

# The Application of Recycled Aggregate for the Urban Sustainability of Hong Kong Construction Industry

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The salvage of aggregate from the recycled demolition waste is receiving more and more attention across the globe due to its importance in sustaining our environment. In addition to environmental protection, conservation of natural aggregate resources, shortage of waste disposal land, and increasing cost of waste treatment are the principal factors for the recycling of demolition waste in the construction industry of Hong Kong. The major solid waste generator producing about 11 million tonnes of demolition waste each year, which amounts to 4 times of the municipal solid waste. The recycling of the demolition waste could produce 2.3 million tonnes of useable aggregates which contributes to 10% of the total aggregates demand annually which may give a substantial relief to the urban sustainability. This paper analyzes the scope and various possible applications of recycled aggregates in Hong Kong with emphasis on the use of recycled aggregates which have been identified as an integrated approach to overcome these constraints.

**Key Words:** Sustainable Development, Waste Management, Recycled Aggregate, Concrete

## Introduction

In Hong Kong, the extensive building and infrastructure development projects as well as the redevelopment of old districts have led to an increase in construction waste generation in the last two decades. The construction industry is the major solid waste generator. The average construction waste from 1991 to 2006 had been about 35,800 tonnes per day (13 million tonnes per year), which is roughly 4 times heavier than the average municipal solid waste generated in the same period. Figure 1 shows the quantities of construction waste generated from 1991 to 2006 (EPD, 2007).

In order to manage such a huge quantity of construction waste in Hong Kong, the inert portion (e.g. debris, rubble, earth, concrete, bricks and rocks) of construction waste is deposited at public filling areas for land reclamation from sea and the non-inert portion (e.g. bamboo, timber, vegetation, packaging waste, organic materials) at municipal solid waste landfills. It can be observed from Figure 1 that the disposal of construction waste to municipal landfills is gradually decreasing and major portion is being disposed of to public filling area in recent years.

One of the aims of this disposal arrangement of construction waste is to minimize the amount needed for disposal so that the life span of the municipal landfills can be extended. On the other hand, in recent years, public concerns and objections have often delayed, stopped or reduced the scale of the implementation of planned reclamation projects. This has reduced the expected

provision of reclamation sites and reduced the outlet capacity for the inert construction waste. Thus, there is a need to explore alternative uses of inert construction wastes so as to tackle the reduction in demand from reclamation sites for inert construction wastes (Poon et al., 2001).

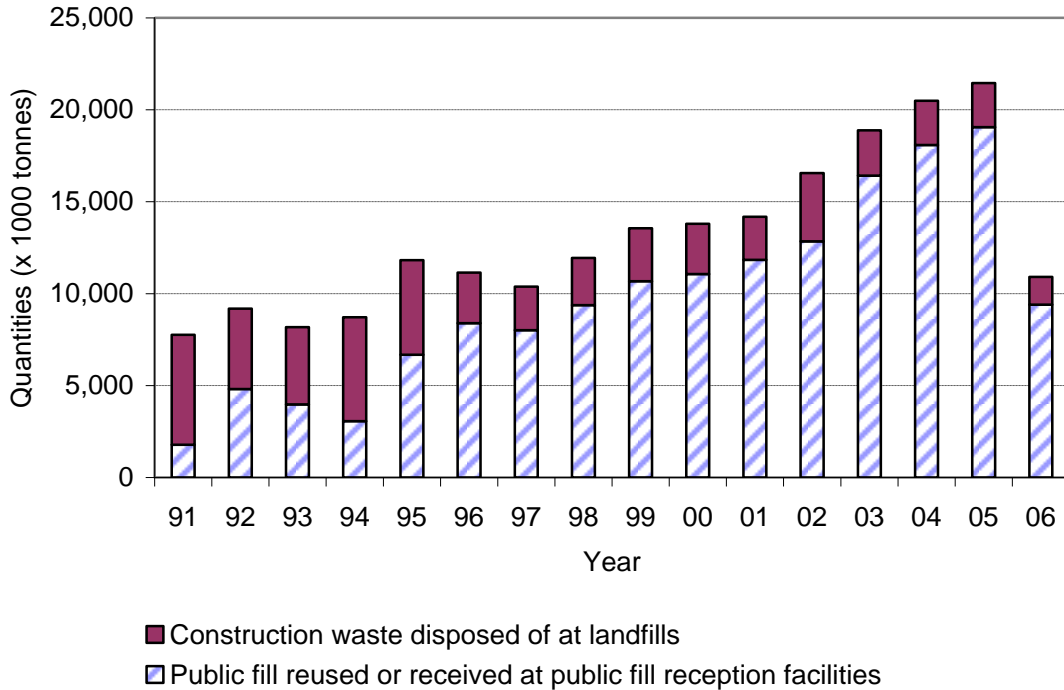


Figure 1: Quantities of construction waste generated in Hong Kong from 1991 to 2006 (EPD, 2007)

