USE OF GLASS CULLET AS BACKFILL MATERIAL FOR RETAINING STRUCTURES

Krishna R. Reddy, Ph.D., P.E.
Associate Professor of Civil & Environmental Engineering
University of Illinois at Chicago
Chicago, Illinois 60607

ABSTRACT

The market is usually good for clean, color-sorted glass, used in the production of new glass containers. However, much of the glass collected in recycling programs becomes shattered, making color sorting a large and expensive proposition. Non-container glass and non-glass debris mixes in the supply, and as a result, much of the collected glass requires disposal in landfills, diminishing our efforts to protect the environment now and for future generations. In order to check the feasibility of alternative uses for glass cullet, several studies have been recently initiated. This paper investigates a potential application of glass cullet as an alternative backfill material for retaining structures. It is shown that glass cullet is a viable alternative to conventional granular soil backfill with both economic and environmental benefits.

INTRODUCTION

The United States Environmental Protection Agency (USEPA) reported that a total of 206.1 million tons of waste is generated annually (USEPA, 1997). Glass comprises 6.2% of this waste, meaning that approximately 12.8 million tons of glass is discarded annually. Of the approximately 12.8 million tons of glass disposed of per year, about 31% is reused by glass container manufacturers for re-melt and remold applications, 7% is used for a host of secondary markets such as fiberglass production and construction aggregate, and the remaining 62% is disposed in landfills. Assuming that the container industry has all the cost-effective glass it can use, the 31% should remain static in the years to come. The portion that deserves attention is the 62% of recovered glass that takes up space in landfills throughout the country. Large quantities of recycled glass, or glass cullet, are taking up valuable space in landfills. Recently, prices paid for glass cullet have decreased due to the apparent over-supply of mixed-color glass and green glass, which is not in demand by the container industry. As a result, alternative uses of this commodity are receiving greater scrutiny, and engineers are being challenged to find viable uses for the 9.7 million tons of glass that now take up precious space annually in landfills.

Some states and even the federal government have adopted legislation to increase the usage of recovered materials. The Massachusetts state legislative body, for example, banned metal and glass packaging from being landfilled (Packaging, 1993). This measure would act to enhance the local supply of cullet and stimulate further investigative uses of this material. As part of the Resource Conservation and

Recovery Act (RCRA), the federal government, in May of 1995, attached an amendment that addresses the use of recovered material by requiring agencies that draft or review specifications to: (1) not exclude the use of recovered materials, (2) not require the use of virgin materials, (3) require for EPA designated items, the use of recovered materials (48 CFR Part 23). Such regulatory initiatives are encouraging the use of recycled glass for a beneficial purpose rather than disposal in a landfill.

Using the mixed color and debris laden glass cullet, which is not suited for glass container recycling and is in abundant supply, in the area of civil engineering could potentially eliminate the need to landfill a large portion of recovered glass. This paper first presents different uses and engineering properties of glass cullet. Then, an assessment of using glass cullet as backfill material for retaining structures is provided.

ALTERNATIVE USES FOR RECOVERED GLASS

As the supply of recovered glass has grown due to the proliferation of recycling programs, the need to establish alternative uses for glass cullet has become evident. There is little sense in diverting glass from the waste disposal chain if it will end up in landfills anyway. The container industry guidelines regarding the color sorting and debris level of recycled glass limit the amounts that are economically feasible to use in that industry. The use of recovered glass in the construction aggregate market presents a viable option. The possible uses for glass cullet for civil engineering applications will far surpass the potential supply.

Using recovered glass as a construction aggregate has several advantages over re-using it in the container industry. Color sorting, a tedious and costly undertaking is not required. Ceramics and other non-container glass can be included without diminishing the overall engineering qualities. Depending on the type of application, up to 10% debris level (by weight) is allowed in the mix. The cost savings associated with these less stringent guidelines make it far more economical to use glass cullet as a construction aggregate than in the container industry.

Several studies have been performed on a wide variety of alternative uses for glass cullet, with positive results in a number of areas (Table 1). Some of these uses require further processing, and removal of any non-glass debris, but most require no more than crushing to gravel or sand sized particles. Some uses utilized the glass cullet alone, while the others used cullet and soils in various combinations. These studies have shown that glass cullet can replace or supplement sand or gravel, with equal (or even improved) engineering qualities, often at considerable savings.

