Impact of Transportation on Cost and Energy for Recycled Concrete Aggregate

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Transportation distances can have a huge impact on cost and energy for concrete recycling. This study looks at the alternative methods that could be used for the procurement of coarse aggregate. It examines the feasibility of recycled concrete aggregate over virgin aggregate in terms of cost and energy. The goal was to determine the extent to which transportation distance impacts the cost and energy. A case study was undertaken using Gainesville, Florida, as the location of the jobsite and tested for varying transportation distances. The conclusions from the analysis of the results showed (1) that using a portable crusher onsite to crush the demolished concrete and reuse it on the same site is the most favored option in terms of cost and energy; and (2) that the transportation distance has a direct impact on cost and energy and determines the preferablity of recycled concrete aggregate versus virgin aggregate.

Keywords: Recycled Concrete Aggregate, Energy, Portable Crusher, Construction and Demolition Waste

Introduction

Earth's natural resources have been exploited to a point where the availability of virgin aggregates (VA) is now scarce if not unrealizable in some states, requiring the material to be hauled for lengthy distances, and elevating the projects expenses. Furthermore, disposal problems have risen from excessive volume of construction and demolition waste (C&D) evolving into a drastic escalation of tipping fees for dumping refuse at a site. There is an acceptable solution to these problems. If old demolished concrete was crushed to acceptable sizes, removing impurities such as steel ties, PVC pipes, and rebar along the way, it could easily be utilized for road base material (Chini et al., 2001). Numerous other possibilities exist for the use of recycled concrete aggregate (RCA) such as for pipe bedding, drain fields, parking lots, highway shoulders, etc. Regardless of its use, by not throwing away demolished concrete at a landfill location, the amount of natural raw materials produced yearly could decline vastly.

Concrete can be recycled by hauling the concrete debris to a permanent recycling facility for crushing and screening or it can be crushed and screened at the demolition site where the aggregate is reused when it is processed. The total benefit of concrete recycling could be assessed only through analyzing its economic and environmental impacts. Two major parameters that should be considered are the cost and energy consumption. Sometimes the cost and/or energy consumption for RCA are more than for virgin aggregate. This largely depends on the transportation distances. This study will compare the cost and energy consumption for production and transportation of virgin aggregate and RCA by giving different values for the transportation distances to show the impact of transportation on cost and energy consumption.

Virgin Aggregate

According to the U.S. Geological Survey (USGS, 2009), in 2008 crushed stone valued at $12 billion was produced by 1,450 companies operating 3,620 quarries, 86 underground mines, and 193 sales/distribution yards in 50 states. Leading states, in descending order of production, were Texas, Pennsylvania, Missouri, Georgia, Illinois, Virginia, North Carolina, Florida, Indiana, and Ohio, together accounting for 51% of the total crushed stone output. Of the total crushed stone produced in 2008, about 69% was limestone and dolomite, 15% was granite, 7% was traprock, and the remaining 9% was shared by miscellaneous stones. According to the USGS (2009), it was estimated that 1.36 billion tons of crushed stone were consumed in the United States in 2008. Of the 666 million tons reported by use, 83% was used as construction aggregates, mostly for highway and road construction and maintenance; 11% for cement manufacturing; and 6% for special and miscellaneous uses and products.

Environmental Impacts

According to USGS (2009), there is a shortage of quarries in some urban and industrialized areas due to local zoning regulations and land development alternatives. This issue is expected to continue and to cause new crushed stone quarries to locate farther from large population centers, causing longer distances of travel for the procurement of material to the jobsite. The crushed stone industry continues to be concerned with environmental, health, and safety regulations (USGS, 2009). According to Hsiao, et.al (2002), through the late 1990s, more than 90% of the aggregate supply has been extracted from domestic riverbeds and banks. Years of digging have left ecological damage and a depleted reserve base as a legacy, causing the depletion of non-renewable resources. Continued unauthorized extraction causes severe erosion of riverbeds and infrastructure (Hsiao et al., 2002). Virgin aggregate deposits have already been depleted in many areas. According to Langer and Arbogast (2003), the major impact effects of aggregate mining are loss of habitat, noise, dust, vibration, chemical spills, erosion, sedimentation, changes to the visual scene, and neglect of the mined site. Therefore the use of virgin aggregates has a huge environmental impact.