### Recycled Aggregates from Construction Waste

Among the inert construction waste, the concrete and masonry rubble has the largest proportion and hence its recycling is the most important. Many laboratory and field studies have shown that the size fraction of the concrete and masonry rubble corresponding to coarse aggregate can be satisfactorily used as a substitute for natural aggregate in concrete and pavements. A comparison of the properties of concrete made from natural aggregate and the recycled aggregate shows that the later would give at-least two third of the compressive strength and the elastic modulus of the natural aggregate (Mehta and Monteiro, 1993). Similarly, such aggregates can be safely used as a sub-base or base layer in pavements (Sherwood, 1995). A more recent study in Hong Kong recommends that the maximum content of recycled coarse aggregates could be raised to 50% from a current practice of 20% for Grade 30 concrete and below, and to 30% for Grade 35 to Grade 45 concretes. Lower replacement levels are suggested for recycled aggregates of lower quality (Fung, 2005). Similarly other properties of recycled aggregate concrete (RAC) have also found satisfactory and its use in Hong Kong for structural application is now gradually increasing.

The construction industry in Hong Kong consumes on average about 21 million tonnes aggregates each year. A large proportion, about 88%, is used as aggregate in the production of concrete. Asphalt production consumes around 5.5% and the remaining 6.5% is used in pavement sub-bases and other civil engineering works. It is estimated that each year about 2.3 million tonnes of recycled aggregate can be produced from the recyclable construction waste, out of which about 1.2 million tonnes could be utilized as pavement sub-bases, trench backfilling material and drainage fill, etc. This left around 1.1 million tonnes of recycled aggregates which should be utilized in the production of concrete (Cheng, 2000).

This paper looks in detail the scope and various possible applications of recycled aggregates in the Hong Kong construction industry. An up-to-date review about the successful international construction projects utilizing recycled aggregates has been presented. The study also identifies the barriers in the use of recycled aggregates and proposes an integrated approach to overcome the barriers.

### **International Experience in Recycled Aggregates**

With the increasing concern about environmental protection and sustainable development, many countries are introducing legislation and policy measures to encourage the use of recycled aggregates. The incentive to the construction industry often comes due to the higher landfill costs, and therefore more inspiration towards the production of recycled aggregates. This policy is particularly well established in the Netherlands and the Copenhagen district of Denmark; both of these areas recycle over 80% of their demolition waste (Collins, 1994).

In the state of Texas, concrete from existing roadways, pavements, airfields, and buildings can be reused. After the material is crushed and steel rebar removed, the remaining aggregate is screened to produce the desired consistency, ranging from different sizes. In the 1990s, the reconstruction of Houston's Interstate 10 was the first project in the state in which all recycled aggregate was used for pavement concrete. Today, crushed concrete is used extensively in the state of Texas as well as in the redevelopment of the Houston International Airport.

Appendix at the end of paper summarizes the list of successful construction projects around the globe in which recycled aggregates were utilized. No major problems were reported in any of the mentioned projects till date.

### **Scope of Recycled Aggregates in Hong Kong**

The General Specification for Civil Engineering Works in Hong Kong generally prohibits the use of recycled inert construction waste except its use as fill materials in reclamation and earth filling projects. A summary of these specifications is presented in Table 1.

A quick review clearly indicates that these specifications are highly conservative about the use of recycled aggregates. There is no provision about the use of recycled aggregates in concrete and other major civil engineering works. In the less important works, the decision is given to the

engineer. In the absence of any suitable guidelines, it is quite difficult for the engineer to allow the use of recycled materials and his decision will definitely be towards the use of virgin materials.

To promote recycled construction waste in the Hong Kong construction industry, it is necessary to make these specifications more liberal otherwise the use of recycled aggregates in permanent works other than reclamation and earth filling is almost impossible.

