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About this Manual

This manual was developed under the three-year project until April 2017 titled "Fostering Resource Efficiency and Sustainable Management of Secondary Raw Materials" (in short: Resource Efficiency). The German Federal Ministry of Environment, Nature Conservation, Building and Nuclear Safety (BMUB), under its International Climate Initiative (IKI), commissioned GIZ to implement jointly with the Indian Ministry of Environment, Forests and Climate Change (MoEFCC) the Resource Efficiency Project. European Union Delegation to India under its Resource Efficiency initiative (EU–REI) will carry forward the work on enhancing resource efficiency in construction sector.

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Abbreviations

BAI	Builders Association of India
BIS	Bureau of Indian Standards
BSB	Brick Sub-Base
C&D	Construction & Demolition
CDW	Construction & Demolition Waste
CES	Center for Ecological Sciences
CIB	International Council for Research and Innovation in Building and Construction
CPCB	Central Pollution Control Board
CPR	Cardiopulmonary Resuscitation
CREDAI	Confederation of Real Estate Developers' Associations of India
CRRI	Central Road Research Institute
CSE	Centre for Science and Environment
CSEB	Compressed Stabilised Earth Block
CTE	Consent to Establish
DDA	Delhi Development Authority
DEFRA	Department for Environment, Food and Rural Affairs, UK
DfD	Designing for Deconstruction
DGMS	Director General of Mines Safety
EC	European Commission
EMP	Environment Management Plan
EU	European Union
FICCI	Federation of Indian Chambers of Commerce and Industry
FRP	Fiber Reinforced Plastic
GDP	Gross Domestic Product
GGBS	Ground Granulated Blast Furnace Slag
GHG	Greenhouse Gas
GPS	Global Positioning System
GSB	Granular Sub-Base
HCC	Hydraulic Concrete Crushers
HFL	High Flood Line
HID	High-Intensity Discharge
HWM	Hazardous Waste Management
IBEF	Indian Brand Equity Foundation
IEISL	IL&FS Environment Infrastructure Services Limited
IISc	Indian Institute of Science
IIT	Indian Institute of Technology
IRN	The Institutional Recycling Network
LCV	Light Commercial Vehicle
MCD	Municipal Corporation of Delhi

MHUPA	Ministry of Housing and Urban Poverty Alleviation
MoEF	Ministry of Environment and Forests
MoEFCC	Ministry of Environment, Forest and Climate Change
MoRTH	Ministry of Road Transport and Highways
MRTS	Mass Rapid Transit System
MSW	Municipal Solid Waste
MTPA	Million Tons Per Annum
NA	Natural Aggregates
NABL	National Accreditation Board for Testing and Calibration Laboratories
NBCC	National Buildings Construction Corporation
NDTG	National Demolition Training Group, Scotland
NSDC	National Skill Development Corporation
OHS	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated Biphenyls
PCC	Plain Cement Concrete
PM	Particulate Matter
PME	Powered Mechanical Equipment
PPE	Personal Protective Equipment
PPP	Public-Private Partnership
PPP	Polluter Pays Principle
PWD	Public Works Department
RA	Recycled Aggregates
RAC	Recycled Aggregate Concrete
RCA	Recycled Concrete Aggregate
RCC	Reinforced Cement Concrete
RMC	Ready Mix Concrete
RSPM	Respirable Suspended Particulate Matter
SCM	Supplementary Cementitious Material
SPCB	State Pollution Control Board
SSD	Saturated Surface Dry
TIFAC	Technology Information, Forecasting and Assessment Council
TPD	Tons Per Day
TPH	Tons Per Hour
ULB	Urban Local Body
UN	United Nations
UV	Ultra Violet
VSI	Vertical Shaft Impact
WCP	Waste Collection Point
WtE	Waste to Energy

Preface

This manual has been prepared as part of the Indo-German bilateral cooperation project "Fostering Resource Efficiency and Sustainable Management of Secondary Raw Materials" (in short: Resource Efficiency), funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) under its International Climate Initiative (IKI). The project is being implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, in cooperation with the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. One of the important areas of focus of this project is the construction sector.

The construction sector is not only very important to the economy in terms of GDP and employment, but is also one of the largest resource consuming sectors in India. Due to rapid current and projected growth rates in housing and infrastructure needs, resource demands for the sector are expected to multiply many times in the coming decades. Absent mitigation steps, this is likely to constrain development of basic infrastructure, in addition to negative environmental impacts arising from resource extraction and manufacturing of building products. India is already experiencing serious environmental degradation due to mining and quarrying of soil, sand and stones for construction in many regions leading to bans and restrictions. This is already having an effect on the material availability and financial operation of the construction industry in many parts of the country.

Recovery of materials from older buildings/infrastructure slated for demolition and their effective reuse in new construction provides a partial solution to this problem. "Deconstruction" implies a planned and controlled form of demolition that maximises recovery of materials and is commonly practiced in many European countries such as Germany. Such careful recovery produces segregated waste streams which are also widely reused and recycled in those countries. However, in India, methodical deconstruction is practically non-existent and quick demolition to save time and money is the norm. While the informal sector often salvages materials of immediate market value such as metals, wooden frames, etc. from demolition sites, material recovery is far below what can be potentially achieved. At the same time, management of Construction and Demolition (C&D) waste is very poor in India with only a small fraction used for backfilling purposes and the rest disposed of. Some of it ends up in landfills while the rest is dumped in unauthorised places causing myriad environmental, safety and nuisance problems. These trends are all expected to worsen substantially in the coming years and decades with rapid urbanization producing more demolition waste and more dumping problems.

Fortunately, the Government of India has recognised this problem with the MoEFCC notifying the C&D Waste Management Rules in 2016, setting time-bound targets for C&D waste management with the division of responsibilities among different stakeholders. The construction industry, as primary generators of C&D waste, bears important responsibility both in terms of maximizing recovery of materials from demolition as well as utilization of recovered materials in new construction. However, because this is a new issue in India, very little awareness or expertise exists in the Indian construction industry about either approaches. This manual intends to fill this gap by helping in capacity development of the Indian construction industry on methodical deconstruction, segregation and on-site reuse, processing and utilization of recovered materials in new construction.

IL&FS Academy of Applied Development (IAAD), has prepared this manual under the Resource Efficiency project, by bringing together a uniquely qualified team of experts from research institutions and the construction industry in India. The team has also benefited immensely from the firsthand experience of the IL&FS group, which was the first company to setup and operate a C&D waste processing plant in India. Finally, the entire manual has been peer reviewed by eminent national and international experts. We sincerely believe that this detailed manual, which is tailored to Indian circumstances, will make an important contribution to the goal of efficient recovery and utilization of construction materials after demolition and thus benefit the economy, environment and society in India.

Uwe Becker
Project Director
Fostering Resource Efficiency and Sustainable Management of Secondary Raw Materials
GIZ-India
(New Delhi, May 2017)

Acknowledgements

Pete Seeger, American folk singer and social activist, once said "...*if it cannot be reduced, reused, repaired, rebuilt, refurbished, refinished, resold, recycled or composted, then it should be restricted, redesigned or removed from production*...". This Deconstruction Manual derives inspiration from similar concepts and provides knowledge and recommendations for the entire value chain relating to managing demolition waste, i.e. from planning for deconstruction to technologies and commercial contracts for executing projects.

I believe that this is the beginning of a long journey and we have a long way to go in enhancing sustainability in the buildings sector. However, as the saying goes, well begun is half done. So I will like to take this opportunity to thank everyone who has contributed to developing this manual, thereby providing an excellent platform to implement scientific deconstruction, enhance recycling and reuse of materials.

The manual is a result of a collaborative approach which IAAD has been known for from its inception. The strategy of combining academic inputs with practical experience from IL&FS projects is an effort in blending the best of both worlds. It is however easier said than done. It demands patience, ability to assimilate varying perspectives and fine tuning inputs so that the collective product is more than the sum of the parts.

From the academic side Dr. Prasad Modak (IAAD), Prof. Babu Narayan and Prof. Subhash Yaragal (NIT Surathkal) were the lead contributors and prepared the initial outline of the manual. Their understanding of the civil engineering and environmental sustainability aspects enabled the manual to be firmly anchored in theory. Mr. Mohan Ramanathan (ACT Technologies), Mr. Shajahan Ali and Mr. Rajkumar (IL&FS Environment) wrote key sections of the manual on technologies available, processing and recycling. I will like to place on record our gratitude for their contributions and very effective collaboration. Mr. Ramanathan's work on some of the largest projects using cutting edge technologies provided a unique perspective and we hope to continue collaborating with him in the future as well.

The manual underwent multiple reviews by domestic as well as international reviewers. In India, Dr. Lakshmy P. and Dr. Guru Vittal (CRRI) and Dr. A K. Minocha (CBRI) provided detailed comments. Mr. Mohan Ramanathan also served as a reviewer for sections written by other authors. On the international side, Dr. Christian J. Engelsen (SINTEF, Norway), IFEU and VDI (both from Germany) provided valuable inputs which helped in improving the manual. We appreciate their support and thank them for the time they spent in reviewing the manual to provide invaluable feedback.

The project management support was provided initially by Dr. Shrikar Dole (IAAD) but more substantively by Mr. Gagan Nigam (IL&FS), who worked tirelessly to ensure that all activities were delivered smoothly and that the team functioned effectively. Ms. Odette D'Silva (IAAD) provided excellent research support to the team and deserves full credit for the same.

I would also like to thank Mr. Mahesh Babu (CEO, IL&FS Environment) for readily agreeing to provide us with experts from his team to work on the manual and more importantly for involving me in the related activities. It has been an enriching experience to see the operating C&D facilities of IL&FS Environment and interacting with various plant managers and experts. Last but not the least,

I deeply appreciate the opportunity provided to me by Mr. Hari Sankaran (Vice Chairman and Managing Director, IL&FS), who has also been a great mentor, to lead IAAD, which enabled my association with this project.

From my experience of over two decades, I have learnt that demanding and involved clients ensure best outcomes in any project. In this case, GIZ team led by Mr. Uwe Becker provided superb guidance and Mr. Abhijit Banerjee went an extra mile to work hand-in-hand with us to improve the manual by adding details, providing inputs such as references, case studies and editing the entire final version. We are greatly indebted to GIZ for giving us the opportunity to work on this project and to both of them for enriching the manual and providing their wholehearted support. Waste management is a very challenging sector and the country needs more champions like them.

We interacted with a large number of people for consultations and it is difficult to include all their names here. The most striking aspect however was the enthusiastic support from almost everyone. It has raised our hopes that a difference can be made. IAAD will strive with renewed vigour to enhance our work in the sustainability domain, particularly on waste management challenges.

The song which Pete Seeger was most associated with was "…*We shall overcome*…"! We believe in it, completely!

Dr. Gaurav Bhatiani
Dean, IAAD
May, 2017

1. INTRODUCTION

1.1 Background

India is urbanising at a rapid pace. UN projects that India's total population will increase from 1.28 billion in 2015 to 1.62 billion by 2050. During the same timeframe, urban population will increase from 400 million to over 800 million i.e. double over next three decades (UN Habitat, 2016). Increasing urbanisation has and would further lead to increased demand for commercial and residential buildings and associated infrastructure.

Indian construction industry is a major contributor towards India's GDP, and is expected to grow at 30% over the next decade (IBEF, 2017). The construction industry is the second largest employer; it employs roughly 33 million people (FICCI, 2016) - with around 30% in real estate sector and around 70% in infrastructure sector (NSDC, 2009).

With rapid urbanisation, the need to replace old structures is increasing, thereby leading to an increase in the quantum of Construction & Demolition (C&D) Waste. A major challenge in the Indian context is the lack of segregation of different types of waste and scientific approach to its management by most urban local bodies (ULBs).

In order to move towards more organised approaches to waste management, it is important to define and characterise their origin, composition and properties.

As per Indian C&D Waste Management Rules 2016 - waste comprising of building materials, debris and rubble resulting from construction, re-modeling, repair and demolition of any civil structure is defined as C&D waste (MoEFCC, 2016).

The European Union (EU) likewise defines Construction and Demolition (C&D) wastes as those generated from the construction or deconstruction of buildings and other infrastructure. They are important because they account for around one third of the controlled waste within the European Union.

With proper handling, storage and treatment, C&D waste has potential to meet a significant demand for natural aggregates in the construction industry.

Fig. 1.1 Mixed demolition waste

(Photo courtesy: Mohan Ramanathan)

Estimates of C&D waste in India

The total quantum of C&D waste generated in India was estimated to be between 11-15 million tons per annum by TIFAC (2001). Most experts believe that these numbers are grossly underestimated. CSE (Somvanshi, 2014) estimates the quantity of C&D waste to be approximately 530 million tons per annum, which makes India amongst the top C&D waste generators globally, as can be referred from table 1.1.

Table 1.1 Estimated country wise C&D waste generation

Country	Generation (MTPA)	Per capita generation (Ton/ capita)	Year
China[1]	2,190	1.6	2011
EU-27[2]	461	0.9	2005
India[3]	530	0.4	2013
USA[4]	170	0.6	2007
Japan[5]	123	1.0	2007
England[6]	100	1.6	2012

[1]Lu, 2014
[2]European Commission (DG ENV), 2011
[3]CSE, 2014
[4]Calkin, 2009
[5]Zimring, 2014
[6]DEFRA, 2015

(Source: GIZ, 2015)

Current Disposal Practices

The disposal of demolition waste is becoming a major concern with the increasing demolition of old/ deteriorated structures. There is no uniform and systematic process followed for the disposal of C&D waste anywhere in India.

This lack of policies have aggravated public problems related to the disposal of C&D waste, with the illegal disposal of C&D waste being frequently observed in places such as streets, pavements, wastelands, hillsides and stream and river beds.

Fig. 1.2 Dumping C&D waste on the streets

(Source: Somvanshi, 2014)

A large fraction of this waste is also being used to illegally fill up urban water bodies and wetlands to reclaim land for more building construction.

Fig. 1.3 C&D waste disposal in water bodies

(Source: Indiawaterportal)

The growing population of our cities and requirement of land for other uses has reduced the availability of land for waste disposal.

Box 1.1 illustrates how C&D waste is leading to ecological and environmental damage to natural resources like clean air and water.

Box 1.1 Environmental damage caused by C&D waste

Bengaluru used to have 937 lakes in 1937. Today they have reduced to just 80 out of which only 34 are live lakes. According to a study conducted by the Centre for Ecological Sciences (CES), Indian Institute of Science (IISc) in Bengaluru, the water bodies of the city have reduced to less than 1.5 percent in 2005 from 3.4 percent in 1973, while the built up area increased to 45 percent from 27 percent. The 30.5 acre Kundalahalli Lake in Brookefield Layout - one of the many lakes facing similar plight –

is under serious threat as a 100 ft hillock of construction debris has come up adjacent to it and needs to be urgently cleared (Roy, 2016).

Delhi generates over 5,000 tonnes of demolition waste daily (Chatterjee, 2015) which accounts for more dust than the construction dust. Much of it is more toxic due to use of fibres such as asbestos in old structures, and with no measures taken to cap the dust. Moreover, post demolition these sheets are dumped near sites without even covering them, despite asbestos being a known carcinogen. Combined with burning of waste and road dust, C&D waste contributes to an estimated over 20% of air pollution in Delhi.

There is an urgent need for systematic planning and management of C&D waste in India.

1.2 Objectives of the manual

This manual is prepared for the Indian building and construction industry, by combining local knowledge and incorporating lessons from international best practices wherever applicable.

The objective is to suggest model specifications for dismantling of commercial buildings to enhance construction waste reduction, reuse and recycling through feasible on-site segregation.

Chapter 4 and 5 of the manual underline useful and significant role played by large scale demolition technologies in deconstruction projects.

The manual can also be used for training and capacity building of ULBs, engineers and students in various engineering disciplines.

1.3 Scope and objectives of deconstruction

Deconstruction is the systematic disassembly of a building/structure, with the purpose of recovering valuable materials for reuse in construction, renovation or manufacturing into new products. It is an environment friendly alternative to demolition, salvaging as many reusable materials as possible for productive reuse and diverting them from local landfills.

Deconstruction is an integrated and comprehensive approach for recovery of secondary resources for reuse, repurpose and recycling from the waste generated. It is recognised, supported and practiced in many countries to make the construction industry more sustainable. Deconstruction is also consistent with India's cultural values and traditional architecture as glorified by the noted architect L. W. “Laurie” Baker (fig 1.4) whose centenary is being celebrated this year.

Box 1.2 Quotes from Laurie Baker's official website

“Here, as an aside, I would like to mention that I believe that Gandhiji is the only leader in our country who has talked consistently with common-sense about the building needs of our country. What he said many years ago is even more pertinent now. One of the things he said that impressed me and has influenced my thinking more than anything else was that the **ideal houses in the ideal village will be built using materials which are all found within a five-mile radius of the house.** What clearer explanation is there of what appropriate building technology means than this advice by Gandhiji?

Fig. 1.4 Renowned architect Late Laurie Baker

..I suppose it took many years before I really understood and wholeheartedly believed that wherever I went I saw, in the local indigenous style of architecture, the results of thousands of years of research on **how to use only immediately-available, local materials to make structurally stable buildings** that could cope with the local climatic conditions, with the local geography and topography, with all the hazards of nature (whether mineral, vegetable, insect, bird or animal), with the possible hostility of neighbours, and that could accommodate all the requirements of local religious, social and cultural patterns of living. This was an astounding, wonderful and incredible achievement which no modern, twentieth century architect, or people I know of, has ever made."

(Source: http://www.lauriebaker.net)

Various features of Baker's work such as using **recycled material, natural environment control and frugality of design** may be seen as sustainable architecture or green building with its emphasis on sustainability. Almost 80% of "The Hamlet"- Baker's home (fig 1.5) since 1970 was built using recycled materials.

Fig. 1.5 The Hamlet (House of Laurie Baker)

(Source: http://www.lauriebaker.net)

Unlike demolition, deconstruction aims at optimisation of resources, and needs to be promoted along with the practices like restoration, strengthening, retrofitting and rehabilitation to reduce the need for deconstruction.

Deconstruction should be considered, for retrieving reusable materials with the aim of -

i. Pollution prevention by promoting reuse and recycling of materials;

ii. Reduction in the use of virgin materials;

iii. Conserving energy;

iv. Increasing competitiveness by way of cost reduction;

v. Making construction industry more sustainable.

Deconstruction involves in all practical sense: stripping, dismantling and demolition of the remaining structure (which is always the case). Nearly all structures undergo demolition as the final step.

The practice of 100% deconstruction or dismantling is still rare globally. Very few buildings are today designed for dismantling and reuse of 100% of the products deconstructed. To design for proper deconstruction, manufacture of construction products would have to be done in a different way than they are today.

However, the practices of stripping a building (reusing and recycling the stripped products and materials), demolishing it and recycling the demolished material have come far in some countries in Europe.

In India, several projects have undergone stripping. Doors, windows, etc., have been sold by dealers before the building skeleton has been demolished. Therefore, deconstruction and demolition are practiced in the same projects in nearly all cases.

Reducing the industry's consumption of virgin materials will help preserve natural resources and protect the environment from air, land, and water pollution related to extraction, processing of raw materials as well as disposal of waste.

Deconstruction should be done in a scientific and controlled manner to ensure minimal damage to recovered building material. Deconstruction is particularly essential for any future development (on that site) that responds to the challenges of environmental sustainability, low carbon emissions and minimal resource depletion.

By decreasing the amount of waste going to landfills, deconstruction abates the need for new landfills and incinerators and potentially contributes to greenhouse gas reduction. Perhaps most importantly, it helps to steer the C&D industry away from traditional consumption and disposal patterns and towards sustainability.

Commonly recovered items include doors, windows, flooring, ceiling tile, countertops, cabinets, light and plumbing fixtures, moulding, joint fixtures, roofing, etc. Contractors recycle these items frequently but the remaining debris is seldom reused, either on-site or off-site, after processing.

1.4 Economic and environmental impacts of deconstruction

The Indian real estate market is expected to be valued at US$ 180 billion by 2020 (IBEF, 2017). Due to high growth in the sector, the demand for construction materials is rising rapidly, resulting in severe shortage in supply of natural resources such as sand, stone and wood.

Projections for building material requirement of the housing sector indicate a demand of aggregates up to 55,000 million m^3. Additionally, 750 million m^3 would be required for achieving the targets of the road sector (Ponnada and Kameswari, 2015).

On the other hand, unscientific dumping of C&D waste is putting severe pressure on environment and land resources, creating a major issue in urban waste management, such as increase in the flooding due to the illegal dumping of waste obstructing surface run-off, resource depletion, and shortage of landfill space.

Often, this waste is dumped in low lying areas and water bodies in an unauthorised manner. Such dumping strewn across the city, chokes surface drains, disrupts traffic and is an eyesore on the urban landscape. About 10-20% finds its way into surface drains, choking them. It also blocks natural ground water charging channels.

This leads to depletion of groundwater resources and accentuates likelihood of floods due to blocked channels.

One of the most important environmental benefits of reuse and recycling of C&D waste is the reduced use of virgin construction materials.

Demolition of "pucca" and "semi-pucca" buildings on an average generates 500 and 300 kg/square meters of waste respectively. Estimated waste generation during construction is 40 to 60 Kg. per sq. m. Waste generation during renovation/repair work is estimated to be 40 to 50 kg/square meters. (TIFAC, 2001)

Cost analysis of the Indian construction industry shows that material cost comprises nearly 40-60% of the project cost (Rani and Gupta, 2016). Thus, scientific deconstruction and reuse represents a significant opportunity in economic and monetary terms.

In addition, reuse and recycling of material from C&D waste provides substantial cumulative saving of embedded energy used in extraction and processing of virgin materials.

For example:

i. Using recycled aggregate from C&D waste can reduce the consumption of fresh stones and sand, which can lead to conservation of huge quantities of sand and soil per day.

ii. Recovery of 10 mm aggregate from C&D waste can be mixed with cement and sand to make RMC, saving virgin materials.

iii. The C&D waste processing facility in Delhi uses wet processing system that results in clean soil which can be used for landscaping.

iv. During the reconstruction of super highways (outbound) in Germany, old concrete pavements were broken up and processed at a pre-planned nearby recycling site, with recycled aggregates used in producing concrete Grade 45 in an adjacent batching plant for use in new pavement construction.

v. London Olympic 2012 Stadium used 30% recycled concrete in its construction.

Fig. 1.6 London Olympic 2012 stadium

(Source: The Telegraph)

1.5 International best practices and current Indian regulatory framework

Across the globe, regulations are increasingly focused on systematic deconstruction and material recovery (CSE, 2014; Somvanshi, 2014). For more information, see Appendix IV.

Europe: a target of 70% material recovery of C&D waste by 2020 is set in the European Commission Waste Framework Directive (2008/98/EC). Achieving this target will help to meet the European goal of a more resource efficient society, in addition to reducing environmental impacts (European Commission, 2016).

Hong Kong: C&D waste tax on developers lowers C&D waste at landfill by 60%. 100% waste utilisation is charged at $27 per tonne. More than 50% waste needing landfill disposal is charged at $125 per tonne. Revenue is used to subsidise recycling centres.

South Korea: C&D waste management is part of the Low Carbon Green Growth strategies. They have separate building codes for recycled asphalt concrete aggregates, recycled concrete aggregates, and road pavements. The effective recycling rate is 36% with a target of 45%.

New York City: The waste disposal practices are more efficient than the rest of the US. It forces the developers to segregate waste at site, dismantle and not demolish, in addition to other measures.

The Government of India has provided a frame work for management of C&D waste through the Construction and Demolition Waste Management Rules, 2016. These rules clearly distinguish between:

"Deconstruction": means a planned selective process in which salvage, re-use and recycling of the de-constructed structure is maximised;

"Demolition": means breaking down or tearing down buildings and other structures either manually or using mechanical force or by implosion using explosives.

As per the rules, waste generators who generate more than 20 tons or more in one day or 300 tons per project in a month shall:

i. Segregate the waste into four streams such as concrete, soil, steel, wood and plastics, bricks and mortar;

ii. Submit waste management plan and get appropriate approvals from the local authority before starting construction or demolition or remodeling work;

iii. Pay for the processing and disposal of construction and demolition waste generated by them, apart from the payment for storage, collection and transportation against charges set by the local authority/ state govt.

However, no further reference is made to or support provided to encourage deconstruction processes vis-à-vis current industry practices. According to a study commissioned by Technology Information, Forecasting and Assessment Council (TIFAC), 70% of the construction industry is not aware of recycling techniques.

This manual will enable regulatory authorities to propose changes to existing statutes to make deconstruction activity more meaningful and engaging.

2. PLANNING DECONSTRUCTION

2.1 Goals of deconstruction

While planning for deconstruction it would be pertinent to remember the underlying goals of deconstruction, which are:

- Re-use as many products and /or materials as possible in a cost-efficient matter.
- Decrease the outtake of virgin materials and thus contribute to sustainable resource management.
- Remove the structure from the site.

These goals should be achieved while adhering to health and safety regulations to ensure that no accident happens during the process.

Before planning deconstruction, industry should consider Processes and Techniques such as **Rehabilitation, Retrofitting and Restoration** to add, delete, modify, and substitute existing building components. These are more economical and environment friendly options than deconstruction.