ENGINEERING PROPERTIES

A review of the engineering properties of glass cullet was performed to compare cullet with other granular materials presently in use such as sands. The size distribution of

Table 1. Engineering Applications of Glass Cullet

Application	Cullet Content (%)	Debris Level (%)
Retaining Wall (structural backfill)	20-30	5
Retaining Wall (non-structural backfill)	100	10
Utility Bedding	100	5
Embankments	20-30	5
Foundation Drainage	100	5
Pavement Base	20	5
Trench and Foundation Backfill	100	5-10

glass cullet considered for civil engineering applications generally consists of 67 to 84% greater than 4.75 mm, 16 to 32% between 0.075 to 4.75 mm, and 0.4 to 1.4% less than 0.075 mm in size. The potential for cullet to cut, puncture, or wedge into moving parts of construction equipment, as investigated by the ASTM D2488 procedure, is found unlikely for cullet with a size range of 0.5 to 20 mm. In general, the particle shape of cullet is angular in nature. The level of debris up to 5 to 10% is shown to have little effect on the engineering performance of the cullet. Debris may consist of labels (paper, plastic, and foil), caps (plastic and metal), cork, paper bags, wood, food residue, grass, and soil.

The engineering properties of interest include: specific gravity, unit weight, hydraulic conductivity, durability, compactability, shear strength, thermal conductivity, and chemical resistance. A comparison of these properties for cullet and sand is shown in Table 2. The specific gravity and unit weight of cullet are less than that of sand. Constant head permeability tests indicate glass cullet has a high permeability, similar to clean sands, which is proportional to grain size and level of debris while inversely proportional to the degree of compaction. This high permeability makes glass cullet good for retaining wall backfill material, since low permeability leads to a build-up of hydrostatic pressure. The Los Angeles Abrasion test results show that cullet durability is still close to the normal limiting values of 30-40% for roadway aggregate. Debris level had minimal effect on the durability. Compactability tests show that cullet maximum dry unit weight values were less than or similar to sands and the unit weight of cullet is relatively insensitive to moisture levels, which is an advantage in wet weather applications. The shear strength of cullet matched or exceeded the shear strength of sand, with friction angles ranging from 49 to 53 degrees. Debris level in the cullet samples had no appreciable affects on shear strength. Cullet compacted to a dense state is rigid and strong, due to compactness of the bulk material, high shear

Table 2. Comparison of Properties of Cullet and Sand

Property	Test Method	Cullet	Sand
Specific Gravity	ASTM D 854	1.96-2.52	2.6-2.8
Unit Weight (pcf)	ASTM D 4254	76-109	80-130
Hydraulic Conductivity (cm/s)	ASTM D 2434	10^{-1}-1	10^{-3}-10^{-2}
Durability	ASTM C 131	30-42	NA
Compactabilty:	ASTM D 698		
Optimum Moist Content (%)		5	8-10
Maximum Dry Density (pcf)		105-124	116-133
Shear Strength :	ASTM D 3080		
Cohesion (c')		0	0
Friction Angle (ϕ)		49-53	32-38
Thermal Conductivity (W/mK)	ASTM C 518	0.26-0.64	2.9-7.7
Chemical Resistance (%)	ASTM D 3042	99.8	70.1

strength of the individual particles, and high inter-particle frictional resistance. The thermal conductivity of glass cullet ranged from 0.26 to 0.64 W/mK, which is lower than that of sand. The glass cullet possesses excellent chemical resistance as compared to sand, even under highly acidic conditions.

DESIGN OF THE RETAINING WALLS

For the purpose of this study, it is considered necessary to build a retaining wall system at a slightly sloping terrain in the Chicagoland area. It is considered necessary to level the sloping area to build a proposed road. To provide an adequate level surface for the road, a cut into the sloping hillside must be made. The retaining wall will hold back material which is not excavated so the soil does not slide down into the road. The soil at the project site is assumed to be silty clay, which is a common type of soil encountered in the Chicagoland area. Because of low hydraulic conductivity, silty clay is not considered to be an ideal backfill material. The silty clay has very poor drainage characteristics which results in increased hydrostatic pressure behind the wall. The retaining wall must be designed to withstand higher pressures, resulting in a larger retaining wall and increased costs. An alternative to using the existing soil behind the wall is to excavate behind the retaining wall and replace the silty clay with a suitable backfill material, which can produce a more economical design.