Recycled Concrete Aggregate

Recycled aggregate consists mainly of reclaimed asphalt pavement (RAP) and recycled concrete aggregate from construction and demolition (C&D) debris. They are the most abundant and available substitutes for natural aggregate in urban areas.

According to Sandler (2003) total building-related and infrastructural C&D waste concrete, generated annually in United States, is estimated to be 182 million metric ton (mmt). It is estimated that 50% (91 mmt) of waste concrete is recycled annually into usable aggregates. This is roughly 5% of the 1.8 billion metric tons total aggregates market (Chini, 2007). An estimated 68% of aggregate recycled from concrete is used as road base, and the remainder is used for new concrete (6%), asphalt hot mixes (9%), and low value products like general fill (Deal, 1997). The low usage rate of RCA in new concrete and asphalt hot mixes compared to higher usage rates in lower valued products is related to real and perceived quality issues. The specific gravity of coarse RCA ranges from 2.0 to 2.5, which is slightly lower than that of virgin aggregates. The differences become more pronounced with decreasing particle size. The specific gravity of RCA fines is in the range of 2.0 to 2.3 (ACPA, 1993). RCA can be expected to have higher absorption values than virgin aggregates. This is particularly noticeable in crushed fine material. Absorption values for fine-grained RCA generally range from 4 to 8 percent (compared with 2 percent or less for fine virgin aggregates) (ACPA, 1993).

Methodology

The primary objective of this research was to compare the cost and energy consumption for the three alternative methods used in handling concrete demolition waste and also to determine the best alternative for the disposition of the demolished concrete. A case was therefore created in which a four-story concrete structure is demolished. This theoretical building is located in Gainesville, Florida at the intersection of University Avenue and 13th Street. Three different demolition and disposal alternatives were examined. The first case considered was to crush the concrete at the demolition site using a portable crusher and to use the RCA as a base material at the same site. The second case considered was to dispose the demolished concrete at the nearest landfill and then buy new virgin aggregate from the nearest quarry. The third case considered was to dispose the demolished concrete at a concrete recycling plant and then to buy the RCA from the same recycling plant.

The cost and energy consumption for all the three cases were determined. Data were collected by visiting the nearest concrete recycling plant and quarry.

Cost

The overall quantity of concrete that has to be processed and RCA to be purchased is 6,169 metric tons. The quantity of virgin aggregate to be purchased was reduced by ten percent (5,608 mt) to consider the fact that RCA aggregate typically has a density lower than quarried VA. The cost was determined based on price quotes from local aggregate suppliers. The cost for case 1 involves the cost for using a portable crusher onsite to crush the demolished concrete and to use the same as base material in the same site. The portable crusher, rented from Florida Concrete Recycling Inc is located at a distance of 2.41 km from the jobsite. The cost for using a portable crusher was $5.44 for every metric ton of concrete crushed. An additional cost of $5,000 was charged for mobilization, installation, and getting permit to use a portable crusher (see Table 1).

The cost for case 2 involves the cost for disposing the demolished concrete waste at the landfill and buying new VA from the quarry. The landfill that was considered in the study was the Watson C & D landfill located at Archer, Florida, at a distance of 26.5 km from the jobsite. The cost for landfilling was $5.98 for every metric ton of concrete waste. This landfilling cost includes the cost for loading/unloading, transportation, dumping fees, and any other regulatory agencies fee. The virgin aggregate was bought from Limerock industries Inc, which is located in Newberry, Florida at a distance of 24.7 km from the jobsite. The cost for buying virgin aggregate was $10.84 for every metric ton, and this cost includes the material and delivery. The VA required for this site is 5,608 metric tons (see Table 2).

