20.6	20.8	15.6
12	20.1	20.6	16.1
14	18.4	20.2	15.6

Similar tests were carried out on two more samples and we found that maximum dry density varies from 20.5 to 21.5 kN/m^3at 8-12% water content. But this test was performed on aggregates and fines passing through 11.2 mm sieve and hence cannot be taken as standard for the base course and sub base course as we used aggregates up to 100 mm size during construction of pavements. However this can be treated as reference for compaction of pavement during construction.

3.6 Field investigations of sub base and base course of pavements constructed using CDW aggregates

In this section testing on pavement has been carried out. The two field tests that were carried out are density-moisture testing and plate load test for settlement of pavement. This is further correlated with the theoretical requirement and failure criteria's as laid down in the various IRC codes. Discussion and analysis of the field test has been presented in this work in next stage.

CHAPTER – 4

ANALYSIS AND DISCUSSION OF RESULTS OF LABORATORY EXPERIMENTAL PROGRAM

This chapter presents the analysis and discuss the results obtained in laboratory tests carried out for characterisation of CDW aggregates to be used in sub base and base course of flexible pavements. All laboratory experiments were carried out in Delhi Technological University, Delhi and also at the site of construction at Crossings Republic, Ghaziabad. The results of experimentation program are compared with the standard requirement of aggregates used for flexible pavement construction given in specification. If the results obtained does not fulfil the requirements than the impact need to be analysed in view of its effect on pavements. We can compare the results obtained in the following two broader requirements.

Physical properties such as specific gravity, shape i.e. flakiness and elongation index, water absorption.

Engineering properties i.e. gradation of aggregates, Los Angles abrasion value, aggregate crushing value, CBR value and density moisture relationship.

4.1 Specific gravity

The MoRTH specification (2001) has not specified any particular value of specific gravity but an acceptable limit is 2.55 to 2.75. We have found that the recycled construction and demolition waste has specific gravity values vary from 2.54-2.67. Hence these aggregates will give almost same density of compacted base course as that of the natural mineral aggregates. The comparative specific gravity values have been plotted in fig-4.1. From this comparison we found that the specific gravity of all the different types of recycled construction and demolition waste aggregates is within the permissible range and hence acceptable for the construction of base and sub base course of flexible pavements.

4.2 Water absorption

We have tested all types of recycled construction and demolition waste aggregates for 24 hours water absorption and found that it was minimum for the concrete waste aggregates and maximum for the mortar and brick work waste aggregates. We also found that the water absorption in all the cases is more than the acceptable limit of 2% as per MoRTH specification (2001). The comparative water absorption values of CDW aggregates and MoRTH requirements for aggregate have been plotted in fig-4.2. Although all the recycled materials were having water absorption more than the acceptable limit but we found that this excess water absorption has not created any negative effect on strength properties of base and sub base course as all the materials were having zero cohesion and plasticity. Tests on the aggregates showed that the recycled concrete aggregates have lower specific gravity and higher absorption capacity than the original crushed granite aggregate. (Ravindrarajah 1985)

4.3 Los Angeles abrasion value

In the laboratory testing we found that the Los Angeles abrasion value of demolition waste was varying between 38.5 to 41.3 and has average value of 39.66 where as the values for concrete waste aggregates varies from 35.7 to 37.2 and average value comes out as 36.46. As per the MoRTH specification (2001) the Los Angeles abrasion value for aggregates for water bound macadam is 40% and also for wet mix macadam it is 40%. The comparative Los Angeles abrasion values of CDW aggregates and MoRTH requirements have been plotted in fig-4.3. From the comparison we found that both the demolition waste as well as concrete waste aggregates fulfil the code requirements and hence can be used in the construction of sub base and base course of flexible pavements.

Los angles value of recycled aggregates is slightly higher than the crushed stone because the aggregates of these aggregates were having mortar adhered with them and it was not possible to fully remove the mortar from surface of aggregates.

Test of Mortar and brickwork waste was not performed as aggregate size small and this waste was used as granular sub base course (GSB).

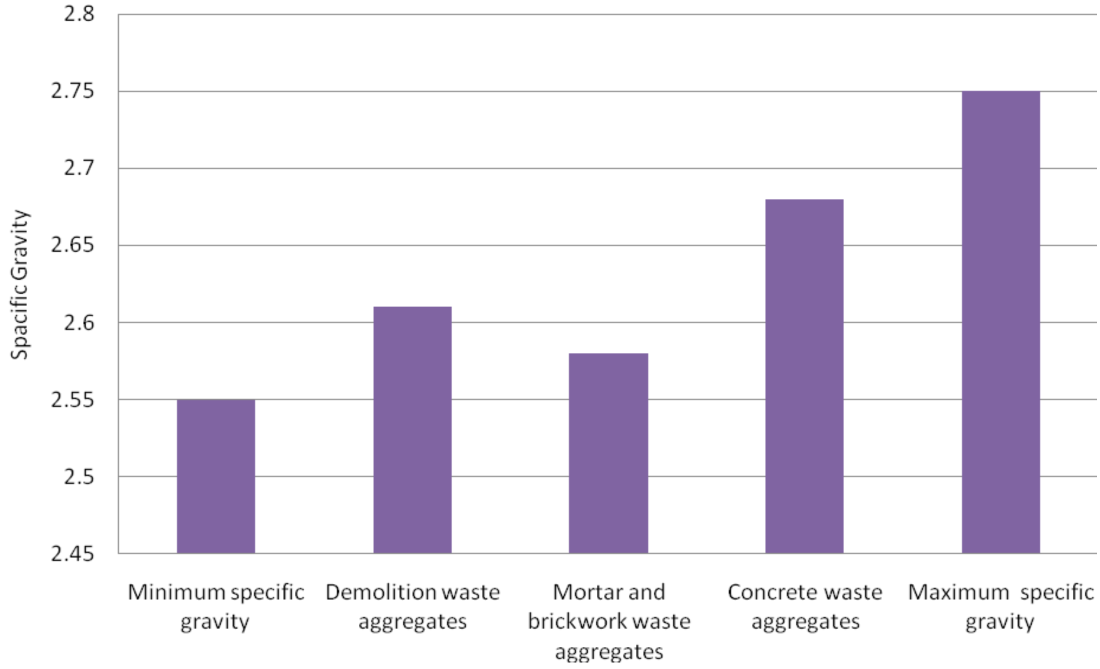


Fig-4.1 Comparison of specific gravity of recycled aggregates with recommended values

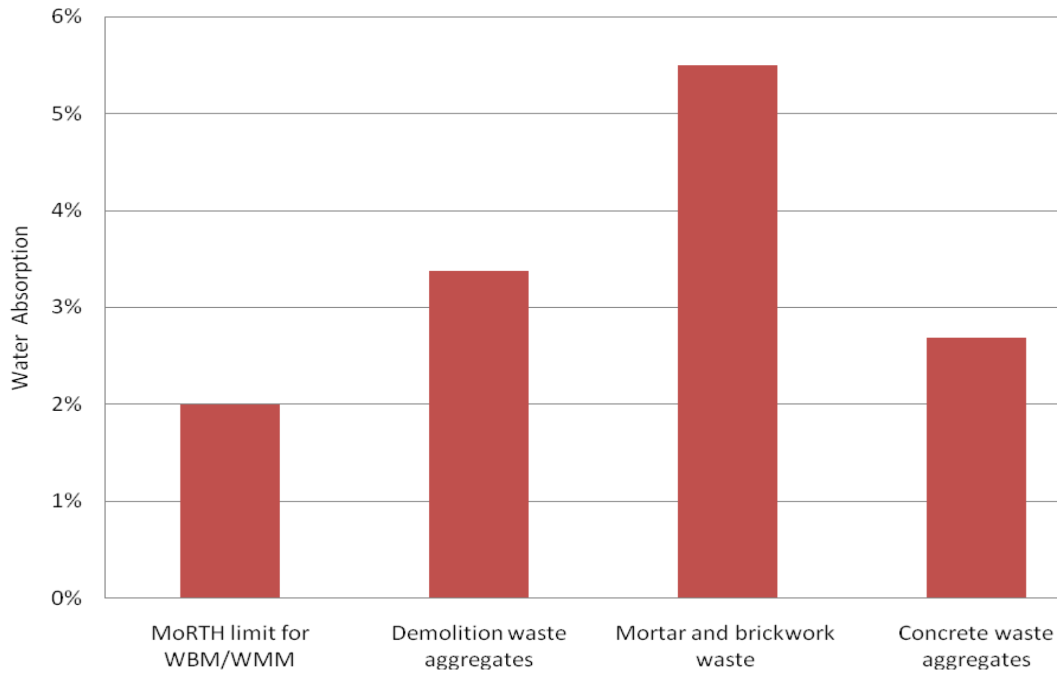


Fig-4.2 Comparison of water absorption of recycled aggregates with acceptable value

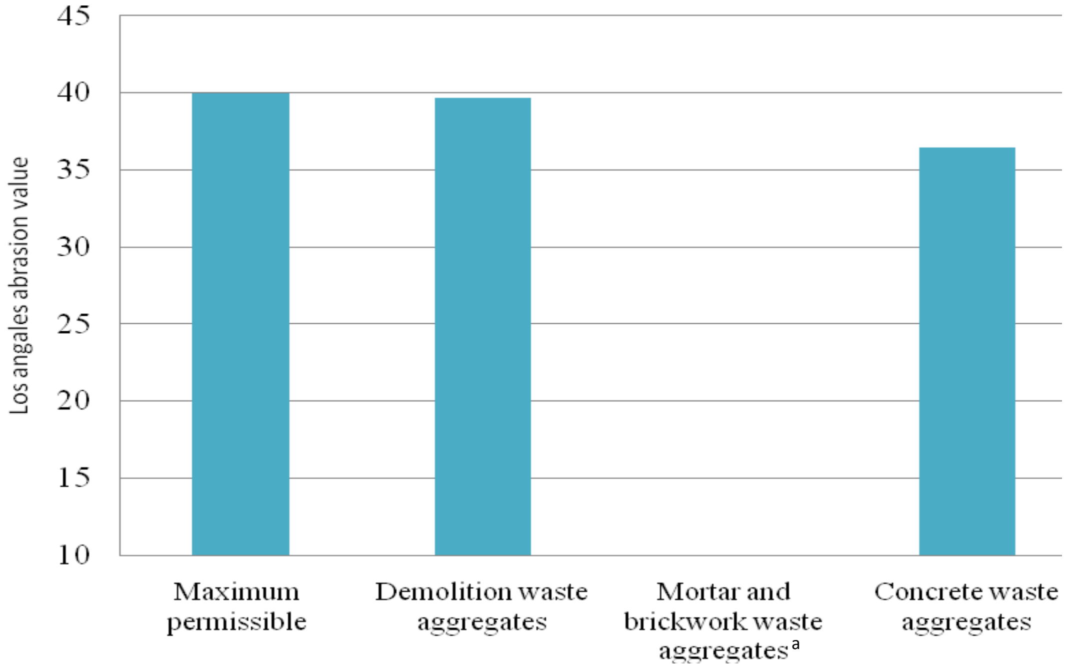


Fig-4.3 - Comparison of Los Angeles abrasion value with recommended value
[a] used as granular sub base hence not required

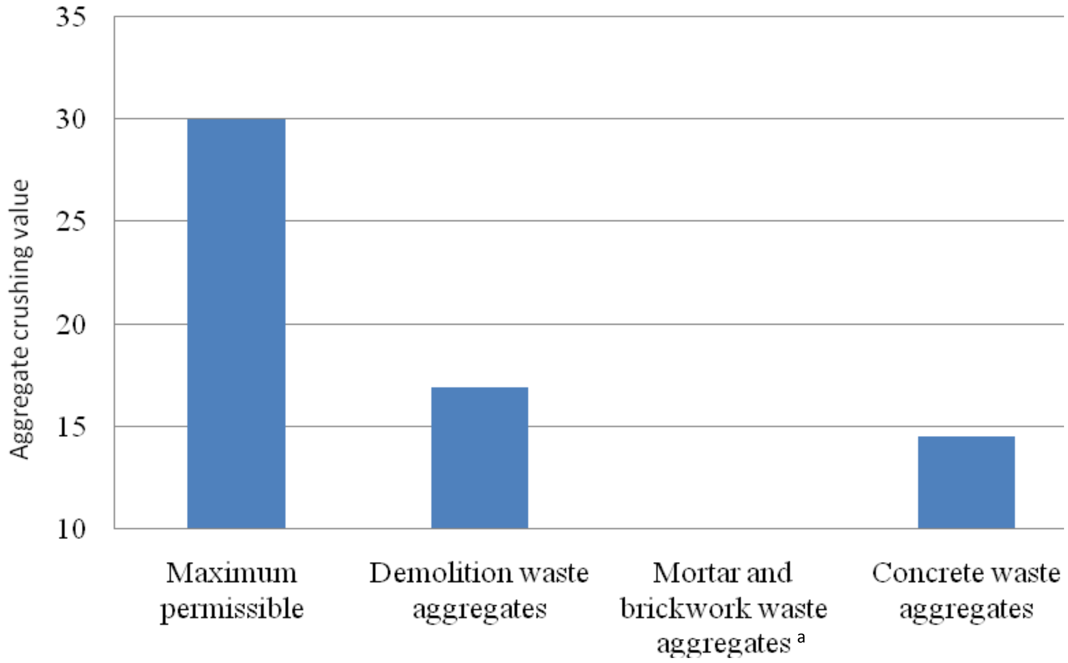


Fig-4.4 - Comparison of aggregate crushing value with recommended value
[a] used as granular sub base hence not required

4.4 Aggregate crushing value

In the laboratory testing we found that the aggregate crushing value of demolition waste was varying between 13.5 to 19.48 and has average value of 16.89 where as the values for concrete waste aggregates varies from 14.26-14.8 and average value comes out as 14.53. As per the MoRTH specification (2001) the aggregate crushing value for aggregates for water bound macadam is 30% and also for wet mix macadam it is 30%. The comparative aggregate crushing value of CDW aggregates and MoRTH requirements have been plotted in chart-4.4. When the aggregates taken for aggregates crushing value the aggregates are comparatively clean and hence the result found is less than maximum permissible. Hence we found that both the demolition waste as well as concrete waste aggregates fulfil the code requirements and hence can be used in the construction of sub base and base course of flexible pavements.