There are several suitable materials to use as backfill and the purpose of this project is to test the suitability of glass cullet as backfill. This was done by comparing a retaining wall design using conventional backfill, in this case sand, with the design obtained for the same situation using glass cullet as backfill. To make a thorough comparison, cantilever reinforced concrete retaining walls were designed for three different heights, 10 ft, 20 ft, and 30 ft, first using sand and then glass cullet as backfill. A cost estimate was done for each retaining wall and backfill. Comparing the costs for constructing retaining walls using sand as backfill and glass cullet as backfill shows whether the use of glass cullet is economical or not.

The following assumptions were made in designing the retaining walls: (1) no surcharge loading exists behind the wall; (2) existing soil behind and below the retaining wall is silty clay with the following properties: cohesion c = 1224 psf, friction angle $\Phi = 17°$, unit weight $\gamma = 130$ pcf, and footing friction = 18°; (3) clay behind the wall must be excavated and backfilled with a permeable material to prevent the build-up of hydrostatic pressure behind the wall; and (4) the angle of backfill at the top of the retaining wall is 14°. The properties for sand used for the design were: cohesion = 0; friction angle = 38°; unit weight = 125 pcf; and wall friction = 20°. The properties of glass cullet used for the design were: cohesion = 0; friction angle = 51°; unit weight = 93 pcf; wall friction = 34° (2/3 of friction angle).

Using the above assumptions, the geotechnical design of the retaining wall was performed to ensure safety against sliding, overturning, tension, and bearing capacity (Coduto, 1994). Figure 1 shows the geotechnical design for a 10-foot high wall with sand and cullet as backfill material. It can be seen that the dimensions of the wall with cullet as backfill are smaller than the corresponding wall with sand as backfill, leading to a less expensive design. The factors of safety against sliding and overturning were higher for the glass cullet walls than for the sand walls. For the sand-filled walls, the sliding factors of safety were 4.15, 1.68, and 1.54 for the three increasing heights. In the same manner, the sliding factors of safety for the cullet-filled walls were 12.03, 6.58, and 4.81. The factors of safety against overturning applying to the walls with sand backfill were 2.10, 1.84, and 1.65 for the 10, 20, and 30-foot walls. For the walls filled with glass cullet, the overturning factors of safety were 1.87, 1.84, and 1.75.

The structural design of the 10, 20 and 30-foot high retaining walls was performed to meet the ACI Code requirements (Coduto, 1994). Figure 2 shows the structural design for the 10-foot high walls with sand and cullet as backfill. It can be seen that the reinforcing steel required in cullet-walls are lower than that of the sand-filled walls, leading to less costly design.

COST ANALYSIS

Cost estimates were made for 10, 20, and 30-foot high and 100-foot long retaining walls with sand and glass cullet as backfill materials to determine the economic advantages of using glass cullet as a backfill material. Figure 3 summarizes these