The cost for case 3 involves the cost of disposing the concrete waste at the recycling plant, which is slightly less than the cost of disposing at the landfill, and the cost for buying RCA from the same recycling plant. The recycling plant chosen for case 3 is the same recycling plant considered in case 1, which is the Florida Concrete Recycling Inc. located at a distance of 2.41 km from the jobsite. The overall cost for disposing the waste concrete at the recycling plant was $4.35 per metric ton. The overall cost of buying RCA from the same plant was $10.34 for every metric ton. Quantity of 6,169 metric tons of RCA was required for the site (see Table 3). A tax of 6.75% was charged for the overall cost for the activities in all the cases.

Energy

The two major areas in which energy consumption was calculated were for crushing and transportation in all three cases. The energy consumption was calculated based on Building for Environmental and Economic Sustainability (BEES) Technical Manual and User Guide. According to BEES 4.0 (Lippiatt, 2007), the energy used in the production of crushed aggregate is 82 kJ/kg, and following Bonilla and Salling (2008), the energy required for the transportation of material for every 100 km is 265.5 kJ/kg.

The energy consumption in the first case involves the energy for transporting the portable crusher to the jobsite and the energy for crushing the demolished concrete. The round trip distance from the recycling plant to the jobsite was 4.81 km. The total quantity of waste concrete required to be crushed by the portable crusher was 6,169 metric tons. Using these values, the total energy consumption in the first case was calculated (see Table 4).

The energy consumption in the second case involves the energy consumed in transporting the waste concrete from the jobsite to the landfill, energy for transporting the virgin aggregate from the quarry to the landfill, and the energy for the production of virgin aggregate. The distance between the jobsite and the quarry pit was 24.7 km and the distance between the jobsite and the landfill was 26.5 km. Using these values, the total energy consumption in the case 2 was calculated (see Table 5).

The energy consumption in case 3 involves the energy for transporting the waste concrete from the jobsite to the recycling plant, energy for transporting the recycled concrete aggregate from the recycling plant to the jobsite, and energy consumed in crushing the demolished concrete at the recycling plant. The distance between the jobsite and the recycling plant is 2.41 km. By using these values, the total energy consumption in the third was calculated (see Table 6).

List of Assumptions

1. The study begins after the building is demolished and the concrete debris is separated from steel and stockpiled.
2. The energy consumption for producing crushed virgin aggregate and recycled concrete aggregate is the same.
3. The energy consumption for transportation of virgin aggregate or recycled concrete aggregate per kilometer is the same in all the cases considered in this study.

Limitations of the study

1. Crushing concrete debris and using the RCA onsite may take longer than buying virgin aggregate from the quarry. This factor was not considered in the study.
2. The use of a portable crusher onsite requires a minimum threshold limit of at least 1,000 metric tons of waste concrete for it to be economically feasible.
3. The use of a portable crusher onsite requires enough space for crushing and stockpiling the waste concrete.
4. The use of a portable crusher onsite requires at least two weeks prior notice for getting the permit for the use of portable crusher at the jobsite.

Results

Data was collected for energy and cost for three different cases separately. The data from all three cases were then analyzed by comparing them with each other.

Table 1

Cost Calculations for case 1

Cost for using portable crusher to recycle concrete onsite per ton	$5.44	/mt
Quantity of concrete to be recycled	6,169	mt
Cost	$33,559	
Cost for mobilization and installation	$5,000	
Tax 6.75%	$2,265	
Total cast	$40,824	

Table 2

Cost calculations for case 2

Cost to landfill demolished concrete per ton	$5.98	/mt
Quantity of demolished Concrete	6,169	mt
Cost to landfill demolished concrete	$36,891	
Cost for buying Virgin aggregate per ton	$10.84	/mt
Quantity of virgin aggregate needed	5,608	mt
Cost for buying Virgin aggregate	$60,790	
Total cost	$97,681	
Tax 6.75%	$6,593	
Total cost	$104,275	

Table 3

Cost calculations for case 3

Cost for disposing concrete at the recycling plant	$4.35	/mt
Quantity of concrete to be disposed	6,169	mt
Cost for disposing concrete at the recycling plant	$26,860	
Cost for buying RCA per ton	$10.34	/mt
Quantity of RCA needed	6,169	mt
Cost for buying RCA	$63,787	
Total Cost	$90,647	
Tax 6.75%	$6,119	
Total Cost	$96,766	

Comparing the costs for all three cases (see Figure 1) shows that using the portable crusher from the first case is the most cost-effective and buying virgin aggregate from the second case is the least cost-effective.

