Chapter 2
Demolition Techniques and Production of Recycled Aggregate

2.1 Introduction

At the time of construction in the past, no one was thought of re-use of building materials after completion of their service life. Even present-day, profoundly not investigated the demolition of structures/buildings as one favourable scheme at the end of their service life. While buildings from the second half of the previous century reach end of their service life, and rebuilding the structures at the same places becomes always more important and further, demolition techniques become progressively significant. Any uncontrolled method of demolition is no longer suitable due to the situations of high traffic rates and compact buildings (Kamrath and Hechler 2011).

Another problem concern was the waste management. Rise in urban population due to industrial development and new zoning bye-laws, legitimization of squatter settlements have led to the demolition of structures in the greater cities. Insufficient capacity of old road bridges for present and future growing traffic and rejuvenation of highway bridges desires the demolition of old bridges too. Further, many structures are destroyed due to either natural disasters like earthquakes, cyclones etc. or man-made disasters. Hence, today the whole world is facing the problem of handling the waste material generated from the demolition of structures. Especially in Europe where the areas of largely populated, the demolition of structures generated the recycled concrete or masonry is almost twofold as much as the necessity for recycled material, for example as a substitute to natural aggregate (Kamrath 2013). Normally the availability of natural resources mainly decides the requirements of recycled aggregates from the crushed concrete or masonry. Thus, if the availability of natural resources (aggregates) is less abundant locally, inclination towards the use of recycled products is higher and recycling becomes more imperative as an alternative resource (Kamrath 2013).

Demolition may be defined as the dismantling, destroying, ruining or wrecking any building or structure or any part thereof by pre-planned and precise way.

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Demolition may be a complete or partial dismantling of a building or structure. The method of demolition may depend on many factors such as the area and its location, type of building/structure, its condition, purpose of demolition and the possible ways of disposal, construction materials present, building height, building base plant area, surrounding available area, weather conditions and C&DW management (Fueyo 2003; AEDED 2008). The selection of demolition method is a function of cost and the equipment availability with the demolition contractor (da Costa 2009). Duration of demolition is also one of the factors which affect the cost of demolition. Normally time saving methods are more costly than the slower ones. Further, if dust, sound and vibrations are to be controlled during demolition the cost of demolition increases. Demolition is one of the most precarious activities in the construction sector. The demolition of a building or structure can be partial or full. In general, the full demolition is meant for the recovery of the area for subsequent re-use, while partial demolition is targeted at the retrieval of the building for refurbishing or rebuilding. Patel (2011) stated that the total demolition generally related to the buildings for which their service life is completed. It is normally performed with machineries furnished with demolition hammers and pneumatic cutters or more simply with normal excavators.

2.2 Methods of Demolition

A careful study shall be made about the building or structure which is to be demolished and all of its surrounding environments before the actual execution of demolition. This includes particularly the study of the way in which the demolition of different parts of the structure are supported and how far the safety of the contiguous structure affected by the stage by stage demolition. The manner in which the loads of various structural parts are supported decides the appropriate plan of the procedure of the demolition work. The concerned engineer in-charge shall prepare and approve the plan of demolition and it shall be followed strictly as nearly as possible during the execution of the actual demolition project. The demolition work shall be carried out in such a way that (i) it produces the least damage and annoyance to the surrounding structures and the public and (ii) it satisfies all the safety requirements to elude any kind of accidents (IS 4130). The steps involved in demolition process mainly (i) surveying (ii) removal of hazardous material (iii) preparation of plan and structural stability and (iv) safety measures. Two types of survey shall be carried out: Building survey and structural survey. In building survey the following information should be collected.

- Types of construction material used
- Usage of building before and present during demolition
- The existence of wastewater, matters arising from toxic chemicals, hazardous materials flammable or explosive and radioactive materials, etc.

- Drainage conditions and possible problems on water pollution, flooding and erosion
- Common facilities with adjoining building, including staircases, partition walls
- Pedestrian and vehicular traffic conditions adjacent to the demolished building/structure
- The sensitivity of neighborhood with respect to noise, dust, vibration and traffic impact.

The structural survey mainly involves the structural materials used, method of construction, structural conditions of the adjoining structures, the structural system and structural conditions of basements, underground vaults and tanks, etc., and stability of the building. If any hazardous materials found during the investigation of site for demolition, it should be removed prior to the demolition of building/structure. Based on the survey an appropriate demolition plan shall be prepared which covers the location of the structure/building to be demolished, a topography of the site and its surroundings, distance between the demolished building and adjacent structures, streets, etc., structural supporting system of the building, method of demolition to be adopted, plan of safety measures, process of handling of debris and time required for the completion of demolition process. A stability report shall also be supplemented with the demolition plan (Building Department 2004).

The choice of demolition method depends on the project conditions, site constraints and sensitivity of the neighborhood and availability of the equipment (Building Department 2004). At present there are various methods of demolition available like

(i) Non-engineering demolition
    (a) Manual demolition
(ii) Engineering demolition
    (a) Mechanical method
    (b) Implosion or Explosion
    (c) Deconstruction method
(iii) Top-down demolition

2.2.1 Non-engineering Demolition

This is a manual demolition technique. Normally this is carried out by contractors using manual tools which are portable like Sledge hammer, Jack hammers and drillers (Fig. 1.1).

Fig. 2.1 Manual tools (**a**) Jack hammer (**b**) Drill and (**c**) Sledge hammer (Adopted from Prakash 2014)

2.2.2 Engineering Demolition Techniques

2.2.2.1 Mechanical Methods

Mechanical methods are classified into

(i) Wrecking ball method
(ii) Pusher arm technique
(iii) Thermal process
(iv) Non-explosive demolition
(v) Abrasive process
(vi) Deliberate collapse method
(vii) Pressure jetting

Wrecking Ball Method Most of the structures can be demolished by using this technique, but it requires skilled practice that cannot be self-taught (NZDAA 2013). This technique is a viable and most effective for the demolition of multistory structures that have suffered from the structural damage and a hazard assessment determined in the structure. In this technique, a steel ball (weight approximately 0.5–1.0 tonne) anti spin device is suspended by a steel rope and swung by a drag rope from a crane of adequate capacity. The structure is demolished by hitting with

Fig. 2.2 Demolition by wrecking ball technique (Adopted from Prakash 2014)

a steel ball (Fig. 2.2). This method is much faster than manual method. Converted drag lines are the best machines as they are robust and stable. Cranes with hydraulic rams must not be used for balling (NZDAA 2013).