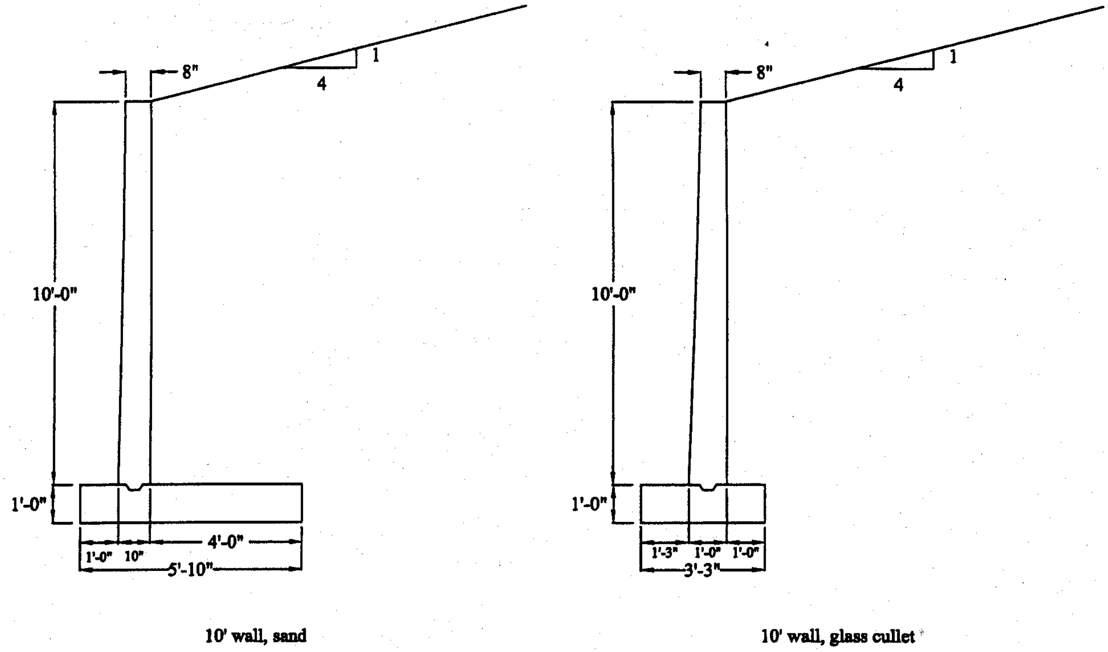

Figure 1. Geotechnical design of retaining walls with glass cullet and sand as backfill material

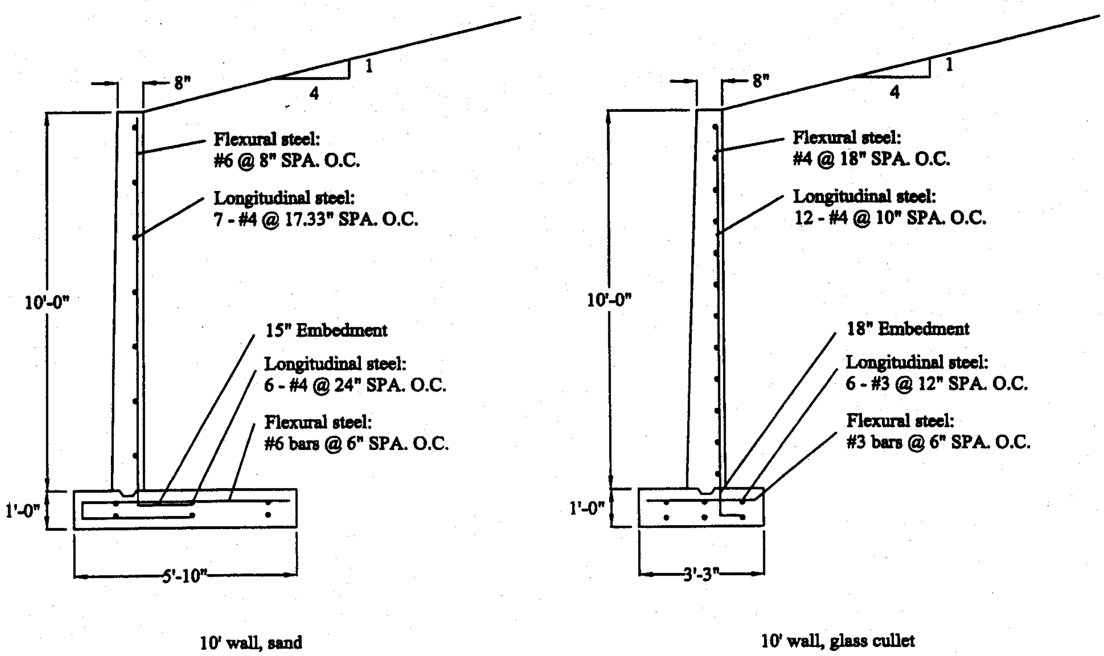

Figure 2. Structural design of retaining walls with glass cullet and sand as backfill material

results. The savings on the backfill material alone amounts to over 80%; however, the total cost savings of the backfill material and construction ranges from 36% for the 10-foot wall to 50% for the 30-foot wall. These results clearly show the enormous savings resulting from the use of glass cullet as backfill material.