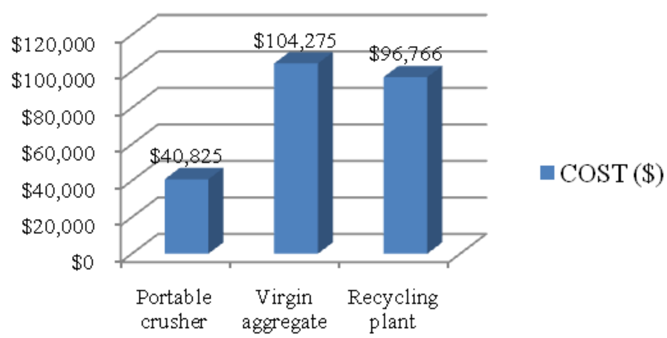

Figure1: The cost ($) incurred in each case

Table 4

Energy calculations for case 1

Energy to recycle 6,169 mt of the demolished concrete (82 KJ/Kg)	505,858,000	KJ
Distance from the recycling plant	2.41	Km
Approximate Weight of the portable crusher	5000	Kg
Energy required for transportation (265.5 KJ/Kg/100Km)	63,985	KJ
Total energy consumption	505,921,985	KJ (506 GJ)

Table 5

Energy calculations for case 2

Energy required to produce 5,608 mt virgin aggregate (82 KJ/Kg)	459,856,000	KJ
Distance from the jobsite to the landfill	26.50	Km
Energy to transport demolished concrete to landfill (265.5 KJ/Kg/100Km)	434,035,400	KJ
Distance from the quarry pit to the jobsite	24.70	Km
Energy required to transport VA from quarry pit to the jobsite	367,764,200	KJ
Total Energy	1,261,655,600	KJ (1,262 GJ)

Table 6

Energy calculations for case 3

Distance from the jobsite to the recycling plant	2.41	Km
Energy to transport demolished concrete to the recycling plant	39,472,600	KJ
Energy to recycle 6,169 mt of the demolished concrete (82 KJ/Kg)	505,858,000	KJ
Distance from the recycling plant to the jobsite	2.41	Km
Energy to transport RCA to the jobsite (265.5 KJ/Kg/100Km)	39,472,600	KJ
Total Energy	584,803,200	KJ (585 GJ)

Comparing energy consumption for all three cases (see Figure 2) shows that the first case in which portable a crusher is used onsite to recycle the concrete is the most energy efficient and the second case, which involves the disposal of demolished concrete and the buying of virgin aggregate, is the least energy efficient.

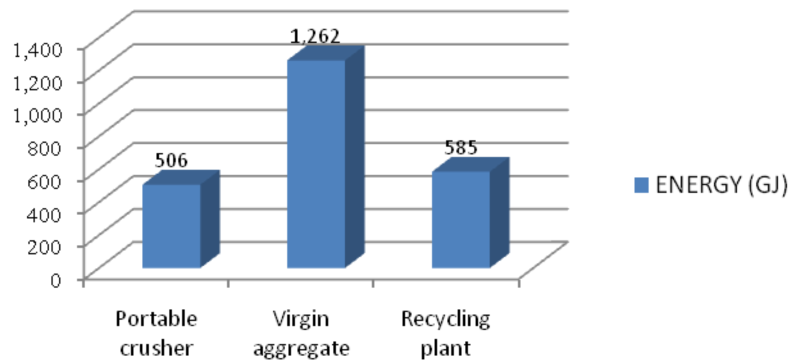

Figure 2: Energy consumption (GJ) for each case

Impact of Transportation on Cost and Energy

The results from all the three cases show that the first case in which portable crusher is used, is the most preferred option. The distance between the recycling plant and the jobsite is only 2.41 km, which is much less than 24.7 Km, the distance between the jobsite and the quarry pit. Therefore, to test the impact of transportation distance on cost, and energy consumption, the distance between the jobsite and the recycling plant was changed at the increment of 5 km from 5 km to 30 km (see Tables 7 and 8). The distances between the jobsite and landfill and the jobsite and quarry pit remained the same.