Pusher Arm Technique A hydraulically powered pushed arm machine is mounted on tracked or wheeled chassis. These machines are extremely mobile, having high output and are able to work on vertical faces and floors above standing level. The main disadvantage is that it requires adequate access, a relatively flat and firm base to work from and can only work within the reach of their booms (NZDAA 2013). For effective and efficient operation, the length of the boom when fully extended should be at least 1.5 m above the height of the building being demolished. This technique is best suitable for masonry infill structures, but not suitable for confined sites or large buildings. The resistance of a brick wall against the power of an excavator is low, so it is possible to push a wall inside the building with the help of the backacter or to put the backacter on top of a wall and to pull the wall outwards (Fig. 2.3; Kamrath 2013).

Thermal Process For practical demolition purposes generally a very high temperatures are not required (general fusion temperature of steel is 1600 °C), the applications of these techniques are somewhat specialized. Therefore these techniques are likely to be applied in cases of special structures such as nuclear power plants and at job locations which are difficult to access (Coelho and De Brito 2013a). Thermal demolition process can be classified into three categories (Manning 1991).

(i) Drilling and thermal cutting using torches, laser or plasma (Fig. 2.4)
(ii) Removal of concrete through heating of steel reinforcement
(iii) Surface concrete removal by direct heat application.

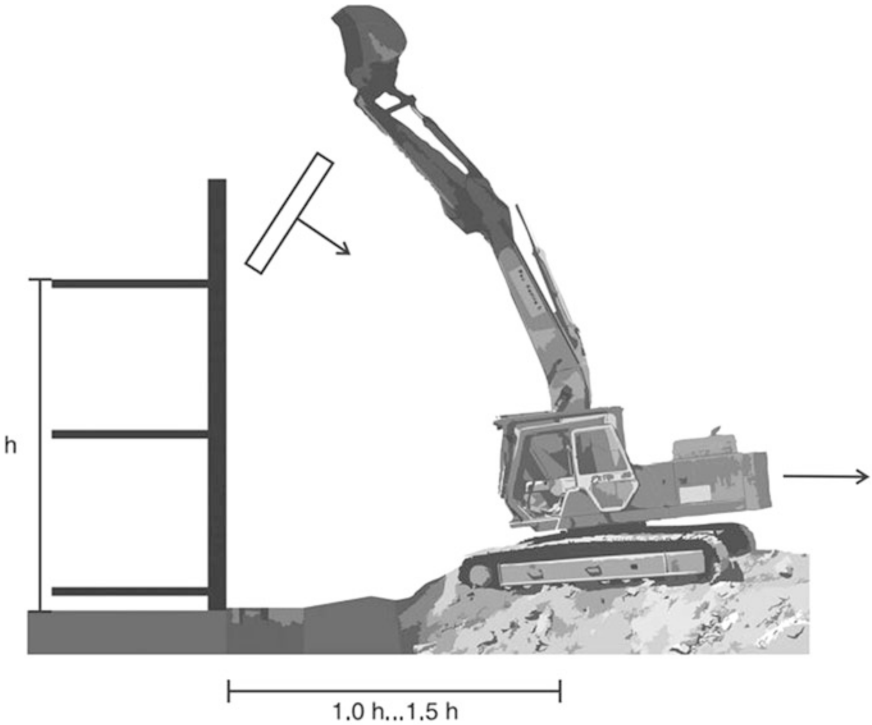


Fig. 2.3 The excavator pulls on a wall (Kamrath 2013)

Fig. 2.4 Cutting of reinforcement through high temperature (Prakash 2014)

Non-explosive Demolition A series of holes are drilled along the desired line of separation on the concrete surface and filled with slurry of special nature. After filling with slurry, the water is poured into the desired holes and after few hours the slurry expands which would results cracks in the concrete structures which will help to demolish the structure easily (Prakash 2014).

Abrasive Process This process is normally done with very hard materials such as diamond, carborundum or with high pressure water. This technique generally limited to partial demolition, as this technique could be highly expensive for complete demolition of a building/structure (Coelho and de Brito 2013a). Diamond discs can cut through concrete and steel (RCC or Pre-stressed) with a 40 m^2 area cutting surface yield. Although wireless diamond disc cutting machines available in the market, water refrigerated cutting discs are usually adopted (Da Costa 2009). The diamond string cutting is more efficient than discs cutting and the diamond strings are mostly used with granite, marble and concrete. Coelho and De Brito (2013a) stated that according to Fueyo (2003), using diamond strings the cutting produces 3 and 5 m^2/h, while the string velocity can be as high as 40 m/s.

Deliberate Collapse Method The Collapse is commonly achieved either by removing key structural elements (e.g. with explosive charges) or by wire rope pulling at a high level of overturn. It needs engineering expertise to decide which structural element should be removed to cause a collapse. This method is best suitable for silos, bridges, chimneys and isolated structures or heavily controlled and secure sites. A survey may be conducted to know the height and radius of the structure so that the fall area can be find out and proper protection can be made to prevent involuntary entry during collapse (NZDAA 2013).

Pressure Jetting Generally the jet heads are small and therefore action of jet is mainly to loosen the aggregates by washing out softer mortar (water with high pressure) (Fig. 2.5). Demolition with highly pressurized water (Hilmersson 1999) is a high yielding technique. It does not damage the overall structure, does not produce dust, vapour or slag, has no induced vibrations, has small reaction forces, and has a vast application range. However, it cannot generally be used to cut through reinforcement and cracks can slow down the progress.