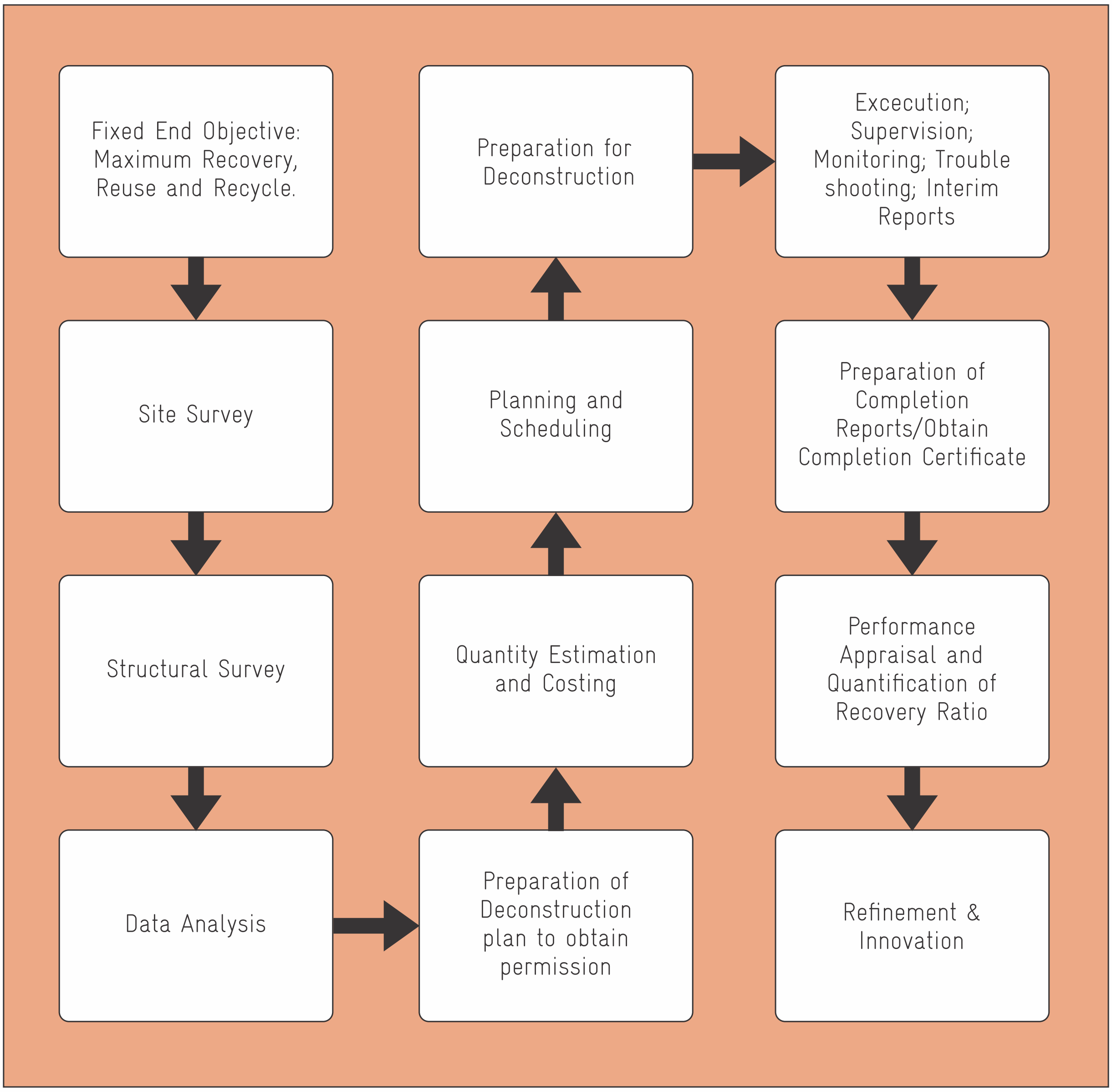
2.2 Deconstruction assessment

The first step in the deconstruction process is to capture key information regarding any building. This should be ensured during the process of awarding occupancy certificate. A standardised format (to be uniformly used all across India) needs to be developed and made available by ULBs. The form should capture details of material used for construction, their quality, the layout, construction process used, and life of various components and the building itself.

At the time of planning deconstruction, a detailed assessment by experts is essential to recommend deconstruction methodology and technologies. Agencies with necessary technical knowhow and expertise should perform the assessment and also furnish the justification.

The flow chart in Fig. 2.1 below shows activities for the entire deconstruction process.

Fig. 2.1 Activities flow chart for entire deconstruction process



2.3 Building survey

Building survey is one of the key steps to initiate the process. The survey should be mandatory for any deconstruction or demolition project over a certain size (for example, project size above Rs. 250 crores or any project that is expected to generate 20 ton C&D waste per day).

Building surveys should capture estimated C&D waste likely to be generated, further also classified under various types of material such as wood, concrete, glass, metal and plastic. This should be systematically compared and documented with the actual result after completion of the deconstruction.

The survey can include a walk-in on the site of deconstruction, for observations, oral enquiries and inspection by a team of structural engineers, deconstruction specialists, environmental engineers, utility engineers and safety experts.

In addition, information should also be collected from available architectural and structural detailing, records, measurements. Relevant information should then be analysed to develop most appropriate methodology for deconstruction, recycling and establishing the business case.

Building survey items

Drawings including layout plan with details of adjoining properties, walkways, roads, streets, etc. should be retrieved, analysed and recorded in the report for purpose of planning and smooth implementation.

The essential survey items that need to be included -

i. Details of building materials used.

ii. Locations of past and present utilities and contemplated utility needs in future.

iii. Public and semi-public utilities like fire hydrants, parking lots and street-vendors' stalls, etc.

iv. Threats/hazard potential of materials that could cause air/ soil pollution, or are toxic, inflammable, or radioactive.

v. Potential dangerous areas which are likely to trap gases such as enclosed voids, non-ventilated light wells and abnormal layouts need to be properly marked.

vi. Status of adjoining properties with emphasis on presence of slopes, retaining structures, infrastructure facilities.

vii. Noise sensitive receptors (including, but are not limited to, hospitals, schools, day care facilities, elderly housing and convalescence facilities) in the neighbourhood with respect to noise, dust and vibrations.

viii. Terrain and topography in relation to water and waste water flow to and from the site.

ix. Common facilities with adjoining structures that would get affected during deconstruction.

x. Space availability for on-site material storing and handling.

xi. Available headroom, distance of building and clear spaces that are likely to affect the storage for on-site reuse, loading operation and debris transportation during deconstruction.

xii. Traffic data in and around the site for purpose of planning any road blockages and movement of heavy equipment.

xiii. Catch-fan, covered platform and shielding needs.

Identification of hazardous materials

Competent agencies like material testing laboratories certified by the National Accreditation Board for Testing and Calibration Laboratories (NABL) should sample test and identify materials containing hazardous substances and advice on their removal, clearance and disposal.

Based on the findings of building survey and first report, detailed structural survey and if required, analytical and experimental investigations, should be carried out.

2.4 Structural survey

Data acquired from available architectural and structural detailing, records, observations, measurements and oral enquiry should be analysed to ascertain the need for a structural survey.

Information as listed under should be gathered for structural survey –

i. Material of construction

ii. Structural configuration

iii. Construction method

iv. Observation of distress in elements and the degree of distress

v. Structural status of adjoining buildings and the impact of deconstruction on them

vi. The likely break in continuous structures during deconstruction

vii. Presence of lateral load resistance systems like bracing exposed or concealed

viii. Infill and their structural significance

ix. Overhanging suspended and counterweighed structural elements and forms, etc.

2.5 Special structures

Special structures generally have unique functions and behaviours. They represent advances in analytical techniques, design standards and construction practices. They include structures such as space frames or grids; cable-and-strut and tensegrity; air-supported or air-inflated; cable net; tension membrane; lightweight geodesic domes; and thin shells, among others.

As per the Hong Kong Code for Building Demolition (2004), precautionary site care should be taken in dismantling of:

i. Pre-cast concrete structures – simple pre-cast construction, continuous pre-cast construction

ii. Pre-stressed concrete structures – pre-cast pre tensioned, pre-cast post tensioned, segmental post-tensioned construction, circumferential pre-stressed tanks, etc.

iii. Statically determinate structures (having characteristics of large deflection and high stress concentration at critical positions) – Cantilevered, Hinged or Pin-jointed trusses

iv. Composite structures and steel structures

v. Cladding walls

vi. Hanging structures

vii. Oil Storage facilities – contain hazardous petroleum products

viii. Marine Structures – water front

ix. Underground structures

x. Structures supporting ground or sitting on slopes.

Additional information for such structures to be part of structural survey and should indicate –

i. Authenticity of structural detailing and data on revisions, if any.

ii. Information on elements that have been modified or that need special attention.

iii. A detail of special techniques to be adopted during deconstruction owing to constrains and restrains.

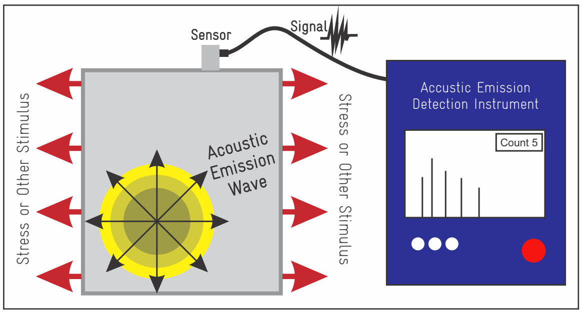
2.6 Investigations and testing

When structural details are not readily available, data should be obtained from measurements, tests, observations, and oral enquiries. Fig. 2.2, 2.3 and 2.4 below show popular techniques for testing.

Fig. 2.2 Non-destructive testing (Rebound Hammer Test)

(Source: Civilblog)

Fig. 2.3 Acoustic emission test



(Source: NDT Resource Center)

Fig. 2.4 Pulse velocity test

(Source: The Constructor)

2.7 Stability report

The stability report should be prepared on the loading conditions; addition and alteration works; structural defects, damage, distress, deformation, deterioration; and overall structural integrity and stability, by a structural expert. Conclusions drawn from building survey and structural survey and stability/instability report should be used in preparation of deconstruction plan.

2.8 Stability monitoring report

Stability monitoring report on stability of structure at all stages of deconstruction should be prepared to demonstrate that the sequence, technique, tools, plants, equipment and machinery employed do not endanger the stability of the structure or the neighbourhood.

2.9 Deconstruction plan

A deconstruction plan for a site aims to maximise resource recovery. The plan should include data and details from various surveys and investigations to provide staff with relevant information on the project. It should also be included as part of the application for permission required for deconstruction.

The plan should include the following:

i. Building's location, layout of the surroundings with details of levels (Contour map if necessary), setbacks and adjoining streets and utilities.

ii. Layout plans indicating functional use, structural systems, building materials, and common facilities with the neighbourhood.

iii. Details and current status of structural systems, construction method and existence of special features and systems.

iv. Deconstruction methodology, procedure (sequence) and schedule with timelines and details of technique.

v. Expected quantity of different types of materials.

vi. Material handling and storage of intended end use of the various components, such as on-site (reuse) and off-site (recycle) and scientific disposal of residual waste.

vii. Route plan of mobile units movement, specific location from where they can operate and strengthening details of existing elements (if necessary) to facilitate usage of such units.

viii. Identification of hazards such as those relating to material, pollutants and individual safety.

ix. Health and safety plans to ensure workers' safety and compliance with statutory obligations.

x. Precautionary measures to be adopted for the safety of adjoining properties.

xi. A plan showing the arrangement for shoring and temporary supports for building.

xii. Clearly mark location, security and protection of storage areas (for on-site reuse).

The deconstruction plan should be prepared in conjunction with the waste management plan (see Section 6.3).

For all practical purposes, these plans should be one document, e.g. Deconstruction plan with an annex clearly specifying the waste management plan.

2.10 Utilities

Contractors in cooperation with utility agencies should ascertain the implications of deconstruction on the services/utilities to the structure or to the neighbourhood.

Effect of deconstruction on utilities

In deconstruction, the following common utilities are encountered and assistance/cooperation of utility providers should be sought in deconstruction exercise:

i. Electrical installations

ii. Water supply and sanitary connections

iii. Gas pipelines

iv. Communication networks of overhead and underground cables

v. Tunnels and shafts

The deconstruction plan should have details of service providers who will shut down the utilities during the deconstruction and provide temporary services as and when required. More importantly, the plan will ensure that the process does not impact utilities in neighbouring areas adversely.

Before the process of deconstruction is initiated, the authorised person should liaise with utility companies so as to –

i. Keep record of available utilities at the site and

ii. Terminate all utilities and provide temporary services whenever required.

Maintenance of utilities

All basic utilities necessary to maintain the safety and health of deconstruction team should be retained and maintained such as -

i. Water for deconstruction work and for abatement of dust.

ii. Communication networks for security and communication needs.

iii. Adequate measures should be taken to ensure uninterrupted electricity supply for lighting and other needs for deconstruction.

2.11 Hazardous materials

Need for handling hazardous material should be ascertained and necessary precautions should be undertaken. Advice of experts should be sought for identifying and mitigating hazards from materials like Asbestos, Lead, Polychlorinated Biphenyls (PCBs), contaminated dust, combustible materials, Petroleum products and Radiation contamination, etc.

Asbestos containing material

As defined by Occupational Safety and Health Administration (OSHA), asbestos is a known human carcinogen and can cause chronic lung disease as well as lung and other cancers. Symptoms and/or cancer may take many years to develop following exposure.

During deconstruction, identification of source, sampling, need for special handling methods and agencies should be considered and such cases should be handled in compliance with regulations.

As per the Australian Code of Practice for Demolition (SafeWork Australia, 2016), only the asbestos that is likely to be disturbed during the demolition of that part of the building or structure is required to be removed, so far as is reasonably practicable.

Soil contamination

A variety of sources can cause soil or sub-surface contamination. Deconstruction activities normally leave behind large debris of materials like wood, metals, bricks, plastics, etc. that may lead to soil contamination.

Accidental spills of stored toxic materials may infiltrate and cause contamination. Underground storage tanks used for storing large quantities of liquids should be checked for leakage due to corrosion of tanks causing contamination.

Leakage from buried/underground pipelines that exist to transport liquids, effluent discharges from septic tanks, and application of industrial sludge on land are other examples.

Tanks with such liquids should be solidified or removed. In many countries, it is now mandatory to remove and safely dispose these tanks. All such issues should be identified and recorded in the deconstruction plan.

Lead containing material

Lead is well known to be toxic. Exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. It can cause poisoning and serious injury to the brain, nervous system, red blood cells, and kidneys and can even lead to death. Inhalation and ingestion are the two routes of exposure, and the effects from both are the same (Wuana and Okieimen, 2011).

Lead is found in paint, old water pipes and other plumbing fittings, sheet lead, solders, lead flashing, lead light windows and glass.

As per the Australian Code of Practice, the age of a structure may be directly related to the sources of lead in the structure, as highlighted in Table 2.1.

Table 2.1 Date and sources of lead

Approximate date of construction	Sources of lead hazards
1920 - 1978	Paint
1920 - 1978	Plumbing
1923 - 1986	Automobile exhaust (may accumulate as ceiling dust)

(Source: SafeWork Australia, 2016)

The precautions which should be taken when demolishing materials containing lead include:

i. Minimising the generation of lead dust and fumes
ii. Cleaning work areas properly during and after work
iii. Wearing the appropriate Personal Protective Equipment (PPE)
iv. Maintaining good personal hygiene.

In order to dispose the debris, sampling may be done for representative waste items to determine whether lead's presence is hazardous (with reference to the Hazardous Waste Management Rules 2016) and disposed off in accordance with the rules.

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls are a group of 209 different chemicals which share a common structure but vary in the number of attached chlorine atoms. The International Agency for Research on Cancer and the US Environmental Protection Agency classify PCBs as a probable human carcinogen.

Workers can be exposed to PCBs when dismantling electrical capacitors and transformers or when cleaning up spills and leaks. Appropriate control measures should be implemented when handling damaged capacitors to ensure that there are minimal spillages. Any spillage should be handled with extreme care. Adequate ventilation or approved respirators should be considered for spill clean-up.

Any equipment or parts containing PCBs should be placed in a polyethylene bag and then placed into a marked sealable metal container.

If PCBs cannot be transported immediately for disposal, all containers should be stored in a protected area which prevents any discharge of PCBs to the environment.

PPE (Personal Protective Equipment) including gloves, made of materials that are resistant to PCBs (e.g. polyethylene, nitrile rubber or neoprene), should be provided to workers and worn when there is any likelihood of exposure to PCBs.

2.12 Protection of adjoining properties

In relation to the structural survey and deconstruction report, adequate and necessary provisions for stability and safety of the building being de-constructed and protection of adjoining properties should be undertaken, by adhering to the deconstruction plan.

Party walls and external walls

Walls that are common to adjoining properties should be handled as per deconstruction report. Waterproofing, proper maintenance of drainage facilities, adequate temporary and permanent supports should be ensured.

Foundation support

Deconstruction below grade needs very careful assessment and appropriate ground improvement techniques such as grouting, guniting, shotcreting, shoring, strutting and underpinning, depending on the quantum of deconstruction and the vicinity of other structures and facilities should be adopted.

2.13 Site access

Access to and from the deconstruction site should be ascertained and if necessary modified. In exceptional cases, site access can be altered to suit the deconstruction plan and practices. Provision of necessary clearances for movement of deconstruction machinery to and from site and at site for separation and stacking should be ensured. The premises should be adequately illuminated.

2.14 Adjacent traffic

Necessary permissions from concerned authorities should be obtained for operation and movement of deconstruction machinery as required and movements should be planned so as to avoid interference, interruption and closure of adjacent traffic. If inevitable, closure of adjacent traffic should be planned and necessary permission should be obtained from concerned authorities.

2.15 Health and safety considerations

Top priority should be accorded to safety and health issues. There should be zero tolerance towards compromises and/or short cuts. The same should also be communicated to the Project Manager and the rest of the team. A daily morning briefing and safety pledge should be part of the routine. Markings in bold should be provided in English and local language to identify potentially dangerous equipment, materials and site.

The safety plan should include: worker orientation, safety training, CPR/First Aid training, hazard identification and handling training, tool use guidelines, respiratory protection, fall protection, emergency procedures, Occupational Safety and Health Administration (OSHA) forms, job-site daily log, Personal Protective Equipment (PPE) use, and procedures for correcting unsafe behaviour. The Site Supervisor/Safety Manager must ensure that safety and health issues are within their control.

Training and communication

All involved in deconstruction should undergo necessary training and should be informed of the hazards associated. Special training sessions, meetings, mock drills should be conducted on regular basis. Sensitisation of deconstruction team, neighbours and other stakeholders regarding health and safety should be undertaken before the start and on regular basis.

Dedicated broad themes to have trainings may be as under, inter alia:

- Planning for Deconstruction
- Material Handling
- Rules and Regulations
- Safety
- Recycling and Reuse

These can be for various levels of people, i.e. from project managers, foremen and supervisors to contractors and individual operators.

Examples of specific courses listed under the UK's National Demolition Training Group (NDTG) website are:

- Demolition and Refurbishment Operative
- Control of Substances Hazardous to Health
- Waste Management
- Environment Management
- Working at Height
- Manual Handling

Common safety signs displayed at work site are shown in Fig 2.5.

Fig. 2.5 Construction site safety signs

(Source: Vijay Industrial Engineering)

Equipment maintenance

Tools, equipment and machines should be subject to tests, calibrations and inspections before use. Records of tests, calibrations and inspections should be maintained.

Electrical safety

Power source should be acquired from authorised provider or a mobile unit arranged in compliance with the regulations.

Fire

Fire-fighting facilities should be in place. Isolation of all flammable goods and their proper storage must be ensured.

Occupational safety and health

Ensuring safety is of the utmost importance for successful deconstruction. Accordingly, it is imperative that the workers are aware of their location, the location of co-workers, any utility services or lines, the weight of the materials being worked with, etc. at all times.

Any oversight or misjudgement can result in serious injury or other problems. During the actual deconstruction, it is important to ensure strict adherence to occupational safety and health regulations with emphasis on exposure to dust, chemicals, heat, noise and occupational diseases.

Emergency exit routes

Emergency exit routes should be clearly identified, planned and detailed for use, if need arises, all concerned should have information about emergency routes and plans. Drills should be carried out to check the efficacy of route and preparedness of the project team.

Vibration

Generally vibrations due to deconstruction are not a significant issue. However if necessary, vibration mitigation measures such as isolation or damping should be adopted.

2.16 Environmental precautions

An impact assessment should be done to assess the need for and the methods of minimisation of environmental degradation and hazards.

Air pollution

Nuisance dust emissions from deconstruction activities are a common and well-recognised problem. Fine particles (less than 10 mm in diameter, known as PM10) from these sources are now recognised as significant causes of pollution. Owing to their small size, they can be carried from sites even in light winds and may therefore have an adverse effect on the local environment and on the health of local residents, as well as on those working on the site.

Pollution from dust should be mitigated by adopting techniques that minimise dust emissions. The most common methods for controlling demolition dust are surface wetting and airborne capture. With surface suppression, the goal is to prevent dust by wetting the source before particles can become airborne, usually with hand-held hoses or movable sprinklers. Dust screens, sprinkler and specialised dust suppression systems should be employed to control the spread. Further, burning of waste at site should not be allowed and project team needs to be clearly informed about the same. Fig. 2.6(a) and (b) depict dust control techniques at deconstruction site.

Fig. 2.6 (a) Dust control during deconstruction

(Source: LHSFNA)

Fig. 2.6 (b) Dust control during deconstruction

(Source: Mohan Ramanathan)

Noise

Measures to control noise pollution that affects site workers and noise sensitive receptors in the vicinity should be adopted. Silent type powered mechanical equipment (PME) should be used to reduce noise impact as much as practicable.

Demolition activity shall not be performed within restricted hours as established by the local body.

Water

Effluent discharge from deconstruction site should be avoided. If inevitable, necessary actions should be undertaken to comply with regulations. For e.g. as per pollution prevention guidelines at C&D sites (Environment Agency, 2012), mud leaving the site on delivery vehicles should be reduced through road sweeping or wheel wash facilities on entrance and exits from site.

Hazardous materials

Care and precautions, are necessary in identifying, handling and removal of hazardous material. Advice should be sought from agencies with necessary knowhow.

Identification of hazardous materials may be done following existing classification system and limit values for hazardous chemical substances (as per the Hazardous and Other Wastes (Management and Trans-boundary Movement) Rules, 2016).

2.17 Risk management

Risks identified during survey, planning and scheduling should be analysed and appropriate mitigation measures identified. Risk management plan should be prepared along with risk register and necessary insurance covers should be obtained. Risks listed in the risk register should be monitored during the course of execution.

Control measures

The control measures for deconstruction work must ensure following:

i. The avoidance of premature collapse;

ii. The protection of workers and members of the public from falls and falling material;

iii. The safe siting and use of tools, equipment, plant, and vehicles;

iv. Ensuring protection from dust, fumes, noise and vibration;

v. Employment of competent and skilled work force;

vi. Sensitisation and preparedness for hazards.

Supervision of complex structures

Buried structures, conduits and service utilities need utmost care in planning, execution and delivery of deconstruction. A thorough inspection before deconstruction has to be made, to make an assessment and recommendations on precautionary measures.

Service connections need temporary bypasses during deconstruction and restoration to normalcy afterwards.

Appraisal of de-constructed facility in relation to parts remaining (if any) and to the surrounding should be made to ensure safety and compliance with statutory obligations.

2.18 Other

Need for compliance with other statutory obligations and insurance requirements should also be addressed. Some of the good practices employed in construction will also be applicable for deconstruction.

3. PREPARATION FOR DECONSTRUCTION

The Deconstruction Plan should be reviewed and updated, if need be, as a first step in preparation for actual deconstruction. At a minimum, following details should be prepared:

i. Checklist of activities.

ii. Inventory of tools, plants, equipment required.

iii. Enlisting skilled and unskilled work force.

iv. Organising sequence and schedule of deconstruction.

v. Plan for material handling.

vi. Setting up on-site and/or off-site facilities for waste segregation.

vii. Emergency response plan and procedure for conducting drills.

3.1 Site preparation

Preparation of the site entails several steps, particularly focused on ensuring safety. Further, it is relevant to consider and provide protective measures for minimising impact on surrounding buildings, roads, bridges and natural environment.

Safe access must be provided at all time. If work cannot be carried out safely on the building, a scaffold or machine-lifted platform should be used. Hazard assessment of the site should be done to ascertain the appropriate controls. The contractor needs to undertake such exercise beforehand.

All persons must be fully trained in the correct and safe use of equipment for fall arrest systems. Guardrails or barriers should be put up to avoid fall risk. Wearing a properly anchored safety harness is only to be implemented if all other controls cannot be used.

At the end of each day, make sure the building is safe. Guying or propping may be necessary to avoid hazards from wind or vibration. If only part of the building is knocked down, make sure that what is left can stand safely.

Hoarding

Hoarding is a temporary structure of solid construction, erected around the perimeter of sites to prevent unauthorised access. It is an important component in ensuring health and safety, for site workers, visitors and the general public. It also serves as site security system to prevent theft or vandalism. The site hoarding should include appropriate signage identifying key risks and advisory for members of public to stay away. Emergency contact details should also be included. For very large scale or sensitive deconstruction projects, it may be relevant to consider video monitoring and recording of site activity. Fig. 3.1 shows hoarding at deconstruction site.