Table 1

***Summary of clauses related with aggregates for civil engineering works in Hong Kong (Desmyter, & Vyncke, J, 2000)***

Specifications	Clause	Brief description	Scope of recycled aggregates
GS (Civil Engg. Works)	1.36 (1)	Materials for inclusion in the permanent works shall be new or other material as stated in the Contract or approved by the Engineer.	May be
GS (Building Works)	1.45	Material for permanent works should be new.	No
	2.09	Brick rubble and other hard material can be reused as hard-core subject to compliance with the specification for filling.	Yes
GS Section 16 (Concrete)	16.08 (1)	Aggregates shall be obtained from a source approved by the engineer	May be
	16.08 (2)	Fine aggregate shall be clean, hard, durable crushed rock, or natural sand, complying with BS882.....	No
	16.08 (3)	Coarse aggregate shall be clean, hard, durable crushed rock complying with BS882. The 10% fines value shall be at least 100 kN. The water absorption shall not exceed 0.8%. The flakiness index shall not exceed 35%.	No
GS Section 9 (Road Works)	9.02	Sub-base material shall be crushed rock and shall have the properties stated in.....	No
GS Section 6 (Hardcore)	6.07 (5)	Granular material shall consist of clean, hard, durable material.	May be
	607 (6)	Rock fill material shall consist of pieces of hard, durable rock of which in the opinion of the Engineer not more than 30% by mass is discolored or show other evidence of decomposition. Concrete, masonry, brick and similar materials shall not be used unless permitted by the Engineer.	May be
GS Section 5 (Drainage)	5.21 (1)	Aggregates for granular bed shall be obtained from a source approved by the Engineer.	May be

works)

5.21 (2) The aggregate shall be clean, hard, durable natural stone complying with BS 882. The size of aggregate to be used for .....

No

### Possible Applications of Recycled Aggregates in Hong Kong

The possible applications of recycled aggregates in the Hong Kong construction industry are summarized in Table 2. For each possible application, the type of recycled construction waste is specified and relevant quality standards are mentioned to ensure good performance and long service life.

Table 3

*Possible uses of recycled aggregates in Hong Kong (Cheng, 2000; Desmyter & Vyncke, 2000; Collins 1998)*

No	Possible use	Type of C&D material	Quality control
1.	<i>Fill material</i>		
a.	Hardcore for filling up soft spots in a foundation or under a load.	Mixed <sup>1</sup> recycled aggregate of 150 mm down	No limit on mix proportions; Organic matter < 3%; 10% fines value > 50 kN (BS812: Part III)
b.	Fine fill material for back filling of utility trenches	Mixed recycled aggregate of 75 mm down	
2.	<i>Road Works</i>		
a.	Sub-base material for road construction	Mixed recycled aggregate of 37.5 mm down containing crushed concrete or mixture of natural rock and crushed concrete, or Mixed recycled aggregate containing reclaimed bituminous material and crushed concrete	All materials should comply with the particle size distribution specified in the GS for Civil Engineering Works, HK (1992 ed.); Fine material passing BS 425 µm sieve should be non-plastic, 10% fines value > 50 kN (BS812: Part III)
b.	Sub-base and base material for cycle tracks and foot paths	Mixed recycled aggregate of 37.5 mm down containing crushed concrete with brick	
c.	Unbound material for road construction	Reclaimed bituminous material mixed with crushed concrete and heated unto suitable temperature	
3.	<i>Drainage works and filter layer</i>		
a.	Granular bedding material for drainage pipes	Mixed <sup>1</sup> recycled aggregate of 20 mm down	10% fines value > 50 kN (BS812: Part III)
b.	Filter material for drainage	Mixed <sup>1</sup> recycled aggregate	Particle size distribution

layers under carriage-ways and filter layers behind sea walls.	complying with particles size distribution of filter material and free from deleterious impurities.	should be specified in individual contract.
<b>4. Concrete production</b>		
a. Low-tech applications such as paving blocks, pedestrian paving slab, curbs, road meridians, anti-crash barriers, rural drainage works, railway platforms etc.	Recycled concrete aggregate of 20 mm.	10% fines value > 70 kN (BS812: Part III); Density of aggregate > 2000 kg/m <sup>3</sup> ; Concrete grade > 15 MPa
b. Mass concrete applications such as bridge abutments, seawall blocks, shore protection works	Recycled concrete aggregate of 20 mm down with max. 10% masonry aggregate	10% fines value > 100 kN (BS812: Part III); Density of aggregate > 2000 kg/m <sup>3</sup> ; Concrete grade > 20 MPa
c. High grade applications like railway track sleeper beams, divider walls, precast products.	Recycled concrete aggregate of 20 mm down mixed with suitable proportion of natural aggregates	10% fines value > 100 kN (BS812: Part III); Density of aggregate > 2000 kg/m <sup>3</sup> ; Concrete grade > 35 MPa
1. A mixture of concrete and masonry (including tiles) with Min. 50% crushed concrete rubble (density > 2000 kg/m <sup>3</sup> ) and Max. 50% masonry rubble (density > 1600 kg/m <sup>3</sup> )		