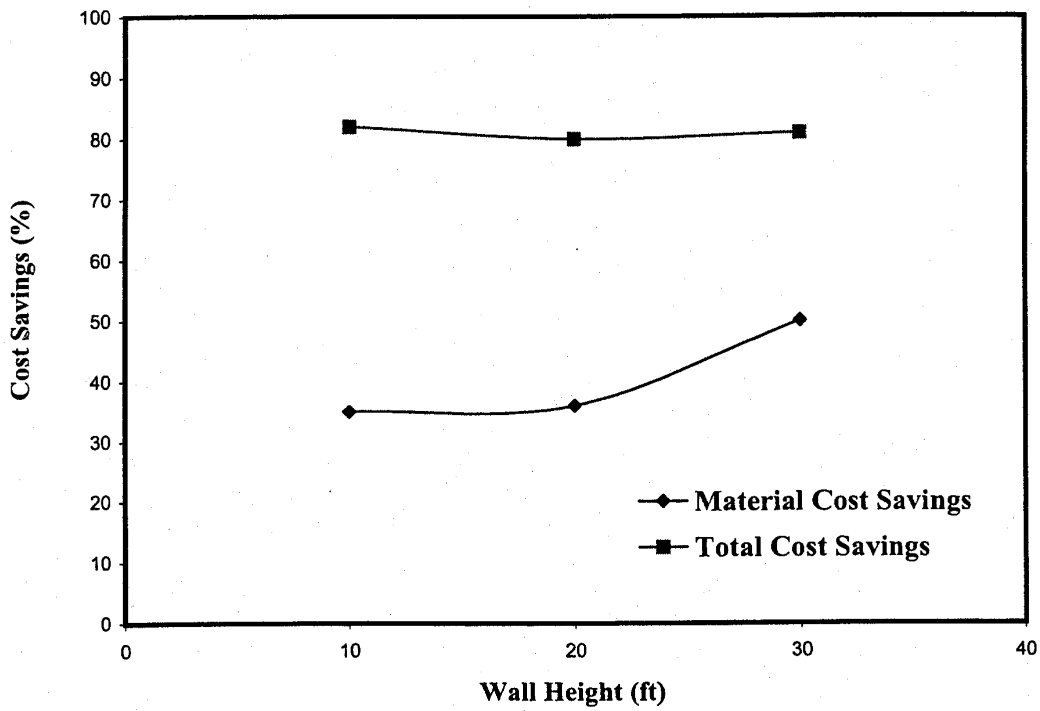

Figure 3. Cost savings using glass cullet as backfill instead of sand as backfill

SUMMARY

This project demonstrated that glass cullet is a feasible alternative to conventional granular soils when used as backfill material for retaining structures. When compared with sand, cullet has higher permeability, equal or higher friction angles, and lower specific gravity and unit weight. These properties make it a suitable choice for use as backfill material for retaining structures. From an economical point of view, the average total cost savings resulting from cullet use can be as high as 50%. Although the price of cullet may vary according to many factors, such as source location, availability, and quality, even the highest cullet price can produce large reductions in cost. In conclusion, glass cullet is a sound and cost-effective alternative to granular soils in civil engineering applications, while presenting a practical solution for environmental concerns.

REFERENCES

1. American Concrete Institute. Building Code Requirements for Reinforcement Concrete (ACI 318-89) and Commentary (ACI 318R-89). Detroit, 1992.
2. Coduto, D. P. Foundation Design. Englewood Cliffs: Prentice, 1994.
3. Lambe, W.T. and Whitman, R.V. Soil Mechanics. John Wiley and Sons, Inc. 1969.
4. Holtz, R.D. and Kovacs, W.D. An Introduction to Geotechnical Engineering. Englewood Cliffs: Prentice, 1981.
5. Shin, C. J. and Sonntag, V. Using Recovered Glass as Construction Aggregate Feedstock. Transportation Research Record 1437, 1994
6. King County Department of Transportation – Road Services Division. Glass Cullet Backfill Demonstration Project. March, 1996.
7. Cornwall, W. "Recyclers Out on Their Glass in Idaho Falls." POST-REGISTER. Knight-Ridder/Tribune, Idaho Falls, ID, 1997.
8. Glass Packaging Institute. Glass Recycling Percentage of Glass Containers Recycled in the U.S. Indianapolis, IN, February, 1998.
9. "Massachusetts Prepares for Landfill Ban." Packing. Reed Publishing USA. Boston, 1993.
10. United States Environmental Properties Agency (USEPA). 1997 Almanac. Washington, D.C., 1997.