Fig. 2.5 Demolition by water jet (Prakash 2014)

2.2.2.2 Demolition by Implosion or Explosion

Implosion or explosion demolition is an effective and efficient method of demolition, and it can reduce both cost and time to bring dangerous multi-storey structures to ground in comparison to conventional demolition methods (NZDAA 2013). In most of the cases, the demolition by explosion can reduce the time by about 80% with the majority of the being spent on the period of preparation and cleaning process following implosion. Before adopting this procedure, the blue print of the building should be properly studied to identify the key elements at different levels from bottom to top for explosion. There are two main types of explosives for demolition i.e. commercial or military. The commercial explosives are mostly dynamite based with detonation speeds ranging from 3000 to 7000 m/s. whereas, military explosives have high detonation period ranging from 6000 to 9000 m/s (Coelho and De Brito 2013a).

2.2.2.3 Deconstruction

Deconstruction is a slow and careful process that is almost reverse process of construction. It involves the systematic and manual disassembly of the affected sections of a structure, saving as many of the components as possible for reuse or recycling. Generally this technique is applied when recycling and re-use of construction material is significant from environmental, economic and social reasons. Coelho and De Brito (2013b) mentioned that according to ITEC (1995), the main features of the deconstruction technique is as follows.

- Official information shall be made to all entities that may be affected by or have jurisdiction over the deconstruction activity
- Deconstruction area setup
- Disconnection of all services those are still active in the building
- Erection of scaffolding
- Bracing construction elements that may collapse if their internal state of stress changes significantly
- Preparation and execution of personnel protection measures
- Routing and separate storage space for recovered materials
- Workers individual safety measures.

In all the demolition techniques, the first three features are common. To avoid unexpected structural failure due to sudden changes in stress condition in structural elements, bracing system in deconstruction technique is usually adopted. Further, to remove façade elements or if certain elements are to be sent directly to the out of building, scaffolding is essential in this technique. Job site routing is essential to have maximum material recovery for both re-use and recycle.

2.2.3 Top-Down demolition

According to Building Code Hong Kong (2004) demolition by Top-down means the one starts demolition from roof to ground in a progressive way. Depending up on the site conditions and structural elements to be demolished, the particular sequences of demolition may vary. The demolition sequence is determined according to the building layout and constraints, as well as conditions of the site. Normally, the following sequence can be applied:

- First all overhanging elements such as verandahs, balconies, cantilever projections, emergency stairs, etc. should be demolished prior to the main building demolition. Roof installations like lifts, air conditioning units, etc. should be removed to avoid them fall down during the demolition process.
- Demolition of floor slabs should begin at mid-span, and progress towards the supporting beams.
- Floor beams are demolished in the following order

  (i) cantilevered beams;
  (ii) secondary beams; and
  (iii) main beams.

- Non-loading bearing beams are first removed. Subsequently, load-bearing beams are removed from the top down.
- As soon as possible, the ground floor should be wrecked to avoid demolition waste lying on it. Due to huge load, this floor could otherwise collapse.
- Columns and load bearing walls shall be removed after removal of beams on top.

General demolition of top-down of a building demolition is presented in Fig. 2.6 (Kamrath 2013). The summary of various methods of demolition is presented in Table 2.1.

2.3 Production Technology of Recycled Aggregates

A recycling plant is quite similar to the plant producing crushed natural aggregate. The recycling plant incorporates various types of crushers, screens, transfer equipment and devices for removal of foreign materials. A number of different processes are possible for the crushing and sieving of construction and demolition waste. A typical layout of a closed system which is usually recommended for the production of recycled aggregates is shown in Fig. 2.7 (Hansen 1985). An open system (Fig. 2.8) has an advantage of having larger capacity but maximum aggregate size is less well defined and this can lead to greater variations in the size of the end product, particularly when the input flow changes (Hansen 1985). Both these plants treated as first generation plants. These plants do not have facilities to remove the contaminants and are generally used for pavement rehabilitation and recycling projects.

Fig. 2.6 Typical demolition from top to down. After demolition of all non-bearing structures, the bearing columns are left. In the next step, the columns will be demolished beginning with the top level. After that the demolition starts again with the next field (Kamrath 2013)

A clean concrete waste is not available always, based on the first generation plants, certain provisions are made to remove the foreign materials in the second generation plants and a typical layout of it is presented in Fig. 2.9.

As per Simonds Group (1999), the construction and demolition waste (C&DW) recycling plants can be classified as Level 1, Level 2 and Level 3 (Fig. 2.10). Level 1 plant is suitable for the processing of inert C&DW; Level 2 plants have metal removal and more complex sorting and sieving provisions and is therefore suitable for mixed C&DW; and Level 3 plants have additional facilities like hand sorting, washing plant for other C&DW (wood) than Level 2 and is suitable for any C&DW (mixed and contaminated).

As stated above Level 3 plants have additional facilities and higher quality control and automation apart from the methods and technologies adopted in Type 1 and Type 2 plants, yields in higher purity and variety in recovered material fluxes (Coelho and De Brito 2013b). The installation of these plants may be mobile or stationary.

