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PREDICTIVE CRITERIA FOR CONSTRUCTION/DEMOLITION SOLID WASTE MAN--ETC(U)
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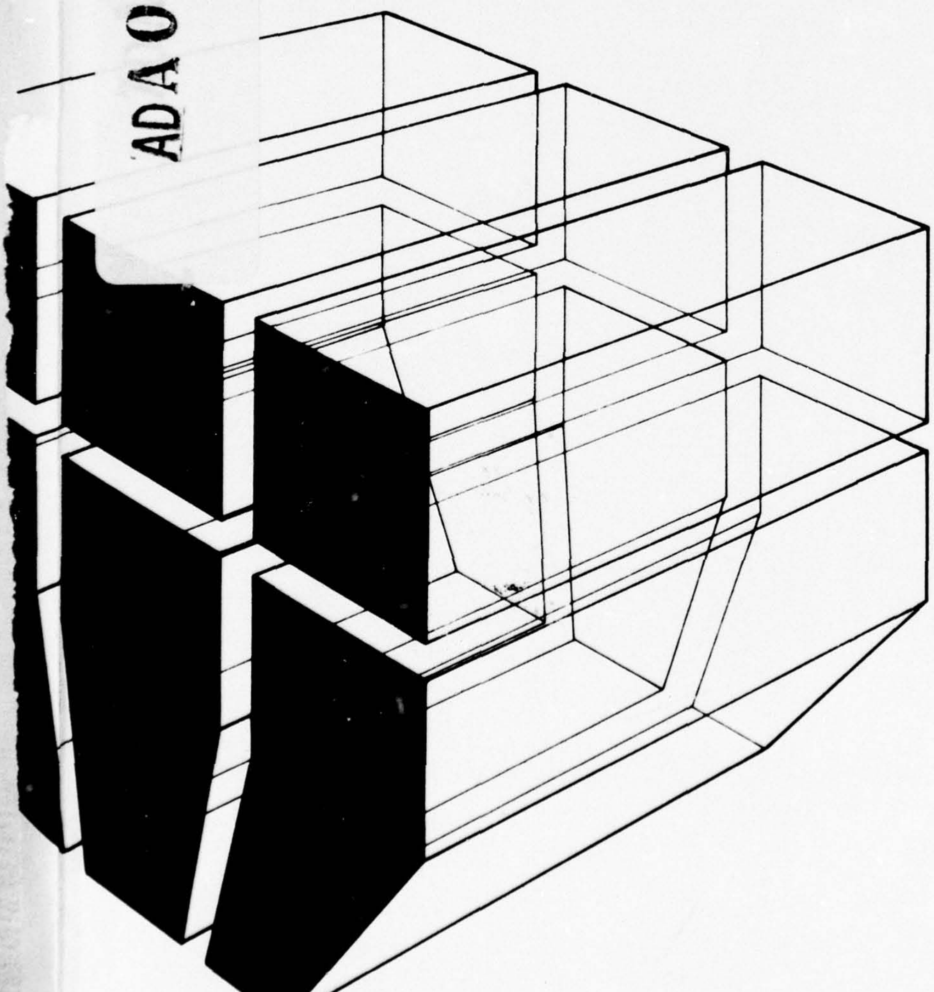
TECHNICAL REPORT N-14
December 1976
Development of Application Tools for Protection
of the Environment During Construction)

PREDICTIVE CRITERIA FOR CONSTRUCTION/DEMOLITION SOLID WASTE MANAGEMENT



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study basically expands on the current state of the art of construction solid waste management. The available information on solid waste generation rates, composition, disposal alternatives, and disposal costs has been compiled. In addition, data relating to waste generation rates, composition, and disposal costs for selected Army post construction activities have been compiled, analyzed, and documented.

Several selected waste management alternatives have been assessed in

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detail. These alternatives are:

- Waste-to-Landfill Alternatives,
- Incineration,
- Production of Thixite,
- Waste-to-Bricks Process - Tekbricks,
- Ecological/Recycled Pavements,
- Wood Waste-to-Energy Alternative,
- Mulching,
- Pulverizer Systems,
- Handling of Special Wastes, and
- Integrated Management.

Detailed documentation of the assessment analyses has been developed in this report. Relevant information relating to the above alternatives is summarized in the following two pages.