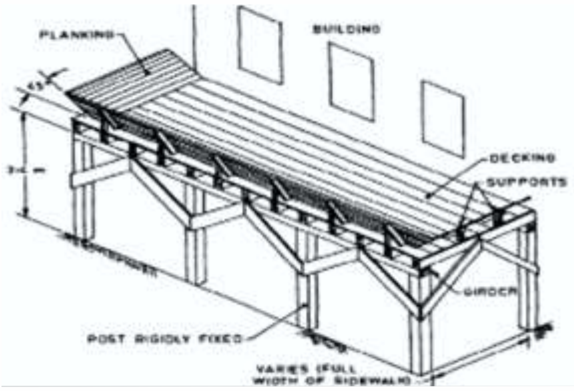
Fig. 3.1 Construction site hoarding

(Source: Solid Horizon)

Covered walkway

To ensure a safe walk-way for pedestrians and to minimise disruption, covered walkway should be provided. A catch platform on the covered

Fig. 3.2 Sketch of a sidewalk shield



(Source: BIS, 1997)

walkway should be made to contain debris and facilitate roof drainage. Fig. 3.2 shows covered walk away (sidewalk shield).

Height of the building under deconstruction and adjoining features decide the need for hoarding, covered walkway and catch platform. Relevant information on designing hoarding, covered walkway and catch platform is provided below:

i. If setback around the building is more than the height of the building, hoarding alone is sufficient.

ii. Where setback is less than building height, covered walkway should be provided.

iii. When setback is less than half the height of the building, in addition to covered walkway, catch platform should also be provided.

iv. For building less than 4m in height, catch platform may not be required.

v. Provision of hoarding, covered walkway and catch platform is essential for full length of site boundary adjoining public thoroughfare.

Lighting

Proper and adequate illumination should be provided and maintained at the site as well as in covered walkways. It is important to ensure that all signages are clearly visible. Given the high safety risk associated with deconstruction, all sensitive areas should also include provision for emergency lighting in case of power failure. Fig. 3.3 represents lighting adopted for deconstruction site.

Fig. 3.3 Lighting at deconstruction site

(Source: Alamy)

Scaffolding

Scaffolding is a temporary structure (made of timber or metal) to support a work crew and their tools and equipment. Scaffolding used should comply with stability, strength, safety and serviceability standards.

All vertical and lateral load transferring elements should properly channelise the loads to the supports. The platforms designed should be cleaned regularly to remove debris accumulated.

Fig. 3.4 Scaffolding

(Source: Superior Scaffold Services)

Scaffolding installed at a work site is demonstrated in Fig. 3.4.

Screen cover

Fabrics and nets are used as screen covers on the external scaffold face to provide enclosure for retaining dust and debris. The fabrics and nets should be light weight, resistant to UV light deterioration, fire resistant and should have good retaining characteristics.

The screen covers should be arranged so as not to deflect debris onto the ground. The screen covers should be secured and at a minimum horizontal and vertical overlaps of 300 mm. Net screen covers for retention of dust and debris are depicted in Fig. 3.5.

Fig. 3.5 Net (Screen cover)

(Source: FenceScreen)

Catch-fan

Catch-fans work in conjunction with platforms and screens and are used for trapping small pieces of debris falling from a height. Hence, catch-fans are installed at distances not exceeding 10 m below the work floor. A minimum horizontal extension of 1.5 m from the exterior scaffolding face should be provided at an inclination to horizon between 20° and 45°. A pictorial view of catch-fan is shown in in Fig. 3.6.

Fig. 3.6 Catch-fan

(Source: Tammet Systems)

Propping Support

Propping supports, prepared on the basis of site survey and structural survey to adjoining structures should be erected and maintained. Temporary support employed at a work site is represented in Fig. 3.7.

Fig. 3.7 Temporary supports – shoring and strutting

(Source: WES Consulting)

All supporting and propping systems should be identified, planned, erected, maintained and dismantled as recommended in the deconstruction plan.

3.2 Deconstruction sequence

Deconstruction is usually executed in reverse sequence to that of construction. However, the type of structure and materials used have a significant bearing on the sequence. Other considerations include location, availability of time, reuse and recycling aspects and the available budget.

Structure status specific

The need for deconstruction may arise from aging, non-performance of components, accidents or willful damage in rare cases.

Structure status assessment and failure analysis is important for optimal deconstruction.

Structure type specific

Structure type specificity is related to the utilitarian needs or the functional requirement of the structure being de-constructed. Utility of the building, viz. residential, commercial, industrial, institutional, recreational, public or semi-public, healthcare, etc., and also the size, whether small, medium, large and very large complex determine the deconstruction sequence.

Material type specific

Material type specificity means considerations of the materials that have been used in the construction of structure and also to their recoverability.

Location and time specific

Following are relevant in formulating deconstruction sequence based on the structure's location and time constrains:

i. Site accessibility (transportation network facilities)

ii. Surroundings (existence of hospitals, educational institutions and other dust/noise sensitive receptors)

iii. Available time (activity restricted to select times of the day)

iv. Emergent need.

The survey report duly indicates the necessary inputs for deconstruction sequence including special structures and or presence of hazardous material that need special care and considerations. In addition, whether the whole structure is being deconstructed or a part, the utilitarian needs also affect the sequence.

4. METHODS OF DECONSTRUCTION

Deconstruction methods should be judiciously chosen from amongst the many standard methods available. It must be remembered that the methods to be employed are always situation specific. Some of them are detailed below.

4.1 Soft-stripping

Reclamation of non-structural components like floors, doors, windows, ventilators, appliances and decorative elements is also termed as soft-stripping. An example of window removal soft-stripping is presented in Fig 4.1(a) and a stripped building in 4.1(b).

Fig. 4.1 (a) Non-structural deconstruction – Window

(Source: Erle, 2014)

Fig. 4.1 (b) Building is fully stripped and prepared for demolition

(Source: Engelsen, 2013)

4.2 Selective deconstruction

It involves deconstruction and removal of wastes of the same category one at a time.

The goal is to accumulate same type of waste to facilitate recycling for beneficial reuse, thus minimising the burden on municipal landfills.

4.3 Top down method

To undertake the deconstruction of high and medium rise buildings, it is usually safe to demolish one floor at a time, starting with the roof.

The method requires scaffolding around the building. It ensures adequate control, thereby protecting those working in and around the deconstruction site. Part of each floor is taken out so that the debris can fall through. Debris can be dropped down a chute or a lift shaft. Guardrails should be provided around shaft openings for safety.

Debris should not be allowed to pile up on floors. An overloaded floor could collapse onto the floor below. It must be removed regularly and floor below should be propped, to ensure that the walls of the building do not collapse.

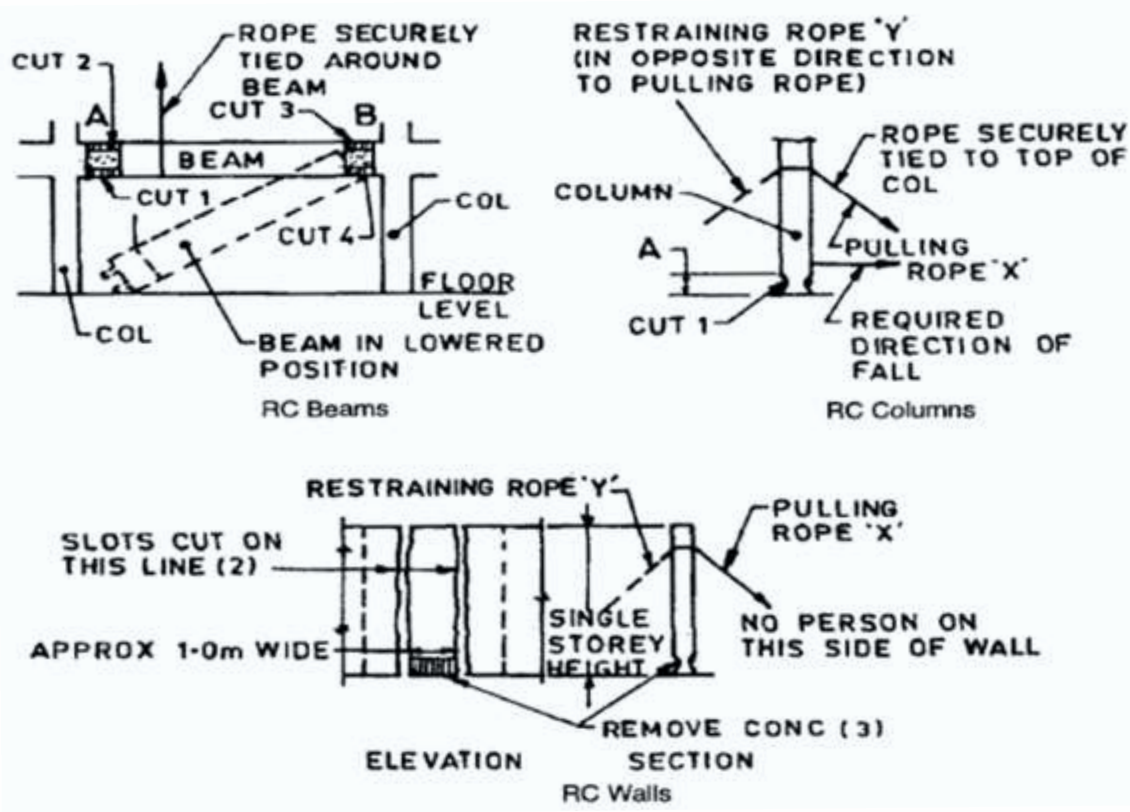
Manual deconstruction

Manual deconstruction is relatively slow method, as only hand tools are used. However, cranes and shear legs may be used to hold or lower beams during cutting.

Chutes or crane-and-skip are used to get debris safely from the upper stories to the ground. In addition, on rare occasions additional equipment such as pallet jack, forklift, scissor-lift, heavy duty truck with a lift-gate attached to the back, etc. may be required.

The manual method proceeds from roof to ground using appropriate handheld tools such as hammers, saws, cutters, torches, levers, chains, pulleys, ropes, winches, slings. Fig 4.2 presents the technique of manual deconstruction of concrete structures.

Fig. 4.2 Manual deconstruction of in-situ concrete structures



(Source: BIS, 1997)

Mechanical deconstruction

Top-down deconstruction by machines resembles the manual method but is done with the use of machinery in place of manual labour. The machinery is hoisted to the working level.

The process is technically challenging and requires a good knowledge of the construction of a building and the engineering controls that need to be put into place.

The hydraulic crusher that operates from outside the installation or inside if space permits, breaks the concrete and reinforcement by the brute hydraulic thrust that operates through long booms and arms attached to the system.

4.4 Other methods

Massive concrete elements require use of explosives for deconstruction. Such blasting may not be permitted in certain locations. Silent deconstruction chemicals also known as non-explosive agents can be deployed in such cases.

Holes are drilled at pre-determined locations to required depth and in suggested grid or pattern. The chemical is placed in the holes and watered. The expansion of the chemicals causes the concrete in its vicinity to crack and reduces the effort required in breaking of the structure. This approach is low on noise and other pollution. Further, it also ensures recoverability and recycling of embedded steel.

Fig 4.3 (a, b, c & d) show the efficacy of silent deconstruction chemical.

Fig. 4.3a, 4.3b, 4.3c, 4.3d
Silent deconstruction chemical

(Source: Dexpan)

Summary of general characteristics of deconstruction methods has been provided in Appendix I.

4.5 Special structures

Special structures are complex structures that incorporate challenging geometries and materials. Some special structures are stand-alone projects. Others are components of larger, more conventional projects. All require unconventional approaches to deconstruct.

Special structures often transcend the boundaries between disciplines, combining structural evaluation and design, facade engineering, sustainability analysis and construction support engineering.

Such special structures require specialised knowledge for deconstruction. These elements need to be noted in the deconstruction plan and highlighted in tendering for contractors to evaluate their skills for such an assignment.

Other methods, including thermic lances, drilling and sawing can be used in conjunction with the methods outlined in this section. These are specialised uses, and must be carried out only by fully trained and competent personnel.

Deconstruction procedures to be employed for special structures have been detailed in Appendix III.

5. DECONSTRUCTION TECHNOLOGIES

5.1 Deconstruction

With land area becoming a precious commodity, especially in the urban areas of India, the concept of redevelopment has caught on big time in the country. Demolition of existing structures as part of redevelopment projects is fast becoming a multimillion industry in itself.

'Deconstruction' is a relatively new term that has evolved from the concept of demolition with recycling and reuse in mind.

Over the years, C&D waste materials such as steel, bricks, tiles, wood, metal have typically been recovered from demolition sites. However, concrete and masonry materials that constitute about 50% of the C&D waste have generally not been recycled. While demolishing a building, efficient and effective equipment have to be utilised to bring down the structure in the safest manner possible. Technology exists both in form of mammoth and tiny but highly efficient equipment for deconstructing structures and from handling scrap to recycling it.

5.2 Equipment and methods

When deployed with a hydraulic excavator, backhoe loader, compact excavators or even skid steers, the right attachment can dramatically increase productivity at the demolition site and can make the recycling of the sourced materials easier.

It is well known that the wrecking ball is a hazardous tool that is extremely difficult to control. Instead, the high reach excavator fitted with the right tool provides flexibility to control the demolition, which is especially critical in urban areas. The effectiveness of an excavator depends predominantly on the attachments.

The most popular attachments include hydraulic breakers, demolition crushers, steel scrap shears and demolition grapples. Hydraulic power is advantageous when working with concrete and steel sections, enabling a contractor to process more in a given time frame, while reducing carrier wear.

In addition to the task of demolishing a structure, contractors are faced with a variety of recycling related tasks that include the primary sizing and separation of material. It is common practice for a contractor in a controlled demolition site to remove any material with salvage value, such as wires, conduits, pipes and electrical equipment, using small shears, grapples on skid-steer loaders or mini and standard-size excavators.

A small sized excavator is the most suitable carrier for a hydraulic attachment. It is better suited than a skid steer because it permits positioning the tool in multiple angles and can complete jobs on walls and structures, while a skid steer can only break up concrete on the floor.

However, given their compact size, low weight, agility and ever-increasing versatility, skid-steer loaders are widely used in selective demolition jobs, like refurbishment of residential and office buildings. A skid steer with a bucket attachment is extremely useful for lifting material and loading it out. It is also imperative to mention here the new range of interior demolition – remote controlled robots that are posing a tough challenge to skid steer and mini-excavators abroad but have still not found acceptance in India.

The process of demolition is constantly evolving, dynamic and increasingly complex. With contract periods becoming shorter, tougher legislations and availability of skilled labour as constraints, demolition contractors are on the lookout for the most efficient, cost effective and safe equipment for deconstructing buildings and structures.

It comes as no surprise that demolition has today become a highly specialised area, driven forward by the advent of various types of specialised machinery.

Some of the available technologies for deconstruction projects are presented below. These are arranged based on "Highest to Lowest" usage.

Hand-held Breaker

The traditional hand-held breaker, often called as Jack Hammer, is powered by electrical / compressed air or hydraulic power. Refer fig 5.1.

Fig. 5.1 Hand-held Breaker

(Source: Atlas Copco)

Fig. 5.2 Pneumatic Hammer

(Source: Atlas Copco)

Fig. 5.3 Hand-held Concrete Crusher/ Splitter

(Source: Husqvarna)

Fig. 5.4 Hand-held Diamond Saw

(Source: Husqvarna)

Pneumatic Hammer

Despite the many advantages that Pneumatic Hammers (Fig 5.2) offer over other types of hammers, it constitutes a very small portion of the total hammers in use today. These hammers can be mounted on lighter carriers, since their external air compressor negates the extra hydraulic demands of a Hydraulic Hammer. Moreover, Pneumatic Hammers work better in confined spaces than Hydraulic Hammers due to their high weight-to-power ratio and are more conducive to underwater use.

Hand-held Concrete Cutter

These are very handy equipment with heavy duty power designed to quickly break away large, thick pieces of concrete. The benefits include less dust, support a clear view at the rescue scene, no vibrations and they prevent risk of secondary collapse. Refer fig 5.3 and fig 5.4

Table 5.1 Applications of Pneumatic Hammer

Applications	Drill, break up or chip tough materials such as concrete, asphalt and tiles

Table 5.2 Leading brands of Hand-held Concrete Cutters

Leading brands	DARDA / HYCON / HUSQVARNA

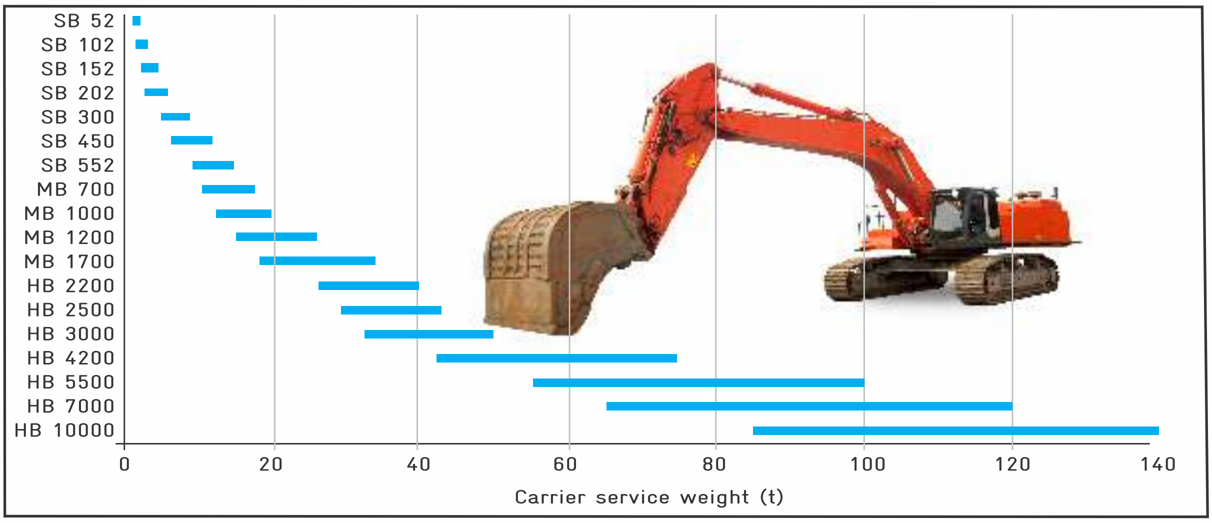
Fig. 5.5 Hydraulic Excavator with Hydraulic Breaker fitted

(Source: Volvo)

Fig. 5.6 Skid Steer with Hydraulic Breaker fitted

(Source: Bobcat)

Fig. 5.7 Typical breaker selection chart



(Source: Atlas Copco)

Mounted Hydraulic Breakers

The demolition industry changed dramatically in 1968 when the first hydraulic breaker was mounted on a backhoe. These demolition hammers vary greatly in size to accommodate almost any carrier application available, from the smallest skid-steer loader to the largest class of excavators. Some examples can be seen in fig 5.5 and 5.6.

It is important that the right tool is chosen based on the size of job and budget (refer fig 5.7). Attaching a hammer to a lightweight carrier not only decreases the boom's reach, it also can potentially be the cause of an overturning accident. Breakers that weigh 27 kilograms and above can handle heavy reinforced concrete jobs such as demolishing roads, pavements and thick concrete. Due to their unmatched versatility when compared to other demolition equipment, their speed of processing without the footprint and safety zone requirements of explosion and wrecking ball demolition, these breakers present an excellent option.

Several models of hydraulic breakers are now available in the Indian market. They are being extensively used for demolition work, especially high reach demolition jobs, apart from applications such as concrete cutting, for which they make the ideal attachment. Table 5.3 can be referred for applications, specifications and leading brands.

Table 5.3 Applications, specifications and leading brands of Mounted Hydraulic Breakers

Applications	Demolition/Foundation Work/ Tunnelling/Trenching/ Underwater work/ Boulder size reduction in quarries
Specifications	Working weight range: 35 Kg to 10,000 Kg
Leading brands	Atlascopco / Furukawa / Soosan / Chicago Pneumatic / Dozco / Allied /Arrowhead / Bobcat / Caterpillar / BTI / Huskie / Indeco /Montabert / Sandvik / Fein

Hydraulic Concrete Splitters and Busters

Hydraulic Concrete Splitters and Busters (various types shown in fig 5.8, 5.9 and 5.10) are generally applied to partial or integral demolition of concrete facilities that include walls, concrete roads, machinery base and bridge building parts. The equipment deploys a shaft popularly known as a plug-and-feather assembly. When inserted into a drilled hole and forced downward by the tool's piston, it creates the lateral forces that results in breaking of concrete. No heavy impact is utilised to form the crack, which spreads quickly and without any noise between the pre-drilled holes until the concrete is split into manageable pieces.

Hydraulic splitting eliminates both shocks and vibrations associated with large impact tools. It can split the rock or concrete in seconds, and the direction of breaks can be controlled as required. It is suited for a place where there are strict limitations on noise, dust, flying debris, vibrations and exhaust gas. It is thus widely used in conditions where the demolition has to be non-explosive and blasts are forbidden. Applications, specifications and leading brands can be referred from table 5.4.

Table 5.4 Applications, specifications and leading brands of Hydraulic Concrete Splitters

Applications	Bridge Decks / Bridge Abutments / Retaining Walls / Concrete Walls / Floor Slabs / Reinforced Concrete / Foundations / Wall Openings / Brick and Rock Walls / Culverts / Locks Dams / Road Barriers / Concrete Roads / Underwater Demolition / Sidewalks / Curbs / Most types of Rock / Machine Blocks
Specifications	Typical force weight: 150-400 Tons
Leading brands	NPK / DARDA / Unique Engineering / Elco / GB Engineering

Fig. 5.8 Hydraulic Rock Splitter

(Source: Darda)

Fig. 5.9 Rock/ Concrete Splitter

(Source: Darda)

Fig. 5.10 Concrete split with Buster

(Source: Darda)

Fig. 5.11a Hydraulic Combi-Cutter

(Source: Atlas Copco)

Fig. 5.11b Hydraulic Combi-Cutter

(Source: Atlas Copco)

Fig. 5.12 Mini Concrete Crusher

(Source: Atlas Copco)

Hydraulic Concrete Crushers (HCC)

Hydraulic Concrete Crushers (shown in fig 5.11a, 5.11b and 5.12) is an excavator mounted mechanical tool for demolition works. The action of HCC is controlled by the opening and closing of its jaws to crush concrete, powered by the hydraulic fluid supplied by the excavator. The main noise source from HCC is from the excavator itself.

The interchangeable jaws in some crushers, including cracking jaws, shear jaws and pulverising jaws are commonly deployed to work along with various types and configurations of jaw teeth in order to better fit the crusher to a particular job.

Secondary concrete crushers generally come with some type of pulverising jaws and are used on jobs where primary demolition is accomplished by hammers, crushers, blasting, ball and crane, or sawing. Primary demolition work creates large quantities of concrete rubble which the secondary crusher further reduces, separating concrete from reinforcement.

There are a few smaller hand-held concrete crushers which work on the same principle. Table 5.5 can be referred for applications and leading brands.

Table 5.5 Applications and leading brands of Hydraulic Concrete Crushers

Applications	Demolition Building, Concrete Walls and Panels / Very thin Concrete Walls / Partial Demolition / Making an Opening in a Concrete Wall / Capping off Concrete Piles / Rock Excavation / Splitting Stratified Rock
Leading Brands	Demerac Indeco / Terex / Komatsu / Kenco /MBI / Stanley / Genesis / Darda / Cedima / Tyrolit

High Reach Demolition Excavator

The discussion on demolition equipment is incomplete without a mention of the actual equipment that carries all these different types of attachments. Fig 5.13, 5.14 and 5.15 can be referred for pictures. Excavators that have been specially modified through added reinforcements, along with a long reach boom are the staple of demolition. Various parts of the excavators such as the cab and the undercarriage are designed keeping in mind the tough work that these machines will be put through.

High reach excavators are increasingly being deployed, though their full potential remains unexploited. Their applications, specifications and leading brands can be seen in table 5.6.

Table 5.6 Applications, specifications and leading brands for High Reach Demolition Excavators

Applications	Designed to reach the upper storey of buildings under demolition and pull down the structure in a controlled fashion. It has largely replaced the wrecking ball as the primary demolition tool.
Specifications	Upto 50 meter vertical reach
Leading brands	Hitachi / Volvo / Kocurek / Caterpillar / Hyundai / Komatsu / Kobelco

Fig. 5.13 High Reach Demolition Excavator with Hydraulic Crusher

(Source: ACT)

Fig. 5.14 High Reach Demolition Excavator with Hydraulic Crusher

(Source: Edifice Engineering)

Fig. 5.15 High Reach Demolition Excavator with Hydraulic Crusher

(Source: Matte & Associates)

Fig. 5.16 Pulverisors for secondary demolition work

(Source: Mantovanibenne)

Pulverisers

With redevelopment projects on the rise, Grapplers and Pulverisers (fig 5.16) are increasingly being deployed. Grapples or Grabbers, also known popularly as Shears have become a familiar scene across construction sites in the country. Used for removing large boulders and rubble, they also play a crucial role in demolition. Also known as 'Pulverisers', they can quite literally 'chew' the rubble. Rotating shears are the staple these days in most demolition jobs. Rotating grapples ensure savings on the cost front, since there is no need to reposition the excavator. Table 5.7 can be referred for applications, specifications and leading brands

Table 5.7 Applications, specifications and leading brands of Pulverisers

Applications	Primary demolition of concrete elements /Secondary demolition of concrete elements /Separation of concrete and rebar
Specifications	Weight: 2,320-33,000 lbs (1,050-15,000 kg) / Capacity 0.6-10 m^3
Leading brands	Mantovanibenne / Atlas Copco / La Bounty / Genesis

Fig. 5.17, 5.18, 5.19 and 5.20: Steel Scrap Shear mounted on Hydraulic Excavator on demolition, scrap handling and ship building jobs

(Source: Edifice Engineering)

Steel Scrap Shears

These are powerful attachments to cut through steel sections such as plates and sections like a large scissor. These can be seen in Fig 5.17, 5.18, 5.19 and 5.20. These equipments eliminate the use of Oxy-acetylene torch, which is labour intensive, environmentally unsustainable and highly risky. These equipments have been deployed in India.