Table 2.1 Summary of the general characteristics of demolition methods (Building Code Hong Kong 2004)

Method	Principle	Applicability					General conditions	Remarks
		Column	Beam	Slab	Wall	Foundation		
Top down with manual jack hammer or pneumatic	Breaking away the concrete by hand held jack hammer or pneumatic hammer	Very effective					• On a floor by floor downward sequence • Need precautionary measures for restricted site	• Broad scope of application • Effective in narrow and localized place
Top down machine/ Percussive breaker	Breaking away structure by machine mounted percussive breaker	Very effective					• 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 with hydraulic crusher	Breaking away structure by machine mounted hydraulic crusher	Very effective				Moderately to slightly effective	• 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 with long boom	Breaking away structure by machine mounted hydraulic crusher with long arm extension	Very effective				Moderately to slightly effective	• Restricted 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
Wrecking ball	Destruction by impact of steel ball suspended from a crane	Very effective	Moderately to slightly effective		Very effective	Not efficient	• Restricted entry to work area • Flat and firm working ground	• Good efficiency • Poor application for underground columns and foundations

(continued)

Table 2.1 (continued)

Method	Principle	Applicability					General conditions	Remarks
		Column	Beam	Slab	Wall	Foundation		
							• Adequate clear space	
Implosion	Use of explosives	Very effective		Not efficient		Very effective	• Protection from noise, debris and vibration • Qualified blaster • Notification and evacuation of neighbourhood • Check and cautiously handle of miss fire	• Excellent demolition strength • Could shorten the work period and reduce labour • Risk assessment required to continued
Wire saw cutting	Cutting with wire saw	Very effective				Not efficient	• Solid working platform • Arrangement for hoisting out cut section • Counter measure to prevent danger of wire breaks	• Allows precise separation • Good for cutting massive structures
Drilling	Coring, drilling and cutting by stitch drilling	Moderately to slightly effective		Very effective			• Solid working platform	• Allows precise separation • Good for cutting massive structures
Thermal lance	Use of intense heat by fusion of metal	Moderately to slightly effective				Not efficient	• Protection of person and properties from intensive heat	–
Water jet	Jetting of water at high pressure	Moderately to slightly effective				Not efficient	• Protection of person and properties from high pressure water	–

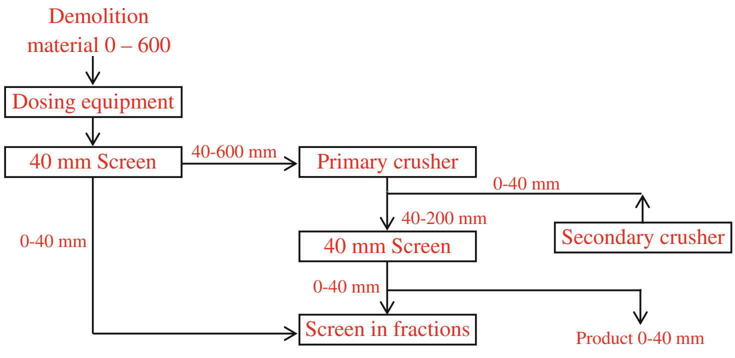


Fig. 2.7 Flow chart of typical plant for production of RA from concrete debris which is free from foreign matter, closed system (Hansen 1985)

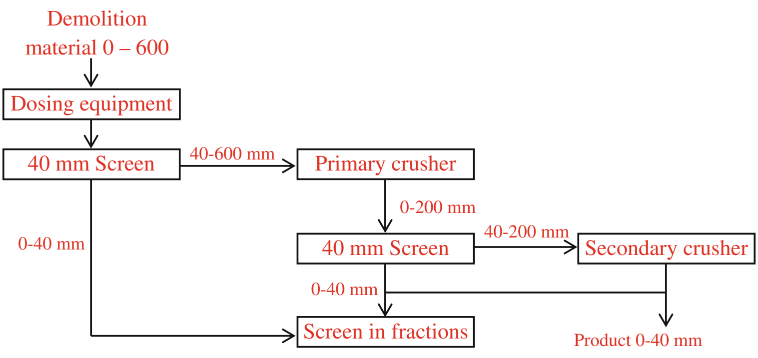


Fig. 2.8 Flow chart of typical plant for production of RA from concrete debris which is free from foreign matter, open system (Hansen 1985)

2.3.1 Mobile Plants

Mobile C&DW recycling plants have become more popular due to the need for conventionally fixed equipment, such as feeders, crushers, magnetic separators and vibrating screens used at different times and locations. Sometimes technically or economically even better to place a simplified version of mobile plant at site, instead of transporting the C&DW to a fixed plant located far away from the site (Coelho and De Brito 2013b). The technology adopted in mobile plants is same as in fixed plants, through limited to feeders, crushers, magnetic separators and vibrating screens. Mobile plants are mounted on tracks but tire mounted plants are also available commercially. The main advantages and disadvantages of mobile plants are as follows (Lindsell and Mulheron 1985). A typical mobile plant fitted with jaw crusher is shown in Fig. 2.11 (Kumbhar et al. 2013).