SUMMARY OF SELECTED WASTE MANAGEMENT ALTERNATIVES

Name of Process	Process Description	Cost Information: Capital Cost $/Ton	Operating Cost $/Ton	Revenues $/Ton	Net Operating Cost, $/Ton	Remarks
Waste-to-Landfill Alternatives	(1) Separate Open Dumps	0.40	0.50 to 0.90	--	--	This alternative may cause serious environmental problems.
	(2) Sanitary Landfill	0.80 to 2.00	1.50 to 3.00	--	--	This is a safer alternative, but it results in waste of resources.
Incineration	Waterwalled incinerator burns combustible solid wastes to reduce volume to 10 to 30 percent	13,000 ($/Ton/Day)	2.50 to 6.00	2.00 to 4.00	0.50 to 2.00	This alternative converts wastes to energy; however, use of this system depends on the composition of available wastes.
Pyrolysis	Thermal conversion of the organic waste to burnable gas	10,000 to 18,000 ($/Ton/Day)	9.50 to 13.50	1.50 to 4.50	8.00	The process is still experimental; it also requires a large organic waste component.
Thixite Process, Lakewood, Colorado	(1) Crushed glass, concrete and bricks are mixed with a resin binder in certain proportions and fired at a temperature of 1500° F. Capacity: 242,000 panels/year	6.00 million (entire plant)	17.60	20.60	3.00 (Profit)	Operation still experimental. A prototype plant will be developed soon.
	(2) A tile making equipment for conventional brick manufacturer (See Appendix C)	10.00 thousand (Equipment installation cost)	0.45 per sq. ft. tile	2.00 per sq. ft. tile	1.55 per sq. ft. tile (Profit)	Operation still experimental. A prototype plant is being developed in San Francisco, California, and Albuquerque, New Mexico.
Waste-to-Bricks Process - Tekbricks (Lake Park, Georgia)	It includes a pulverizer, a mixer, and a high-pressure mold. Complete automation. Capacity: 25 million bricks per year	1.90	13.00	15.00	2.00 (Profit)	A plant is in operation in Atlanta, Georgia. Should be studied for possible implementation in future.

SUMMARY OF SELECTED WASTE MANAGEMENT ALTERNATIVES (Continued)

Name of Process	Process Description	Cost Information: Capital Cost $/Ton	Operating Cost $/Ton	Revenues $/Ton	Net Operating Cost, $/Ton	Remarks
Ecological/Recycled Pavements	Crushed waste concrete and glass can be mixed in proper grading and proportion with bituminous binder or cement and water to produce an excellent paving material	--	2.50 to 10.50 per sq. yds. pavement	--	--	Experimental system. Has been tested in one prototype operation.
Wood Waste-to-Energy Alternative	Hydrogenation of wood to low-sulfur oil	NOT AVAILABLE YET			Expected to be profitable	A prototype will be tested shortly.
Mulching	Brush and wood wastes can be shredded to form topsoil and seeding mulch	600 ($/Ton/Day)	4.00	5.00	1.00 (Profit)	Certain technical problems of using wood waste as mulch need to be resolved.
Pulverizer	Stationary shredder for bulky wastes Capacity: 100 Ton/Hour	0.95 million (entire plant)	2.84	--	--	Assumes one shift operation. This is one of the most economic pulverizers available for use.
Handling of Special Waste	Containerized disposal into landfills	--	0.25 per gallon	--	--	Possible to share existing hazardous waste disposal facility or a sanitary landfill.
Integrated Management	(1) Union Electric supplementary fuel system	6,000 ($/Ton/Day)	6.05	5.45	0.60	Recycling of wasted resources makes it a profitable venture.
	(2) Bridgeport, Conn., supplementary fuel and dry separation processes	27,000 ($/Ton/Day)	11.00	4.00	7.00	If the cost of collection and disposal is less than $7 per ton, such systems can be profitable and make more effective use of resources.

FOREWORD

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Mr. W. J. Mikucki, Chief of the CERL Environmental Engineering Team, Environmental Division (EN), was the CERL Technical Monitor.

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Dr. R. Jain is Chief of EN. COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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CHAPTER I. INTRODUCTION

Objective

The objective of this study was to develop data and predictive criteria on the quantity, costs of disposal, and disposal alternatives for construction solid wastes. Supplementary information about demolition and waste management of debris was also gathered for this study.

Approach

The approach of this study was first to gather and analyze data on construction/demolition solid waste management at two Army posts (Chapter II); and then to assess various waste management alternatives, their costs, and their advantages and disadvantages (Chapter III).

Scope

This is one of two reports covering construction and demolition solid wastes. This report deals mainly with construction solid wastes; a companion report* deals primarily with demolition wastes.

Background

Construction and demolition activities generate large volumes of solid waste. These wastes are an important component of the overall municipal and industrial solid waste management problem. Existing information relating to these wastes is so scattered in the literature that analyses of the problems of construction and demolition waste management have been impeded. An effort has been made in this report to accumulate and document the available data on construction/demolition solid wastes.

* "Development of Predictive Criteria For Demolition and Construction Solid Waste Management," Technical Report N-15, U.S. Army Construction Engineering Research Laboratory (CERL) (1976).

Much of the available literature in the field of construction and demolition solid waste management has been reviewed under a recent research program sponsored by the U.S. Army Corps of Engineers. A bibliography of references reviewed is presented at the end of this report. The available solid waste information has been abstracted and categorized under the following headings:

(1) Solid Waste Generation Rates

(2) Solid Waste Composition

(3) Disposal/Recovery Alternatives

(4) Disposal/Recovery Costs

A discussion of major references and their documented information is summarized in this report.