### **Barriers in the Use of Recycled Aggregates in Hong Kong**

The following barriers are identified by the Civil Engineering and Development Department, Hong Kong about the use of recycled aggregates in Hong Kong (Cheng, 2000):

#### *Free Disposal of Construction Waste*

In Hong Kong, construction waste is either disposed off in landfills or reused as public fill in reclamation sites. At present, there is no charging scheme for both facilities and construction waste can be disposed off free of charge. Although the Government is planning to levy a suitable charge on disposal of solid waste including construction waste in landfills, inert construction waste can still be disposed off in public filling areas free of charge. There is no incentive for demolition contractors to reduce the amount of construction waste through sorting of coarse inert materials such as broken rock, concrete and brick/tile etc for recycling.

#### *Economic Barrier*

From an economical point of view, recycling of construction waste is only attractive when the recycled product is competitive with natural resources in relation to cost and quality. Recycled materials will normally be competitive where there is a shortage of both raw materials and

suitable deposit sites. Since rock is widely available in the Mainland China, the price of crushed rock is cheaper than recycled aggregates. However, the capacity of landfills and public fills is at alarming stage. Therefore, economic instruments, such as special taxes and fees in favor of recycling, should therefore be introduced to encourage recycling and the use of recycled materials. In this way, the construction and demolition contractors will be more willing to pay the recycling industry for delivering the construction waste to the sorting plant.

Another possible option is to force the construction industry to use a special percent of recycled products in their development projects through legislation. As a result, the construction industry is subsidizing the recycling industry through mandatory use of recycled products even these products are more expensive.

### *Current Practice in Demolition Projects*

A fundamental condition for recycling of construction waste is careful sorting of the material. In general, the composition of construction waste from new construction sites is rather simple and the separation of the material into different material categories is rather easy. The sorting of the construction material from demolition, is however, a more complicated process. Demolition has been regarded as a low technological process. Rapid demolitions and disposal of structures are the main aims of the contractors. Special measures to separate the different types of materials are not possible due to site constraints and time factor. As a result, construction waste from demolition projects is mixed with different types of materials and increase the cost and difficulty of the sorting process.

### *Supply of Recycled Aggregates*

The supply of recycled aggregates is sporadic, and depends on a number of factors, including volume and type of construction and demolition activities and the recycling infrastructure. Since the production of recycled aggregates is not profitable, it can only rely on the Government to provide the required recycling infrastructure.

### *Quality of Recycled Aggregates*

Although research works had indicated that recycled aggregate could be used for production of concrete, it is generally perceived by practicing engineers that recycled aggregates are inferior to natural aggregates. It will take some time to demonstrate to the professionals in construction industry that the quality of recycled aggregates is comparable to that of natural aggregates.

### *Specifications for Civil Engineering Works*

The General Specifications (GS) for Civil Engineering Works (Hong Kong Government, 1992 edition) generally prohibits the use of recycled inert construction material except its use as fill material in reclamation and earth filling projects. Without the change in the specification, it can be seen that the use of recycled aggregates in permanent works other than reclamation and earth filling is almost impossible in Hong Kong.

## **Recommendations**

To promote the use of recycled aggregates in the construction industry of Hong Kong, the following recommendations are suggested by the authors.

### *Development of Appropriate Specifications*

A major obstacle in the use of recycled aggregates in Hong Kong is the lack of suitable specifications and guidelines to help the engineers, consultants and contractors while selecting materials for construction. The current Civil Engineering Specifications should be modified to create a room for the application of recycled aggregates in the Hong Kong construction industry.

### *Opportunities in the Precast Industry*

Opportunities should be searched in the precast industry about the use of recycled aggregates as it is easier to ensure quality in such products due to the presence of an existing quality assurance system. In Europe, many precast industries are blending a small portion of recycled aggregates (10%-20%) with natural aggregates and achieving the same quality (Collins, 1998). Such a scheme can be implemented in Hong Kong with proper coordination of precast industries and government agencies. The targets products can be partitioning walls, road dividers, bridge fencing, noise barriers, paving blocks, etc., which do not require very high quality standards.

### *Changes in Legislation*

Appropriate changes in legislation should be made about the use of recycled products particularly in the Government projects. The new legislation should bind the contractors/consultants to use a suitable portion of recycled products in their projects.