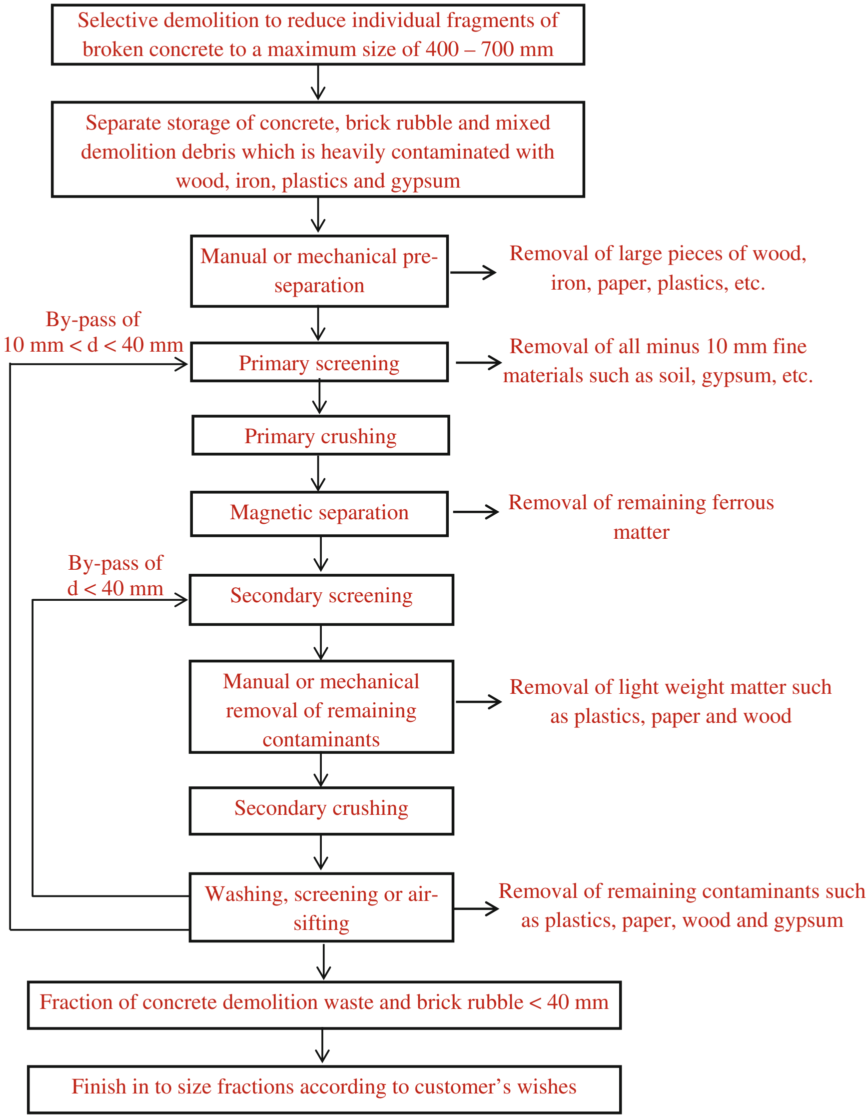


Fig. 2.9 Processing procedure for building and demolition waste (Hansen 1985)

Advantages

- Transport in the vicinity of the site is reduced, particularly if the rubble is produced, recycled and reused on the same site
- Disposal costs are reduced due to less dumping
- The local supply of aggregates are increased and therefore less quantity of aggregates required to be imported into the site area

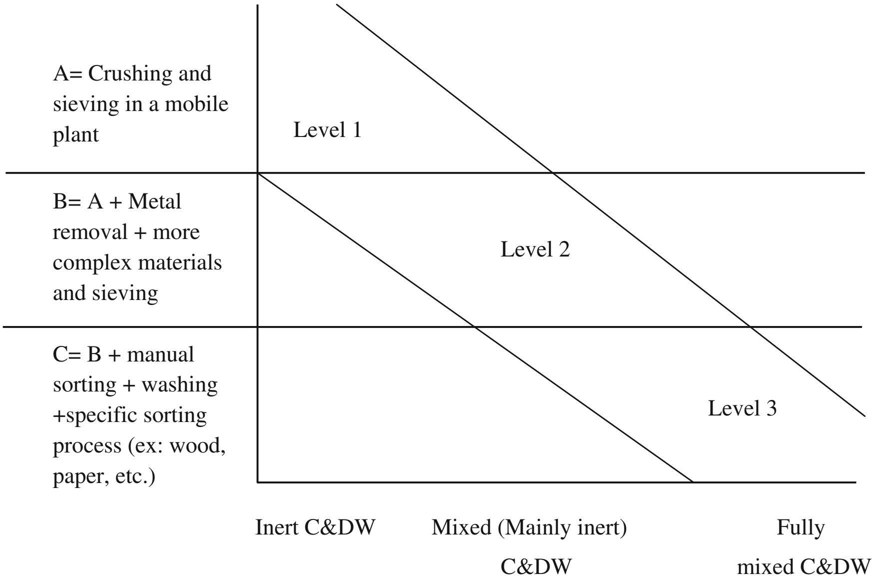
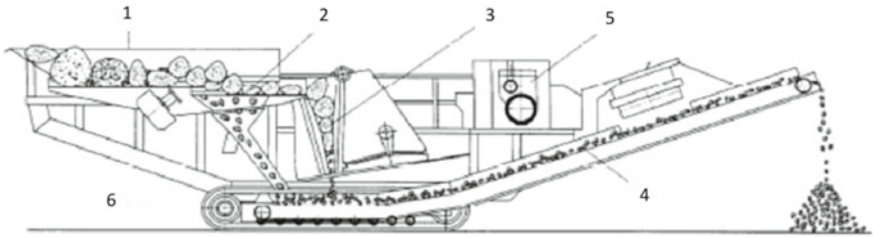


Fig. 2.10 Classification of C&DW recycling plants (Symonds 1999)



1.Feeding hopper; 2.Oscillating conveyor; 3.Jaw crusher; 4.Discharging transport belt; 5. Diesel engine as a power belt; 6. Mobile by wheels, Crawlers or skids

Fig. 2.11 Mobile crushing plant (Adopted from Kumbhar et al. 2013)

- The recycling plant can be relatively easily movable to the another site
- Economical for C&DW of 5000–6000 tonne per site (Kumbhar et al. 2013).

Disadvantages

- The recycling plants can cause high levels of noise and dust which would not be acceptable to the surrounding residential areas
- This type of plant can be used only, if there is a sufficient quantity of rubble on the site to justify the expense of setting up the recycling plant.

2.3.2 Stationary/Fixed Plants

Stationary recycling plant normally consists of a large primary crusher working in combination with a secondary or tertiary crusher. It also attached with various cleaning and sieving devices, to generate high quality recycled aggregate. Furthermore, magnets, air sifters and/or float separators, jiggers, spirals, etc. can be included in the stationary plant depending upon the type of C&DW and quality of recycled aggregate desired. According to Silva et al. (2016) the advantages and disadvantages of stationary plants are as follows. A typical layout of a stationary recycling plant is shown in Fig. 2.12.

Advantages

- The recycling is capable of producing high quality RA
- Better efficiency than mobile recycling plant because different recycled products of various particle sizes can be produced
- Due to less disposal the cost of dumping is reduced
- High manufacturing capacity.

Disadvantages

- The initial investment may be high for setting up of such plants
- Since the plants are installed far away from the sites, the transportation cost of C&DW increased
- The production is mainly depends on the constant input supply.