Test of Mortar and brickwork waste was not performed as aggregate size small and this waste was used as granular sub base course (GSB)

4.5 Combined flakiness and elongation index

In the laboratory testing we found that the combined flakiness and elongation index of demolition waste was varying between 24.88-28.22 and has average value of 26.00 where as the values for concrete waste aggregates varies from 20.44-21.66 and average value comes out as 21.21. As per the MoRTH specification of roads and bridges the combined flakiness and elongation index for aggregates for water bound macadam is 30% and also for wet mix macadam it is 30%. Hence we found that both the demolition waste as well as concrete waste aggregates fulfil the code requirements and hence can be used in the construction of sub base and base course of flexible pavements. Test of Mortar and brickwork waste was not performed as aggregate size small and this waste was used as granular sub base course (GSB).

4.6 CBR value

During the experimental testing program we have found that the CBR value of all the three types of construction and demolition waste aggregates is more than the minimum required for the granular sub base materials. The CBR value of demolition waste and concrete waste aggregates are sufficiently high enough to be used as base course of flexible pavement. Following chart shows the CBR values obtained with respect to the IRC standard requirement of granular sub base.

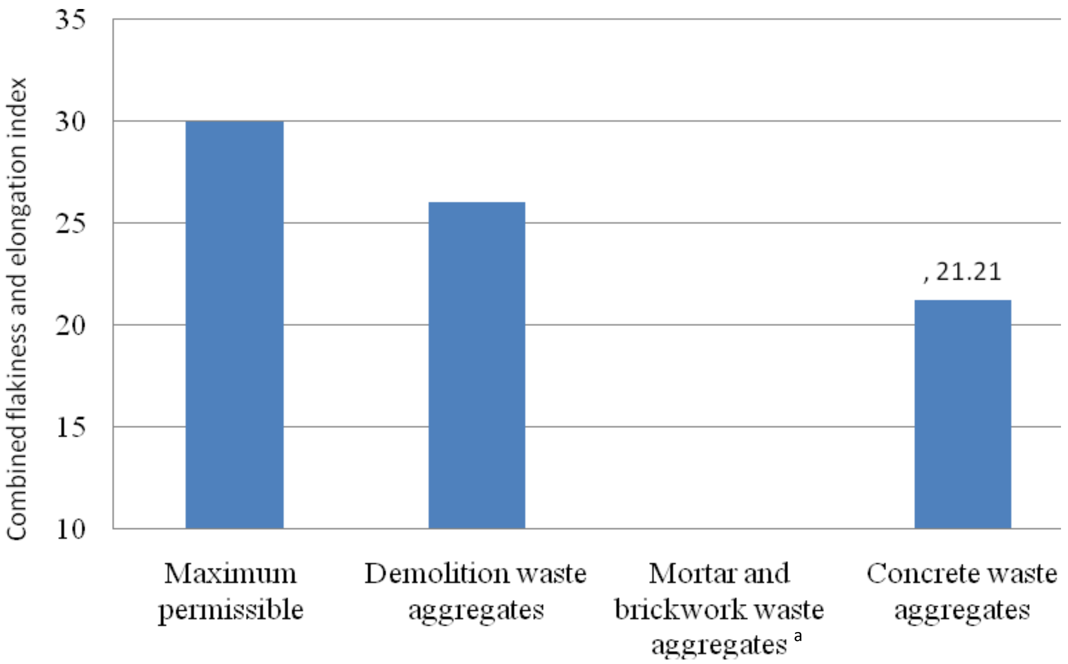


Fig - 4.5 Comparison of combined flakiness and elongation index with IRC requirement
[a] used as granular sub base hence not required

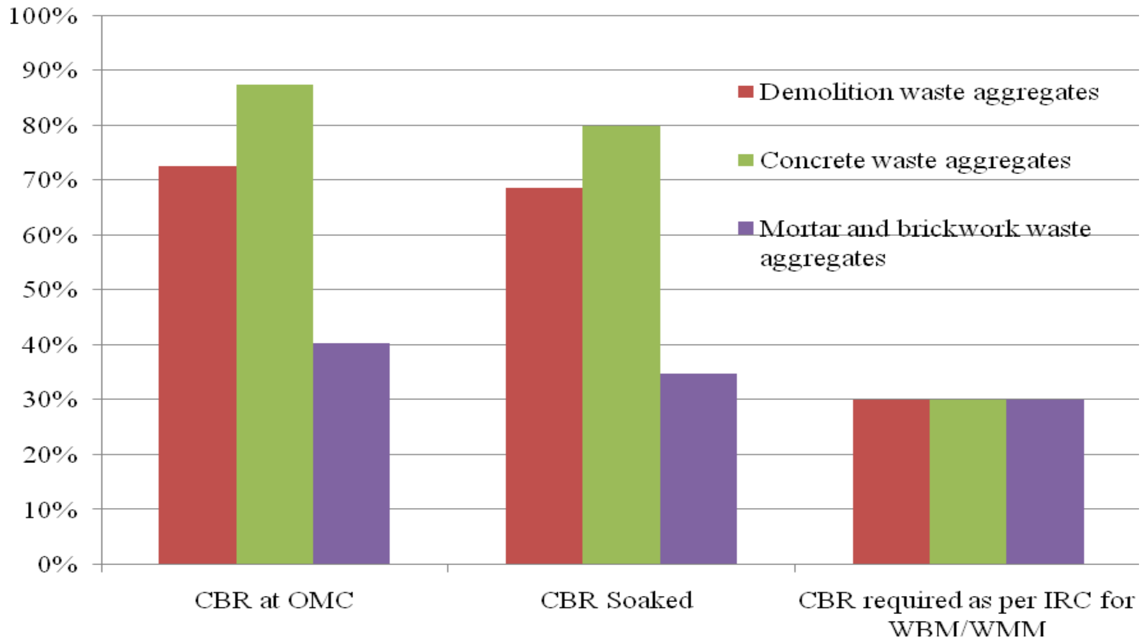


Fig- 4.6 Comparative CBR values of various recycled materials

4.7 Comparison of results of Procter compaction maximum dry density and moisture content

Compaction characteristics i.e. optimum moisture content and maximum dry density (MDD) of demolition waste aggregates, concrete waste aggregates and mortar and brickwork waste aggregates has been determined by standard Proctor test as per IS2720: part-7. A moisture content-dry density plot for demolition waste aggregates, concrete waste aggregates and mortar and brickwork waste aggregates in present case along with the similar test data of course sand is plotted in the following chart.

The density of compacted pavement achieved is also in the range of density of crushed stone water bound macadam and wet mix macadam. This is pertinent to note here that these test were performed on aggregates and fines passing through 11.2 mm sieve and hence cannot be taken as standard for the base course and sub base course as we used aggregates up to 100 mm size during construction of pavements. However this can be treated as reference for compaction of pavement during construction.

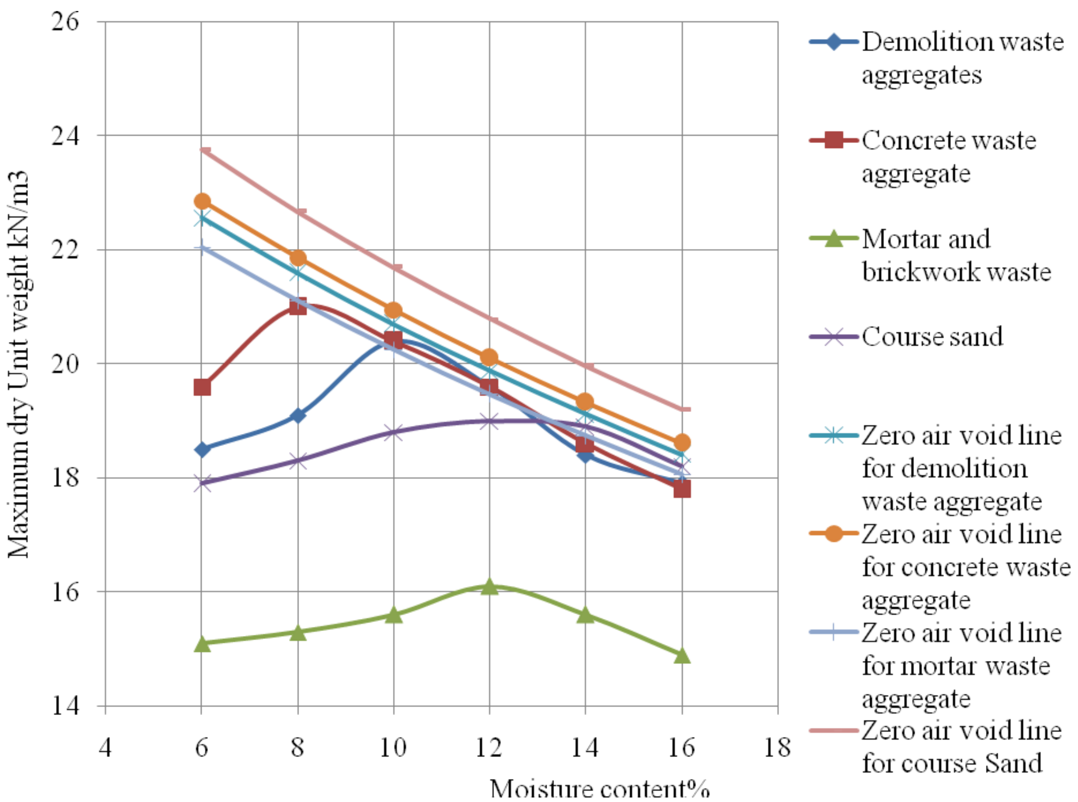


Fig- 4.7 Dry density - moisture content curve for various recycled materials

4.8 Grading of aggregates

The grading is the most important engineering property in regards to strength and density of finally compacted base course of flexible pavement. This is the property which we can change as per the requirements to achieve maximum dry density and hence the load carrying capacity of pavements.

In the initial phase of this work we were not having any mechanical portable or stationary crusher and grading unit and hence we have carried out this work manually and hence it has some non standard grading of aggregate. Secondly some of the lumps specially mortar lumps of plaster and flooring were very week as course aggregates and hence got crushed during the rolling of pavement surface with the help of vibratory rollers. We have noted that this inherited problem of demolition waste has not resulted in any drawback in terms of strength or compaction of the pavement.

4.8.1 Comparison with IRC standard requirements of water bound macadam grading

Following chart shows the grading of various types of recycled material i.e. demolition waste aggregates, concrete waste aggregates, plaster and brickwork waste aggregates and a mixture of 50:50 of concrete waste aggregates and plaster and brickwork waste vis a vis IRC standard requirements of water bound macadam grading.

4.8.2 Comparison with IRC standard requirements of granular sub base material grading

The finer portion of the demolition waste and almost total mortar and brick work waste was very close in IRC requirements of physical and engineering properties and grading of granular sub base material. Following chart shows the grading curves for recycled materials and three grading requirements of granular sub base.