Table 5.8 Leading brands for Steel Scrap Shears

Leading brands	Mantovanibenne / Atlas Copco / La Bounty / Genesis

Fig. 5.21 and 5.22 Rotary Drum Cutters on RCC demolition job

(Source: Rockwheel)

Fig. 5.23 Pile Crusher

(Source: Mantovanibenne)

Fig. 5.24 Special Pile Cutter

(Source: Motocut)

Rotary Drum Cutters

Rotary drum cutters (shown in fig 5.21 and 5.22) are extensively deployed for trenching hard stone. Ushered in as a replacement for traditional rock breakers, these cutters can also be used instead of bucket crushers, in some projects. The attachment is a popular choice owing to their versatility. They can be used for profiling, pile head cutting, trenching and general foundation excavation, apart from finding use in demolition jobs. Rotary cutters with power output ranging from 20 to about 200 hp are suited as attachments with excavators in the carrier weight range of 2 to over 120 ton capacities that are now available in India. With their ability to cut through concrete and asphalt, they have become a star attraction in the Indian market. Their applications, specifications and leading brands can be referred in table 5.9.

Table 5.9 Applications, specifications and leading brands of Rotary Drum Cutters

Applications	Tunneling / Trenching / Demolition / Refurbishment / Under Water Excavations
Specifications	3-70 tons
Leading brands	Erkat / Simex / Rockwheel / Alpine

Pile Crusher & Cutters

While earlier, saws and jack hammers were used for demolishing unwanted foundation piles, they have been now replaced by Pile Cutters. Pile Cutters (shown in fig 5.23 and 5.24) offer the best option in confined urban areas. They also offer a much quieter method of demolition, when compared to the traditional method of using jackhammers.

Additionally they also eliminate the need for other types of equipment including diamond saw cutting, cutting torches, air compressors and blasting equipment, among others.

Applications and leading brands can be referred in table 5.10.

Table 5.10 Applications and leading brands of Pile Crushers and Cutters

Applications	Cut and crush concrete piles
Leading brands	Mantovanibenne / Taets / Mottocut

Diamond Wire Saw

A loop of diamond wire mounted on a flywheel is driven by a hydraulic or electric motor. Using diamond beads strung on special aircraft cable separated by springs or plastic, the wire can be wrapped around any length, depth, or configuration of reinforced concrete. Pictures can be seen in fig 5.25, 5.26 and 5.27 and leading brands may be referred from table 5.11.

These lightweight, portable saws have changed the character of building modification. Cutting an opening on a concrete wall with diamond tools causes no structural damage and requires little patch work. Diamond wire saws are more efficient than circular saws, able to cut concrete of almost any thickness. This effectively makes them most suited for heavy demolition works such as in bridges, dams and thick concrete structures. Another feature of the tool is that it does not create dust, noise and vibration, making them ideal for demolition work within and very close to inhabited structures. If time is money, then, this tool is superior to all.

Applications: Continuous type wire saws are used to cut walls and other large constructions. They are also used in mining industry to cut hard stone into large blocks.

Table 5.11 Leading brands of Diamond Wire Saw

Leading brands	Hilti / Husqvarna / Tyrolit / Cedima / Pentruder

Track Wire Saw machine

This is a relatively new concept where the power of the prime mover can vary from 75KW to 125KW. These are hence versatile equipment for special jobs and very large cuts upto 50 sq. m. can be done with these machines. Cutting speeds of upto 10 sq. m. per hour can be achieved. Fig 5.28 and 5.29 can be referred for pictures and table 5.12 for the leading brands.

Table 5.12 Leading brands of Track Wire Saw

Leading brands	Hanjin / Diamond Products / Egun

Fig. 5.25 Diamond Wire Saw machine

(*Source: Cedima*)

Fig. 5.26 Diamond Wire Sawing job in airport

(*Source: ACT*)

Fig. 5.27 Diamond Wire Sawing job for bridge pier

(*Source: ACT*)

Fig. 5.28 Diamond Track Wire Saw machine

(*Source: Egun System*)

Fig. 5.29 Diamond Track Wire Saw on large bridge pier demolition

(*Source: Egun System*)

Expansive Demolition Agents

Expansive Demolition Agent (fig 5.30 and 5.31) is a cementitious powder that is mixed (using a drill with mixing attachment) in a bucket and poured or tamped into drilled holes. As the mix hardens and expands, the concrete cracks between the drilled holes. As the hairline cracks develop over the slab, they run outward into each other and grow wider, until the slab literally falls apart under an expansive force that can exceed 83,000 kpa.

Used correctly, expansive demolition agents produce little dust or debris. The only labour involved is in drilling the holes, mixing and applying the agent, and then finally hauling the broken up pieces of concrete away. Applications and leading brands can be referred from table 5.13.

Table 5.13 Applications and leading brands of Expansive Demolition Agents

Applications	Machinery Bases / Dam and Powerhouse Modification / Bridge Footing and Widening / Concrete Piers / Underwater Demolition/ Thick Slabs and Walls / Boulders / Embedded Rock / Tunnelling /Trenching Near Existing Utilities /Marble Quarrying / Limestone and Granite Quarrying
Leading brands	ACCONEX / CORDEX / BETONAMIT

Fig. 5.30 and 5.31 Typical cracking using expansive agent

(*Source: Betonamit*)

Fig. 5.32 Wrecking ball for building demolition

(*Source: The Archive Attic*)

Fig. 5.33 Wrecking ball

(*Source: Wikimedia Commons*)

Fig. 5.34 Wrecking ball for chimney demolition

(*Source: Advanced Construction Technologies*)

Wrecking Balls

The discussion on demolition cannot be complete without a mention of the original – wrecking ball (Fig. 5.32, 5.33 and 5.34). While these heavy weight balls swung from cranes are gradually giving way to more sophisticated pieces of machinery, they are still used in many parts of the country because of the fact that they are especially effective against masonry. The fact that they are not easy to control and produce high noise is leading to their gradual obsolescence.

Table 5.14 Applications and specifications of Wrecking Balls

Applications	To demolish roofs and other horizontal spans
Specifications	1,000 kg to 5,000 kg

Remote Controlled Demolition Robots

These specialised robots (shown in fig 5.35 and 5.36) are being used in tricky demolition jobs, especially those involving bringing down interiors of a building. These machines score high on the manoeuvrability front and are gradually finding an increasing number of takers, especially in urban reconstruction projects.

Globally, Brokk is considered a market leader in the field of demolition robots. The company offers a wide range of remote controlled demolition equipment.

Table 5.15 Applications, offerings and leading brands of Demolition Robots

Applications	All types of Demolition activity / Sawing / Drilling / Cutting
Offerings	Telescopic Boom / Outriggers
Leading brands	Husqvarna / Brokk / Toptec / Avanti

Fig. 5.35 Brokk Robot

(Source: Brokk)

Fig. 5.36 Husqvarna Robot

(Source: Husqvarna)

Fig. 5.37 Bucket Crusher in a quarry

(Source: Advanced Construction Technolgies)

Fig. 5.38 Bucket Crusher for recycling

(Source: MB Crusher)

Fig. 5.39 Bucket Crusher in recycling

(Source: Simex)

Portable Bucket Crushers

This impressive piece of demolition equipment crushes concrete into reusable coarse and fine aggregate, which can then be recycled on-site. With the help of such concrete crushers, you can recycle thousands of tons of concrete every year. Examples can be seen in Fig 5.37, 5.38 and 5.39. After tearing down a building, the concrete slab is pulled up and cut into 2-foot (60 cm) squares to run through the crusher. The machine then grinds it into gravel-sized chunks, which can be used for road compaction, structural fill, pipe bedding and other applications.

Bucket Crushers are the modern approach to process and recycle stone, asphalt and concrete debris on-site. These sturdy buckets can eliminate the expense of separate crushing and handling equipment, and make costly dumping and transport unnecessary. An electromagnetic iron-separating magnet is optional and easily installed on-site. It allows materials to be recycled, resulting in significant savings. Dust suppression sprays are also included as optional/ add-ons.

Table 5.16 Applications, specifications and leading brands of Portable Bucket Crushers

Applications	Concrete Crushing / Construction Waste
Specifications	Coarse Crushing / Medium Crushing / Fine Crushing
Leading brands	Gamzen / MB / DSMAC / Powerscreen / Atlas Copco / MB / Rockwheel

Implosion

By implosion or controlled demolition method (shown in Fig 5.40, 5.41 and 5.42), a structure can be demolished in seconds, which otherwise is cumbersome and time consuming. This method is widely used in urban areas for demolishing large structures in developed countries. Many structures in India were also demolished using implosion techniques. Structures like chimneys can be demolished in a short span of time, sometimes even less than a day. Larger structures may take up more time in preparation such as to remove columns and walls before firing the explosives.

The controlled demolition is done by placing a series of small explosives in strategic locations in the structure and its detonation is so timed that a structure collapses down on itself with gravity, minimising any damage to its surroundings. Most commonly used explosives are Nitroglycerin and Dynamite to blast reinforced concrete structures. Explosives are then detonated progressively throughout the structure. This method can also be used for demolition of most tall structures built in concrete, steel and masonry. For steel structures, high velocity plastic explosives are used. This is a highly specialised operation to be carried out only by experienced agencies. Simulation studies are also done to predict the fall direction and debris spread.

Taisei Ecological Reproduction System (Tecorep)

A Japanese firm, 'Taisei' has launched a revolutionary process to demolish high-rise buildings in Japan. Named Taisei Ecological Reproduction System (Fig 5.43), the technology ensures that the working environment is safer, less noisy and free of dust by keeping all the disassembly work inside the building. Taisei explored the option of using a building's roof to create a closed working site and bringing cranes inside the building. The roof is held up by temporary columns that are lowered by jacks as the higher floors come down. It is a kind of disassembly factory putting a big hat on top of the building and it shrinks from the top. This “hat” benefits everyone, according to the company. By working in an enclosed space, outside noise is reduced by 17 to 23 decibels while dust is cut by as much as 90% and weather will not be a hurdle and work can continue. Like regenerative braking, the cranes use the weight of their loads to create electricity, which in turn powers lights and machinery on the construction site.

Fig. 5.40 Implosion of building

(Source: CDI)

Fig. 5.41 Implosion of building

(Source: First Post)

Fig. 5.42 Implosion of steel bridge in USA

(Source: Federal Highway Administration)

High Impact Blow Breakers

These are special machines used as hydraulic attachment to excavators (shown in Fig 5.44, 5.45 and 5.46). These new generation equipment have special mechanism to deliver high impact blows. The energy per blow can vary from 5,000 joules to 20,000 joules and the blow rate can be upto 60 blows per minute.

Fig. 5.43 Taisei system

(Source: Taisei Corporation)

Pavement Rubblisers

These are highly specialised and custom built machines for breaking concrete pavement, airport runway and aprons. They work on the principle of multiple breakers working in tandem. Fig 5.47 can be referred for example.

Fig. 5.44 Fractum Breaker

(Source: STM)

Fig. 5.45 MEP Breaker

(Source: MEP Steel)

Fig. 5.46 Terminator Breaker

(Source: Rocktec)

Fig. 5.47 Proprietary rubblisation equipment

(Source: Antigo Corp.)

Fig. 5.48 and 5.49 Specialised drive lines chimney breaker

(Source: MEP Steel)

Fig. 5.50 and 5.51 Hydro Demolition Robot

(Source: Aquajet AB)

Chimney breaker

This is a special equipment for demolition of tall chimneys and silos. These are remote controlled machines with hydraulic breakers (Refer Fig 5.48 and 5.49).

Hydro demolition

Hydro demolition (Example shown in Fig 5.50 and 5.51) uses water under very high pressure to cut through concrete. Water under very high pressure (upto 3,500 PSI) is directed on concrete to break the bond and dismantle it. It us used mainly in rehabilitation and retrofitting work. The range of machines vary from simple hand hold ones to Robotic multi-jet models with remote controlled operation.

Table 5.17 Leading brands of Hydro demolition robots

Leading brands	Karcher / Bosch / Conjet / Aquajet / Sase

5.3 Useful role played by demolition technologies in deconstruction

While large scale demolition technologies such as implosion, wrecking ball, etc. have been used in the past for rapid demolition without sufficient thought for segregation and material recovery, these technologies can still play a role in deconstruction if selected recoverable materials (eg. door/window frames, tiles, fixtures, etc.) have already been stripped selectively. What is left behind is then the shell of the building mainly consisting of brick/mortar and reinforced concrete. This debris after demolition can be sent directly to recycling plant for processing into mixed recycled aggregates after recovery of the metal from reinforced concrete beams.

6. DECONSTRUCTION MATERIAL HANDLING, PROCESSING AND RECYCLING

Due to increase in economic growth and rapid urbanisation, not only has construction and demolition activity increased drastically, but C&D waste has increasingly become a major issue in urban solid waste management. Environmental issues such as increased flooding due to dumping of C&D waste in drains and water bodies, resource depletion, shortage of landfill space, etc. are evident all over the country.

For the purpose of management in India, C&D waste has been defined as "waste which arises from construction, renovation and demolition activities". Also included within the definition are surplus and damaged products and materials arising in the course of construction work or used temporarily during the course of on-site activities (MoEFCC, 2016).

Based on the TIFAC (2001) study, average quantity of waste generated during construction in India is of the order of 40-60 kg/m^2, while during demolition, waste generated is about 300-500 kg/m^2. Based on a recent IIT-Madras study, quantity of C&D waste generation is approximately 100 kg/m^2 during building construction and approximately 1,500 kg/m^2 during demolition of different types of buildings (Satyanarayana, 2016).

6.1 Problems in current C&D waste management

- Illegal dumping and accumulation of C&D waste all over the city.
- No systematic collection, storage, reuse and disposal of C&D waste.
- Most local bodies do not have designated collection points and disposal sites.
- C&D waste is dumped in roadsides, drains, public lands and low-lying areas causing road block, choking the flow of stormwater and sewage, etc.
- Causes obstruction of traffic and hampers routine municipal maintenance work.
- C&D waste is mixed with Municipal Solid Waste (MSW) causing severe problems during processing of MSW.
- Concrete and masonry wastes (>50% of C&D waste) are not being reused or recycled in India.

6.2 Need for C&D waste management

C&D waste is heterogeneous in nature. These wastes consist of mostly inert and non-biodegradable materials like concrete, bricks, plaster, metal, plastics, etc. of which most of the materials are recyclable. There has been an increase in the usage of new materials for construction in recent years, and also waste disposal in the landfill sites. To address these problems, processing and recycling of C&D waste is needed to utilise waste materials, reduce usage, production and transportation of new materials, conserve natural resources, reduce the load on landfills and increase economic resource recovery.

Recycling of these wastes would be vastly increased and result in higher economic benefits if these materials are source segregated. Out of the inert waste, concrete waste is the most valuable waste. If this is source segregated, it can be processed into Recycled Concrete Aggregate (RCA) which can be used in Plain Cement Concrete (PCC) and Reinforced Cement Concrete (RCC) works as prescribed by IS 383: 2016 depending on the concrete waste quality. Mobile wet processing plants are very expensive to procure and operate and these would not be economically feasible in Indian scenario. Hence mixed waste processing can be carried out on-site wherein recycled aggregates of lower specifications and filler material can be obtained. The resultant materials can be transported to the centralised off-site C&D waste processing and recycling facility for scrubbing to make RA, and filler materials can be used on-site or nearby sites. If efforts are taken at the site to segregate at least most of concrete waste, it can be transported to off-site centralised processing facility for making RCA.

6.3 Waste management plan

A waste management and disposal plan should be prepared and implemented to avoid accumulation of debris. On-site segregation of waste is strongly recommended.

All waste materials arising from or in connection with deconstruction work should be sorted on-site and be separated into different groups prior to leaving the site.

Dust

To prevent dust generation, dust suppression systems are available in India. Such systems are presently being used in cement, steel, power plants and mines under guidance from DGMS (Director General of Mines Safety).

In this system, pressurised water passes through the Ruby Insert Nozzles which turn the water into a soft mist. The ruby-tipped nozzles produce extremely fine water droplets which are comparable to the dust particle sizes. Also, ruby being the second hardest material after diamond, it is practically abrasion resistant and suitable for use even with hard/waste water. The mist is driven by strong airflow generated by a powerful fan yet efficient axial ventilator thereby creating a huge beam of mist containing extremely fine water droplets, which in turn enhances the agglomeration and immediate settling of dust particles.

This dust suppression system is very effective to control dust at demolition sites and should be recommended in all construction and demolition sites.

Fig. 6.1 Dust suppression system

(Source: Mohan Ramanathan)

Debris

It should be ensured that the routing and movement of debris from each floor to the holding area is monitored and also that it is disposed of promptly. Existing lift-shaft, light-well and openings on floor may be used to convey debris down the building floors. Excessive accumulation of debris can cause over-loading condition and should be avoided. The propping design should include the debris loading. When loaders and trucks have to work on the site, the route of loaders and trucks should be checked to avoid conflict with temporary propping supports.

Transportation of debris from site to other locations should be done employing vehicles that have all necessary features complying with requirements like adequate covers to reduce airborne dust menace during transportation.

Better site management and practice would prevent the mixing of the inert portion with the non-inert portions. It will facilitate on-site sorting and separation at source for better ruse and recycling, thereby minimising landfill disposal.

6.4 On-site C&D waste management

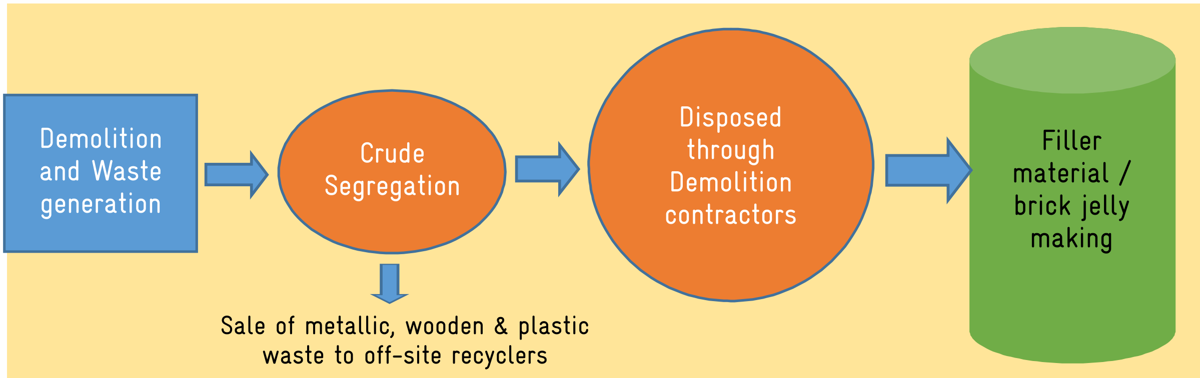
On-site C&D waste management refers to the segregation, processing, recycling and reusing of C&D waste at site of generation. It helps in waste minimisation, increased waste recycling, reduction in C&D waste transport cost and has associated environmental and other benefits.

Hazardous waste designation before demolition of buildings

Buildings that are to be demolished must be assessed (a process known as hazardous waste designation) to determine if they contain any other waste other than C&D waste including hazardous waste or e-waste.

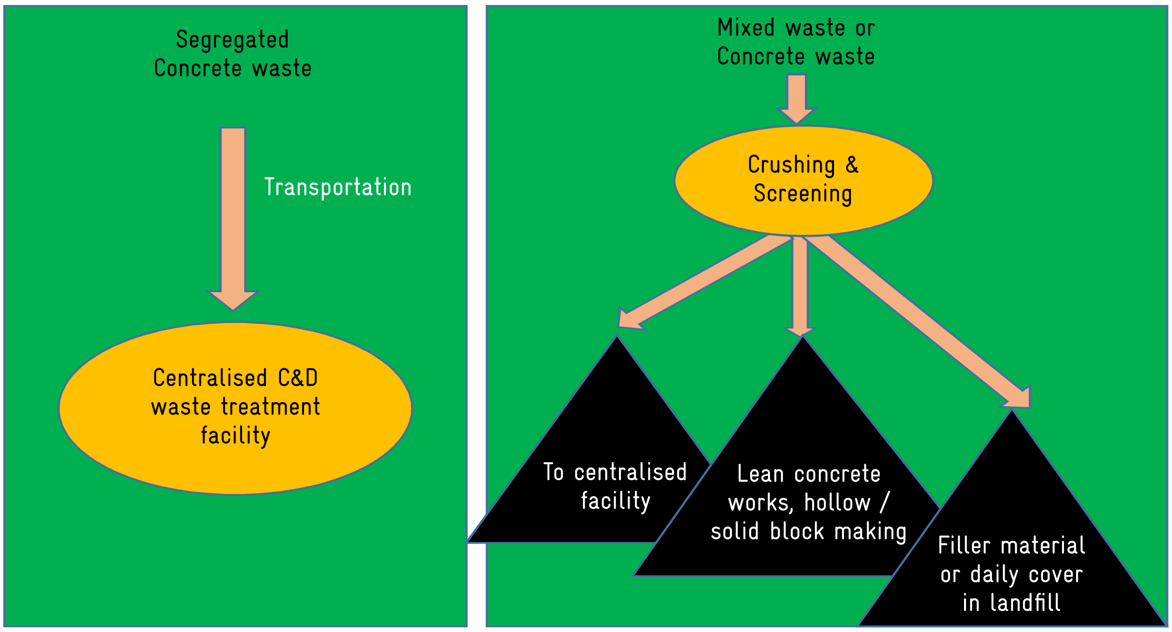
Hazardous materials may not be moved before the start of demolition or before the authorised recyclers have ascertained that. Safety guidelines and restrictions should be followed for handling and disposal of toxic elements such as lead, asbestos or any radioactive materials.

Fig. 6.2 Existing on-site C&D waste management practices in India



(Source: IEISL)

Fig. 6.3 Feasible options for on-site C&D waste management in India



(Source: IEISL)

Current on-site C&D waste management practices

Currently on-site C&D waste management is done very rarely by some government agencies like Maharashtra Airport Development Company, railways and redevelopment of old colonies wherein huge quantity of C&D waste is generated during demolition. No specialised equipment is used for on-site processing and only crude segregation is carried out. The segregated C&D waste is disposed through demolition contractors for filler materials and brick jelly making. Other wastes such as metallic, wood, plastic wastes etc. are sold to off-site recyclers. Fig. 6.2 describes the existing on-site C&D waste management practices in India.

Feasible options for on-site C&D waste management in India

Fig. 6.3 describes the proposed storage, segregation and processing practices of C&D waste in India for effective utilisation of the waste.

In the proposed on-site C&D waste management system, the transportation of waste quantity to the off-site C&D waste processing and recycling facility can be reduced.

Segregated concrete wastes shall be directly transported to the centralised off-site C&D waste processing and recycling facilities for making RCA. Mixed waste or concrete waste shall be crushed and recovered materials can be used for lean concrete works, hollow / solid block making and all the filler materials can be used in the construction site itself or sent to the sanitary landfill site for daily cover. Other recycled aggregates should be transported to the centralised off-site C&D waste processing and recycling facilities for further processing.

On-site C&D waste management is feasible if the generated waste is of substantial quantity and the transportation cost outweighs the benefit of transporting to the facility and recycling the waste. Recent studies show that on-site partial processing is financially viable if the C&D waste generation on that site for the entire period is at least 25,000 tons.

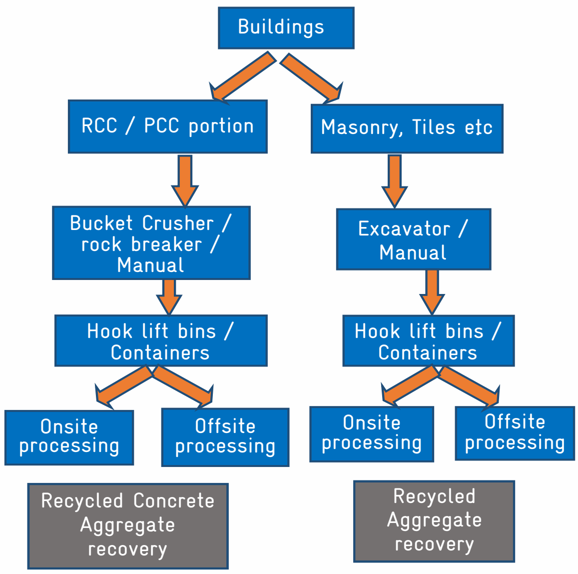
6.5 On-site segregation of C&D waste

On-site segregation is the process of segregating/separating the components of C&D waste at site/source itself. On-site segregation into concrete waste and other inert wastes would enable separate processing of concrete waste and enable recovery of more valuable coarse aggregate both for on-site processing and recycling of C&D waste and for off-site processing.

In on-site segregation, backhoe loader would reach the deconstructed material storage area and level the waste heap so that segregation would be convenient.

Manual segregation is the most effective method of on-site segregation for segregating small quantity of C&D waste. During manual demolition, care should be taken to separate the concrete waste and other inert wastes.

Fig. 6.4 Alternate concrete and masonry part demolition and waste segregation



(Source: IEISL)

Manual demolition / deconstruction and segregation is a time-consuming process which can be used for separating doors, windows, frames, plastics, wires, wooden materials, carpets, whole bricks, steel, bulbs, switches, pipes, etc.