The choice of the type of recycling plant is difficult and case to case basis is to be analysed by taking many factors like technical, financial and environmental issues

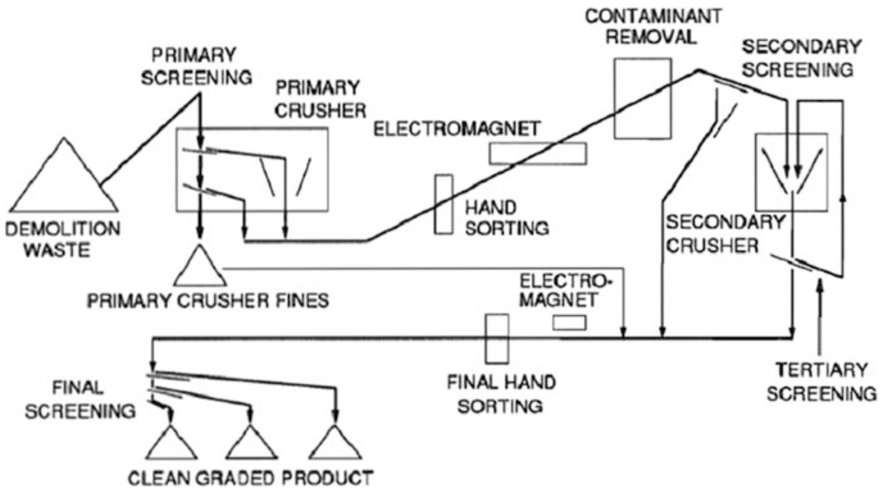


Fig. 2.12 Layout of a stationary plant (Adopted from Kumbhar et al. 2013)

(i.e. plant capacity, transportation cost, amount of C&DW, hauling distances, scale of economy, price of natural aggregates, etc.) into account (Zhao et al. 2010).

2.4 Process of Recycling Technology

A flow chart of possible combinations of recycling process that can produce a relatively of better quality of RA, with least contaminants, without spending too much energy presented in vide Fig. 2.9. In some cases like plain concrete blocks, manual or mechanical removal of contaminants can be bypassed, thus saving energy (Silva et al. 2016). After reaching of C&DW to the recycling plant, it may either directly be fed into the processing operation or required to be broken down using hydraulic breakers mounted on tracked or wheeled excavators to obtain required workable particle sizes. In both the cases to minimize the degree of contamination, separation of large pieces of iron, wood, plastic and paper by manually may be needed. Three types viz: Jaw, impact and gyratory crushers are mostly used for crushing of C&DW.

2.4.1 Jaw Crusher

A jaw crusher operates by allowing material to pass through the two jaws, one of which is in stationary and the other oscillates back and forth relative to it. The distance between the jaws reduces as the material travels downward under the effect of gravity and the motion of the movable jaw, until the material completely passes through the lower opening. The jaw crusher can endure large pieces of reinforced concrete, which would possibly cause other types of crushers to breakdown. Therefore, before going through the other types of crushers, the material is initially reduced in jaw crusher (Silva et al. 2016). The degree of size reduction of particle depends on the minimum and maximum size of the space at the plates. Molin et al. (2004) reported that the most suitable grain size distribution of RA for concrete production can be obtained by using jaw crushers.

2.4.2 Impact Crusher

An impact crusher breaks the construction and demolition waste by striking it with a high speed rotating impact, which imparts a shearing force on the rubble. An impact crusher consists of a heavy steel frame equipped with a rotor fastened with a series of hard steel blades. Material fall onto the rotor and are caught by the hard steel blades mounted on the rotor, which hurl them against the breaker plate, smashing them to smaller size particles. Normally the impact crusher has larger reduction factor and is defined as the ratio of input particle size to the output particle size (Lindsell and Mulheron 1985). Therefore, the impact crusher produces larger amount of fines. One advantage of the impact crusher is its high efficiency and less sensitive to the material which cannot be crushed i.e. reinforcement. Consequently impact crushers suffer high wear and tear and hence, high maintenance costs (O' Mahony 1990).

2.4.3 Gyratory Crushers

Gyratory crushers work on the same principle as the cone crushers, which are characterized by a gyrating mantle mounted within a deep bowl. Gyratory crushers provide continuous crushing action and are used for both primary and secondary crushing of hard, tough and abrasive materials. These crushers are relatively low energy consumption, reasonable amount of control over particle size and production of low amount of fine particles (Silva et al. 2016).

A typical jaw, impact and gyratory crushers are shown in Figs. 2.13, 2.14 and 2.15 respectively.

Silva et al. (2016) stated that to produce expectable grading curve, it is better at least to process material into two crushing stages. It may be possible to consider a tertiary crushing stage and further, which would produce better quality course recycled aggregate (i.e. less attached mortar and with a rounder shape) undoubtedly. However, concrete produced with RA subjected to a tertiary crushing stage may have somewhat better performance than that made with RA from a secondary crushing stage (Gokce et al. 2011; Nagataki et al. 2004). At the same time, more crushing stages would yield products with decreasing particle sizes, which opposes the mainstream use of coarser RA, which generally preferred. These factors should be taken into account from the view point of economic and environmental while

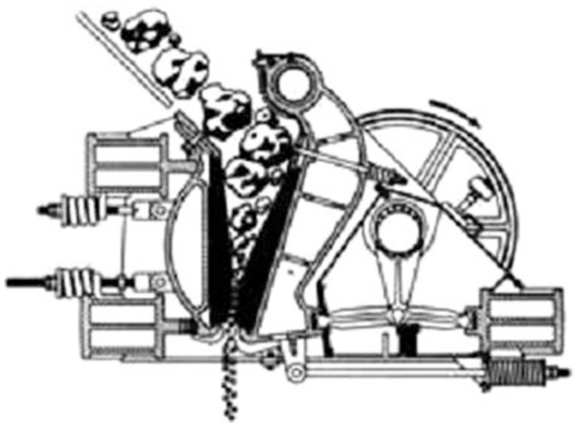


Fig. 2.13 Jaw crusher (Adopted from Silva et al. 2016)