Table-4.1 Gradation of recycled aggregates vs IRC requirement for WBM and WMM

IS sieve (mm)	WBM[a] grading-I	WBM[a] grading-II	WBM[a] grading-III	WMM[a] grading	Demolition waste[b]	Mortar and brick work waste[b]	Concrete waste[b]	50:50 mix of mortar waste & concrete waste[b]
100	100	100	100	-	98.92	97.10	100.00	100.00
90	80-100	100	100	-	98.59	95.16	99.47	99.50
63	55-90	70-100	100	100	71.42	79.56	92.26	94.86
45	35-65	50-80	65-95	95-100	49.01	68.56	75.83	85.66
22.5	25-55	40-65	50-80	60-80	21.65	60.10	49.84	76.28
11.2	20-40	30-50	40-65	40-60	13.53	48.25	14.86	53.58
4.75	5-10	15-25	20-35	25-40	8.01	28.25	5.62	30.87
2.36	3-10	3-10	3-10	15-30	2.92	12.12	1.17	13.92
0.425				8-22	1.19	1.81	0.21	4.24
0.075				0-8	0.87	0.60	0.25	0.50

[a] MoRTH specification (2001) [b] Present work

Table-4.2 Gradation of recycled aggregates vs IRC requirement for GSB

IS sieve (mm)	GSB grading-I[a]	GSB grading-II[a]	GSB grading-III[a]	Demolition waste[a]	Mortar and brick work waste[b]	Concrete waste[b]	Mix of mortar waste & concrete waste (50:50)[b]
100				98.92	97.10	100.00	100.00
90				98.59	95.16	99.47	99.50
63	100	-	-	71.42	79.56	92.26	94.86
45	-	100	-	49.01	68.56	75.83	85.66
22.5	55-75	50-80	100	21.65	60.10	49.84	76.28
11.2	-	-	-	13.53	48.25	14.86	53.58
4.75	10-30	15-35	25-45	8.01	28.25	5.62	30.87
2.36	-	-	-	2.92	12.12	1.17	13.92
0.425	-	-	-	1.19	1.81	0.21	4.24
0.075	<10	<10	<10	0.87	0.60	0.25	0.50

[a] MoRTH specification (2001) [b] Present work

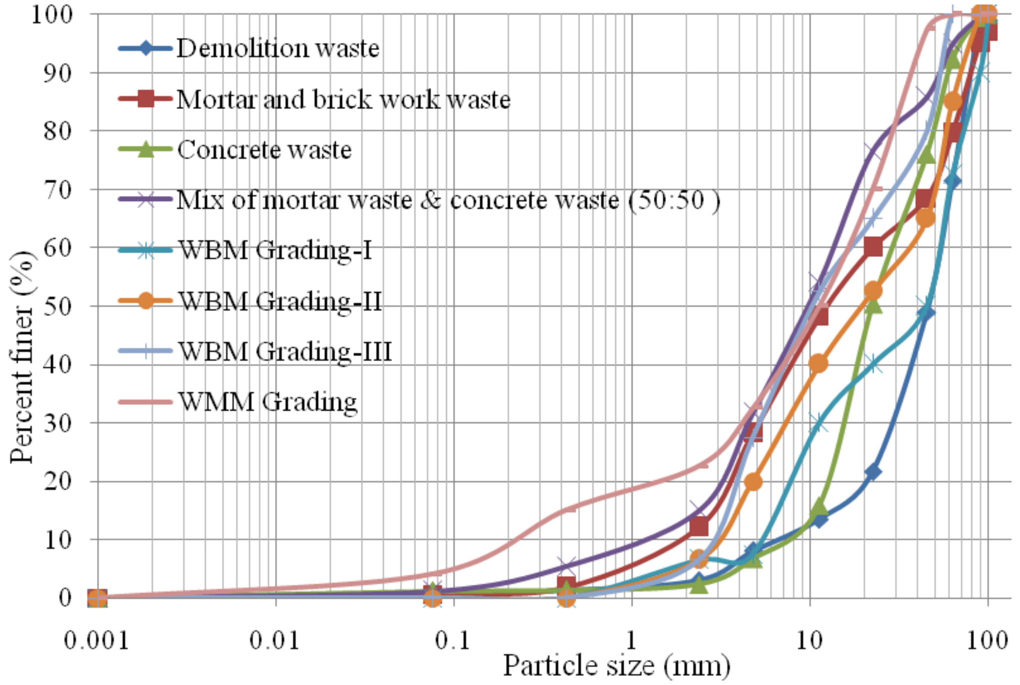


Fig- 4.8 Gradation of recycled aggregates vs IRC requirement for WBM and WMM

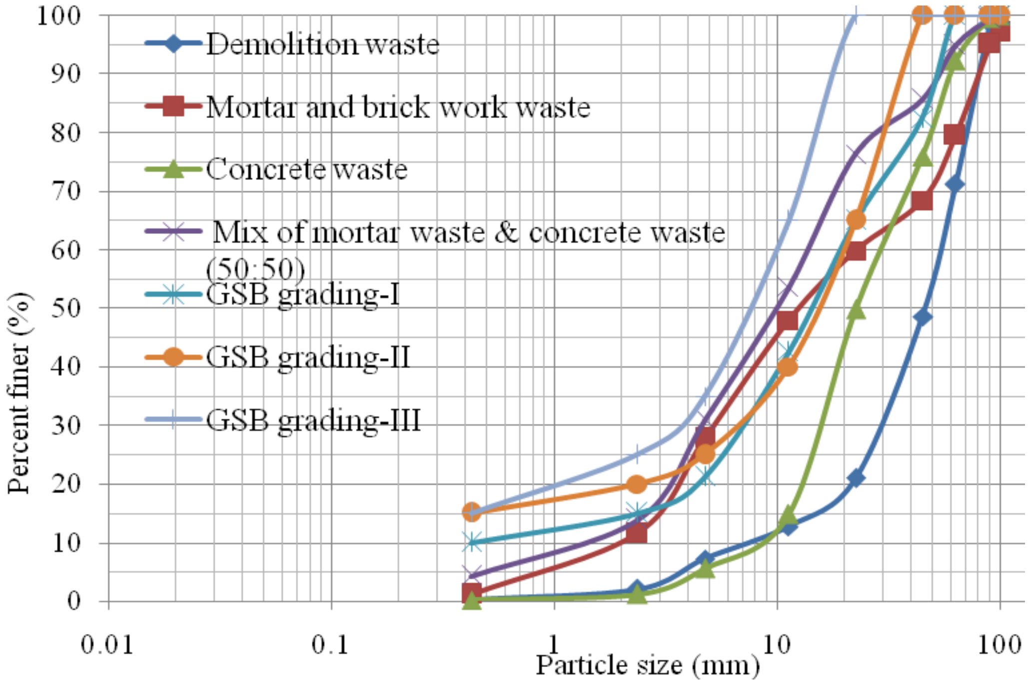


Fig- 4.9 Gradation of recycled aggregates vs IRC requirement for GSB

From the above table it is clear that the grading of recycled CDW is finer than the grading of crushed stone course aggregates used in the water bound macadam. But it is courser than the aggregate grading required in water mix macadam. Hence the recycled CDW is a good alternative material for the road construction. Moreover by proper planning and mixing of some individual size of aggregates it can be same as that of the WMM required as per MoRTH specification.

4.9 Comparison of test results with the similar works on recycled materials

A comparison of physical properties such As specific gravity, Los Angeles abrasion values and water absorption has been made between the values of C&D waste aggregates with that of Crushed concrete aggregates, crushed stone aggregates and gravel as found by Park(2003).

Table-4.3 Comparison of physical properties CDW and natural aggregates

Tests	Crushed stone aggregates[a]	Gravel aggregates[a]	Demolition waste aggregates[b]	Concrete waste aggregates[b]	Mortar and brickwork waste aggregates[b]
Specific gravity	2.62	2.64	2.61	2.68	2.58
Water absorption %	1.8	1.3	3.38	2.69	5.50
Los Angeles abrasion %	31.2	--	39.66	36.46	-
Aggregate crushing Value %	--	--	16.89	14.43	-
Combined flakiness and elongation index	-	-	26.00	21.21	-
CBR value			72.5	87.4	40.4
Proctors density at OMC kN/m^3	2.05	--	2.06	2.12	1.61
Optimum moisture content	11	--	10	8	12

[a] Park(2003)
[b] Present work

A comparison of CBR value of CDW aggregates consists of concrete, mortar and broken bricks that of only crushed concrete and specified mixes, which have been carried out by Bachir Melbouci (2010), reveals that the CDW has less CBR value as compared the crushed concrete aggregates.

A comparison has been made between CBR values for the CDW aggregates and Concrete aggregates with or without additions. It indicates that CDW aggregates are having less CBR as compared to crushed concrete aggregates with or without additions.

Table-4.4 Comparisons of CBR test results

Description of materials	CBR at OMC	CBR soaked
Concrete aggregates (CG)[a]	85	128
CG + bricks[a]	87	83
CG + 10% sand[a]	93.5	93
CG + 10% cement[a]	139	>150
demolition waste aggregates[b]	72.5	68.6
concrete waste aggregate[b]	87.4	79.8
Mortar and brickwork waste aggregate[b]	40.4	34.8

[a] Tests conducted by Bachir Melbouci (2009)

[b] Present work

4.10 Design of flexible pavement based on results of experimental program

The pavement has been designed on the bases of results obtained in laboratory test results. The design method used is IRC 37: 2001 recommended California bearing ratio design charts for flexible pavement designs. This trial stretch has then been examined for a period of 5 years.

The trial stretch was the main entrance two lane two way traffic road of a new township. There was no traffic as it was a new road but has been designed for anticipated traffic of 15 MSA as large amount of construction have been planned. It has been presumed that since it is going to be main entrance of township under construction and hence in next five years there will be incoming traffic of heavy commercial vehicle carrying building material and dumpers on an average 250 trucks per day and outgoing traffic of 250 earthen dumpers and trucks.

4.10.1 Assumption of design variables and results obtained from laboratory testing

Initial Commercial vehicle per day (CVPD) is taken as 500 numbers in both directions. We have taken vehicle damage factor from IRC 37:2001 table -1 for CVPD more than 150 but less than 1500 for plain and rolling terrain as 3.5. It has been presumed that vehicle in both direction are equal and increase in traffic is taken as 20% for first five years and 6% in next 10 years to calculate total design traffic.

The CBR value of stabilised soil sub-grade has been tested in laboratory and average of three samples found as 8% which is taken for design of pavement. The lower layer or sub base is laid with fine CDW aggregates having size less than 11.2 mm for which CBR results obtained in laboratory test as 64.8%. The upper layer or base course is made of aggregates of size more than 11.2mm having CBR 68.5%, but the upper layer is then wet rolled with aggregates of less than 11.2 mm as filler hence an average CBR is taken as 66% for design purpose.

Hence:

Design Period	=	15 years
Initial traffic	=	500 vehicles/day in both direction
Rate of growth of Traffic	=	20% for first 5 years and than 8% for next 10 years
CBR (Soaked) of sub grade	=	8%
CBR (Soaked) of sub base	=	64%
CBR (Soaked) of base course	=	66%
Vehicle damage factor	=	3.5 as per IRC37:2001 Table-1 for 1500>CPVD>150
Distribution of commercial vehicles over carriageway for two lane single carriageway	=	0.75 as per IRC37:2001

4.10.2 Calculation of design traffic

The design traffic is termed as cumulative number of standard axles to be carried in its design life. This can be calculated as

$$N= 365*[(1+r)^{n}-1]*A*D*F/r$$

Where,

N	=	Cumulative standard axle load to be carried in the design life.
A	=	Initial traffic in the year of construction in terms of CVPD
D	=	Lane distribution factor
F	=	Vehicle damage factor
N	=	Design life in years
r	=	rate of growth of traffic

Calculation of design traffic = Traffic Carried in first 5 years with annual increase of 20% + Traffic carried in next 10 years with annual increase of 8%

Traffic in first 5 years N_1 = $365*[(1+0.20)^5 -1]*500*0.75*3.5 / 0.2$

= 3564992 Nos.

For next 10 years

The initial traffic after 5 years will be = $500(1+0.2)^5$

= 1244 vehicles/day

Now traffic in next 10 years

N_2 = $365*[(1+0.0.08)^{10} -1]*1244*0.75*3.5 / 0.0.08$

= 365*0.85*1244*0.75*3.5/0.08

= 12677897 Nos

So total Traffic = $N_1 + N_2$

= 3564992 + 12677897

= 16.24×10^6

= say 16.25 msa

Now we can use pavement design catalogues for sub grade having CBR = 8%

The chart has been used from IRC37:2001

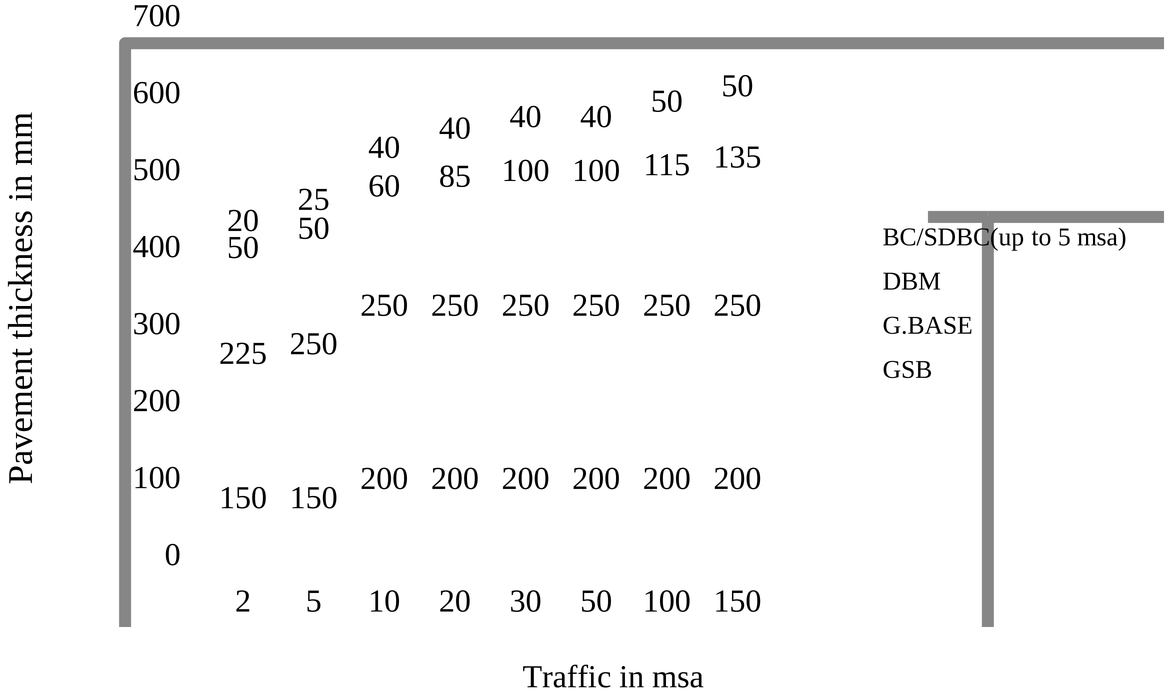


Fig - 4.10 Pavement layer thickness – CBR 8%

Thickness of sub base course	=	200 mm
Thickness of base course	=	250 mm
Thickness of bituminous concrete	=	75 mm
Thickness of DBM	=	40 mm