Fig. 6.5 Manual handling of demolition waste

(Source: Salvage Warehouse)

Possible options for segregating and processing of C&D waste

Mechanical equipment designed for deconstruction purposes like bucket crusher and excavator can be used for demolishing and unloading large quantity of concrete wastes and masonry wastes respectively in tractor trolleys or in hook lifter bin or dumper placer bin or lorry. Based on this, suitable transporting vehicle, such as tractor or hook lifter or dumper placer, have to be used. This will reduce multiple handling and facilitate demolition, collection and transport of the segregated concrete waste to processing facility on-site or off-site. Hence segregated wastes can be effectively processed by C&D waste processing equipment at on-site or off-site. The possible option of alternate demolition of concrete and masonry part is shown in Fig. 6.4.

Segregation of hazardous material and e-waste in C&D waste

In India, Hazardous and Other Wastes (Management and Trans-boundary) Rules 2016, focus on generation of hazardous wastes from industrial activities and import / export of scrap containing hazardous waste. It does not address waste generated in domestic, non-industrial activities, etc. However, many hazardous wastes arise during demolition of old buildings. Older buildings are often painted with lead paint and paints containing mercury-based biocides. Old buildings also have lead pipes, asbestos insulation, mercury-containing fluorescent lamps and PCB ballasts (commonly known as choke) and contain many other hazardous materials. Besides, wastes generated during new building construction include treated wood, paint and solvent wastes, glues and roofing tars. Many buildings have to be carefully deconstructed for material reuse, and these types of projects can also generate hazardous wastes. Usually, deconstructed materials that are reused are not regulated as waste. For example, a door painted with lead-based paint could be reused as is, which would otherwise be regulated as hazardous waste if disposed.

Hazardous wastes commonly found in a building demolition project include (DEC Alaska, 2011):

- Lead painted materials
- Lead pipe and solder
- Lead based paint
- Liquid paint wastes
- Unused solvent based paints
- PCB wastes with concentration > 50 ppm

E-wastes commonly found in a building demolition project include (DEC Alaska, 2011):

- Wires, switches, fire alarm systems, etc.
- Mercury switches
- Fluorescent tubes and spent incandescent bulbs
- PCB containing transformers, light ballasts, etc.

Hazardous wastes in demolition projects

Even though HWM rules in India do not list most of the hazardous wastes from building demolition projects, according to international best practice, hazardous materials are source-segregated and disposed of properly by following rules prescribed by regulatory authorities.

i. Asbestos

A building should be analysed for the presence of asbestos sheets. They should be also analysed whether they are friable or non-friable and accordingly stored separately and sent to asbestos products making units or shall be disposed off in sanitary landfill.

Fig. 6.6 Asbestos waste

(Source: IEISL)

ii. Lead Paint

A lead paint survey must be provided for any building constructed prior to 1980 and for any exterior structure (e.g. painted handrails) that may be affected by a construction project, regardless of age. Materials identified as having lead paint must be further characterised to determine if they are subject to hazardous waste disposal restrictions. If so, it shall be handled as hazardous waste and sent to lead recycling units.

iii. PCB Caulking

Samples of caulking in buildings constructed prior to 1978 must be analysed for the presence of Polychlorinated biphenyls (PCB) if the material will be impacted by renovation or demolition activities. Caulking containing concentrations of PCBs equal to or greater than 50 ppm shall be handled and disposed of as hazardous waste in hazardous waste incineration plants.

E-wastes in building demolition projects

Even though E-Waste Rules in India do not list most of the e-waste from building demolition projects, according to international best practice, several categories of e-waste are recognised from building demolition projects such as old wires, switches, fuse and fire alarm systems, lamps, lamp ballasts, etc.

i. Lamp Ballasts

All ballasts (PCB and non-PCB) must be collected for disposal; containers for ballast disposal can be obtained from the authorised recyclers. These barrels must be labeled and covered shut. PCB ballasts must be segregated from non-PCB ballasts and shall be disposed off to the authorised e-waste recyclers.

ii. Lamps and HID Light Bulbs

Fluorescent and High-Intensity Discharge (HID) bulbs must be disposed off to the authorised e-waste dealers. Other specialty bulbs which may also contain mercury must be handled by authorised e-waste dealers as well. All spent lamps, or the container/s which they are in, must be labeled clearly. Protect lamps from breaking and the containers from moisture.

iii. Mercury switches and mercury containing equipment

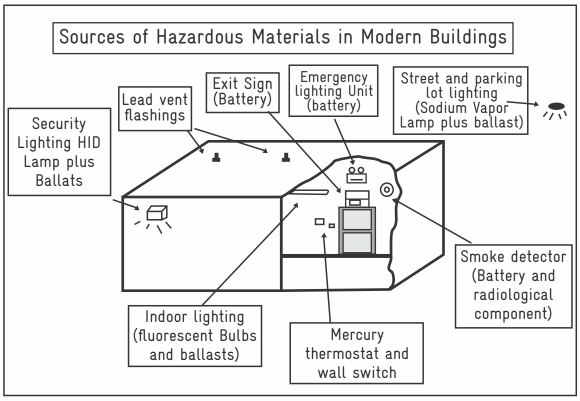
There are many types of equipment in C&D waste that may contain elemental mercury.

Before disposing of any of these types of equipment, it should be verified that they do not contain mercury. Mercury containing devices should be handled with caution to prevent spillage. Devices should be handled intact, sealed, and packaged to prevent breakage and given to authorised e-waste recyclers.

Examples of mercury containing equipment:

- Heating and air conditioning thermostats
- Tilt switches used in silent light switches
- Pressure gauges, displacement/ plunger relays
- Flow meters
- Float switches
- Drain traps in old buildings

Fig. 6.7 Sources of Hazardous Materials in Modern Buildings



(Source: DEC Alaska, 2011)

Hazardous waste and E-waste segregation

In case of C&D waste, source segregation should take place on the demolition site itself. The contractor should provide and clearly label skips for wood, bricks, metals, hazardous waste, e-waste, etc. Where separation of mixed wastes takes place subsequently off-site, the activity is regarded as a sorting, rather than segregation operation. All types of waste should be stored separately. Hazardous waste and e-waste should be handled with utmost care and it should be ensured that the disposal of these wastes is carried out through SPCB authorised recyclers.

Proper handling of hazardous and e-waste material on demolition site

Health and safety procedures should be adhered to in accordance with the requirements of the authorised recyclers in the removal of hazardous waste and e-waste material during the demolition process. The procedures and processes for removal of hazardous waste material should be identified in the Project C&D Waste Management Plan.

Special or hazardous wastes or e-waste should be retained in isolation from other wastes to avoid further contamination. Any hazardous materials, if mixed with non-hazardous materials - for e.g. lead based paint tins discarded onto a stockpile of brick and concrete - the entire quantity of material becomes hazardous and must be managed as hazardous waste. Hence the hazardous waste and e-waste from building demolition projects should be segregated properly, stored in separate bins, covered, packed, labeled and then disposed off properly to authorised recyclers or as per the norms stipulated in the Hazardous and Other Wastes (Management and Trans-boundary) Rules 2016 and E-waste (Management) Rules, 2016.

Advantages of on-site segregation

(Ponnada and Kameswari, 2015)

- Generation of clean, processable and recyclable materials
- Removal of hazardous waste from C&D waste streams in order to minimise health risks to the general population, particularly the waste handlers
- Improved working conditions in on-site C&D waste processing and recycling plants
- Improved quality of end-products
- It reduces the complicated off-site waste segregation during off-site processing and recycling of C&D waste.

Disadvantages of on-site segregation

(Ponnada and Kameswari, 2015)

- Multiple containers are required at site to store various types of materials
- Large space required at site
- Demolition and reconstruction time would increase
- Workers must separate the materials or separately demolish the waste.

6.6 On-site storage, processing and recycling

On-site storage of C&D waste

On-site storage means storage of C&D waste materials (both separated and/or mixed) at or near the source of generation before primary collection. Separate places with adequate area are required to store segregated wastes.

Properly covered waste storage containers are essential to store hazardous waste from construction and demolition activities. The separated hazardous wastes shall be safely stored and disposed according to the procedure mentioned in the latest Hazardous Waste Management Rules 2016. Care and safety should be taken while handling hazardous wastes.

Fig. 6.8 On-site storage of C&D waste

(Source: EPD Hong Kong)

Separate containers can be used for storing electrical fixtures, small metallic waste, electrical wires, etc. Concrete waste and other inert wastes (masonry, brick bats, mortar, broken tiles, etc.) can be stored in two transferable containers or in two heaps. Reusable materials/structures like doors, windows, whole bricks, marbles, granite, steel, etc. have to be kept separately in storage sheds. Gypsum boards can be separated and stored in container or in a heap.

Storage of recovered materials

Separate bins/containers / space for heap need to be provided for recovered materials such as Recycled Concrete Aggregates, Recycled Aggregates and filler materials. Storage of materials should be such that no mixing of material happens.

Key points for proper on-site segregation and storage

Each directly recyclable material (metal, paper, plastic, cardboard, etc.) / hazardous material should be segregated as it is generated and placed in the appropriate container.

- **Minimising containers at site:** Having too many containers on site increases the possibility of confusion and contamination. One container can be kept on-site for mixed debris, and one or two additional containers for the specific wastes generated during each phase of the job (IRN, 2005).
- **Choosing containers depending on the waste generated:** A container having capacity of 30-40 cubic meters can be used for storing wood wastes. But scrap metal from wiring and plumbing may need only a 2-5 cubic meter container. Waste like concrete waste, in large quantity can be

stored in heaps. In container selection, site layout and access should be considered (IRN, 2005).

- **Placing containers close to work locations:** An advantage of source separation is that it doesn't require one big central container for all wastes. Smaller containers can often be placed close to the demolition / deconstruction work. Also intermediate containers can be placed right next to the work, then wheeled to a larger waste container at the end of the shift (IRN, 2005).

The remaining waste should be segregated into 3 parts:

i. Whole bricks which will be manually segregated and can be used internally or sold

ii. Big concrete pieces

iii. Mixed C&D waste

All large sized chunks (ii) & (iii) should be resized to 200-400 mm size by mechanical and manual means.

Factors affecting on-site C&D waste processing and recycling

i. C&D waste quantity

On-site C&D waste processing and recycling is possible if the concrete waste quantity is significant. Mobilisation and demobilisation costs of on-site processing equipment will have to be incurred irrespective of the quantity of C&D waste processed on-site. If the quantity of concrete waste to be processed is low, then overall waste processing cost in Rs./ton will highly increase resulting in high unit cost of recovered materials. Moreover, equipment used for on-site processing of C&D waste has capacity to process significantly high quantity of waste per day. Most urban buildings in India would have low plot area (less than 2,400 sq. ft./223 m^2). Space would be a constraint to store waste, process waste and store recovered materials. Moreover, it may not be economical to process and recycle small quantities (<200 TPD) of C&D waste on-site.

ii. Waste characterisation

The characteristics of C&D waste varies due to use of different materials in different places in the demolished structures or works. Typical C&D waste consists of 50% soil/sand, 35-40% of brick and masonry, 5-10% of concrete and remaining 5% consists of other materials. C&D waste consists of steel from doors, windows, RCC structures and roofs, staircase railings, sheds, large slab stones, wood/timber materials (doors, windows, etc.), iron and plastic pipes, electrical fixtures (wires, plastic switches, wire insulation, bulbs, etc.), panels (wooden, laminated), window and door fittings, paints and plastics, etc. (Hemalatha et al., 2008).

Higher quantity of concrete and brick and masonry in C&D waste would help on-site processing and reuse in site whereas higher quantity of soil in C&D waste could lead to partial and limited reuse of C&D waste on-site. Higher quantity of other materials such as MSW in C&D waste would result in significant quantity of waste to be transported to MSW processing facilities and higher quantity of interior decoration products would require careful deconstruction, segregation and transport to off-site recycling markets or disposal in sanitary landfills.

Hence C&D waste with more RCC and bricks is most suitable for on-site processing and recycling. C&D wastes containing more mud or earth are not suitable for on-site materials recovery and it can be mostly used as filler material.

iii. Area of demolition and re-construction site

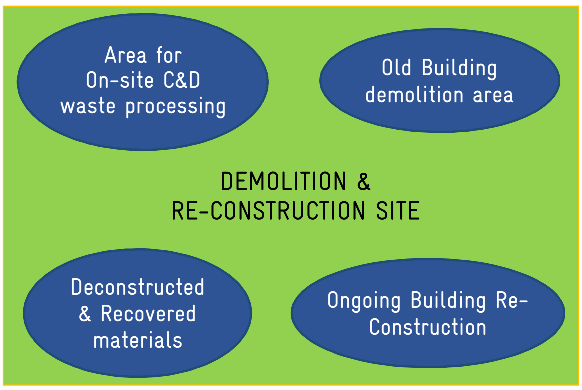
On-site storage and processing of C&D wastes is possible in sites having large plot area to

Fig. 6.9 Mixed C&D waste

(Source: IEISL)

accommodate storage of deconstructed and recovered materials, construction and deconstruction activities and C&D waste processing facilities. On-site storage area required for deconstructed materials depends upon the total built-up area to be demolished, type of structure and materials used in that structure. In smaller sites, it's not possible to store the deconstructed materials and set up onsite processing facilities. The site should be assessed whether on-site processing of C&D waste is possible or not, cost of waste processing, etc. before commencement of demolition activities. Fig. 6.10 represents the layout of demolition and re-construction site.

Fig. 6.10 Layout of demolition and re-construction site



(Source: IEISL)

Suitable projects/facilities for on-site segregation, storage and processing should be there for large area redevelopment projects such as:

- Townships
- Housing quarters
- Large multi-storied buildings, etc.
- Old large educational institutions, hostels, etc.
- Infrastructure projects like metro rail.

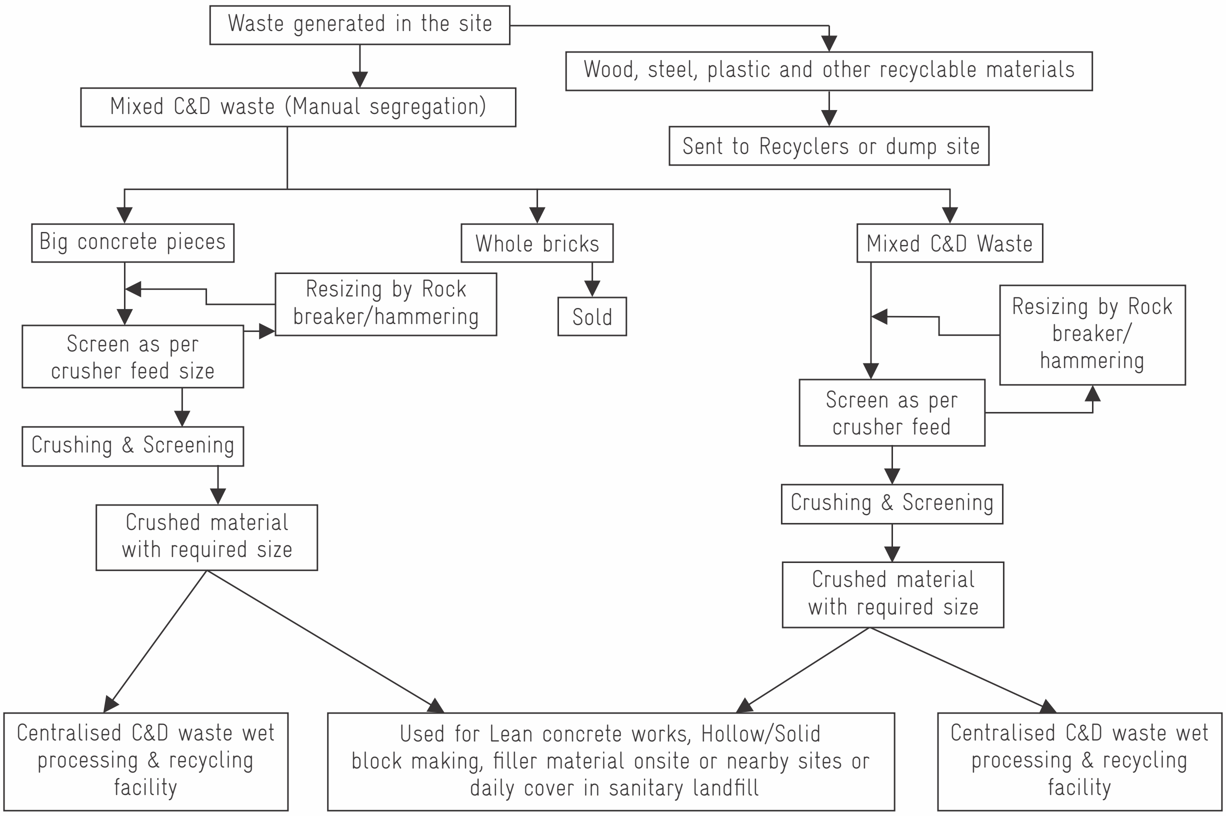
On-site C&D waste processing

On-site processing has to be designed on a site specific basis considering many factors such as C&D waste quantity, demolition time period, space availability for storage, on-site plant, area of the site, redevelopment project period, schedule and its requirement for use of recycled materials, transportation cost of C&D waste to off-site C&D waste processing and recycling facility, cost of new materials and fresh products. Comprehensive C&D waste processing including wet processing on-site may not be financially viable in most of the demolition and reconstruction/ redevelopment projects in India. Only partial processing to reduce transportation cost and reduce filler materials cost can be carried out on-site.

On-site processing is one of the most effective and sustainable ways to achieve resource recovery. It reduces hazards and diverts different fractions of material present in the waste stream to locations for appropriate treatment in the C&D waste management. On-site processing is a good technique for handling large amounts of waste.

The generic flow chart of C&D waste processing on-site is shown in Fig. 6.11.

Fig. 6.11 Flowchart for on-site C&D waste management



(Source: IEISL)

On-site treatment of C&D waste can be mostly done by mobile crushing and screening plant of varying capacity. Mobile plants are easily transportable to the site using hook lift lorry and ready to operate in a short period of time. The unwanted materials like large textile pieces, large twigs and woody pieces, styrofoam, consumer durables, etc. have to be segregated manually before feeding the waste into the crusher. The big concrete pieces, mixed C&D wastes and stones can be fed into the screening section designed as per crusher feed size before the crushing. Oversized materials from screens should be resized by rock breaker/hammering and returned to the screens. Based on the nature of waste feed to the plant, either recycled concrete aggregate or recycled aggregate would be obtained.

Features of on-site mobile C&D waste processing equipment:

- Basically crushing and screening equipment
- Skid mounted available in India
- Easily transportable
- Can be quickly installed, operated and decommissioned
- Mostly powered using diesel engines

i. Crushing and screening

Primary crusher preferably of Impact type receives input waste, which crushes the bigger sizes of C&D waste into smaller sizes to the required size. The crushed materials can be used for lean concrete works, hollow and solid concrete block making or transported to the centralised C&D waste processing and recycling facility or used as a filler material on-site or nearby sites or daily cover in sanitary landfill. On-site mobile crushers of Rubble Master, Terex, Kleemann are shown in fig 6.12, 6.13, 6.14 & 6.15.

Fig. 6.12 a and 6.12 b Rubble Master with hook lift lorry

(Source: RubbleMaster)

Fig. 6.13 Rubble Master mobile crusher

(Source: RubbleMaster)

Fig. 6.14 Terex mobile crusher

(Source: Terex)

Fig. 6.15 Kleemann Evo 130 impact crusher

(Source: Kleemann)

ii. Minimum requirements for on-site processing facility:

- Minimum space required: 1 acre or 0.4 hectare
- Minimum quantity required: 25,000 tons
- Average capital expenditure required: Rupees 2 crores

Available on-site mobile crushing and screening units (Fig. 6.12, 6.13, 6.14 and 6.15):

- Rubble Master (80, 120, 200, 250, 350 TPH)
- Terex (50 – 200 TPH)
- Kleemann (350, 450, 475, 550 TPH)

iii. Reuse

Reuse extends the life of existing materials and decreases the new resources needed. Entire buildings can be reused through renovation, whether for the same or new use, saving both resources and money. The reuse or salvage of building components, common in historic renovations, is being extended to non-decorative elements such as doors and light fixtures as well. This approach can be pushed further by not assuming that new always performs better. Materials like wooden doors, windows, frames, whole bricks, bulbs, electrical fixtures and plastic pipes can be reused at site.

On-site reuse guidelines for excavated earth

- **Quantification of different types of soil from excavation work:**
  - Determining quantity and characteristics of strata to be excavated by drilling sufficient number of boreholes in site and laboratory analysis of samples (number of boreholes for sampling varies depending upon area of the site).
  - Quantification of different types of soil to be excavated in the site.
  - Carry out soil and other tests for making CSEB with or without cement / lime stabilisation. Cement stabilisation and lime stabilisation will be better suited for sandy and clayey soils respectively (Auroville Earth Institute, 2017).
- **Preparing the excavated soil utilisation plan:**
  - Estimate the requirement of backfilling soil, compressed stabilised earth blocks, excavated topsoil for landscaping and horticulture purposes at site.
  - If excess quantity of above will be there, prepare and execute agreement with prospective off-site user/s.
  - Municipal bodies / PWD / Housing Boards, Infrastructure Development Agencies and Government schemes like 'Housing for All by 2022' etc. shall specify minimum mandatory use of products made from excavated earth for constructing partition walls, non-load bearing walls, etc. in their projects.

Advantages of on-site recycling and reuse

- It reduces the consumption of energy through reuse of goods by consumers and use of minimum quantities of materials in industry.
- It minimises the demand for raw materials for new products.
- Reduces transportation costs.

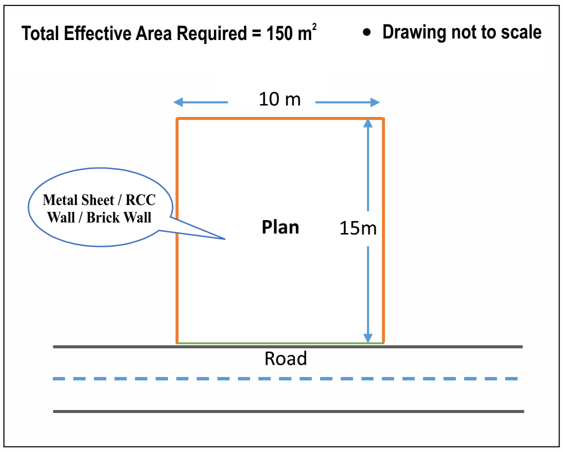
Disadvantages of on-site recycling and reuse

- Large space requirement at site.
- Extends duration of the work.

Interventions required for on-site recycling of C&D waste

- Waste management plan should be made mandatory.
- Implementation of source segregation criteria (e.g. minimum 50% of total CDW generated).
- Motivation of waste generators
- Awareness
- Economic incentives
- Laws and legislation can be implemented for compulsory use of recovered materials from C&D waste.
- Increase knowledge about reuse of RCA, RA as per IS 383:2016.
- Research in recovered material usage.

Fig. 6.16 Typical layout of C&D waste collection point with insufficient land



(Source: IEISL)

6.7 C&D waste collection, transportation, off-site (centralised) processing, recycling and disposal

Need for multiple waste collection points in a city

C&D waste generation is different from MSW generation as waste generation is not uniform at all the places at all times. Points of generation of C&D waste are different on different days. In most cases, it is not possible to know the generation point in advance. Quantity of generation in a point or area is different on different days. Most of the small quantity generators generate far less than full capacity of a large sized truck (15-20 T). It is uneconomical to transport C&D waste in small sized vehicles < 15 T over distance of more than 10 km to a processing and recycling facility. Hence many C&D Waste Collection Points (WCP) are required in a city.

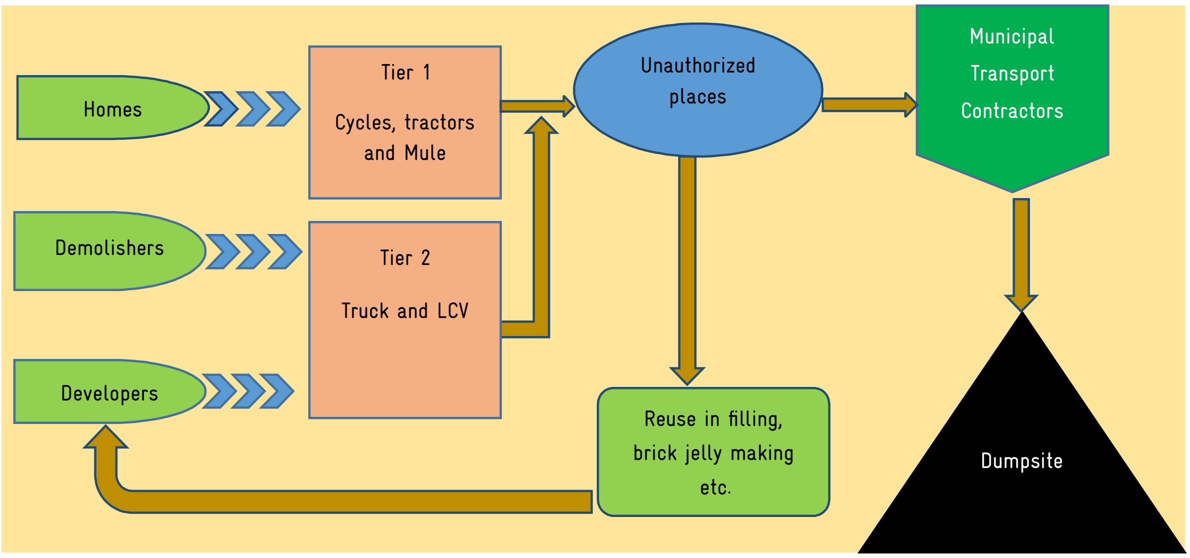
C&D waste collection points

In reality, every Waste Collection Point (WCP) acts as a mini transfer station or point. Quantity of waste in a WCP should be inspected and assessed on a regular basis. Once the WCP reaches its holding capacity, JCB would be sent to the WCP to load C&D waste on secondary transport vehicles of 15-20 T capacity. These vehicles would take the waste to the processing and recycling facility. WCPs can be located in small earmarked portions of MSW storage depots, MSW transfer stations, fenced road side areas, burial grounds, play grounds, parks, river, nullah and canal banks (beyond HFL), below elevated MRTS / metro lines, etc. Plan for C&D WCP where land is insufficient is shown in Figure 6.16.