Research studies worldwide have proven that 20% portion of natural aggregates can be safely replaced with recycled concrete aggregates without impairing the quality of final concrete (Hendriks, & Pieterse, 1998). It would be appropriate that this concept should be tested for the recycled aggregates in Hong Kong and if it works, suitable changes in legislation should be made to bind the contractors to at least use a small portion (maximum 20%) of recycled concrete aggregates in the concrete production.

### *Quality Assurance*

A Quality assurance system should be developed to assure the quality of recycled products. Quality assuring certificates should be issued by independent certifying institutions if the requirements for the installation, the production process, the quality-check and the finished product of the recycled aggregate producers, all comply with the quality requirements. This can promote the image of recycled aggregates and enhance its competitiveness.



### *Research and Development Activities*

There is a misconception in the field of civil engineering materials that recycled aggregate is a waste product which has substandard quality and so there is little drive in recycling this material. The strength of resulting concrete usually depends on the strength of parent materials, i.e. the recycled aggregates, their strength level determination is very important. Traditionally, engineers have experienced lower compressive strength and workability in the use of recycled aggregate in the concrete and it was determined that 20% was the maximum amount of recycled aggregate fines as a rule of thumb that would be allowed in the concrete. Initially, there was a lack of information on the cost benefits and performance of recycled aggregate and the lack of quantitative data. As such, research studies should be carried out for the quality of recycled aggregates which can be produced in Hong Kong.

The recycled aggregate could be considered as an option with the economics of the low bid system drives the use of recycled aggregate coupled with the environmental impact on sustainability would give rise to the use of this material. Benefits could be realized where there is an ample supply of quality recycled aggregate. It is also recommended that the different products and grades of concrete as mentioned in section on uses of recycled aggregate should be prepared and completely tested in the laboratory and analyzed using statistical techniques to ensure the safe use in the actual field applications. Finally through research, implementation and competition, it is envisaged that using recycled aggregate could provide engineering, economic, and environmental benefits to our society.

### **Conclusions**

The reuse of recycled materials derived from construction and demolition waste is growing all over the world. Many governments are therefore actively promoting policies aimed at reducing the use of primary resources and increasing reuse and recycling. One of the most environmentally responsible ways of meeting the challenges of sustainability in construction is the use of recycled concrete and masonry waste as aggregate in new construction.

Research and experimental works on the use of recycled aggregates for road works and concrete production have been conducted all over the world and it is proven that high quality could also be achieved with recycled aggregates. Many European countries, Japan and the United States have modified their specifications to make provision for the use of recycled aggregates in different construction works.

The construction industry in Hong Kong generates about 11 million tonnes of construction waste each year. In recent years, a major portion of this construction waste (around 80%) is reused as fill material in land reclamation and the rest is dumped in landfills. In view of the scarcity of land for new landfills and the finishing of major reclamation projects in near future, it is necessary to consider the recycling of inert construction waste. The use of aggregates produced from recycled construction waste is proven in other parts of the world and there is no technical reason to restrain their use in Hong Kong.

## References

- Cheng, N. T. (2000). Investigation of opportunities for recycling inert construction and demolition material in Hong Kong. *Technical Note 2/2000*, Hong Kong: Civil Engineering and Development Department.
- Collins, R. J. (1994). The use of recycled aggregates in concrete. *BRE Information Paper IP 5/94*. Watford: Building Research Establishment.
- Collins, R. J. (1998). Recycled aggregates—application and control issues. *Proceedings of the International Conference on the use of Recycled Concrete Aggregates*. Edited by: R.K. Dhir, N.A. Henderson and M.C. Limbachiya. UK: Thomas Telford. p. 169-175.
- Desmyter, J., Vyncke, J. (2000). *Proceedings of the 1<sup>st</sup> ETNRecy.net/RILEM workshop on use of recycled materials as aggregates in the construction industry (posters)*. Paris: ETNRecy.net.
- EPD (Environmental Protection Department) the Government of the HKSAR. (2007). *Hong Kong Waste Treatment and Disposal Statistics*. [WWW document]. URL [http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/stat\\_treat.html](http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/stat_treat.html).
- Fung, W. K. (2005). *The Use of Recycled Concrete in Construction*. Unpublished doctoral thesis, The University of Hong Kong, p. ii.
- Hendriks, C.F., Pieterse, H.S. (1998). Sustainable raw materials—construction and demolition waste. *RILEM Report 22*, France: RILEM Publication Series.
- Mehta, P. K. & Monteiro, P. J. M. (1993), *Concrete: Structures, Properties, and Materials*. New Jersey: Prentice Hall.
- Poon, C. -S., Yu, T. W. & Ng, L. H. (2001). *A Guide for Managing and Minimizing Building and Demolition Waste*. Chapter 1, Department of Civil and Structural Engineering. The Hong Kong Polytechnic University. Hong Kong.
- Sherwood, P.T. (1995) *Alternative Materials in Road Construction*. London: Thomas Telford.