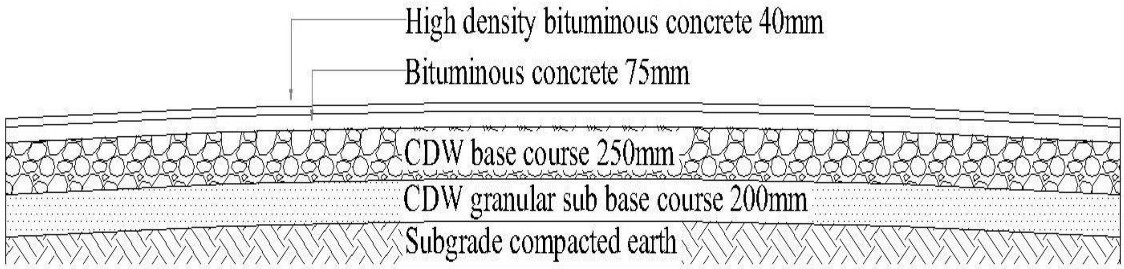


Fig – 4.11 Designed pavement layer thickness using CDW aggregates

CHAPTER – 5

CONSTRUCTION OF TRIAL STRETCH, FIELD TESTING AND PERFORMANCE EVALUATION

This chapter describes detailed method of construction of trial stretch and field tests performed on the trial pavement. The tests for density- moisture content of compacted base course and load -settlement tests by plate load test were conducted to assess the load carrying capacity of pavement. Than the road was overlaid and finished with bituminous layers. The visual inspections were conducted to assess the damage to the road under traffic for a period of 7 years.

5.1 Construction of trial stretch

The CDW obtained from Ganga and Yamuna multi-storey towers in Vaishali Ghaziabad were brought at the Construction Site namely Crossing Republik Township at Ghaziabad and the material was used for construction of trial stretch of 3.0 km length. The road crust was designed as per IRC: 37: 2001 as given in cheptar-5. However, the base course and sub-base course material was replaced by CDW materials.

The trial stretch has been constructed as per the following details and but with manually broken CDW aggregates and performance evaluation has been carried out for a period of 5 years. This road was on embankment of height 1.2 to 1.8 meter from natural ground level and hence the sub-grade was prepared in 300mm layers of good quality local earth compacted by vibratory rollers with 95-98% of relative density. A cross slope of 2% has been provided in the sub grade.

1. Firstlayer of manually separated fine aggregates from debris received from the demolition site of loose thickness 225-250 mm compacted to achieve 95-98% relative density with vibratory rollers. The compacted thickness of this layer was 200-220 mm approximately. This layer was a replacement of standard granular sub base course of pavement.
2. Second layer of 125-150mm loose thickness of manually broken bricks and concrete aggregates of size less than 100mm and fine aggregates were used as filler and binder. The layer has been compacted firstly in dry state with vibratory rollers and then after spreading finer aggregates and silty sand with wet rolling to

achieve 95-98% relative density. The compacted thickness of this layer was 120-130 mm approximately.

3. Third layer of 125-150 mm loose thickness of manually broken bricks and concrete aggregates of size less than 100mm and fine aggregates were used as filler and binder. The layer has been compacted to achieve 95-98% relative density with 10 ton vibratory rollers. The compacted thickness of this layer was 100-120 mm approximately. Hence a total compacted thickness of approximately 450mm has been achieved in three layers. The grading of this material is not of very high standard as the materials available from demolition waste have been used only by manual separation and manual crushing at site.
4. The first bituminous layer of 50mm bituminous concrete made with new aggregates has been laid after scrapping the surface to remove loose soil and application of tack coat of hot bitumen. This surface has then been opened for traffic for first six months to analyse the behaviour and performance of pavement. After six months we found that there is no sign of any failure accept few small pot holes, which have been repaired.
5. After passage of trial time of six months to check the strength of base course we have laid another bituminous concrete layer of 50mm thickness and HDBC layer of 40mm thickness after cleaning with compressed air and application of tack coat.
6. The next bituminous concrete layer of 50 mm and wearing course of 40mm thick of high density bituminous concrete were laid after passage of six month traffic and repairs of pavement of all pot holes occurred during the period.

In these six month period we have decided to construct all roads of Crossings Republic with CDW and all roads of approx. total length of 20 lane km were constructed in the Crossings Republik in next two years using construction and demolition waste.

5.2 Field tests for unit weight- moisture content of compacted base course

The specific gravity of crushed rock aggregates is in the range of about 2.55–2.75 and will produce the sub base and base course of flexible pavements of densities usually in the range of about 19.00 –20.50 kN/m^3.

The field tests for density- moisture content of compacted base course constructed using CDWhas been carried out using sand replacement method and water content of the sample has been tested as per IS 2720: Part 2: 1973.The bulk unit weight of pavement was found varying between 21.6kN/m^3 to 22.3kN/m^3 at an water content of 9.5% to 12.5%. Thus we found that the dry unit weight of pavement varies between 19.2kN/m^3 to 20.4kN/m^3. This is well within the same range as that of the pavement constructed using natural materials.

5.3 Determination of Relative Compaction

Relative compaction (R_c) has been determined for assessing the compaction achieved in the base course and sub-base course as ratio of dry density achieved in the base course to the maximum dry density achieved in the laboratory in standard compaction test.

The values of relative compaction achieved in the field are given in the Table 6.2. The relative compaction obtained in the field trial at two locations was less than 95% which may be due to poor compaction control that could be achieved in the field.

Table-5.1 Results of relative compaction test

Test No.	Field density using sand replacement method (kN/m^3)	Relative compaction (%)
1	20.37	95.50
2	19.91	93.32
3	19.80	92.81

5.4 Plate load test for determination of load bearing capacity of sub grade and WBM pavement

For determination of bearing capacity the plate load tests were performed on the compacted sub-grade surface as well as over the compacted base course of road. These tests were performed to determine the influence of laying the 200mm granular sub base and base course of two layers of water bound macadam of thickness 125mm made of recycled CDW aggregates over the compacted soil sub grade.

For this we have performed six tests on sub grade, two each on plate size 750mmx750mm, 600mmx600mm and 300x300mm and six tests were performed over the surface of top layer of water bound macadam base course just before laying of bituminous concrete. In case of sub grade a seating load of 50 kN/m2 were applied before starting of plate load test and in case of test on WBM surface a seating load of 100 kN/m2 were applied. The load settlement curves of both have been platted and compared and analysed in view of load on pavements.

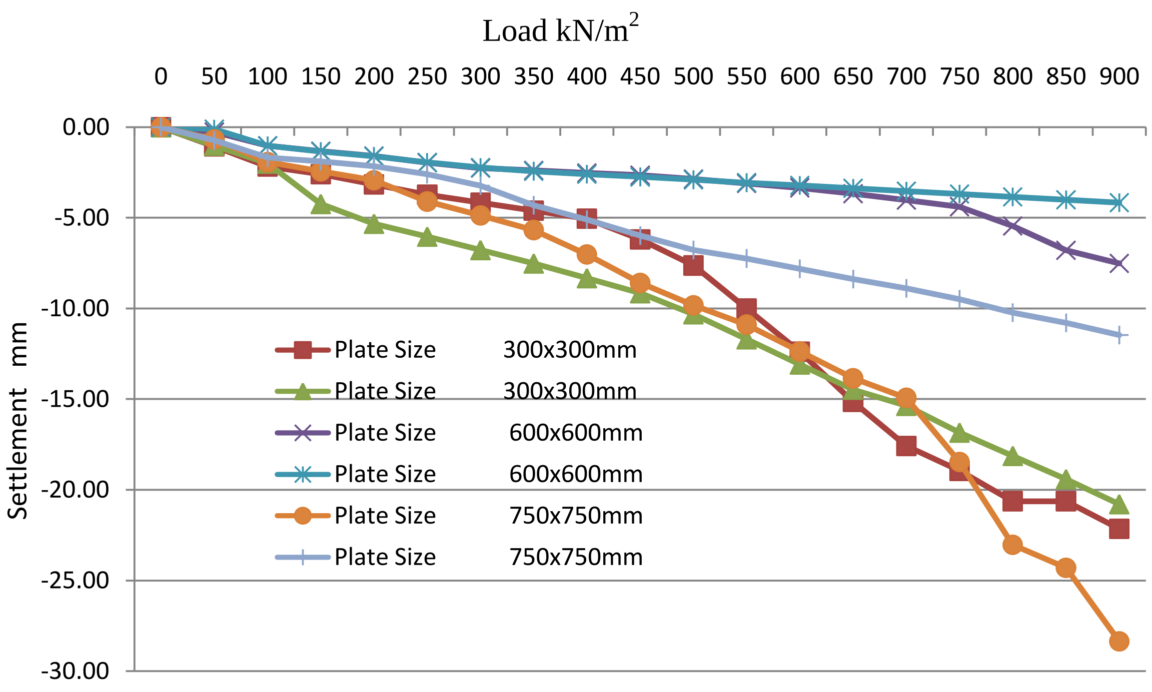
Table- 5.2 Load settlement data of plate load tests performed over the compacted sub grade

Load	Plate size 300x300mm		Plate size 600x600mm		Plate size 750x750mm	
kN/m^2	Settlement mm	Settlement mm	Settlement mm	Settlement mm	Settlement mm	Settlement mm
0	0.00	0.00	0.00	0.00	0.00	0.00
50	-1.06	-1.02	-0.27	-0.11	-0.67	-0.73
100	-2.17	-2.00	-1.02	-1.02	-1.93	-1.67
150	-2.59	-4.23	-1.32	-1.33	-2.43	-1.88
200	-3.15	-5.32	-1.58	-1.60	-2.93	-2.15
250	-3.72	-6.03	-1.95	-1.94	-4.10	-2.59
300	-4.16	-6.77	-2.25	-2.22	-4.86	-3.23
350	-4.60	-7.51	-2.38	-2.42	-5.67	-4.30
400	-5.04	-8.32	-2.52	-2.58	-7.02	-5.09
450	-6.19	-9.15	-2.65	-2.73	-8.59	-5.98
500	-7.62	-10.31	-2.85	-2.89	-9.82	-6.77
550	-10.00	-11.69	-3.10	-3.05	-10.89	-7.24
600	-12.38	-13.08	-3.34	-3.21	-12.37	-7.81
650	-15.14	-14.47	-3.67	-3.36	-13.85	-8.37
700	-17.58	-15.36	-4.02	-3.52	-14.93	-8.89
750	-18.94	-16.84	-4.38	-3.68	-18.46	-9.49
800	-20.62	-18.12	-5.45	-3.83	-23.03	-10.23
850	-20.62	-19.40	-6.79	-3.99	-24.31	-10.79
900	-22.14	-20.78	-7.51	-4.15	-28.36	-11.46