Benefits of multiple waste collection points

- Designated place is available for small quantity generator to dispose off C&D waste in short distance, say 2-5 km.
- Disposal of C&D wastes in un-designated places such as roads, low lying areas, other open areas, etc. would come down drastically.
- Facilitates 'no littering' of C&D wastes by small quantity C&D waste generators and small contractors.
- WCP helps in avoiding daily collection and transportation of C&D wastes in a particular point unlike MSW collection and transportation.
- Reduces the cost of transporting the C&D waste generated by small quantity generators to the processing facility.
- Reduces number of C&D waste transport trips to the processing facility.
- Helps in avoiding mixing of C&D wastes with MSW which in turn improves MSW management.

Fig 6.17 Existing collection, transportation and disposal practices of C&D waste in India



(Source: IEISL)

Current off-site C&D waste management practices

C&D waste and other inert matter makes up almost one third of the total MSW on an average. A significant quantity of this waste is disposed at unauthorised /un-designated public places.

Typically, demolition activity is undertaken by specialised demolition contractors who bring their own equipment, personnel and transport the residual waste. The property owners pay a fee to the demolition contractors, which is decided based on the recoverable value of recycled materials – steel, wood, glass, pipes, etc. by demolition contractors.

The diagram 6.17 depicts the existing collection, transportation and disposal practices of C&D waste in India.

C&D waste transportation

C&D waste is transported through 3 types of transport contractors:

1. Tier 1 transporters: use animals (mules, donkeys, and horses), cycle trolleys and tractor trolleys to transport C&D waste. Animal-based transportation is primarily in congested city areas or small towns where narrow lanes preclude the use of any alternative transport. Animals and cycle trolley can carry small quantities of 100-150 kg and tractor trolleys can carry loads of 1.5 - 2 tons per trip. They are reachable on personal mobile phones that are prominently painted on their trolleys. They transport C&D upto maximum distances of 5-7 km. Often, they identify users of C&D waste for filling use or base layer for paving, property being developed, etc. but they also dump on unauthorised dumping sites / public places. They charge the waste generator for collection, transport and un-authorised disposal of C&D waste.
2. Tier 2 transporters: These are truck operators who also function as entrepreneurs. They are located in the market areas in each zone and hire trucks for transportation as and when business demand exceeds their own capacities. LCV and trucks carry larger quantities and operate with full-time crew of upto 6 people. They undertake upto 3 trips every night, when trucks are permitted to operate in the city.

Tier 1 and Tier 2 waste transporters normally dispose of the waste in the following manner.

- Significant proportion (approx. 60%) of the waste is used for filling private land and in low quality construction works;
- The remaining is dumped at unauthorised locations including low lying areas, drains, road sides and sometimes in dhalaos meant for MSW.

3. Tier 3 transporters are contracted by the Municipal Corporations for C&D waste removal from authorised dumpsites and unauthorised locations These contracted transporters are paid by the Municipal Corporations for their transport services depending upon the distance.

   Tier 3 waste transporters dispose of the waste in designated dump sites, if there is no authorised C&D waste processing facility available within the municipal limit.

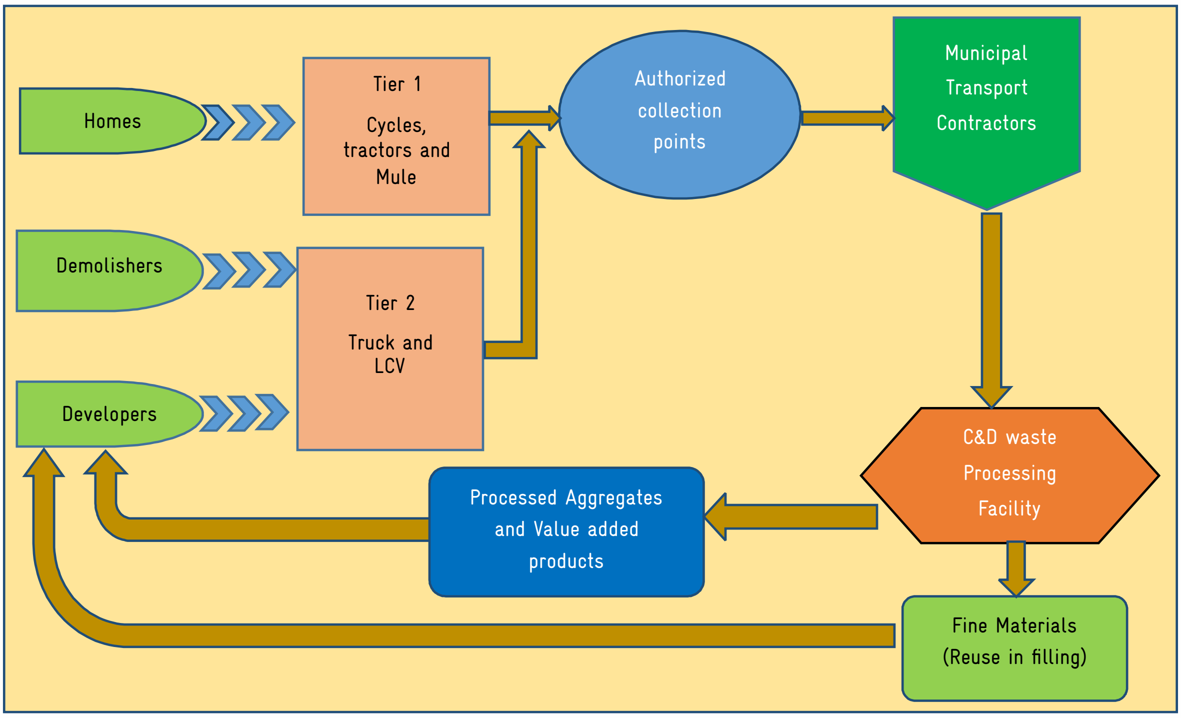
   In order to save the tipping fee, the transported C&D waste is illegally disposed at unauthorised locations or MSW dumpsites without payment of tipping fee. Bulk of the transport costs is presently being borne by municipal corporations and there is no processing of C&D waste before final disposal.

Proposed C&D waste management system

The diagram 6.18 describes the proposed collection, transportation and processing practices of C&D waste in India as per the latest Construction and Demolition Waste Management Rules-2016. In the proposed rules, the transportation network shall be maintained as it is and the waste generators are directed to pay the tipping fee failing which they will attract the penalty.

These tier-1 and tier-2 transporters shall dump their waste in the designated collection points authorised by the municipal corporation. The dump site in-charge will collect money from the transporters depending upon the weight of C&D waste mostly in Rs. per ton basis.

Fig. 6.18 Proposed C&D waste management system



(Source: IEISL)

Designated dump sites

Designated dump sites are the sites authorised by the municipal corporation and mutually agreed by the transporters for dumping C&D waste.

Depending upon the quantity and area of waste generation, the location and number of dump sites shall be decided by the municipal corporation. The size of the dump sites shall be varying from 100 square meters to 1 acre. They will be managed by the Municipal Corporation or by the operators in a systematic manner with weighing scale and provision to store the waste. The waste generators shall dump the generated waste in the nearest designated dumping locations by paying the gate fee.

Transportation from designated dumpsite to C&D recycling facility

Tier 3 transporters are contracted by the Municipal Corporation for C&D waste removal from designated dumpsites. These contracted transporters are paid by the Municipal Corporations for their transport services depending upon the distance.

Tier 3 waste transporters unload the waste in the authorised C&D waste processing facility. Municipal corporation shall make concession agreement with the operator of the facility for the collection, transportation and processing of C&D waste for an agreed tipping fee per ton.

Alternatively, large waste generators shall dispose their waste directly to the processing facility after paying the gate fee. The C&D waste processing facility operator will convert the waste into useful products like processed aggregates and value added products and sell them in the market.

Off-site processing of C&D waste

The C&D waste processing plant typically consists of the following sections (based on Burari plant):

- Receipt and Inspection of C&D Waste
- Weighing of C&D waste
- Manual Segregation and Resizing
- Wet Processing
- VSI Crushing and Batching

C&D waste processing and recycling facility site would consist of (based on Burari plant):

- Weighbridge
- Processing machinery including crushing and screening system, Wet Processing system and filter press
- Heavy Earth Moving machinery like excavator, backhoes, loader, trucks
- RMC plant, Mini mixers
- Solid / Hollow cement block making machines
- Facilities and moulds for making products such as pavement blocks, kerb stones, hollow cement block, tiles, pre-cast RCC slabs, etc.
- Dust suppression system
- Material testing facilities / lab
- Utilities such as generator, internal roads, water supply system, storm water drainage system, boundary wall / fencing, worker rest room and toilet.
- Office

(a) Receipt and Inspection of C&D Waste at the plant

Waste received at the processing facility would undergo inspection at the entrance. C&D waste includes bricks, concrete, rubble and other masonry materials, soils, rock, land clearing debris, etc. C&D waste shall not include (even if they result from construction, remodeling, repair, renovation or demolition of structures or from land clearing activities) any hazardous wastes as defined under Hazardous and Other Wastes (Management and Trans-boundary Movement) Rules, 2016. Thus, truck containing only C&D waste shall be accepted at the facility and will proceed for weighing.

(b) Weighing of C&D waste

A weighbridge of minimum weighing capacity of 40/60 tons will be installed at the processing facility. It shall be equipped with a computerised system for billing and tracking vehicle movement. The platform scales shall have the capability of accurately measuring tare and net weights of range of vehicles. The scales shall have a minimum designated level of accuracy (i.e. ± 5 kg).

The weighbridge will be a permanent facility furnished with appropriate space to maintain and operate the computerised weight recording system, store historical records and have sufficient room for two weighbridge operators.

The weighbridge shall generate and maintain an electronic database for each delivery with time stamp and provide a print out of the specifications and details for each consignment received at the project site.

(c) Segregation and Re-sizing

After weighing, trucks are brought to the waste unloading area. The C&D waste is dumped at the tipping floor. JCB would reach the incoming material storage area, and level the collected waste so that manual segregation can be conveniently carried out. Wood, steel, plastic, etc. is manually segregated and sold through authorised recyclers or sent to the designated landfill or dumpsite for disposal.

The remaining waste will be segregated into 3 parts:

i. Whole bricks which will be manually segregated and can be used internally or sold for use

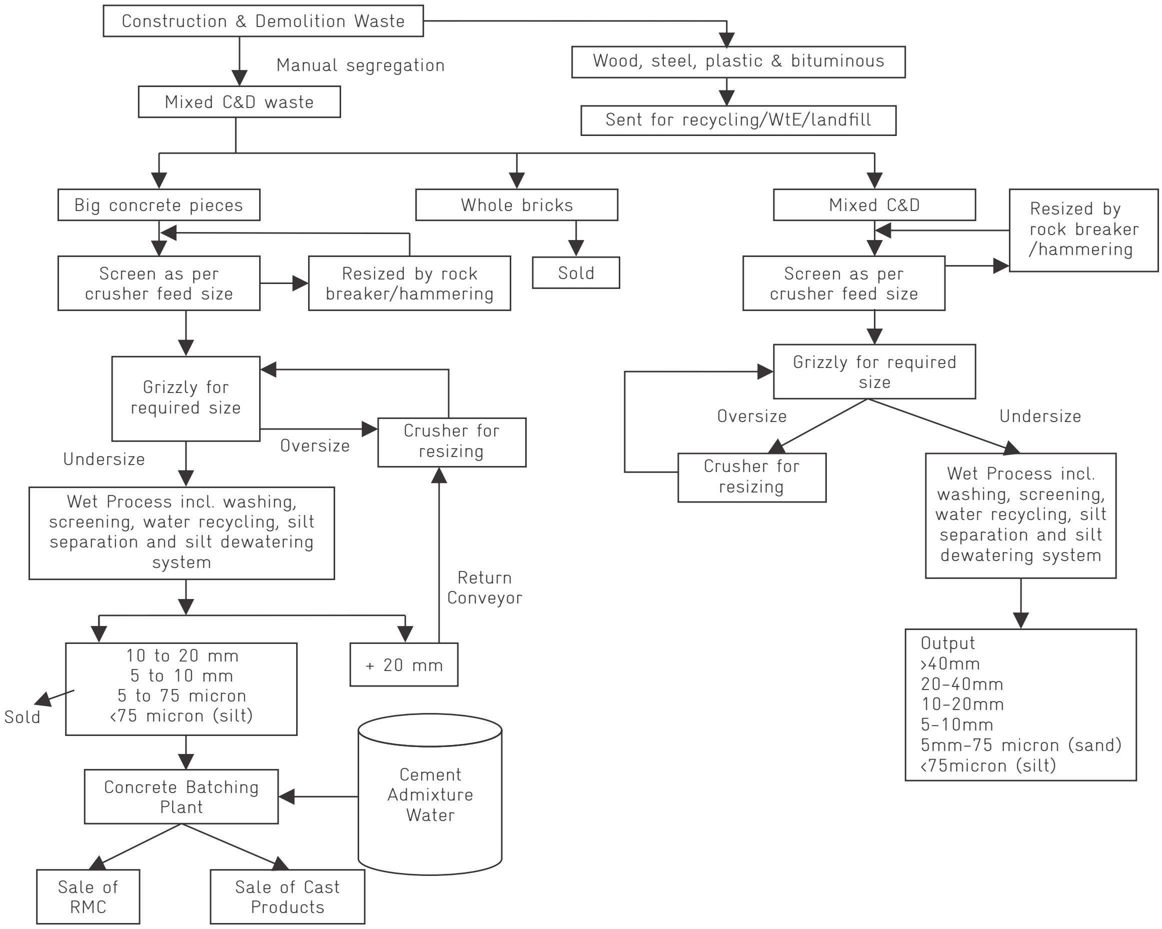
ii. Big concrete pieces

iii. Mixed C&D waste

All large sized (ii) & (iii) will be resized to 200-400 mm size mechanically using excavator attached with rock breaker or manually using hammer.

Fig. 6.19 shows the flowchart for offsite management of C&D waste.

Fig. 6.19 Flowchart for off-site C&D waste processing



(Source: IEISL)

(d) Processing

Initial processing of concrete waste and mixed C&D waste: The big concrete pieces or mixed C&D waste is crushed as per feed size requirements of the crusher using rock breaker or hammer. The output from screens will be discharged on to a main conveyor through feeders. The main conveyor shall discharge the C&D waste to a manual inspection conveyor at elevated level. From the slow moving inspection conveyor, all unwanted objects shall be handpicked at the manual separation station. These are mostly large textile pieces, large twigs and woody pieces, thermocol/styrofoam, consumer durables, which are dropped into the respective chutes for collection. The inspected waste is fed to grizzly system which is designed as per required material size for wet

Fig. 6.20 Concrete waste

Fig. 6.21 Mixed C&D waste

(Source: IEISL)

processing. Oversized materials from grizzly are resized by Jaw or Impact Crusher. Crusher and grizzly size can be selected based on the output requirement and material demand for other works. The crushed materials are returned to the grizzly process followed by wet processing including washing, screening, water recycling, silt separation and silt dewatering system for final materials recovery.

A Jaw Crusher reduces large size rocks or materials by placing the materials into compression. A fixed jaw, mounted in a "V" alignment is the stationary breaking surface, while the movable jaw exerts force on the material by forcing it against the stationary plate. The space at the bottom of the "V" aligned jaw plates is the crusher product size gap, or the size of the crushed product from the jaw crusher. The material remains in the jaws until it is small enough to pass through the gap at the bottom of the jaws.

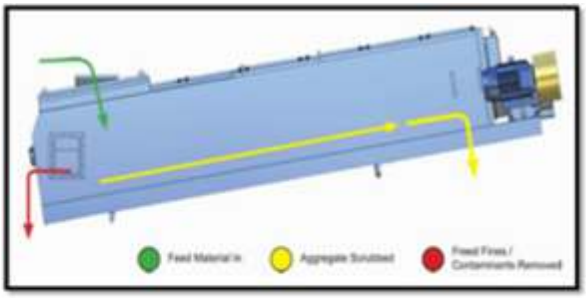
Wet Processing

For the wet process a total set of machinery consisting of Grizzly, Vibro Screens, sand washing systems, Thickener, etc., that is capable of segregating sand from mixed C&D waste is used.

Wet processing involves the following steps:

- Log Washer – Material from the grizzly is fed to the Log Washer to separate light contaminants such as wood and plastic. In the Log Washer, aggregate and dirt bound materials are cleaned through attrition. Plastics and organics are floated off from the rear of the Log Washer and passed to a small trash screen that recovers any water and fine material. The RotoMax Log Washer is a high efficiency, heavy duty unit which allows for the production of commercial grade material from heavily clay bound feed stock and overburden.

Fig. 6.22 Log Washer

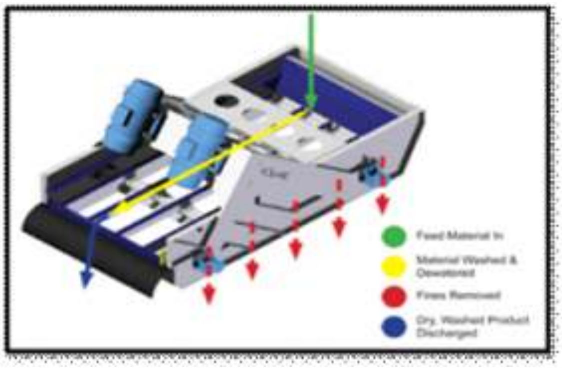


(Source: CDE Asia)

- **Washing and contamination removal -** Rinsing screens are used to wash aggregates with water. A three-deck pro-grade screen is used for screening washed material into different size products. Screens of following sizes are employed:

  - 20 mm
  - 10 mm
  - 3 mm

Fig. 6.23 Aggregate washing system

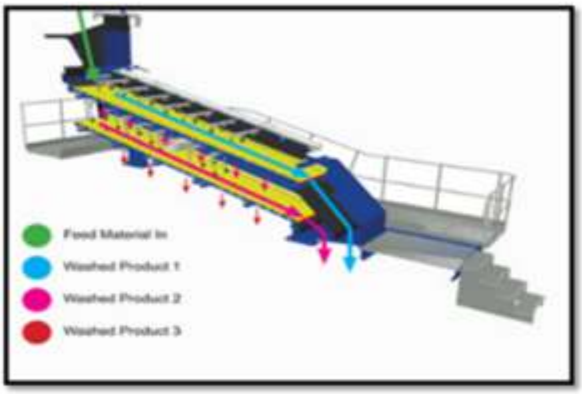


(Source: CDE Asia)

In wet processing, water is added at the screening stage itself to improve quality and to retrieve fine particles. Clean and dry aggregates are sized and stockpiled into bays of the Batching Plant. The outputs of following sizes would be obtained:

- >20 mm
- 10 mm to 20 mm
- 3 mm to 10 mm
- < 3mm

Fig. 6.24 Screener



(Source: CDE Asia)

The >20mm material are fed back into the crusher for further size reduction and <3 mm material are sent to the Aqua Wash for further recovery of fine aggregate.

- Sand washing system – Silt can be separated from sand by various techniques such as bucket & wheel sand washing system, spiral sand washing system, Hydrocyclone systems, etc. Hydrocyclone systems are the most efficient and can recover very high percentage of sand.

i. Bucket Wheel Sand Washers are also used to recover two grades of sand in slurry coming from a washing screen and at the same time remove clay and slime from the sand. In this system, most of the work is carried out by bucket wheels. It recovers more than 95% sand with less moisture content.

Fig. 6.25 Bucket Wheel Sand Washers

(Source: Dernaseer)

ii. Spiral Sand Washing System consists of three weir plates and a screw connected by the electrical motor. These weir plates act as a sedimentation tank and the screw is rotated by the electrical motor which causes separation of sand from the fine materials. Spiral Sand Washing System is a simple structure with easy maintenance requirements.

Fig. 6.26 Spiral Sand Washing system

(Source: Bharath Industrial works)

iii. Hydrocyclone Sand Washing System - Hydrocyclone separates the feed slurry material into different size ranges.

- > 75 microns which is sand
- < 75 micron sized material, which is silt

Hydrocyclone Sand Washing System consists of a cyclone for separation of -75 micron material. Hydrocyclone Sand Washing System also ensures reduction in

Fig. 6.27 Hydrocyclone

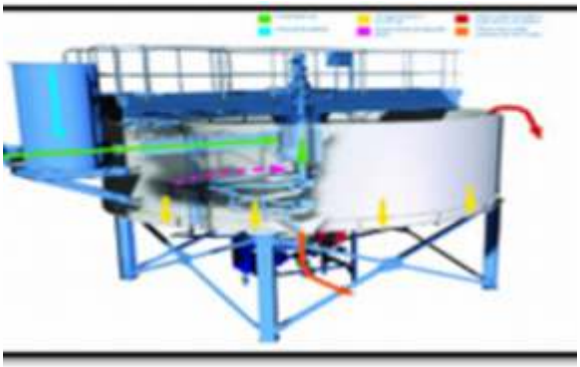
(Source: CDE Asia)

water content of the input feed material. Silt is sent for recovery and recycling of water to the water recycling system.

- **Water Treatment and Recycling**

  -75 micron material is passed to Thickener where specifically selected flocculant is added to it in controlled quantities. This leads to the formation of dense slurry. The supernatant water is recycled.

Fig. 6.28 Thickener



(Source: CDE Asia)

- **Filter Press for dewatering of silt slurry**

  Filter press separates the solid (silt) from the slurry. Filter Press increases solids content up to 90% dry solids which are dropped into bay as final waste by squeezing water from sludge. This sludge may be used as landscaping soil or for brick making.

Fig. 6.29 Filter Press

(Source: CDE Asia)

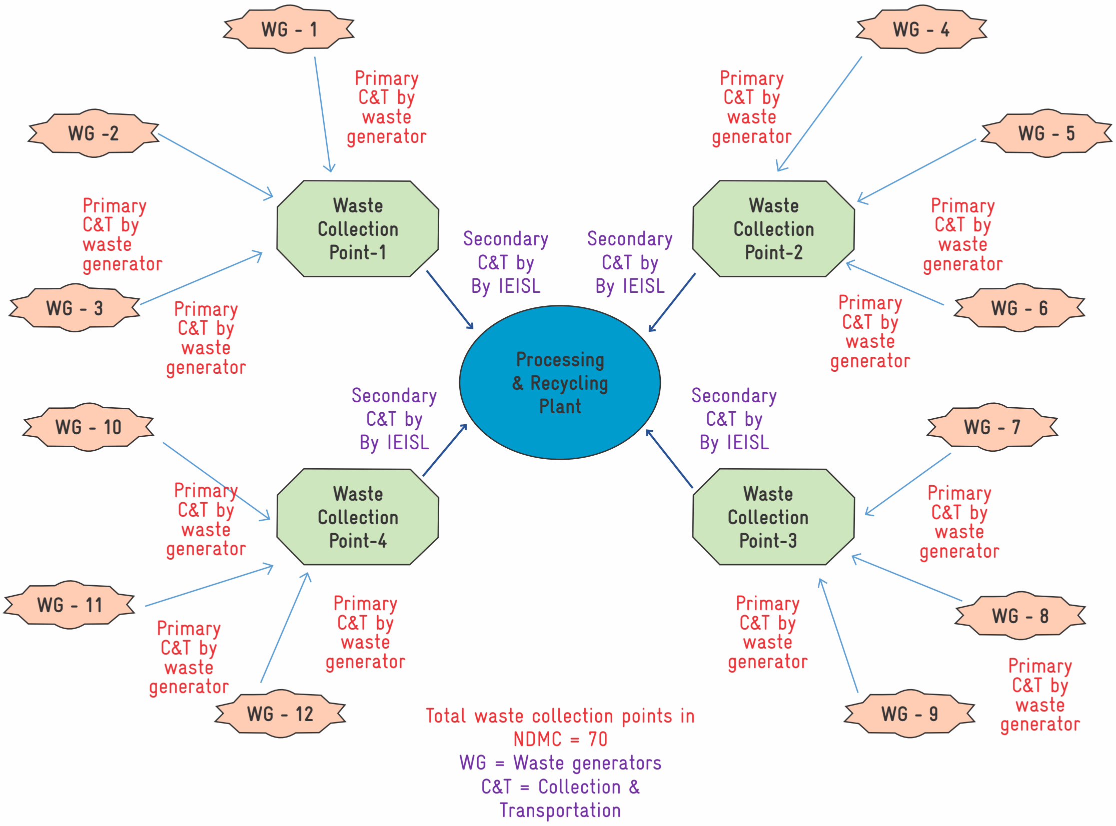
- **Vertical Shaft Impactor (VSI) Crushing**

  All aggregates of mixed C&D waste (3 mm to 20 mm) can be crushed to size of sand using Vertical Shaft Impactor (VSI). The VSI Crushers are known as sand making machine widely used for fine crushing and rough grinding of building aggregate and concrete. The VSI Crushers utilise velocity predominant force to break rock. The product resulting from VSI Crushing is generally of a consistent cubical shape which can be utilised for various purposes. The C&D waste material falls into the high-speed rotating impeller from the upper end of the machine because of high-speed centrifugal force. After it strikes mutually, whirling fluid is produced between the impeller and outer covering. Through repeatedly striking and rubbing, the material is crushed into pieces and comes out straight from the lower end. The operating process circulates repeatedly and thus attains the fineness of the product.