The new results show that when the distance between the jobsite and recycling plant becomes more than 12km, then the use of virgin aggregate becomes a more cost effective option than using RCA in case 3 (see Figure 3).

Table 7

Impact of distance between the jobsite and recycling plant on cost

Distance	5km	10km	15km	20km	25km	30km
Cost	$99,820	$103,350	$106,645	$109,935	$113,230	$116,520

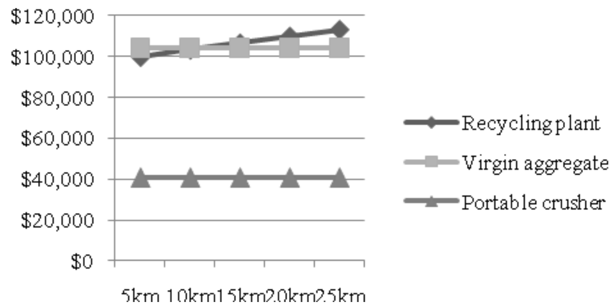

Figure 3: Impact of distance between the jobsite and recycling plant on cost

The results also show that when the distance between the jobsite and the recycling plant become more than 23km, then the total energy consumed for using a recycled concrete aggregate in case 3 becomes more than using a virgin aggregate in case 2 (see Figure 4). At this point, the use of virgin aggregate is a more energy efficient option than RCA.

Table 8

Impact of distance between the jobsite and recycling plant on energy

Distance	5km	10km	15km	20km	25km	30km
Energy (GJ)	670	833	997	1,161	1,325	1,489

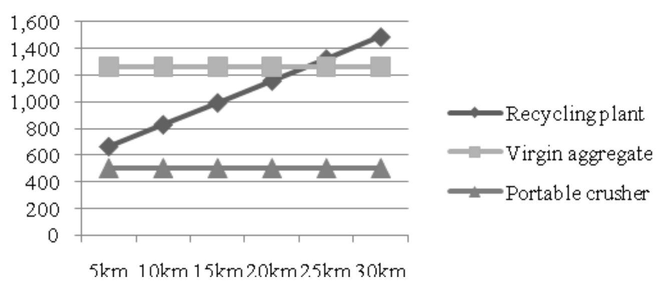

Figure 4. Impact of distance between the jobsite and recycling plant on energy (GJ)

Conclusions

The results from this study show that different approaches can be taken for the use of demolished concrete. For the three cases studied here the first case in which a portable crusher was used to recycle the concrete and use the recycled concrete aggregate at the project site was the most cost effective and energy efficient option. The second case in which the demolished concrete was landfilled and new virgin aggregate was bought was the least cost effective and energy efficient option. Therefore, crushing waste concrete at the demolition site where the aggregate is reused is the most economic and energy efficient option.

The results of this study also showed that the transportation distance has a major impact on cost and energy consumption. When the distance between the jobsite and the recycling plant was increased at the increments of 5 km, there was a point at which virgin aggregate became a more favorable option in terms of cost and/or energy consumption than using a RCA from a recycling plant.

Recommendations for Further Study

This study did not take into consideration the effect on pollution between crushing and screening concrete onsite (urban) and in a quarry (rural). Other limitations of this study that has to be considered in the future are the site logistics, space, time, and the minimum threshold quantity of concrete required for the use of portable crusher onsite to be feasible. Further study in this area will help in the implementation of practical use of a portable crusher onsite. Other environmental factors that need to be considered for similar research are the depletion of natural resources, conservation of land use, and the impact of disposing concrete wastes to landfills.

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