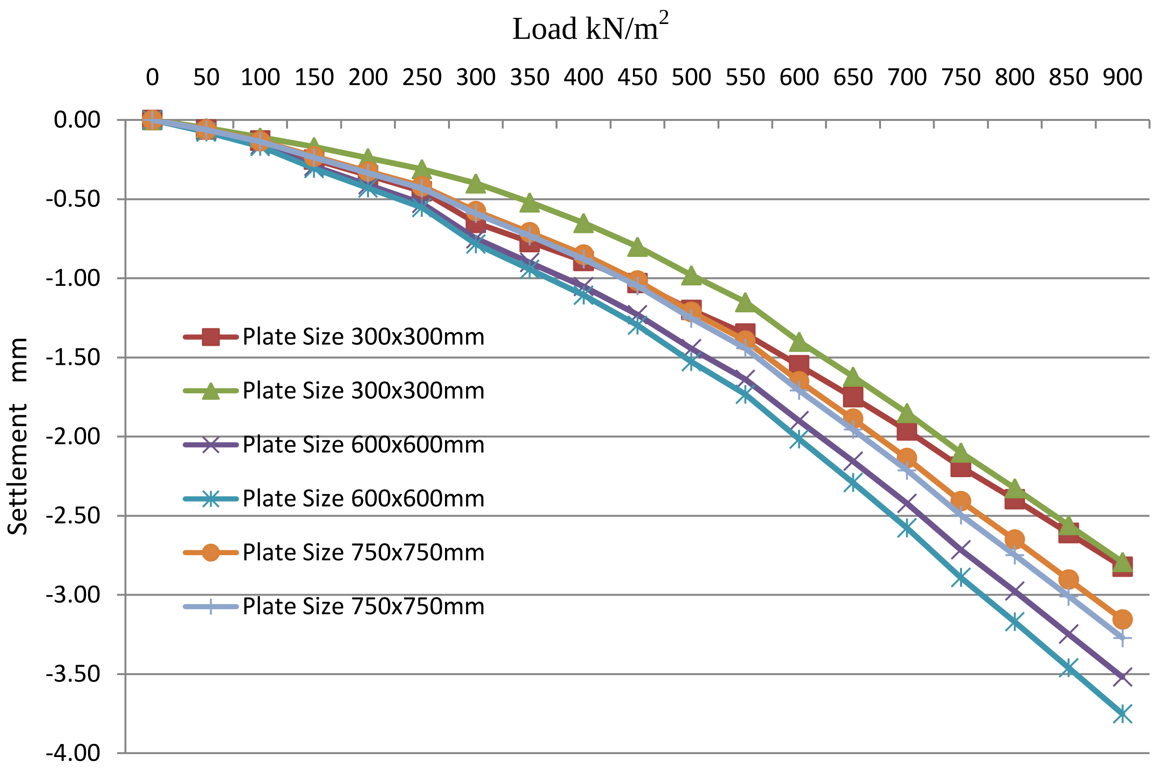
From the analysis and of load settlement curves we found that the effect of load on WBM surface is drastically reduced and the its load carrying capacity has been increased significantly. IRC code allow the maximum axle load on pavement of 82 kN and Indian motor vehicle act allow single axle load as 110 Kn and tandem axle load of 200 kN. The interpolation analysis of load settlement curve of WBM surface indicates that this much load will not be able to create any settlement or deflection in the pavement. In India Motor vehicle act provide a maximum contact pressure equal to 7N/mm^{2}i.e. 70 kN/m^2. The plate load test of compacted WBM pavement will bear this load without any effect on pavement crust and this load will be easily distributed over the sub grade without any failure.

Table- 5.3 Load settlement data of plate load tests performed over the compacted WBM surface

Load	Plate size 300x300mm		Plate size 600x600mm		Plate size 750x750mm	
kN/m^2	Settlement mm	Settlement mm	Settlement mm	Settlement mm	Settlement mm	Settlement mm
0	0.00	0.00	0.00	0.00	0.00	0.00
50	-0.06	-0.05	-0.07	-0.08	-0.06	-0.06
100	-0.13	-0.11	-0.16	-0.17	-0.13	-0.14
150	-0.25	-0.17	-0.29	-0.31	-0.23	-0.24
200	-0.35	-0.24	-0.41	-0.43	-0.33	-0.34
250	-0.45	-0.31	-0.53	-0.55	-0.42	-0.43
300	-0.65	-0.40	-0.75	-0.78	-0.58	-0.59
350	-0.77	-0.52	-0.90	-0.94	-0.71	-0.73
400	-0.89	-0.65	-1.05	-1.11	-0.85	-0.88
450	-1.03	-0.80	-1.23	-1.30	-1.02	-1.05
500	-1.20	-0.98	-1.45	-1.53	-1.21	-1.25
550	-1.35	-1.15	-1.64	-1.73	-1.39	-1.44
600	-1.55	-1.40	-1.90	-2.02	-1.65	-1.71
650	-1.75	-1.62	-2.16	-2.29	-1.89	-1.96
700	-1.96	-1.85	-2.42	-2.58	-2.14	-2.21
750	-2.19	-2.10	-2.72	-2.89	-2.41	-2.50
800	-2.40	-2.33	-2.98	-3.17	-2.65	-2.75
850	-2.61	-2.56	-3.25	-3.46	-2.90	-3.01
900	-2.82	-2.79	-3.52	-3.75	-3.15	-3.27



Fig– 5.1 Load settlement curve for various plate load tests performed over compacted sub-grade



Fig– 5.2 Load settlement curve for various plate load tests performed over WBM surface

Photo 5.1 Plate load test setup at site

Photo 5.2Plate load test setup at site

5.5 Modulus of sub-grade reaction

Modulus of Subgrade Reaction (k) is required for the design of Raft foundation. In the field the method for the determination of its value is conducting 'Plate Load Test' on a 30cm, 60cm or 75 cm plate. Values obtained from this test are corrected for the actual foundation size, which becomes unrealistic when the foundation size is too large.

Keeping in view the technical limitations of the plate load test for the assessment of modulus of sub grade reaction, we have referred and incorporated the recommendations of 'Foundation Analysis and Design, Fifth Edition' by Joseph E. Bowles for calculating the value of k from the allowable bearing capacity as determined from the Geo-technical investigations. For all the practical purposes, Bowles has suggested the value of subgrade reaction to be taken as 40 times the allowable net bearing capacity value in t/m3 for a permissible settlement of 60mm.

Similar value of Modulus of sub grade reaction (k) is obtained as per the guidelines given in the clause 3.1 (f) of IS: 2950 (Part-I) – 1981. IS 1888:1982 method of load test on soils. Sub-grade reaction is usually taken as the slope of line passing through the origin and the point on the curve (Load-deformation curve obtained from 75 cm dia plate) corresponded to 1.25 mm settlement. Experiments were performed on 75 cm x 75 cm plate. The value obtained needs to be modified for 75 cm diameter plate.

Table-5.4 Calculation of modulus of sub grade reaction – compacted earth surface

Sl. no.	Plate size mm	Value of bearing pressure Load kN/m2	Value of bearing pressure N/mm2	Settlement mm	K=P/ 1.25 N/mm2 /mm	Equivalent k value for 750mm plate Ke= K*a/a1	Value of k submerged K/2
1	300x300	64.50	6.45	1.250	5.16	2.06	1.03
2	300x300	68.30	6.83	1.250	5.46	2.19	1.09
3	600x600	112.00	11.20	1.250	8.96	7.17	3.58
4	600x600	126.00	12.60	1.250	10.08	8.06	4.03
5	750x750	78.60	7.86	1.250	6.29	6.29	3.14
6	750x750	74.60	7.46	1.250	5.97	5.97	2.98

Table-5.5 Calculation of modulus of sub grade reaction for WBM pavement surface

Sl. no.	Plate size mm	Value of bearing pressure Load kN/m2	Value of bearing pressure N/mm2	Settlemen t mm	K=P/ 1.25 N/mm2 /mm	Equivalent k value for 750mm plate Ke= K*a/a1	Value of k submerge d K/2
1	300x300	450.00	45.00	1.25	36.00	14.40	7.20
2	300x300	444.00	44.40	1.25	35.52	28.42	14.21
3	600x600	489.00	48.90	1.25	39.12	31.30	15.65
4	600x600	490.00	49.00	1.25	39.20	31.36	15.68
5	750x750	510.00	51.00	1.25	40.80	40.80	20.40
6	750x750	515.00	51.50	1.25	41.20	41.20	20.60

5.6 Performance evaluation of trial stretch constructed using CDW aggregates

The performance of the pavement has been evaluated in terms of its failure due to potholes, rutting and cracking and traffic passed on the pavement.During the pavement performance evaluation for a period of 6 month after laying the first BC course of 50mmm and then for 5 years after the laying of another course of 50mm BC and 40mm HDBC. With the performance of roads of first 6 months we have decided to construct all the roads demolition waste and collected the waste from all the possible sources. The construction of roads were delayed due to some land issues with the farmers and hence completed only in 2010.

We have observed following standard deteriorations in the pavement.

a) Cracking – there was possibility of cracking like fatigue cracking, longitudinal and transverse cracking, reflective cracking, edge cracking etc.

b) Surface deterioration like rutting, depressions, corrugations, shoving and swelling

c) Potholes and patches

d) Defect of surface course like ravelling, bleeding, polishing or delimitation

The pavement performance evaluation has been divided in to the quarterly observation of pavement surface and measurement of defects if any arising during the last three months. Some of the defects are repaired after the observation as they would propagate and may cause pavement non useable and others are left longer to check there propagation and to analyse the impact of traffic on the surface of pavement. The area of pot holes developed has been measured and got repaired within 7 days.

The entire stretch of 1500 meter straight from junction of National Highway 24 to Bridge of Dasna drain near Village Shahberi falling in the District Ghaziabad and 2200 meter of master plan road in the Crossings Republik from main entrance to the Shahberi bridge via central circle. Records are maintained for every month in the first six months and thereafter for every three months for the next 8 years.

Photo-5.3 Satellite view of township land in 2004 before starting of construction

Photo-5.4 Satellite view of township roads under construction in 2007

Photo-5.5 Satellite view of township roads partially completed in May-2008

Photo-5.6   Satellite view of township roads completed in May 2009

Photo-5.7 Satellite view of township roads performing well in January-2010

Photo-5.8 Satellite view of township roads performing well in November-2012

5.7 Performance monitoring of trial stretch

The performance of trial stretch has been checked continuously starting just after the construction of first 1500 meter length of road from National Highway-24 to Shahberi Bridge and then as soon as the new stretch were constructed they were monitored quarterly and hence covering all the 3000 meter length of the trial road. Although further road construction using demolition waste continued for the construction of all the roads and balance patches of roads. This monthly and quarterly visual inspection of pavement and maintenance records of last seven years are given in the tables of record of pavement performance.

The pavement performance monitoring and evaluation has been carried out with respect to the following pavement conditions

i) Edge Cracking
ii) Transverse cracking
iii) Longitudinal cracking
iv) Alligator cracking
v) Ravelling
vi) Surface distortion

For these types of conditions of pavement we need to take one or more of the following actions

a) Do nothing
b) Crack filling and sealing
c) Patch or pot hole repair
d) Shoulder repair and maintenance
e) Milling
f) Laying of one more wearing course (new hot mix layer)

We have to select action depends upon the severity of the condition of pavement. If the cracks are just started and crack width is less than 5mm we can select for do nothing as the filling and sealing of such cracks is very difficult and they may not protrude up to the base course of pavement. But as soon as crack width increases we have to first clean the cracks and then fill them either with hot bitumen or with hot bitumen mixed with fine aggregates as required. In case of pot holes we need to cut the pot holes for standard shape and depth and fill them with hot mix macadam. In case of alligator cracking over a large area of road we need to over lay a new layer of HDBC.

These recorded observation of trial stretch clearly indicate that the maintenance requirement of flexible pavement constructed using construction and demolition waste is almost similar than that of the pavement constructed with new aggregates. The surface relaying was required only after five years of passage of traffic with continuous minor repair and maintenance.

We can easily assess that the properly crushed sieved and graded CDW aggregates can be used in construction of sub base and base course of flexible pavements as the physical and engineering properties of these aggregates and performance of pavement constructed using these aggregates are almost equal if not better than the new aggregates.

Table -5.6 Monthly record of visual inspection of pavement surface as on 01/11/2007

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No visible depression except a single small depression of 25mm of area approx. 0.4 sqm	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	25/0.4	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07							
1750	Sub grade preparation in progress						
2000							
2250							

Table -5.7 Monthly record of visual inspection of pavement surface as on 01/12/2007

Size of defect in maximum depth in mm/ approx area in sqm							
Chainage	Settlement at centre line of road	Settlement at 2m left from centre line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	20/0.3	Nil	Edge Broken at 4-5 places due to side movement of vehicles	Decide to construct edge drains and foot path on drain side and median on central side
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	15/0.4		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	25/0.4		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07							
1750	WBM in progress						
2000							
2250							

Table -5.8 Monthly record of visual inspection of pavement surface as on 05/01/2008

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	Broken edge repaired small potholes of size almost 0.5m diameter were visible at three places	Side drains and foot path under construction. These depression were repaired by first removing all BM and then filled with hot mix bituminous concrete as the depth was hardly 20-30mm
250	Nil	Nil	25/ 0.45	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	15/0.2	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	20 / 0.3	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07							
1750	Not yet finished with BM						
2000							
2250							

Table -5.9 Monthly record of visual inspection of pavement surface as on 03/02/2008

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	Small pot holes found at two location	Side drains and foot path completed. These depression were repaired by first removing all loose BM and then filled with hot mix bituminous concrete as the depth was hardly 50 mm
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	30/ 0.5	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	40/0.55	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07							
1750	BM work in progress						
2000							
2250							

Table -5.10 Monthly record of visual inspection of pavement surface as on 03/03/2008

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	Found satisfactory as no defect found anywhere	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07							
1750	Nil	Nil	Nil	Nil	Nil	BM work completed	construction of side drain and footpath in progress
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		

Table -5.11 Monthly record of visual inspection of pavement surface as on 01/04/2008

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	Found satisfactory as no defect found anywhere	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	construction of side drain and footpath in progress
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		