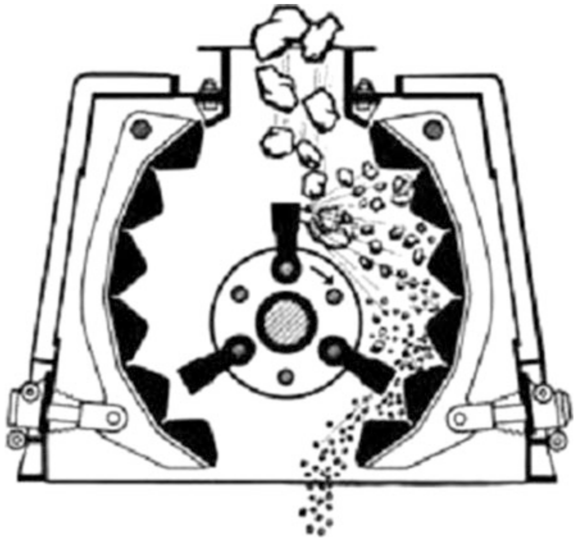


Fig. 2.14 Impact crusher (Adopted from Silva et al. 2016)

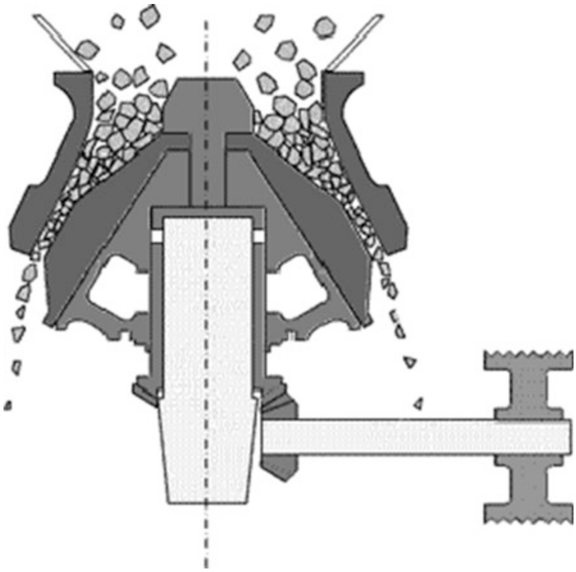


Fig. 2.15 Gyratory crusher (Adopted from Silva et al. 2016)

producing RA. That is relatively better quality of aggregates can be produced with lower energy consumption and with a higher proportion of coarse aggregates, if the number of crushing stages is sensibly reduced.

According to Mahony (1990), the contaminants from the C&DW can be removed in two stages i.e. (i) Pre-crushing separation and (ii) post crushing separation.

2.4.4 Pre-crushing Separation

In this technique, the debris can be sorted while the structure is being demolished. Even though this technique can be expensive and time consuming for the demolition contractor, later it gives large benefits in terms of financial and ecological. Maximum sorting normally takes place after reaching the C&DW to the recycling plant. Once the debris reaches, it is stockpiled according to their major constituents and presence of contaminants. Therefore, the plant operator can take the necessary steps for each case. This initial sorting process can help to optimize the crushing time and product quality e.g. When large amount of clean debris accumulated in a stockpiling, they can then be crushed in a single run, continuous. Since most of the times, primary screening is conducted before the debris arrive to the primary crusher and if the material of required size is already available, then primary crushing can be bypassed. Further, if these should be of concrete based and of low degree contamination, instead of disposing on landfill, it is possible to make use of the material finer than 10 mm in the primary screening stage itself.

On the other side, post crushing separation technique is adopted after number of crushing stages, where several techniques may be employed for removal of different contaminants. The easiest method is the hand sorting, in which the contaminants from the conveyor belt are removed by manually. The efficiency of the hand sorting system is mainly governed by the attention of the operators and the speed of the conveyor belt. Even though the human eye can recognize the contaminants which would be difficult to remove by mechanically (e.g. glass, asphalt), it is also the expensive approach (Silva et al. 2016).

After primary crushing stage, self-cleaning electromagnets normally employed at strategic locations in the conveyor belt to remove the pieces of steel reinforcement and other ferrous materials. The distance between the magnet and debris, the speed of the conveyor belt, the volume of the debris passing on conveyor belt and the angle of the magnet influence the efficiency of the magnet. It is more efficient when it is placed directly above and parallel to a slow moving conveyor belt with low concentration of material. The electromagnets may be in a fixed position above a conveyor belt or take the form of a rotating magnetic belt (Fig. 2.16) (Silva et al. 2016). The advantage of the magnetic belt is that it carries the materials to a side, instead of accumulating them on the magnet. Eddy current separator is a device which can be used to remove the non-ferrous metals like aluminium, copper, brass, etc. present in the C&DW. It works on the principle that the eddy currents are generated in the metal, when a conducting metal led through a varying magnetic field. By keeping this device at the end of the conveyor belt, metals are thrown off the belt and other materials simply fall off due to gravity. As the eddy current separator may get damaged due to ferromagnetic metals, at earlier stage itself these must be removed from the C&DW. By passing the crushed aggregates through a set of scalping screens, the dirt, gypsum, plaster and other fine impurities can be removed at a later stage. Using dry screening, the materials can be separated into different size fractions, which can later be recombined to obtain well graded