## Appendix

### Successful International Construction Projects with Recycled Aggregates (Collins, 1994)

Country	Name of project	Year	Nature of project	Brief description
Netherlands	Rijkswaterstaat water works	1988	Viaduct and marine lock	11,000 m <sup>3</sup> of concrete in which 20% natural aggregates were replaced by recycled aggregates was used in all parts of the structure.
	Ventjagersp laam dam	1992	Rubble mound	Crushed masonry aggregates were used in the core of the rubble mound dam.

			dam	
	Delftse Zoom	1998	Housing project	This project involved the construction of 272 low-rise dwellings and family houses, in which the partitioning walls were constructed of load-bearing prefabricated concrete elements. The coarse aggregate fraction was 100% replaced by recycled aggregates with minimum of 50% crushed concrete aggregates.
United Kingdom	Precast concrete blocks	1998	Beam-and-block flooring systems	Blocks with up to 75% recycled aggregates were made with no difficulty. Results for ultimate load test gave safety factors between 33.7 and 39, and deflection was within limits.
	Precast concrete elements	1998	Recycling of rejected precast elements	Aggregates reclaimed from the rejected precast elements were utilized in the production of new elements. Results indicated that 20% replacement of natural aggregates with recycled ones does not impair the quality and properties of concrete.
	Operations center for Wessex Water, Bath	1999	Office building	The ready mixed concrete (in excess of 4,000 m <sup>3</sup> ) was prepared using recycled aggregate from crushed concrete railway sleepers to replace 40% of the coarse aggregate.
	Environmental building at BRE	1996	Office building	Recycled concrete aggregates from a recently demolished 12-storey office building were used as coarse aggregate in over 1,500 m <sup>3</sup> of concrete supplied for foundations, floor slabs, structural columns and waffle floors.
	Strong floor at BRE laboratory	1996	Heavy industrial building	Mixed brick and concrete recycled aggregate replacing 20% of the natural coarse aggregate were used. The heavily reinforced slab was 0.5 m thick and consumed about 500 m <sup>3</sup> of concrete. The recycled aggregates did not affect the pumping and placing of concrete.
Germany	Itzeheo housing project	1997	Housing scheme	A modern urban housing scheme was developed by demolishing old military barracks. On an area of 200,000 m <sup>2</sup> , 550 housing units, offices and commercial sites were constructed. Approximately 70,000 tonnes of demolition waste was processed and re-used immediately at the site.
Finland	Lahti motorway	1998	4 lane road	2 km long section of the motorway was built with 20,000 tonnes of crushed concrete aggregates in the base layer below the asphalt. The structure was designed for a bearing capacity of 400 MPa while the actual bearing capacity in May 2000 was found to be 689 MPa which is still expected to increase.
Belgium	Berendrecht lock	1988	Marine lock	In view of the expansion of the port of Antwerp, it was decided to build a new lock with a bigger

				capacity near the old Zandvliet lock. The demolition of the old lock yielded 80,000 m <sup>3</sup> of demolition waste. A workable concrete with compressive strength of 35 MPa was prepared using recycled aggregates. After nearly 15 years of service, the Berendrecht lock does not show any durability problems.
Norway	Fornebu housing scheme	1998	Housing scheme	The old Fornebu airport was demolished and the waste was recycled and reused for a housing project developed at the same site.
	RIT 2000	1998	Hospital building	The regional hospital was completely renovated, which includes the demolition of nearly all the existing buildings. The recycled concrete and masonry aggregates were used in low and medium grade concrete applications with design strength of 25 MPa.
Japan	Road works	On-going	Light and medium traffic roads	90% of the demolition waste obtained from different sites is recycled and used as capping later, sub-base or base layer in pavements.
United States	Civil engineering works	On-going	Pavements, non-structural concrete	Recycled aggregates found their main applications in road base or sub-base (68%), new concrete mixes (6%), asphalt hot mixes (9%), high-value rip-rap (3%), low value products like general fill (7%) and miscellaneous applications (7%)

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