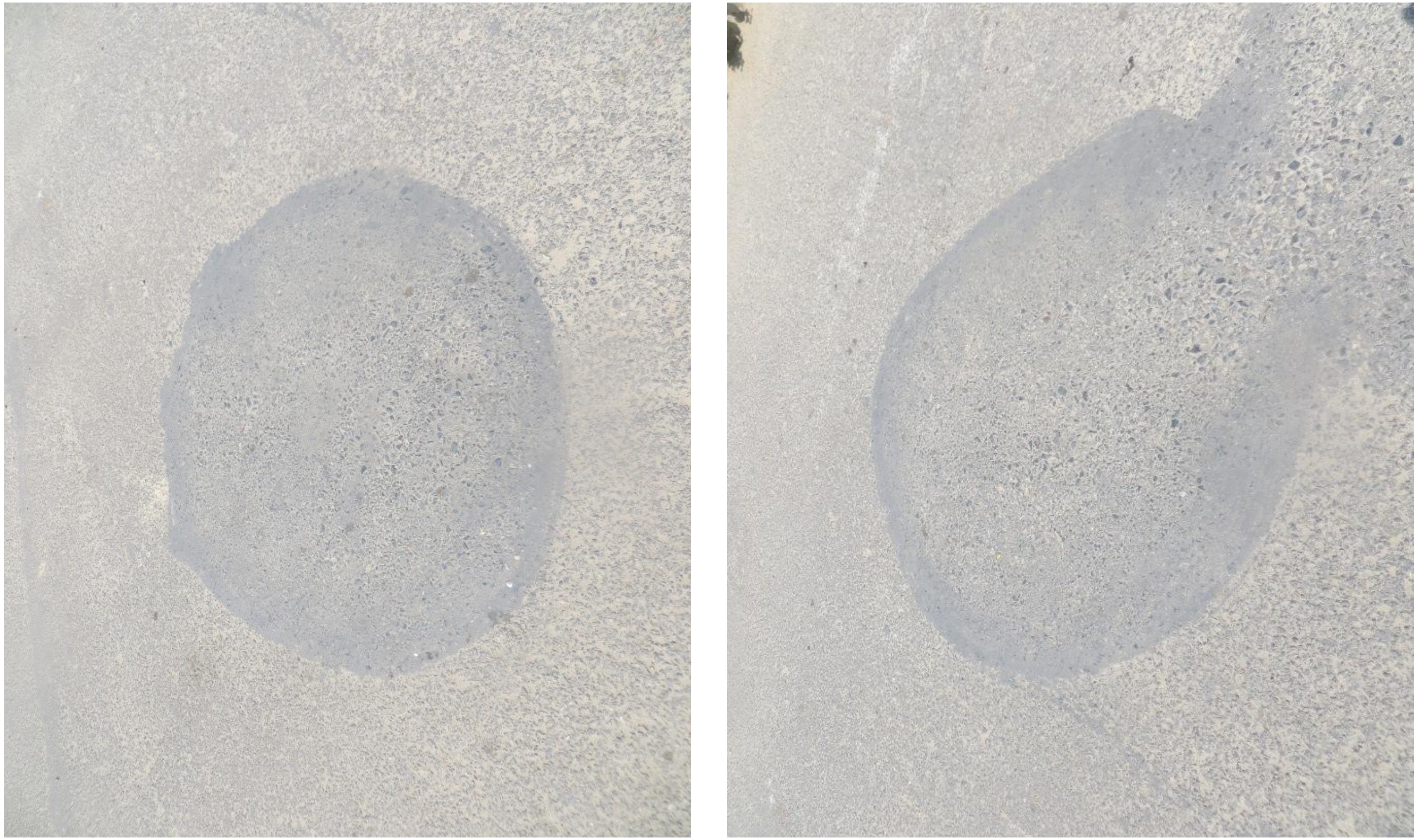


Photo – 5.9 a & b Repaired pot holes of pavement surface

Photo 5.10 Repair at edge Pavement defect

Photo 5.11 Chipping of aggregates from top surface course

Table -5.12 Quarterly record of visual inspection of pavement surface as on 05/06/2008

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	New layer 50mm thick of bituminous Concrete and 40mm HDBC has been laid in the month of March and April on entire Length	Pavement marking in progress
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	1 pot hole found which has been repaired with site mixed hot mix bituminous concrete	Pot hole repaired with site mix bituminous macadam
2000	Nil	40/0.6	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	WBM work in progress						
2750							
3000							

Table -5.13 Quarterly record of visual inspection of pavement surface as on 02/09/2008

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No defect found	Pavement marking completed
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	30/0.8	Nil	Nil	Nil	Nil	Pot holes and edge defects found at four locations	Pot holes and edge repairs completed
2000	Nil	Nil	15/0.4	Nil	Nil		
2250	Nil	Nil	Nil	20/0.6	30/0.45		
2500	WBM work completed						
2750							
3000							

Table -5.14 Quarterly record of visual inspection of pavement surface as on 02/12/2008

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	New layer 50mm thick of bituminous Concrete and 40mm HDBC has been laid in the month of October	Construction of side drain and footpath completed
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	First Layer of 50mm bituminous concrete laid as surface course in October						
2750							
3000							

Table -5.15 Quarterly record of visual inspection of pavement surface as on 08/03/2009

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	Pavement marking in progress
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	25/0.3	Nil	Nil	Potholes found at four locations. repair done in February	New layer 50mm thick of bituminous Concrete and 40mm HDBC has been laid in the month of March 2009
2750	30/0.9	Nil	15/0.4	Nil	Nil		
3000	Nil	Nil	Nil	20/0.6	30/0.45		

Table -5.16 Quarterly record of visual inspection of pavement surface as on 05/06/2009

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	Pavement marking completed
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil	No defect found	Pavement marking in progress
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.17 Quarterly record of visual inspection of pavement surface as on 02/09/2009

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil	No defect found	Pavement marking completed
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.18 Quarterly record of visual inspection of pavement surface as on 02/12/2009

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.19 Quarterly record of visual inspection of pavement surface as on 08/03/2010

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*Some transverse cracking on the surface	No action taken as the crack width is very small
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	*	*	*	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.20 Quarterly record of visual inspection of pavement surface as on 05/06/2010

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	* Cracks width remains the same	Cracks filled with hot bitumen after cleaning with air jet
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	*	*	*	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	A pot hole visible	Pot hole first cleaned and cut to rectangular shape and then filled with site mixed hot bituminous concrete and rolled with hand roller
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	50/0.8	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.21 Quarterly record of visual inspection of pavement surface as on 05/09/2010

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	Three pot holes found	Pot hole first cleaned and cut to rectangular shape and then filled with site mixed hot bituminous concrete and rolled with hand roller
250	Nil	Nil	Nil	Nil	Nil		
500	40/0.4	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	60/0.5	Nil	Nil	50/0.6	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.22 Quarterly record of visual inspection of pavement surface as on 07/12/2010

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*Mild chipping of aggregates of surface at two or three places	Removed all loose aggregates from the surface. No further repairing done.
250	Nil	*	*	*	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	NA	NA
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.23 Quarterly record of visual inspection of pavement surface as on 04/03/2011

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at center line of road	Settlement at 2m left from center line of road	Settlement at 2m right from center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	* Ravelling/Chipping increased	Area cut in a rectangular shape and entire top layer of approx.40mm thickness removed and re-laid with insitu mix hot bituminous concrete and rolled with hand roller
250	Nil	*	*	*	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.24 Quarterly record of visual inspection of pavement surface as on 05/06/2011

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	Pot holes found	All the location were repaired pot hole first cleaned and cut to rectangular shape and then filled with site mixed hot bituminous concrete and rolled with hand roller
250	Nil	Nil	Nil	Nil	30/0.6		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	90/1.2	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	40/0.50	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	* Formation of Ruts and bumps near T-Junction of GH-07	Cutting of bumps to level the surface
2000	*	*	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.25 Quarterly record of visual inspection of pavement surface as on 02/09/2011

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*Surface cracks and mild chipping, small pot holes at two locations	Surface Cracks Left for observation and pot holes repaired.
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	*	*	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	15/0.4	Nil	Nil		
1250	Nil	Nil	Nil	20/0.6	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	**Surface roughened due to cutting of bumps and become undulating	Left for observation
2000	**	**	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	40/0.50	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.26 Quarterly record of visual inspection of pavement surface as on 12/12/2011

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*Surface cracks and mild chipping,	Left for observation
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	*	*	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	**Rough and rutting surface area approx. 3m x 6m, Two potholes found and repaired	complete surface course of area removed after cutting and re-laid with new BC 90mm thickness
2000	**	**	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	40/0.45	Nil		
2750	Nil	30/0.40	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.27 Quarterly record of visual inspection of pavement surface as on 02/03/2012

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*Surface cracks and mild chipping,	surface cracks first cleaned by air jet and then filled with hot bitumen mixed with course sand aggregates
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	*	*	*	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	Sign of surface roughness	Surface cleaned, all loose particles remove and left for observation
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	**	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.28 Quarterly record of visual inspection of pavement surface as on 01/06/2012

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	* longitudinal surface cracks with potholes developed at 2 places and pot holes at three other locations	Left For observation
250	Nil	40/1.2	Nil	Nil	*		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	30/0.8	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	20/0.4	Nil	*	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	No action required
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Photo -5.12 Map cracking of pavement

Photo -5.13 Pavement surface after repair of map cracking

Table -5.29 Quarterly record of visual inspection of pavement surface as on 02/09/2012

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*surface cracks with potholes developed at 2 places and pot holes at three other locations	All the location were repaired Pot hole first cleaned and cut to rectangular shape and then filled with site mixed hot bituminous concrete and rolled with hand roller
250	Nil	40/1.6	Nil	Nil	*		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	50/1.2	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	40/0.6	Nil	*	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	Pot holes found	All the location were repaired Pot hole first cleaned and cut to rectangular shape and then filled with site mixed hot bituminous concrete and rolled with hand roller
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	30/0.8	Nil	Nil	Nil	Nil		
2750	Nil	Nil	15/0.4	Nil	Nil		
3000	Nil	Nil	Nil	20/0.6	Nil		

Table -5.30 Quarterly record of visual inspection of pavement surface as on 02/12/2012

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*The surface cracks which were filled earlier were again developed	Left for further observation
250	Nil	40/0.6	Nil	Nil	*		
500	Nil	Nil	Nil	20/0.4	Nil		
750	Nil	*	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	30/0.5		
1250	Nil	Nil	40/0.8	*	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	Only a small pot hole	Left for observation
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	20/0.2	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.31 Quarterly record of visual inspection of pavement surface as on 02/03/2013

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*The surface cracks which were filled earlier were again developed and increased in area	Left for observation, All pot holes were cut to circular or rectangular shapes and filled with insitu hot mix and compacted with hand rollers
250	Nil	50/0.7	Nil	Nil	*		
500	Nil	Nil	Nil	20/0.6	Nil		
750	Nil	*	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	40/0.8		
1250	Nil	Nil	40/0.9	*	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	** Surface cracks and pot holes found	All pot holes were cut to circular or rectangular shapes and filled with insitu hot mix and compacted with hand rollers
2000	Nil	Nil	Nil	**	Nil		
2250	Nil	20/0.3	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	40/0.3	**	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.32 Quarterly record of visual inspection of pavement surface as on 09/06/2013

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*Longitudinal, transverse and map surface cracks with potholes developed at 5 places and pot holes at three other locations	Now surface needs renewal and hence left under observation
250	Nil	Nil	40/0.6	Nil	*		
500	Nil	40/0.8	Nil	Nil	Nil		
750	Nil	*	Nil	Nil	Nil		
1000	Nil	Nil	30/0.8	Nil	30/0.50		
1250	Nil	20/0.4	Nil	*	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	** Cracking on surface and pot holes at two locations	All pot holes were cut to circular or rectangular shapes and filled with insitu hot mix and compacted with hand rollers
2000	Nil	Nil	**	**	Nil		
2250	30/0.5	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	20/0.4		
2750	Nil	Nil	**	**	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

Table -5.33 Quarterly record of visual inspection of pavement surface as on 12/09/2013

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	*Longitudinal, transverse and map surface cracks with potholes developed at many places and pot holes at three other locations	After cutting and filling the pot holes with BM another layer of HDBC has been laid as surface renewal through out the stretches
250	Nil	Nil	40/0.8	*	*		
500	Nil	50/1.2	Nil	Nil	Nil		
750	*	*	*	*	Nil		
1000	Nil	Nil	30/0.8	Nil	30/0.50		
1250	Nil	20/0.4	Nil	*	Nil		
1500	40/0.6	Nil	Nil	20/0.3	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	** Longitudinal, transverse and map surface cracks with potholes developed at many places	After cutting and filling the pot holes with BM another layer of HDBC has been laid as surface renewal throughout the stretches
2000	Nil	**	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	30/0.8	Nil	Nil	Nil	Nil		
2750	Nil	Nil	15/0.4	Nil	Nil		
3000	Nil	Nil	Nil	20/0.6	Nil		

Table -5.34 Quarterly record of visual inspection of pavement surface as on 10/12/2013

Size of defect in maximum depth in mm/ approx. area in sqm							
Chainage	Settlement at Center line of road	Settlement at 2m left from Center line of road	Settlement at 2m Right from Center line of road	Settlement at left edge of road	Settlement at right edge of road	Remarks	Action Taken
NH-24 to Shahberi bridge							
0	Nil	Nil	Nil	Nil	Nil	No defect found	New pavement marking has been carried out
250	Nil	Nil	Nil	Nil	Nil		
500	Nil	Nil	Nil	Nil	Nil		
750	Nil	Nil	Nil	Nil	Nil		
1000	Nil	Nil	Nil	Nil	Nil		
1250	Nil	Nil	Nil	Nil	Nil		
1500	Nil	Nil	Nil	Nil	Nil		
Shahberi bridge to Gh-07 up to round about							
1750	Nil	Nil	Nil	Nil	Nil	No defect found	New pavement marking has been carried out
2000	Nil	Nil	Nil	Nil	Nil		
2250	Nil	Nil	Nil	Nil	Nil		
2500	Nil	Nil	Nil	Nil	Nil		
2750	Nil	Nil	Nil	Nil	Nil		
3000	Nil	Nil	Nil	Nil	Nil		

The pavement surface visual inspection records from March 2014 to March 2015 indicates that except the surface roughness ravelling at one or two places there was no defect arises and hence records are not being attached here. This pavement surface monitoring charts have indicated that this pavement has performed very well. The performance of this pavement was very good due to the following reasons

1) The pavement has been designed for 15 years and traffic of 15 million standard axle (MSA).