Table 6.1 List of key equipment for a typical 500 TPD C&D waste processing and recycling facility

S. No.	Particular	Quantity
1	Weighbridge (60 tons)	1
2	Jaw Crusher (20 TPH)	1
3	Wet processing (CDE Asia) (60 TPH)	1
4	Batching Plant (20 m^3/hr)	1
5	Silt Dewatering system	1
6	Mini mixer	Based on Product demand
7	Egg laying machine	
8	Excavators (Rock breaker attachment as required)	2
9	Loader	2
10	Trucks	2
11	Electrical Power requirement	250KVA

Fig. 6.30 C&D waste collection system in Delhi



(*Source: IEISL*)

Strategies for pollution prevention from C&D waste processing and recycling facilities (C&DWM Rules, 2016)

- Provision of storm water drains to prevent stagnation of surface water.
- Provision of paved or concreted approach and concrete roads in the processing or recycling facility for minimising dust due to vehicular movement.
- The measurement of ambient noise to be done at the interface of the facility with the surrounding area for preventing noise pollution from processing and recycling plant.
- Monitoring work zone air quality at the processing or recycling site and ambient air quality at the vicinity.
- Provision of green belt area surrounding the processing and recycling facility.

Statutory criteria for siting of C&D waste storage and processing or recycling facilities (C&DWM Rules, 2016)

- The selected site for the C&D waste processing and recycling facility is able to cover all the surrounding area of the city.
- The selected site should be easily accessible by waste transporters.
- The processing or recycling should be large enough to last for 20-25 years at site.
- The processing or recycling site should be away from habitation clusters, forest areas, water bodies, monuments, National Parks, wetlands and places of important cultural, historical or religious interest.
- A buffer zone of no development and green belt area should be maintained around C&D waste processing and recycling facility.

- Processing or recycling site shall be fenced or hedged and provided with proper gate to monitor incoming vehicles or other modes of transportation.

Road Map for setting up a C&D waste processing & recycling facility in an Indian city

- Quantification of C&D waste generation in the city covering:
  - Different sources viz, construction, demolition, repair, renovation, infrastructure works and spatial distribution (different wards/zones).
  - Different types of buildings (masonry structures, framed structures, structures with local building materials, etc.).
  - Determining waste generation factors for different sources in Kg / m^2 of built up area by field surveys, estimating from demolition plans, etc. and weighing in dumpsites and estimating area of construction, demolition, repair, etc. annually in every ward / zone.
  - Carry out future projections for next 10-20 years for waste quantity and characteristics by predicting future construction & demolition activities.
- Characterisation of C&D waste from different sources of generation by studying adequate number of demolition and construction plans in the city in each category and also by sampling of C&D waste received in dumpsites.
- Study and analyse current scenario/practices of C&D waste management.
- Identify and establish C&D waste collection points (based on quantity of C&D waste generation in each area/zone/ward).
- Locate one or more sites for C&D waste processing facility considering waste transportation costs and quantity of waste generation (plant size of at least 300 TPD for large cities).
- Plan the C&D waste processing facility for minimum 20-25 years considering future C&D waste generation (minimum additional capacity after expansion 250 TPD).
- Adopt the polluter-pays-principle for collecting fee for C&D waste generation:
  - Collect the fee at generation point (Rs./m^2) during demolition/ construction approval process.
  - In case of waste generation during repair and maintenance, it may be worked out and included in property tax (Rs./m^2/year) based on building age (incremental rate for every 5 year rise in age).
- Prepare Pre-feasibility Report, RFP and float a tender for a Public-Private Partnership (PPP) Project for C&D waste secondary transport (collection point to recycling facility) and recycling facility.
- Obtain Consent To Establish (CTE) for the C&D waste processing facility.
- Appoint project management consultant for monitoring of implementation stage.
- Make mandatory use (at least 20%) of recycled materials from C&D waste in contracts of municipality – kerb stones, paver block, tiles, hollow and solid concrete blocks, pre-cast PCC & RCC slabs for pedestrian pathways, non-structural use, GSB for roads, etc.

6.8 Products made from recovered materials and their use

Use of materials made from C&D waste and its products
(C&DWM Rules, 2016)

- The coarse fraction of recovered materials from C&D waste having size from 2 mm to 4.75 mm can be used as Drainage Layer in leachate collection system at bottom of Sanitary Landfill, Gas Collection Layer above the waste at top of Sanitary Landfill, and Drainage Layer in top Cover System above Gas Collection Layer of Sanitary Landfill. Further, the coarse fraction of recovered materials can be used for capping of sanitary landfill or dumpsite.

- Fine fraction of recovered materials from C&D waste having size up to 2 mm shall be used for daily cover over the fresh waste. Use of construction and demolition fines as landfill cover shall be mandatory where such material is available. Fresh soil (good earth) shall not be used for such places and burrow-pits shall not be allowed. The use of fresh soil is allowed only when excavated soil during construction of the same landfill is available.

- Recovered materials from C&D waste processing and recycling can be used for non-structural applications such as kerb stones, drain covers, paving blocks in pedestrian areas, etc..

Use of recovered aggregates from C&D waste

The use of the processed C&D waste as aggregates has been studied and prescribed by BIS. It is broadly classified into two categories based on the type of C&D waste processed. If segregated concrete waste is processed by wet scrubbing wherein cement paste adhered to the concrete is removed, Recycled Concrete Aggregates (RCA) emerge as the recovered useful product. Washed RCA in the range of 4.75 mm to 0.075 mm (75 μ) separated from C&D waste using 'wet' process can be used as "fine aggregate" (IS 383:2016).

If mixed C&D waste such as concrete, brick, tiles, stone, etc. is processed, recycled aggregates (RA) emerge as the recovered useful product (IS 383:2016).

Use of RCA and RA is prescribed by BIS in the latest revision of IS 383: 2016 for use of these aggregates as coarse / fine aggregates in making lean, plain and reinforced cement concrete as per limits given in table 6.2 below.

Use of RCA in the sub-base of roads has been studied in detail and found to be environmentally safe regarding leaching of harmful substances (Engelsen, 2013).

Prescribed Use of Recycled Concrete Aggregate and Recycled Aggregate and its Precautions in India
(IS 383:2016)

The fine and coarse fractions of recycled concrete aggregates (RCA) produced from the crushing of concrete wastes can be used in plain, reinforced, lean concrete works as per specification of IS 383:2016 and recycled aggregates (RA) from mixed C&D waste can be used in lean concrete works in less than M15 grade.

Table 6.2 Prescribed extent of utilisation of aggregates from C&D waste in IS 383:2016

S. No.	Type of Aggregate	Maximum Utilisation, %		
		Plain Cement Concrete	Reinforced Cement Concrete	Lean Concrete (less than M15 grade)
1	Coarse Aggregate			
	Recycled Concrete Aggregate (RCA)	25	20 (only up to M25 Grade)	100
	Recycled Aggregate RA)	Nil	Nil	100
2	Fine Aggregate			
	RCA	25	20 (only up to M25 Grade)	100

i. Coarse and fine fraction of Recycled Concrete Aggregates (RCA) (shown in fig 6.32) recovered from processing of concrete waste in C&D waste can be used up to 25% in total proportion of coarse and fine aggregate requirement in making of paver blocks, tiles, kerb stones, hollow and solid concrete blocks and pre-cast concrete slabs without steel. Moreover, the use of coarse and fine fraction of RCA and coarse fraction of recycled aggregates (RA) (shown in fig. 6.31) can be up to 100% in making of hollow and solid concrete blocks, and concrete works in grades less than M15.

ii. In reinforced concrete works, the usage of coarse and fine fraction of RCA is limited up to 20% of total proportion of coarse and fine aggregate requirement upto M25 grade concrete.

iii. RCA shall be free from deleterious material such as organic content, vegetable matter, coal, clay lumps, external substances such as soft fragments like pieces of plastics, paper, etc. RCA shall also be free from chemicals, known to be detrimental for the strength or durability of concrete or steel reinforcement, such as, chlorides, etc. beyond the threshold value.

iv. RCA have to be pre-wetted near to SSD (Saturated Surface Dry) conditions before use to avoid rapid slump loss due to its high water absorption rate. Admixtures with better slump retention effect would be useful.

Fig. 6.31 Recycled Aggregates

(Source: IEISL)

Fig. 6.32 Recycled Concrete Aggregates

(Source: IEISL)

Concrete making

The aggregates recovered from concrete waste processing can be either sold or can be used in preparing fresh concrete. Depending on quantity of concrete that can be produced at site, either Batching Plant commonly known as Ready Mix Concrete (RMC) Plant or mini-mixer can be used to make fresh concrete.

In these plants, cement, hardener and water will be added in pre-determined/ calculated quantities. RMC can be sold or used for making pre-cast products. Concrete from mini-mixers is used for making pre-cast products.

Box 6.1 can be referred to understand the shortcoming posed by RCA and in turn RAC, and how these can be improved.

Concrete block making

Hollow and solid block making is a process of converting concrete into blocks which are generally used for construction of load bearing and partition walls. A block making machinery normally manufactures 5,000 blocks every day in a single shift. After making the blocks, they need to be cured and sun dried for 4 weeks before final use (IS 2185-part I-2005).

While recycling C&D waste, some shortcomings can be experienced; however, these can be overcome using proper expertise. Refer to Box 6.1 below.

Box 6.1 Note an shortcomings of RCA and methods to improve RAC

Recycled Concrete Aggregate (RCA) essentially is a combination of two different materials, the Natural Aggregate (NA) with which the structure was constructed and was eventually demolished and the adhered mortar covering the NA. The high porosity and low strength of adhered mortar is responsible for inferior properties of RCA and the Recycled Aggregate Concrete (RAC) made using it.

The use of RAC is not widespread till date due to the observed variability in properties of RCA and inferior performance resulting in lack of confidence in this material among the user community. Research efforts are in progress to improve the quality of RCA and in turn RAC.

In general, RCA has lower bulk density, specific gravity and mechanical properties and higher water absorption in comparison to NA. The amount of adhered mortar influences the properties of RCA and the properties are influenced by levels of replacement of NA with RCA.

RAC exhibits (i) reduced workability resulting in bleeding and segregation at higher percentage of RCA (ii) reduced mechanical properties such as compressive strength, tensile strength and modulus of elasticity and (iii) increased shrinkage, creep and reduced durability.

Some of the methods widely adopted to improve RAC are (i) removal of adhered mortar by rubbing or heating (ii) pre-wetting and bringing the aggregate to Saturated Surface Dry (SSD) condition (iii) increasing the powder content of mix and (iv) use of super plasticiser. Mechanical properties can be improved by (i) use of Supplementary Cementitious Material (SCM) like fly-ash, silica fume, Ground Granulated Blast Furnace Slag (GGBS), etc. (ii) reduction of water cement (cementitious material) w/c ratio (iii) adopting two stage or triple stage mixing, and (iv) increasing curing period. Some of the above methods are useful in reducing creep and drying shrinkage.

In India, lack of awareness, specifications/ standards related to classification of RCA and mix design of RAC discourages the practicing engineer from adopting this new material for construction. It is to note that the conventional mix design procedure existing in IS10262 cannot be straight away adopted for formulating mix proportion containing RCA.

Use of products from C&D waste

Materials recovered from C&D waste can be used in various applications and manufacture of various types of products as follows:

i. Building construction products

ii. Application in road projects and products for roads

iii. Other applications

i. Building construction products

Hollow cement block, solid cement block, tiles, paver blocks, pre-cast slabs, etc. (see Figure 6.33) can be manufactured from recovered aggregates and other materials from C&D waste and used in construction of residential, commercial and other buildings.

ii. Application in road projects

After detailed laboratory investigations followed by comparing results with conventional natural aggregate at Central Road Research Institute (CRRI), it was concluded that C&D waste can be used in various layers of road and embankment construction. Based on these results from CRRI, the use of C&D waste in road and embankment construction can be summarised as follows (Rao et al., 2014):

- The different fractions may be used for road sub-base, moulding for kerb stones, paver blocks and RMC, etc.
- C&D waste may be used for embankment and sub-grade construction.
- C&D waste may be used for sub-base (the layer above compacted earthen sub-grade) construction.
- Use of C&D waste for Stabilized Base Course Construction.
- Use for Rigid Pavement Construction

Manufactured products from processed C&D waste for roads: paver blocks, kerb stones, stormwater drain cover slabs, etc.

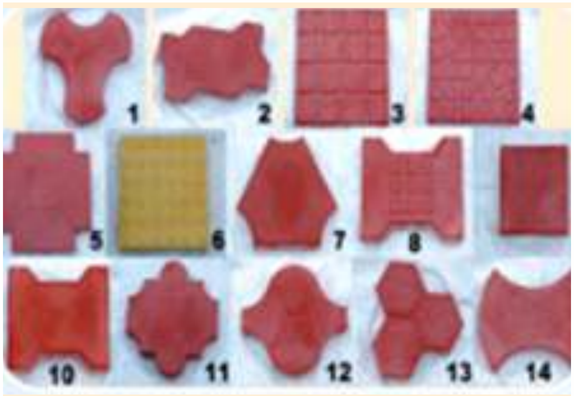
Other applications

Ready Mix Concrete, pre-cast slabs, etc. can be made from recovered aggregates from processing of C&D waste. Examples are shown in Fig. 6.33.

Fig. 6.33 Products from recovered materials in C&D waste processing

Kerb stones

Tiles



Hollow concrete blocks

Paver blocks

(Source: IEISL)

6.9 Environmental management of C&D waste processing and recycling Facility

Environmental Management Plan

The purpose of the Environment Management Plan (EMP) is to mitigate potential negative impacts from various activities associated with the processing facility. This includes understanding and incorporating mitigation measures by the designers and the contractors to ensure that the emissions at site boundary are within the required CPCB and SPCB limits.

Table 6.3 Potential issues and impacts of C&D waste processing and recycling

Activity	Potential Issue	Impact
Site clearing	Dust and noise Loss of biodiversity	Health Air pollution Ambience or visual impact Flora and fauna habitat
Site operations or contouring that permits water to pond on-site	Odour	Health Ambience or visual impact
Uncontrolled or poorly managed site run-off	Surface water runoff resulting in transportation of sediments (i.e. erosion)	Water pollution Soil erosion
Transporting materials to or from site or Stockpiling of wastes or recycled products on site. Crushing, grinding or screening operations	Dust Noise	Health Air pollution
Asbestos contamination in waste loads	Asbestos pieces pass through crushing operations Asbestos from stockpiled material remains in soil	Health Air pollution Land contamination
Sorting of C&D waste	Hazardous waste components of C&D waste	Health Air pollution Land contamination
Litter	Litter from operations or during transportation to or from site	Littering, choking of drains

The EMP will adhere to the guidelines stipulated in the "Construction and Demolition Waste Management Rules-2016" and also the norms stipulated by CPCB and SPCB.

For prevention of pollution from processing or recycling operations, certain provisions have been mandated such as storm water drain and paving or concreting of selected areas in the processing or recycling facility.

However, exemption from dust and noise provisions has been granted for the following projects (C&DWM Rules, 2016):
A) For redevelopment of colonies and markets, where in-situ recycling is carried out, provided; (a) the project is completed within 5 years, (b) minimum 80% of the C&D waste generated at the site is recycled or reused within the same site, and (c) sufficient buffer area is available to protect the surrounding habitation from any adverse impacts.

B) In-situ recycling at large construction sites (minimum 1 hectare so that some buffer area is available), provided (a) the project is completed within 3 years, and (b) minimum 50% of the C&D waste generated at the site is reused or recycled within the same site.

Air emissions

The unloading as well as processing of the waste generates dust. Dust containment

Table 6.4 Acceptable levels of air quality parameters (CPCB, 2009)

S. No	Parameters	Acceptable Level
1	Suspended Particulate Matter	500 μg/m^3(24 hours)
2	Respirable Suspended Particulate Matter (RSPM) or Particulate Matter (PM10) 10 Micron	100 μg/m^3 (24 hours) 60 μg/m^3 (Annual)
3	Particulate Matter PM2.5	60 μg/m^3 (24 Hours) 40 μg/m^3 (Annual)

(covered equipment) and dust suppression using water mist spray are required to reduce such emissions. It can also be reduced by maintaining buffer zone and green belt around the facility.

The ambient air quality monitoring shall be carried out at processing and recycling facility as per the following schedule:

- 6 times a year for cities having a population of more than 5 million;
- 4 times a year for cities having a population between 1 million and 5 million;
- 2 times a year for town or cities having a population between 100,000 and 1 million, or;
- once a year for all towns (including census towns) having a population below 100,000.

Noise pollution

Sources of noise pollution includes truck traffic, crushers, and wet processing systems. Where necessary, enclosures should be provided to ensure that noise levels do not exceed the prescribed standards (85 dBA at 1 m distance from the equipment). For workers' safety, earplugs should be provided and equipment should be maintained to ensure optimum working conditions.

For noise levels, the noise standards recommended by the Central Pollution Control Board (CPCB, 2000) and notified in the Environment (Protection) Rules, 1986 for industrial areas shall be applicable (daytime 75 dB ALeq and night time 70 dB Aleq). The measurement would be done at the interface of the facility with the surrounding area, i.e., at plant boundary.

Occupational Health and Safety (OHS)

All the workers handling C&D waste will be provided with safety gear such as safety boots, helmets, gloves, safety glasses, ear plugs and dust masks.

Risks from moving equipment

There are a large number of moving equipments in the processing plant with the potential for accidents, as mentioned below:

- Crushers: During operation, the hammers may get broken and come out with high velocity. To avoid this, safety features should be built in the equipment design.
- Conveyors: Although conveyors operate at low speed, they can sometimes cause accidents due to negligence of the operating personnel. To avoid this, suitable training should be imparted to all concerned.
- Drives: All moving parts like V-belts, tail end and head end pulleys, sprockets, etc. should be covered using appropriate safety guards.

7. CRITERIA IN DEMOLITION CONTRACT

7.1 Current industry practices

While there exist fringe provisions and codes of practice in special publications, the practice of deconstruction remains isolated in India. When preparing contracts, stakeholders prepare their own specifications. In most instances, the owners call the potential demolition contractors and seek bids. The demolition contractors assess and offer a price to the owner or demand a price from him based on the differences between the possible revenues from output and the cost involved in deconstruction. The contract is awarded mainly on financial criteria and environmental sustainability concerns are addressed only in passing.

The general structure of a typical demolition contract includes following:

1. Definition of Terms 2. Safety: Compliance with Legislation and Local Regulations 3. Site Conditions and Execution 4. Delivery to and Clearance of Site 5. Interference with other Operations and Rights and Trespass 6. Contractor's Workmen 7. Access to Site and Use of Facilities 8. Ownership of Material 9. Assignment and Sub-Letting 10. Contractor's Default 11. Care of the Reserved Material 12. Insurance of the Reserved Material 13. Liability for Damage to Property and Injury to Persons 14. Fire Precautions 15. Statutory Payments 16. Variations 17. Code of Conduct 18. Bankruptcy 19. Acceptance of Conditions 20. Law

7.2 Specifications for introducing deconstruction criteria into existing demolition contracts

There is an urgent need for the site owners to convert the demolition contract into deconstruction contracts by adding suitable criteria:

i. Proposals from contractors with sufficient qualifications and experience at similar work should be invited. Prospective contractors must complete a qualifications questionnaire.

ii. This questionnaire will be reviewed by an expert committee well versed in the area of environmental impacts of demolition and resource recovery.

iii. The purpose of rehabilitation, de-construction, and neighbourhood stabilisation should be stated clearly.

iv. Reuse and recycling should be put into specifications in the contracts with clearly stated targets for resource recovery outcomes.

v. In addition to submitting a financial bid, the contractors must also prepare a technical proposal outlining in detail their deconstruction planning, methods and technologies to be used, segregation and on-site reuse/ recycling, off-site recycling or disposal plan, environmental/safety provisions and plan for dealing with hazardous waste, etc.

Evaluation criteria

In evaluating responses to the Request for Proposals, the evaluators should take into consideration the experience, capacity, methods, recovery plans and costs that are being proposed by the contractor/s. A suggested evaluation rubric based on points is provided below:

i. 15 points for experience in providing required services.

ii. 10 points for the capacity to meet timelines.

iii. 15 points for pricing.

iv. 10 points for their experience in meeting legal requirements including safety provisions.

v. 20 points for their use of environment-friendly practices.

vi. 20 points for on-site reuse and recycling with minimal disposal to landfill.

vii. 10 points for innovations like:

- Community hiring
- Engaging community stakeholders for effective community partnerships and collaborations
- Utilising local suppliers and retailers
- Other green practices.

Effective planning/scheduling and site management including better than quoted quantities/targets for reuse and recycling may be given bonus points at the end of contract, incentivising such efforts.

7.3 International best practices

Many countries have discontinued the traditional practice of demolition and laws mandating deconstruction and resource recovery are in place. A few important lessons can be drawn from their experience.

Aiming for 'Quick Wins'

On any project there are certain key waste streams that can offer significant savings, that can be regarded as 'Quick Wins'. This could be influenced by ease of recovery or good value in local recycling markets, etc. For example, in addition to metal components which typically have good secondary value almost everywhere, recovery of intact bricks and tiles, segregated pure concrete fraction, etc. can be of good demand in secondary markets. Depending on local circumstances, focusing on one or more of these streams can increase overall reuse and recycling rates of waste from standard industry performance by more than 20%.

Target setting

Identify good practices that lead to better recovery rates for a comprehensive range of waste streams. Clients can provide a mandate for action on all projects by setting a requirement for good reuse and recycling practices with resource recovery targets. This simple action will be the crucial first step in realising the key benefits of adopting deconstruction.

International best practices for deconstruction are summarised in Appendix IV.

8. POLICY RECOMMENDATIONS AND CONCLUSION

Deconstruction is an elegant and sophisticated version of what is being otherwise currently practiced as demolition. It is an attempt to improve the environmental impact of the construction industry, which is one of the biggest consumers of natural resources in addition to contributing to significant levels of GHG emissions. Environmental concerns have already forced the industry to seek solutions by substitution, modification of products, processes and technologies. Restrictions by regulation on mining and quarrying of sand and stones in many parts of India have already led to crunch in availability of aggregates, forcing the industry to look for alternate sources. Proper deconstruction has the potential to maximise the recovery of useful material from demolition waste that can then be used as a secondary raw material for construction, thus reducing virgin material extraction. Moreover, proper deconstruction and reuse also has the potential to improve the economic competitiveness of the industry both from avoiding the increasingly high costs of virgin materials and through reducing waste disposal costs. However, to make the practice of deconstruction more widespread in India, several policy measures are necessary.

8.1 Policy recommendations

With rapid urbanisation, there has been a phenomenal increase in reconstruction after demolition in many Indian cities, whether due to age of old structures or simply to make way for higher density development and new infrastructure. Now is the right time to systematically promote and enforce the practice of deconstruction. Better technology selection, trained man-power, public awareness, strengthening institutional mechanisms, enforcement of regulatory provisions and participation of all stakeholders are all key elements in promoting successful deconstruction and sustainable C&D waste management.

Deconstruction and reuse mandates

Local authorities can formulate policies aimed specifically at the promotion of deconstruction and material salvage. For instance, the city of Portland, Oregon in the USA, undertook a program to aggressively promote deconstruction, salvage, reuse and recycling.

Driven by C&D waste statistics, Portland set targets for waste diversion from landfill sites, demanded recycling programs from construction projects, increased landfill tipping fees and enforced regulations (CIB, 2001).

The C&D Waste Management Rules 2016 authorises local government bodies to mandate C&D waste salvage and reuse. This can be achieved through compulsory demolition permits that must be approved before work can begin. Demolition projects above certain project size or project area must have deconstruction or recycling mandates with specific targets. Alternate criteria can be waste generated per day or overall waste generated by the project. Even smaller neighborhood demolition projects should have requirements to send waste to the designated C&D waste collection centers as part of demolition permit. Reuse/recycling targets can be made more ambitious over time as the recycling infrastructure expands and capacity of stakeholders increases.

Incentives for reuse and recycling

The C&D waste Management Rules, 2016 also mention appropriate incentives for promoting salvage, reuse and recycling. Some examples include:

- Attractive PPP models to encourage investors to invest in C&D waste processing/recycling. For example, in Delhi and Ahmedabad, the PPP model provides the concessionaire contracted to collect and process C&D waste with land at negligible cost, plus a tipping fee based on tonnage and distance.
- Technical and financial support to secondary material businesses that distribute and/or manufacture products from salvaged C&D waste. This can include preferential public procurement.
- Relevant specifications and standards should be brought in new construction for use of recycled material.
- Provision for tax relief for salvaged material.
- There should be charges for disposal in landfills, which should be sufficiently high to encourage recycling of C&D wastes, accompanied by well-enforced heavy penalties for deterring illegal dumping.

Centralised database

Construction blueprints for all structures should be saved in a centralised database by the municipal authority and should be made available to the demolition/ deconstruction contractor. Such blueprints should also include information on hazardous materials – location, nature, quantity – in each structure.