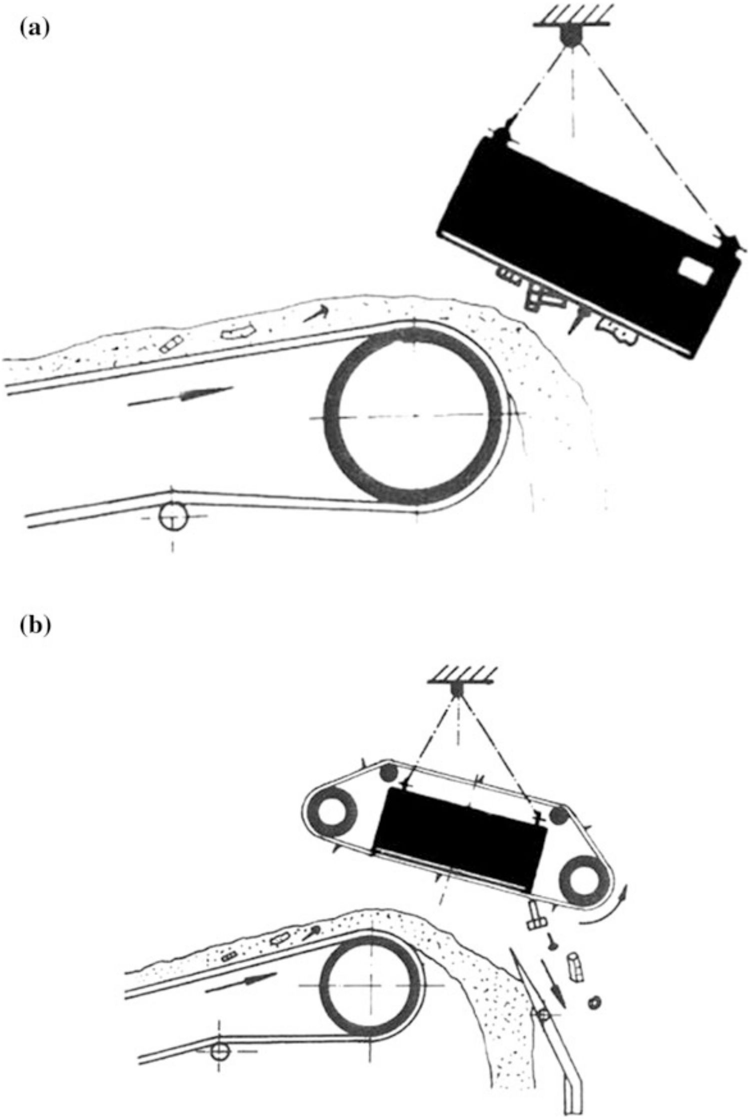


Fig. 2.16 Electromagnets (**a**) fixed and (**b**) rotated (Adopted from Silva et al. 2016)

recycled aggregates. According to Building Contractors Society of Japan (BCSJ) (1981), inclined screens vibrating at low frequencies and large amplitudes are capable to separate the coarse materials more efficiently, while the fine materials can be separated efficiently by using horizontal screens, vibrating at high frequencies and small amplitudes. This process only separates based on the size and shape. Finally the low density contaminants can be removed either by using air sifting or wet separation techniques. In wet separation technique, the material is placed in a tank with full of water and the water is rotated at a faster rate so that currents are setup by water jets. The lightweight impurities and wood which will float in water are removed by combs which move from one end of the tank to the other end. Normally this technique is limited to the materials of size more than 10 mm due to the excessive quantities of sludge which would produce if smaller size fractions are used in a tank. The other technique i.e. air sifting may also be equally effective as wet separation, in terms of removal of lightweight materials such as wood, hardboard, plastics, straw and asbestos fibres and would also avoid the use of large quantities of water, but the wet separation allows the leaching of chlorides and sulphates (Galvin et al. 2014; Weimann and Muller 2004). In unbound or bitumen bound applications the air sifting can be used instead of wet separation, as the chlorides and sulphates have little impact on these applications.

As a compliment to the aforesaid crushing procedures, there are some other methods which can remove the adhered cement mortar from the surface of the natural aggregates and are discussed in Chap. 8.

2.5 Summary

In this chapter various methods of demolition of construction and demolition waste and production technology of recycled aggregate is discussed. Based on the discussion the following observations are highlighted.

- The waste generated from the demolition of structures is one of major components of total waste; simply dumping on landfills severely affects the environment, social and economic life cycle.
- The demolition of the structure shall be carried out in such a way that (i) it causes the least damage and nuisance to the surrounding structures and the public and (ii) it satisfy all the safety requirements to avoid any kind of accidents.
- The choice of demolition method depends on the project conditions, site constraints, and sensitivity of the neighborhood and availability of the equipment. Among all the methods, deconstruction technology is the best suitable method when recycling and re-use of construction material is significant from environmental, economic and social reasons.
- Among the Level 1, 2 and 3 recycling plants, Level 3 recycling plant is more capable of producing the best quality of recycled aggregate from any mixed C&DW, which compliance with the present regulations for RA in production of new concrete.
- The choice of the type of recycling plant is difficult and case to case basis is to be analysed by taking many factors like technical, financial and environmental issues (i.e. plant capacity, transportation cost, amount of C&DW, hauling distances, scale of economy, price of natural aggregates, etc.) into account.

- Mobile plants are preferred when low quality output is acceptable for a given concrete applications and to avoid the transportation and quantity of C&DW is in the range of 5000–6000 tonnes per site. Stationary plants are suitable for recycling of large quantity of mixed C&DW with higher quality output materials.
- The contents of C&DW must be properly analysed before the delivery to the recycling facility so that it is possible to find the most appropriate recycling process to enhance the output's quality. Also, this will reduce processing time, produce higher quality RA, increase the work rate and help to avoid excessive costs incurred by unnecessary recycling stages.
- The number of crushing stages undoubtedly reduces the adhered mortar content and irregularity of the aggregates and thus produces better quality of recycled coarse aggregate. Though the tertiary crushing stage may enhance the quality of recycled aggregates slightly, but it decreases the coarse to fine aggregate ratio and increase the costs and energy. Therefore, by taking the economic and environmental aspects into account, a relatively better quality of aggregates can be produced with lower energy consumption and with a higher proportion of coarse aggregates, if the number of crushing stages is sensibly reduced.

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