2) The pavement was constructed over an embankment of 2-3 meter above ground level with proper drainage system and foot paths on both sides.

3) System of maintenance was in place for regular maintenance and all desirable maintenance has been carried out whenever it was required. No pothole was allowed to continue more than one month. Similarly ravelling was also repaired by removing the surface course from area and relaying the patch with in situ hot mix and compacted with hand roller.

4) The crust has very high strength as calculated by plate load tests on surface of pavement that the load bearing capacity of pavement is of the order of 600 kN/m^2 at 1.25mm settlement hence even if we consider the impact load of wheel it was much lower than the load bearing capacity of pavement.

CHAPTER – 6

PROPOSED FRAMEWORK FOR USE OF CONSTRUCTION AND DEMOLITION WASTE AGGREGATES IN FLEXIBLE PAVEMENTS

This chapter describes about the proposed framework from collection of demolition waste from demolition site to its final utilisation in sub base and base course of flexible pavement. The entire process is discussed in a detailed and systematic step by step system for use of CDW. The use of recycled CDW aggregates is not prevalent in India as is prevalent in European counties. The main difficulty in use of recycled CDW aggregates in India is due to lack of standard specification, scientific testing and performance trials on such materials. This work has attempted to lay the framework with the intention that such framework will accelerate the pace of use of recycled CDW aggregate as sub-base and base material for road works.

The frame work has been worked out based on the work of characterization of CDW aggregates after lab testing and field trial of the same. The suggested framework has included the steps for comparison with established specification for the base and sub base course specified by road authorities. This framework includes the processes, steps and methodology to be followed including characterization, process of production and quality control.

The following methodology may be adopted for successful utilisation of construction and demolition waste in various uses. This chapter describe the final product utilisation in sub base and base course of flexible pavements.

6.1 Collection and transportation from redevelopment site

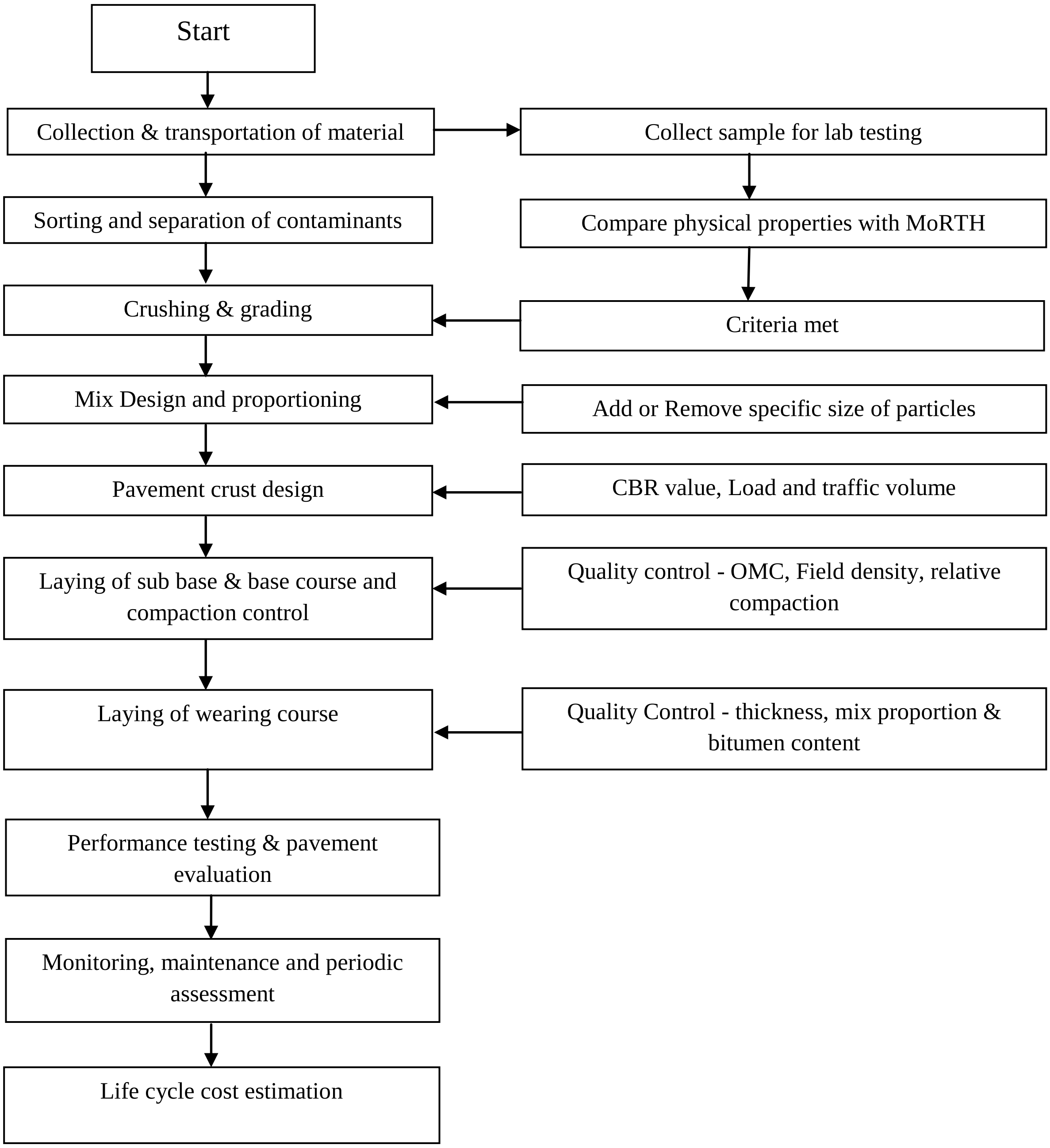
Collection of construction and demolition waste is two way simultaneous processes. In the first we have large dumping sites having large amount of waste and in second we have to collect waste directly from demolition site. When we transport the waste from dumping sites it has many foreign materials which could have dumped in the dumping yard along with the construction and demolition waste. In second case the when we collect the demolition waste directly from demolition sites where old buildings are being demolished for new construction, the waste is non adulterated and contains only the old building materials. The old buildings were majorly load bearing structures having some slabs and columns made of reinforced cement concrete with brick walls, wooden or steel doors and windows with frames, MS or CI pipes, Steel reinforcement etc. Normally the full bricks which come out during the demolition are being used by the owners in new construction and hence separated out at the site. Selective removal of accessible materials with obvious sales value (Kourmpanis et al 2008) is very common and resulting around 30% of waste recycling in India. Similarly the wooden frames with doors and windows, steel pipes and bars are also sold by the owner in secondary market. Hence the debris from such building contains concrete, brick bats and mortar, tiles, glass and some other materials. This waste needs to be broken by concrete breakers and vibratory hammers into smaller pieces before loading into dumpers. Then the same is required to be transported to crusher site for crushing and grading.

6.2 Separation of contaminants from demolition waste

The waste collected and transported to crushing site consists of many contaminants. These contaminants need to be separated out for processing the waste into financially and technically useable materials. This is one of the limiting factors in expanding the reuse and recycling of construction and demolition waste into the usable standard final products. The presence of contaminants is a drawback and restricts the use of recycled aggregates is the contaminations and their effect on base and sub-base course of flexible pavements. The following contaminants are normally found in recycled aggregates. Details of contaminants and their effects on aggregates are described below

Bitumen

The availability of bitumen is not common in the debris generated from the demolition of old buildings as bitumen is not used in building construction except some water proofing works. Hence may present in small quantity which does not affect the performance of recycled materials when used in base course of flexible pavements.



Flowchart-6.1 Framework for recycling of construction and demolition waste

Mortar

Demolition waste debris arising from old buildings consists of large quantity of mortar which gets crushed in crushing operation and separated out during gradation of aggregates by sieving at crushing plants. This mortar becomes the granular materials and used as granular sub base in flexible pavement construction. Some times when debris collected from dumping sites it may contain some excavated earth which get mixed in the dumping yard, this is also separated out in the crushing and grading process in the plant but remain mixed with the sands and mortar. This material can be used as filler for the water bound macadam construction.

Plaster of Paris (POP)

The plaster of paris when comes in contact of water becomes plastic and hence not desirable in the recycled CDW aggregates. Normally a small quantity is present in old building debris as it has been used as POP false works and finishing on wall and ceilings. We need to separate out this plaster of paris during the sieving operation after the crushing. This small quantity when present in the final product acts as filler and binder in the granular sub base materials and hence no negative effect on performance of pavement made of recycled CDW aggregates.

Biodegradable organic materials

The presence of biodegradable organic materials is only possible in the demolition waste collected from dumping yards. The common organic materials like small plants, paper, wood, textile fabrics, joint seals, paint etc may be present in the debris. These materials are required to be separated manually before crushing and grinding of construction and demolition waste. The Biodegradable organic materials are deleterious in base and sub-base course of flexible pavements as they are subjected to shrinkage after degradation. These materials are degradable and may cause voids after passage of time in base course and sub-base course. The presence of some particles of organic waste matter in the voids of base course will not affect the performance of flexible pavements.

Soils and filler Materials

Demolished building debris is frequently contaminated by clay either due to mixing of earth in dumping yards or due to earthen masonry used in construction. The removal of clay once entered or mixed in CDW materials is very difficult. Now washing and cleaning cooperation is included in recycling plants where we can remove silt and clay present in the final product. Some times when the finer portion of waste is being used as filler and bonding material in the water bound macadam layer the presence of silt and clay in small quantity is useful and have positive effect in bonding of the layer.

Glass

The broken glass from windows panes is normally present in the demolished material but the plate glass which has a density almost equal to density of natural aggregate and further glass is non bio degradable, hence it does not affect the performance of pavement constructed using recycled CDW materials. Normally the use of glass in old building is of the order of 1-2% of gross volume of debris hence it is accepted as part of final product as its separation is very difficult and does not affect the performance of materials.

6.3 Crushing of demolition waste

The manually cleaned and broken debris is now fed in the crushers to crush the waste into desirable size of aggregates. The various mechanical sieves (Rao et al 2007) are than placed at the output of crusher to separate the different sizes of aggregates. The oversize particles are returned to crusher for secondary crushing to achieve the best particle size and shape. It is always economic to use single stage crushing instead of multiple crushing. The single crushing using Hammer and impact crushers are usually employed for reducing the material to the required particle size. We are required to take special care during crushing of brick material as this can crushed with lesser effort and may produce finer particle due to less force requirement then the crushing of concrete or primary aggregates.

It is desirable to set up the crushing plants at central locations which can easily accessible to receive material from the entire city and also having some green surrounding so that it will not affect the people living around the location. Portable crushing plants found to be economical to use at dumping sites where large amount of demolition waste is already available. But the mobile crushing plant is not as sophisticated as a stationary plant and hence gives inferior grading and size. The properties of final product govern the selection of stationary crushing plant or mobile crushing plant. In case of final product are used in base course and sub base course of water bound macadam base of flexible pavements, the use of mobile crushing plant is found satisfactory.