Capacity building of stakeholders

In order to build expertise of deconstruction requirements among architects and civil engineers, dedicated modules should be introduced in college curriculums. For example, a specialised full credit course should be introduced. Training and capacity building programs should also be planned for relevant stakeholders in the construction industry such as demolition contractors. Industry training should be led by industry associations such as the BAI, CREDAI, etc. Finally, capacity development is also essential for municipal authorities and other relevant public agencies such as PWD.

Certification of contractors

Municipalities may demand certification of all contractors for demolition jobs with different certifications for different classes of demolition contractors (Ordinary buildings (G+2), Special buildings (G+4) and Multi-storied buildings (> G+4). Certification standards may be set by relevant industry associations and municipalities should maintain a register of all certified contractors.

'Design for Deconstruction'

Most accounts of deconstruction begin with the amount of building debris that goes to landfill. However, the ultimate benefit of deconstruction is about closing the loop of resource use; reusing the "waste" resources to avoid extracting new virgin resources. 'Design for Deconstruction' (DfD) is about designing in such a way that these resources can be economically recovered and reused. In contrast to the conventional linear model of extraction, use, and landfilling following demolition, DfD envisions a closed cycle of use and reuse.

In the long term the construction industry should move towards DfD through appropriate training of engineers/architects through universities/ professional associations. Table 8.1 presents a list of principles that can be used as a guide when considering DfD in projects.

Table 8.1 Principles of Design for Deconstruction

Information	Keep the records of all information relating to the design and construction of a structure, for example: • Architectural plans • Engineering designs • Components used • Materials used • Photographs of connections, location of wiring system, etc.
Building design	Incorporate flexibility into the design (durability, adaptability and building layers), for example: • Consider using modular design (standardisation, prefabrication) • Consider preparing designs for disassembly of the building • Design buildings that can be easily converted to a different use • Consider designing demountable buildings • Choose materials based on life-cycle costs and salvageability (not just capital cost)
Materials	• Use a minimum of different materials • Reuse secondary materials • Use renewable, recyclable and recycled content materials • Avoid materials containing hazardous substances • Choose materials with low embodied energy • Avoid composite materials
Connections	• Use a minimum of connections • Use a minimum of different types of connections • Avoid adhesives and nails • Use standardised connections, i.e. connection points, connectors and building components • Use easily removable, reusable connectors • Use building components designed for repeated use

Material salvage	Always consider the end-use hierarchy when designing for deconstruction, i.e.:
	• Reuse
	  o Building Components
	  o Materials
	• Recycling
	  o Upcycling
	  o Recycling
	  o Downcycling
	• Incineration
	  o Energy recovery
	  o Volume reduction
	• Disposal
	  o Landfill

(Source: CIB, 2001)

Box 8.1 highlights the on-site C&D waste recycling best practices followed as part of the redevelopment of the East Kidwai Nagar project in New Delhi.

Box 8.1 C&D waste recycling by NBCC at East Kidwai Nagar, Delhi

National Buildings Construction Corporation (NBCC) is carrying out the redevelopment of East Kidwai Nagar, Delhi. This project involves construction of approximately 4,747 new houses in place of existing 2,444 old houses in an area of 86 acres. Additionally, commercial space of about 104,413 m^2 will be created to make the project financially viable. NBCC has set up a facility to recycle about 150 tonnes of C&D waste per day at this site. The recycling plant targets "zero" C&D waste disposal off-site, producing about 30,000 bricks/kerb stone which are being used in the same redevelopment project (The Times of India, 2014). With this plant, NBCC expects to save about Rs. 3 crores on transporting C&D waste and another Rs. 6-7 crores from the recycled products, since they will be 30% cheaper than conventional products on the market (Pandey, 2014).

Establishing this recycling plant was an integral part of the NBCC project proposal. Various plant and machinery installed include (i) Block making machine (ii) Block conveyor (iii) Pellet feeder (iv) Crushers (v) Batching and mixing platform, etc. The process involves crushing of C&D waste to a desired size and mixing of additives and thereafter compressing the material to get desired size of bricks. The bricks produced are reported to have compressive strength of 7.5 MPa. Necessary mitigation measures to control dust and noise pollution during production of bricks have also been taken.

Fig. 8.1, 8.2, 8.3 and 8.4
C&D waste generation and recycling at East Kidwai Nagar site

Fig. 8.1 C&D waste generation at redevelopment site

Fig. 8.2 C&D waste segregation at redevelopment site

Fig. 8.3 C&D waste recycling on-site

Fig. 8.4 Bricks produced from C&D waste

(Source: Enzyme Infra Pvt. Ltd.)

8.2 Conclusion

Given India's rapid urbanisation, immense C&D activity is expected to continue for the foreseeable future. If not planned in a scientific manner, this can lead to myriad environmental impacts as well as potential resource shortages.

Deconstruction is an economic and environment-friendly alternative to demolition and is designed to salvage the reusable material and effectively recycle it.

However, at present this is not a widely followed practice in India as this is neither enforced nor incentivised by law. As a result, there is a need to both enforce and incentivise it through legal provisions.

There is also a need to reach out to all stakeholders through capacity building and training programs for disseminating the benefits of deconstruction practice for its wide acceptance and application.

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Appendix V

- IEISL (IL&FS Environmental Infrastructure & Services Ltd.). Burari, Delhi. Available at: www.ilfsenv.com

Appendix I – Deconstruction Methods Summary

Method	Principle	Applicability					Operational characteristics			Pollution Characteristics				Remarks
		Column	Beam	Slab	Wall	Foundation	Wrecking efficiency	Secondary effort	General Conditions	Noise	Vibration	Dust	Others	
Top down manual/ jack hammer or pneumatic hammer	Breaking away the concrete by hand-held jack hammer or pneumatic hammer	○	○	○	○	○	○	None	- On a floor-by-floor downward sequence - Need precautionary measures for restricted site	●	◎	●		- Broad scope of application - Effective in narrow and localised place
Top down/ machine percussive breaker	Breaking away the structure by machine mounted percussive breaker	○	○	○	○	○	○	None	- On a floor-by-floor downward sequence - Adequate floor support for machine - Need precautionary measures for restricted site	●	●	●		- Wide range of application - Good mobility
Top down/ machine hydraulic crusher	Breaking away the structure by machine mounted hydraulic crusher	○	○	○	○	◎	○	None	- On a floor - by-floor downward sequence - Adequate floor support for machine - Need precautionary measures for restricted site	◎	●	●		- Wide range of application - Good mobility - Ability to separate steel bars and frames

Hydraulic crusher/ long boom	Breaking away the structure by machine mounted hydraulic crusher with long arm extension	○	○	○	○	◎	○	None	- Restrictive entry to work area - Flat and firm working ground - Adequate clear space	◎	●	●		- Wide range of application - Good mobility - Ability to separate steel bars and frames
Mechanical method/ machinery	Toppling or breaking away structure by large machinery from outside the building	○	○	◉	○	●	○	Yes	- Prevent toppling in the wrong direction and uncontrolled collapse - Firm working ground	●	●	●	Protection from vibration required	- Good efficiency - Poor application for underground structures
Saw cutting / Circular saw or chain saw	Cutting with circular saw or chain saw	○	○	○	○	●	◉	Yes	-Solid working platform -Arrangement for hoisting out cut section	◉	○	◉	Drainage required	- Allows precise separation
Wire saw cutting	Cutting with wire saw	○	○	○	○	●	◉	Yes	-Solid working platform -Arrangement for hoisting out cut section -Counter measure to prevent danger of wire breaks	◉	○	◉	Drainage required	- Allows precise separation - Good for cutting massive structures
Drilling	Coring, drilling and cutting by stitch drilling	◉	◉	○	○	○	●	Yes	- Solid working platform	◉	○	⊙		- Allows precise separation - Good for cutting massive structures
Non-explosive de-construction agent	Expansion pressure from absorption of CaO or other chemical reactions	◉	◉	●	○	●	●	Yes		◉	○	⊙		- Good for foundation
Thermal lance	Use of intense heat by fusion of metal	◉	◉	●	●	◉	◉	Yes	- Protection of person and properties from intensive heat	◉	○	⊙	Fire damage protection required	
Water jet	Jetting of water at high pressure	◉	◉	●	●	◉	◉	Yes	- Protection of person and properties from high pressure	◉	○	⊙	Drainage required; water recycling preferred	

Explanation of symbols in Table

Applicability	Very effective	Moderately to slightly effective	Not effective	
Symbol Used	○	◉	●	
Wrecking efficiency	Excellent	Good	Poor	
Symbol Used	○	◉	●	
Dust particles	Very little dust	Moderate amount of dust	Significant amount of dust	
Symbol Used	○	◉	●	
Vibration (whether continuous or discontinuous)	Not felt by the human body	Very little effect on human body	Moderate effect on human body	Significant effect
Symbol Used	○	◉	◎	●
Noise*	70 dB (A) or below (30 m locality)	70 - 74 dB (A) (30 m locality)	75 - 79 dB (A) (30 m locality)	80 dB (A) or above (30 m locality)
Symbol Used	○	◉	◎	●

* Noise levels indicated above are for reference only. Actual noise level will depend on the machine used and site condition.

Appendix II - Deconstruction Checklists

A. Site survey

Sr. No.	Detail	Specifics	Observations
1	Name of the building		
2	Locality/address		
3	Details of adjoining property/ies		
4	Enclose sketch (building and surrounding)		
5	Type and material of construction (mud, brick block and mortar, timber, metal, RCC, PSC, etc.)		
6	Age of the building/ service life		
7	Health of the building		
7a		Stability issues	
7b		Strength issues	
7c		Safety issues	
7d		Serviceability issues	
7e		Durability issues	
7f		Architectural/aesthetic	
7g		Legal	
7h		Accident	
8	Quantum of deconstruction (part/ whole)		
9	Potential for reuse, recycling of de-constructed material on-site		
10	Availability of space/yard for organising and stacking storage		
11	Presence of hazardous material and need for specialist advice		
12	Sensitive structures and facilities that may get affected by deconstruction, if any		
13	Adequacy of access to and from site for movement of tools, plants, equipment and machinery		
14	Need for obtaining special permits, licences and consent		

B. Structural survey

Sr. No.	Detail	Observations
1	General observations on the structural elements and structure as a whole	
2	Details of distress/deterioration observed suggesting need for deconstruction	
3	Details of NDT and other tests performed or extracts from maintenance records to justify deconstruction	
4	Recommendations on deconstruction methods, sequence, safety and deconstruction output management	

C. Commencement checklist

Sr. No.	Detail	Observations
1	Enclose survey report	
2	Enclose structural report	
3	Write a brief on justifying the need, outline the methods, sequence and deconstruction output management plan indicating targeted recovery ratio.	

D. Checklist for routine inspection and certification

Sr. No.	Detail	Observations
1	Check for compliance with deconstruction basis report	
2	Check for compliance with health and safety	
3	Check for compliance with environmental protection	
4	Check for compliance with other statutory obligations	

E. Post Deconstruction

Sr. No.	Detail	Observations
1	Deconstruction completion certificate	
2	Check for compliance with health and safety	
3	Indicate accomplished recovery ratio	
4	Check for adequacy in conjunction with deconstruction basis report (quantity short adequate or excess)	
5	Check for compliance with environmental protection	
6	Check for compliance with other statutory obligations	
7	Check if there are complaints, claims and issues with adjoining site and facility	

Appendix III - Deconstruction Procedures for Special Structures

Structure type	Deconstruction Procedure
Pre-cast and pre-stressed concrete	i. Detach connections ii. Lift and shift elements
Statically determinate	Simply supported can be detached, lifted and shifted. Cantilevered need great care if they are counterweighed. Need to be propped if counterweight is to be released prior to dismantling of the structure
Statically indeterminate	As indeterminate structures are continuous, removal of elements changes the behaviour of the leftover part. Releasing all loads on elements, provision of temporary restraints to parts before removal of elements need serious consideration.
Steel and composite structures	The procedure shall be dictated by connection type. Top-down, Lift & Shift and Cut-Lift & Shift are popular methods. In rigidly connected structures, caution should be exercised as detailed under statically indeterminate type.
Cladding walls	Procedure shall depend on the assembly type. If it is a single unit with handling facilities, the whole unit may be taken off. If it is an assemblage of small components, the panels are amenable for dismantling individually.
Hanging structures	Loads are gradually released. Tension members are de-stressed before detachment. Stability is ensured at all stages. Temporary restraints if required are provided.
Underground structures	Lateral stability of surrounding areas by shoring, strutting and under-pinning is ensured. Consideration should be given for utilisation of silent demolition chemicals to avoid hazards.
Structures supporting ground and on slopes	Slope stability is ensured. Adequate ground support by ground improvement techniques is provided if necessary.

Appendix IV -International Best Practices Highlights

Country	Deconstruction Practices Highlights	Remarks
Australia	Most states have Waste Management Strategy and Waste Minimisation Plans with ambitious targets for waste reduction and recycling.	Effective national recycling rate about 55%, but more than 70% in some states
Germany	High landfill charges. Widespread use of recycled aggregates in roads and parking lots. Preferential procurement of recycled products by local governments.	95% recovery achieved
Hong Kong (see sample brochure on the next page)	Modern and effective practices since 2005. High charges for C&D waste disposal with some of the funds generated used to subsidise C&D waste recycling.	60% recovery achieved
Japan	Construction Waste Recycling Law since 2002. Law mandates registration of demolition operators and segregation.	80% recovery achieved
South Korea	C&D waste management part of Low Carbon Green Growth Strategy. Separate codes for use of recycled aggregates in buildings and roads.	Effective recycling rate about 40-50%
The Netherlands	Prohibition of disposal of reusable building waste in landfill. Promotion of design of buildings for deconstruction.	Recovery target - 80%
Norway	Building systems for reuse. ADISA- Assemble for Dissemble, a modular design concept.	Recovery target - 70%
United Kingdom	Site Waste Management Plan mandatory since 2008. Landfill tax: Segregated waste - 2 £/tonne Mixed waste - 11 £/tonne	Recovery target - 70% (by 2020)
United States (San Francisco)	Disposal of C&D waste in landfill banned. Contractors must file Recovery Plan for Demolition Permit approval.	Performance varies widely by state and locality.

(Sources: see References)

Simplified brochure on C&D waste by Hong Kong government is reproduced below

The Construction Waste Disposal Charging Scheme

The construction waste disposal charging scheme comes into operation on **1 December 2005**
Charges for disposal of construction waste are to be paid through accounts opened with the Environmental Protection Department (EPD).

Starting from **1 December 2005,** main contractor who undertakes construction work under a contract with value of $ 1 million or above is required to open a billing account solely for the contract. Application shall be made within 21 days after the contract is awarded. Failing this will be an offence under the law.

For construction work under a contract with value less than $ 1 million, any person from **1 December 2005**, can open a billing account

Construction work contracts awarded or tenders of which closed before 1 December 2005, are eligible for exemption from charges. Application for exemption account must be made on or before 22 December 2005.

Charging for disposal of construction waste starts on **22 January 2006** and from this day any person before using the waste disposal facilities for disposal of construction waste needs to open an account.

I HOW TO OPEN AN ACCOUNT

Get an Application form

1

2 Submit application with the required document in person to the office

3 Pay deposit stated on demand note (not applicable to exemption account and billing account that has not requested for chits)

4 Bring collection note to designated office to collect "chits" or obtain "Chits" by post (for 20 chits or less).

***Offices**

Environmental Protection Department:

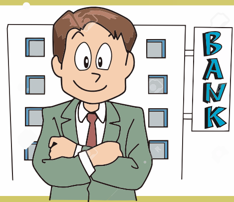
- **Head Office**
  33/F, Revenue Tower,
  5 Gloucester Road, Wanchai,
  Hong Kong.
- **Southorn Centre Office**
  28/F Southorn Centre,
  130 Hennessy Road, Wanchai,
  Hong Kong.
- **Cheung Sha Wan Government Offices**
  8/F, Cheung Sha Wan Government Offices, 303 Cheung Sha Wan Road, Kowloon.
- **Regional Office (East)**
  5/F Nan Fung Commercial Centre,
  19 Lam Lok Street, Kowloon Bay,
  Kowloon.
- **Regional Office (South)**
  2/F Chinachem Exchange Square,
  1 Hoi Wan Street,
  Quarry Bay, Hong Kong.
- **Regional Office (West)**
  8/F, Tsuen Wan Government Offices, 38 Sai Lau Kok Road,
  Tsuen Wan, New Territories.
- **Regional Office (North)**
  10/F, Sha Tin Government Offices,
  1 Sheung Wo Che Road, Sha Tin,
  New Territories.
- **Waste Facilities Group Office**
  2/F, West Wing, 88 Victoria Road,
  Kennedy Town, Hong Kong

Civil Engineering and Development Department:

- **Fill Management Division**
  LF, Civil Engineering and Development Building,
  101 Princess Margaret Road,
  Kowloon.

II HOW TO USE A "CHIT"

1 Account holder makes arrangement for disposal of construction waste



2 Account holder fills in and issues "chit" to waste hauler and retains Part A

: Circled information to be completed by account-holder

3 Waste hauler presents Part B and C of chit to operator of designated waste disposal facility when using the disposal service**.On completion of the service, waste hauler retains part B of the chit.

**If inert content of construction waste cannot meet the acceptance criteria of the designated waste facility, a rejection advice giving reasons for the rejection with the recommended waste disposal facility would be issued to the waste hauler.

4 Where waste transaction information is required, the waste disposal record can be obtained at waste disposal facilities or downloaded from EPD website

III HOW TO PAY

1 EPD issues monthly demand note and waste transaction information to account holder

2 Account holder pays charges within 45 days from the date of demand note.

***If the charges are not paid by due date, the account holder shall pay a surcharge of 5% of the unpaid amount. If the unpaid charges and the surcharge are not paid within 14 days from the date of which the surcharge becomes payable, the Director of Environment Protection may suspend th account and serve a final notice to the account holder. Where the charges and the surcharge are not paid within 14 days from the date of the final notice, the Director may revoke the account

Enquiry- 2838 3111 Email : enquiry@epd.gov.hk Website : www.epd.gov.hk

Appendix V

SUCCESS STORY: Experiences from the first C&D waste recycling plant in India

In 2009, the Municipal Corporation of Delhi (MCD) and IL&FS Environmental Infrastructure and Services Ltd. (IEISL) took an initiative of setting up a pilot project to process 500 tonnes per day (TPD) of construction and demolition (C&D) waste at Burari, Jahangirpuri, Delhi, which was the first of its kind plant in the country. A concession agreement for 10 years was signed on public–private partnership (PPP) model, and 7 acres of land was provided by MCD for setting up the processing unit. Presently, the project is in the jurisdiction of the North Delhi Municipal Corporation.

The project is based on an integrated approach covering collection and transportation of C&D waste from designated points by using skips and bins of different sizes (hauled by dumper placers or hook loaders) or tipping trucks with front-end loaders followed by transportation to the processing facility in vehicles fitted with GPS.

Fig. 1 Process flow of C&D waste collection, processing and recycling at Burari plant

C&D Waste Collection & Transport	Collection of C&D Waste from designated locations
Transportation	Transportation of C&D waste from the Designated Collection Points to the processing site at Burari, North Delhi
Processing	Weighing of C&D Waste Segregation of C&D Waste Wet & Dry Processing
Manufacture & Sale of Recycled Materials/ Products	Recovery of aggregates to produce Ready Mix Concrete (RMC) Manufacture of products like Kerb Stone, Paver blocks, etc. Sub-base is sold as building material

- C&D waste brought by trucks is weighed at site.
- Undesirable items like rags, plastics, metal, Fibre Reinforced Plastic (FRP) sheets, etc. are segregated through mechanical and manual means.
- Remaining waste is segregated into three parts:
  - whole bricks (kept for internal use and sale)
  - large blocks of concrete
  - mixed C&D waste
- Depending on the waste inflow and its quality, the waste is processed.

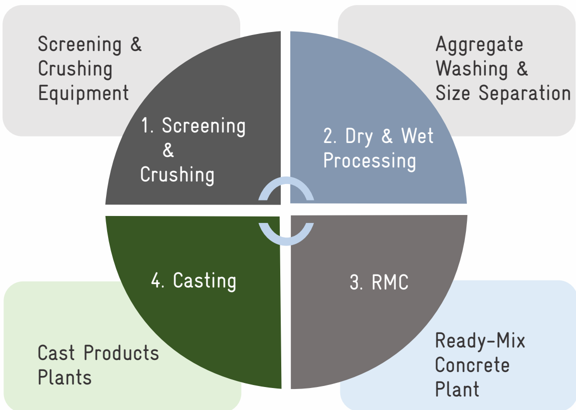
C&D waste processing technology

Initially, the dry process was developed, in which loose soil was removed and the C&D waste was crushed and screened in stages to get the desired range of product sizes. However, in mixed C&D waste, considerable quantity of loose soil and grit is present which cannot be converted into useful products. To overcome this problem, the "wet" process was developed. In this process, the size grade of sand - 4.75 mm to 75 µ (0.075 mm) - was recovered in the form of "silt-free sand". The remaining fraction <75 µ was silt, which was removed. In this process, residue was drastically reduced.

- Collected C&D waste is first screened through the grizzly to remove loose soil and grit.
- Oversized screened materials are collected in the hand sorting section where bricks and concrete are separated.
- Segregated bigger concrete chunks as well as mixed concrete are broken using rock breakers. Thereafter, crushing is done by jaw or impact (horizontal or vertical shaft) crusher, depending on the material, size of operation, and targeted end use.

- Multi-layered vibro-screens with suitably sized interchangeable screens have been used for size grading the crushed material. This is the “dry” process. The different sizes of aggregates are used to make value-added products as mentioned below.
- In the wet process for recovering sand, C&D waste is crushed and then passed through a washing and screening train comprising log washer, vibro-screens (3-deck prograde screen), evo-wash, evo-screen, thickener and filter press to remove the silt material and recycle the water. Only about 15% fresh water is needed to run the wet process

Fig. 2 The recycling process



Salient features of C&D waste processing and recycling facility at Burari, New Delhi are as follows:

- The wet processing technology is effective in controlling dust and noise, which is also important for compliance with the new rules.
- Engineered to process mixed Indian C&D waste
- Reduces usage of natural resources and enhances conservation
- Washing water recycled, only 10-15% makeup water
- Reduces burden on the landfill sites, saving precious urban land
- Reduces air pollution
- Able to recycle/recover about 95% of incoming waste
- A replicable Public-Private Partnership model.

Fig. 3 C&D waste processing and recycling facility at Burari, New Delhi

(Source: IEISL)

Final products and usage

The processed waste is being used for making road sub-base - Granular Sub Base (GSB) -and making pavement blocks and pre-cast products like kerb stones, paver blocks, and square tiles. The loose soil separated by the grizzly is sold. The sand is used for making ready-mix concrete for non-structural applications and lean concrete.

Use of processed C&D waste in road construction

In order to test the application of the recovered GSB from the plant, the roads within the plant as well as the access road to the plant (about 150 m in length) were made with the recycled C&D waste aggregates. Recycled GSB was used to widen the roads both inside and outside the plants. The access roads were constructed entirely with the recycled aggregates. Fig 4 can be referred for pictures of the access roads.

Fig. 4 Construction of access roads to the plant using recycled aggregates

(Source: IEISL)

Pilot project on use of processed C&D waste in NH road project in collaboration with CRRI

IEISL has made a unique collaboration with DDA for construction of a 100 m wide road connecting NH-1 and Bakkarwala using processed C&D waste. This project was awarded by DDA and road design was prepared in consultation with CRRI. The recycled materials used in this project were prepared from C&D waste by sieving with a sieve size of +26.5 mm to 150mm. About 6 lakh tons of Brick Sub Base (BSB) was supplied by IEISL Burari plant in 2 phases for using in base course of the road. Usually Granular Sub Base (GSB) has to be mined and transported from Haryana or Rajasthan to the construction sites in Delhi for this purpose. The recycled aggregates were transported and compacted as per the MoRTH standard.

Fig. 5 Pilot road project by DDA using processed C&D Waste

(Source: IEISL)

A study conducted by IIT Kanpur in 2015 reports that 1.2 tons of PM10 emissions are released per acre-month due to C&D waste dumping. The mining of natural aggregates contributes about 1.2 tons of PM10 emissions per acre-month. Moreover, as per CPCB/MoEF study in 2008, the transportation of mined aggregates through trucks emits 1.24 g of particulate matter per km and 763.39 g of CO_2 per km. Pilot road project phase I (supplying of 300,000 tons of BSB) reduced about 317 tons of particulate matter emission by processing of C&D waste and avoiding mining of fresh aggregates. As per available figures (2015) from Delhi, PM emissions are 143 tons/day. This DDA project alone contributed to a reduction of over 2 days worth of PM emissions arising from all activities in Delhi.

Concrete blocks made from processed C&D waste for new Supreme Court complex

CPWD undertook construction of additional building complex with a built up area of approximately 180,000 m^2 at Supreme Court, New Delhi. As per the recent notification on processed C&D waste materials usage in construction projects, CPWD has decided to use concrete blocks made from recycled aggregates recovered from C&D waste. Hence, CPWD has placed an order of supplying 16 lakh concrete blocks by IEISL made from recycled aggregates.

Fig. 6 Concrete blocks made from C&D waste at Burari plant

(Source: IEISL)

The concrete blocks of M10 grade concrete with a size of 400x200x100 mm will be made at the Burari and Shastri park C&D waste recycling facilities. One concrete block would replace 3 normal size bricks. These concrete blocks can be used in the construction of both load bearing and non-load bearing structures.

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Management of Secondary Raw Materials

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