6.4 Sieving and grading of aggregates

The crushing plant consists of standard sieving system which classifies the materials of different sizes in different stakes. In case of recycling plant we have sieves of sizes 100mm, 63mm, 40mm, 20mm, 11.2mm, 4.75mm and 1mm. The material passed from 100mm sieve and retained on 63 mm sieve has been staked in one stake, similarly material passed from 63 mm sieve and retained on 40mm sieve has been staked in one stake, material passed from 40mm and retained on 20 mm kept in separate stake, material passed from 20 mm and retained on 11.2 mm in separate stake, 11.2mm to

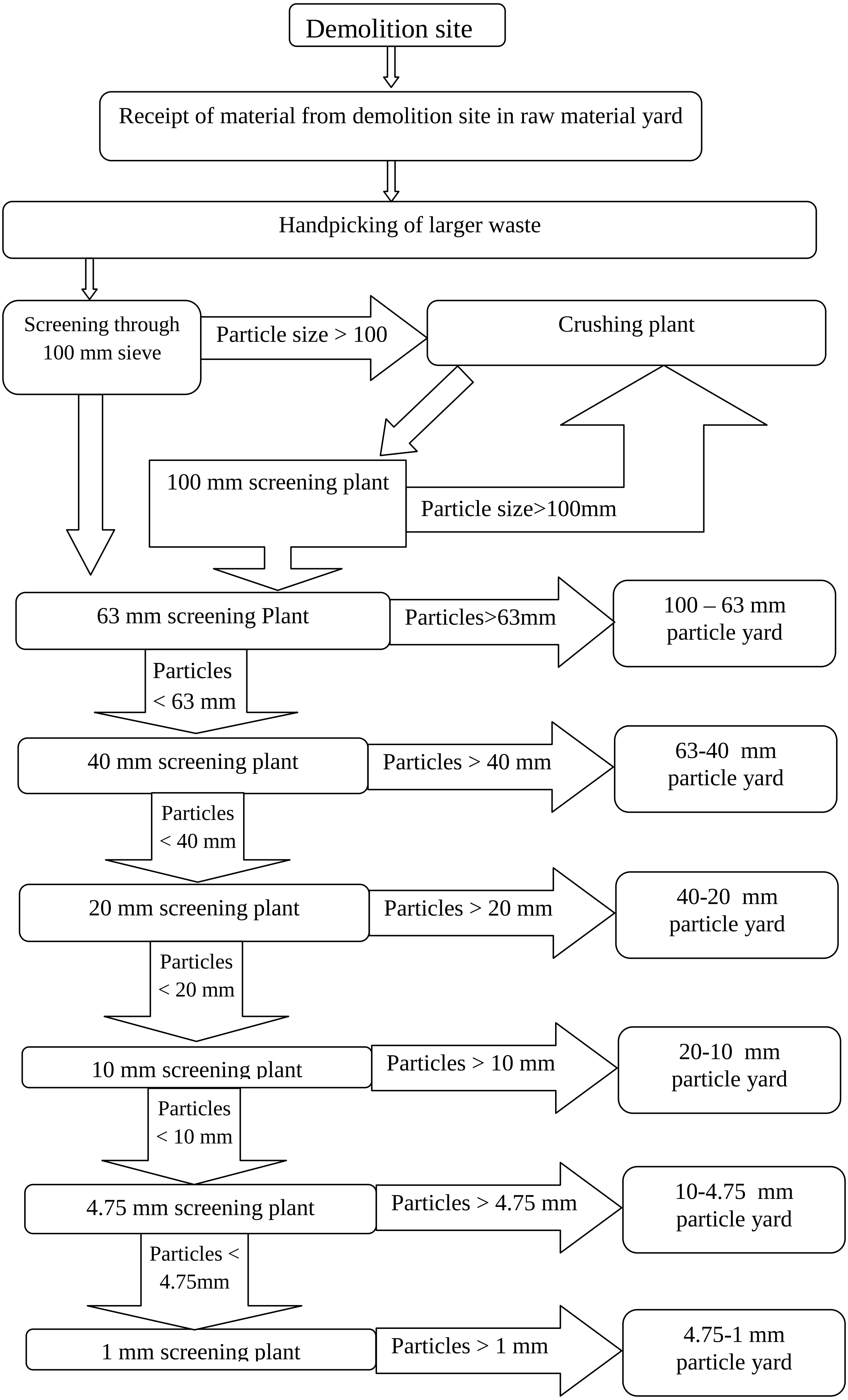
4.75mm in one stake, 4.75mm to 1mm in one stake. And less then 1mm is sent for washing and cleaning plant for separating clay particles from it or used in landfills. Out of these materials suitable percentage has been mixed to achieve most desirable grading as required by the IRC specifications for base and sub-base courses. Mixing and grading of aggregates do not take consider effect of particle shape although particle shape influence the aggregate bonding and resultant strength of base course hence if required a suitable adjustment of crushing process is made based on the value of flakiness index and elongation index.

6.5 Testing of physical and mechanical properties CDW aggregates

The specified physical and mechanical properties such as specific gravity, water absorption, aggregate crushing value, angularity of aggregates, flakiness and elongation index, los angles abrasion value, CBR value and toughness index are found out by lab testing and compared with the specifications recommended for the base and sub-base course as given in the MoRTH "Specification of road and bridge works". Sometimes we may found that there is variation in results of above tests of CDW aggregates, strength and water absorption may be on lower than the required, In such case we may use these aggregates in combination of new aggregates or places where less strength is permitted such as sub base or base of parking slots etc. Following tests as per standard IS codes needs to be carried out for comparison of physical and mechanical properties of recycled aggregates.

Table 6.1 – Recommended tests of aggregate and relevant IS codes.

Sl No.	Test of Property	Relevant IS code
1	Specific Gravity	IS : 2386 (Part III) - 1963 Methods of test for aggregates for concrete – Test for specific Gravity, Density, Water absorption and Bulking
2	Water absorption	
3	Aggregate Crushing value	IS : 2386 (Part IV) - 1963 Methods of test for aggregates for concrete Part-IV Mechanical Properties
4	Aggregate Impact value	
5	Los Angeles abrasion value	
6	Flakiness & elongation Index	IS:2386-Part-1:1963 – Methods of test for aggregates Part-I- Particle size and shape
7	Test for particle size distribution and grading of CDW aggregates	
8	Test for CBR value of aggregates	IS 2720: Part 16: 1987 Methods of test on Soils (Part-16) Laboratory determination of CBR



Flowchart No. 6.2 Layout of recycling plant

6.6 Design of pavement on the bases of physical properties of aggregates

The design of flexible pavement is carried out on the basis of results of laboratory test tests obtained in the experimental program carried out on the CDW aggregates. IRC 37:2001 recommended California bearing ratio design charts for flexible pavement designs. On the basis of the CBR value and physical properties and design loads expressed in million standard axels (MSA), pavement crust design is carried out following the method given in IRC37:2012.

Table 6.2-Minimum requirements of physical & mechanical properties as per MoRTH

Sl No.	Physical or mechanical property	Minimum requirement for GSB	Minimum requirement for WMM	Minimum requirement for WBM
1	Specific Gravity	2.4-2.75	2.5-2.75	2.5-2.75
2	Water absorption	Not Applicable	<2%	<2%
3	Aggregate Crushing value	Not Applicable	<10%	<10%
4	Aggregate Impact value	Not Applicable	<20%	<20%
5	Los Angeles abrasion value	Not Applicable	<40%	<40%
6	CBR value	>20%	>30%	>30%
7	Combined Flakiness and elongation index	Not Applicable	>30%	>30%
8	Particle Size distribution and grading	As per IRC grading requirements		

6.7 Quality control parameters

The field quality control parameters such as maximum dry Density and optimum water content are worked out in the laboratory on the basis of modified Proctor test results. The maximum dry density and optimum moisture content based on modified Procter test are established as field control parameters.

6.8 Lying and Compaction Control

The dry mix is mixed with water in plant and sub base course is laid in the field in layers not exceeding 100mm in thickness. The layer is wet rolled to achieve specified dry density. The water content is checked to optimize the compaction efforts and dry density achieved in the field is checked by sand replacement method or any other specified method. Similarly, specified number of layers as per design is laid for building full sub-base/base course.

6.9 Laying of Bituminous macadam and High density bituminous concrete

After drying of top layer of water bound macadam surface made of CDW aggregates scrapping and cleaning of surface will be carried out and a tack coat of bitumen will be applied to create a bond between WBM and bituminous macadam. The thickness of bituminous macadam has been pre decided in the step-4 as per the load and density of vehicles plying on the road. A suitable thick layer of HDBC will be laid over the bituminous macadam surface to make impervious road surface.

6.10 Performance testing and analysis

The road crust needs to be designed as per IRC: 37: 2012 and constructed as per MoRTH specification. However, the base course and sub-base course material needs to be replaced by CDW material fulfilling the criteria of physical properties and gradation prescribed by MoRTH. The layer was laid and compacted as per specification and field densities were measured for control of compaction. The suitable tests of field densities and settlement will then be carried out to assess the performance of road so constructed. The road was overlaid and finished with bituminous layer and the tests were conducted to assess the settlement by Plate Load Test.

6.11 Monitoring, maintenance and periodic assessment

The visual inspections needs to be conducted to assess the damage to the road under traffic for a period of 3 to 5 years and deficiency so found needs to be got recorded and suitable maintenance will be carried out at frequent interval. On the bases of inspection and maintenance required for a period of 5-10 years the performance analysis will be carried out periodically.

6.12 Life cycle cost estimation

On the bases of all of above an estimation of life cycle cost can be made which will give you the idea of cost comparison between pavement constructed with new materials and pavement constructed with CDW aggregates. The main component of life cycle cost is initial construction cost or capital cost. This depends on the cost and quantity of materials used in the construction of pavement. This is mainly depends on the properties of sub grade soil and traffic of commercial vehicles. The other component is maintenance and renewal cost of pavement during its design life. A well designed and good quality of execution of work substantially reduces the maintenance cost as well as frequency of renewal of wearing course of the pavement.

The lifecycle cost analysis is carried out to find the best suited options of materials or type of pavement. We calculate the total of the initial cost of pavement, present value of its maintenance cost in its life cycle and present value of intermittent renewal cost during its design life.

CHAPTER – 7

CONCLUSIONS

Based upon the laboratory experimentation and field testing of CDW aggregate, field trials and performance evaluation of flexible pavement having base and sub-base course constructed using recycled waste aggregates material, the following conclusions are drawn:

1. CDW aggregates is recommended for use in place of crushed stone aggregate for base and sub-base course of flexible pavements as its physical and engineering properties are comparable to new natural aggregates. It conforms most of the codal specification of materials for road construction except water absorption and Los Angeles abrasion value.

2. The compact-ability of CDW aggregates is close to crushed stone and gravel aggregate hence has the same strength and unit weight characteristics as that of specified for WBM or WMM, which conforms to the codal requirements.

3. The Los Angeles abrasion values of recycled CDW aggregate varies from 42-45% which is slightly higher than the permissible limit (40%)in codes and specification. The higher Los Angeles abrasion value has no effect on the final performance as this was not due to the poor quality of aggregate but only due to the presence of cement mortar and brick bats in the mix, which are having sufficient strength to support loads in mechanically bonded pavements. Based on this study new codal provision are recommended to be enacted to pave the way for use of waste aggregates in sub base and base course of flexible pavements.

4. The water absorption of recycled aggregates varies from 3-5% which is higher than (2%) limit for stone aggregates as per codal requirements. It is due to the presence of cement mortar and brick bats in the mix. All these material are non-deleterious hence does not affect the performance of pavement.

5. The CBR value of waste aggregates varies from 38 for mortar and brick work waste and 78 for concrete waste. The CBR value of waste aggregates is higher than the minimum codal requirement of 30. Hence these aggregate are as good as new aggregates.

6. India has around 45 lakh km of roads, out of this, less than 30% are National highways and Expressways, State highways and Major district roads. The rest of the roads are low traffic density urban or village roads. Based upon this study new codal provisions incorporating higher Los Angeles abrasion value and higher permissible limit for water absorption are recommended for the use of CDW aggregates in construction of low traffic density urban streets, other district roads and village roads.

7. The pavement performance evaluation for a period of seven years has proven that maintenance requirement of pavement constructed using recycled CDW aggregates is within normal maintenance requirements of flexible pavements.

8. A frame work proposed in the form of systematic flow charts and a step by step methodology for utilisation of waste aggregates. It creates scope for the recommendation of CDW aggregates in flexible pavements as an economically viable and environmental friendly recycled material with partial or full substitution of standard natural materials. Any kind of recycled construction and demolition waste can be used within the frame work suggested in this study.

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EXPERIMENTAL STUDIES OF C& D WASTE AS GEOMATERIAL FOR ROAD CONSTRUCTION

A THESIS SUBMITTED IN FULFILMENT OF
THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

CIVIL ENGINEERING

SUBMITTED BY

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DELHI UNIVERSITY, DELHI

SEPTEMBER – 2016

SCOPE FOR FUTURE STUDY

1. Development of suitable recycling plant setup for recycling of construction and demolition waste
2. Establishment of procedures and systems for recycling of CDW aggregates in other non structural uses.
3. Verification of physical and engineering properties of recycled aggregates for other structural and non structural uses.
4. Economic analysis of use of recycled and demolition waste concrete aggregates in comparison to WBM and WMM.

LIST OF PUBLICATIONS FROM THE PRESENT WORK

1. Suitability of CDW Aggregates as Sub-base Layer of Flexible Pavements by Rajiv Goel & Ashutosh Trivedi in proceeding of National Conference 'Geotechnical and Geo-environmental aspects of wastes and their utilization in infrastructure projects' (2013)

2. Evaluating Recycled C&D Waste for Sub-base and Base Course of Flexible Pavements by Rajiv Goel & Ashutosh Trivedi. IRC Journal of Indian Highways (Under process of acceptance)