Solid Waste Generation Rates

There are many different kinds of solid waste generated by construction and demolition activities. On a national scale, the major components of this solid waste are concrete and wood (Jones, 1973). The volume of solid waste streams generated by construction and demolition activities varies with the type of structure, materials used, and procedures employed; yet there are very few data in literature that define these specific relationships.

Some quantitative data on solid waste generation rates have been developed on a macro scale by a few selected investigators. For instance, over a period of 13 years (1957-1969) about 19,600 structures or an equivalent of 32,700 dwelling units were demolished annually in the U.S. The national average solid waste generation rate from demolition work has been about 100 tons per structure or 60 tons per dwelling unit (SCS Engineers, 1972).

In addition, there are a few other investigators like Jones (1973), Black, et al. (1970), Raytheon Service Company (1972), Combustion Engineering, Inc. (1969), Small (1971), American Public Works Association (1970), Bond and Straub (1973), and Glysson, et al. (1972). Much of these data are of limited value due to the high degree of aggregation and guesswork involved in their development. The available generation rate criteria for construction and demolition solid waste are summarized in Tables 1 and 2.

TABLE 1. SOLID WASTE GENERATION RATES FOR CONSTRUCTION/DEMOLITION ACTIVITIES

No.	Predictive Factors	Generation Rates	References
(1)	• Single-family dwelling unit • State of Massachusetts	56 tons per unit	Raytheon Service Co., 1972. Jones, 1973, p. 156.
(2)	• Multi-family dwelling units • Massachusetts state average	35 tons per unit	Raytheon Service Co., 1972. Jones, 1973, p. 156.
(3)	• Remodeling of old dwelling units	0.1 times demolition waste	Raytheon Service Co., 1972. Jones, 1973, p. 156.
(4)	• Demolition/remodeling wastes • Massachusetts state average	0.183 pounds per capita per day	Raytheon Service Co., 1972. Jones, 1973, p. 157.
(5)	• Average construction waste for the state of Massachusetts	0.227 pounds per capita per day	Association of General Contractors. Jones, 1973, p. 157.
(6)	• Construction and demolition wastes • Massachusetts state average	0.41 pounds per capita per day	Association of General Contractors. Jones, 1973, p. 157.
(7)	• Construction and demolition wastes • National average • Industries handling their own wastes excluded	0.18 pounds per capita per day	Black, et al, 1970. Jones, 1973, p. 157.
(8)	• Construction, remodeling and demolition wastes • National average • Based on estimated material use and 40-year* life of structures	4.65 pounds/capita/day or 2.32 pounds/capita/day	Jones, 1973, p. 170.

* The 40-year life of structures is a low estimate. However, the assumption may adjust for the generation of construction and remodeling wastes produced in addition to the demolition wastes.

TABLE 1. (Continued)

No.	Predictive Factors	Generation Rates	References
(1)	• Cities in New Jersey--Patterson, Clifton, Passaic, and Wayne (1967)		
a.	• One-family frame house • New construction • Waste debris	15 cubic yards per unit	Environmental Protection Agency Small, 1971, p. 30.
b.	• One-story, 100' x 200' building • New construction • Waste debris	70 cubic yards per unit	
c.	• One-family frame structure • Demolition waste	160 cubic yards (or 56 tons) per unit	
d.	• One-family brick home with brick salvaged • Demolition waste	160 cubic yards (or 56 tons) per unit	
e.	• Commercial or factory structure • Size 100' x 200' • Demolition waste	4,200 cubic yards (or 1,470 tons) per unit	
f.	• Construction and demolition wastes • Annual city-wide average	2 pounds/capita/day	
(10)	• City of New Orleans (1967)		
	• Total construction waste	1.17 pounds/capita/day	Small, 1971, p. 30.
	• Noncombustible component of construction and demolition waste	1.17 pounds/capita/day	
(11)	• Demolition refuse		
	• National average	0.66 pounds/capita/day	American Public Works Association, 1970, p.9
	• New England	0.84 pounds/capita/day	Bond and Straub, 1973, p. 57.
	• Southeast	0.16 pounds/capita/day	

TABLE 1. (Continued)

No.	Predictive Factors	Generation Rates	References
	• Great Lakes	1.16 pounds/capita/day	
	• Pacific Coast	0.12 pounds/capita/day	
(12)	• Tree and landscape refuse		American Public Works Association, 1970, p. 9. Bond and Straub, 1973, p. 57.
	• National average	0.18 pounds/capita/day	
	• New England	0.21 pounds/capita/day	
	• Southeast	0.81 pounds/capita/day	
	• Southwest	0.40 pounds/capita/day	
	• Great Lakes	0.13 pounds/capita/day	
	• Pacific Coast	0.34 pounds/capita/day	
(13)	• Demolition and construction waste	0.72 pounds/capita/day	Glysson, et al., 1972, p. 29
	• Urban municipal		
(14)	• Tree and landscaping	0.18 pounds/capita/day	Glysson, et al., 1972, p. 29.
(15)	• Construction and demolition waste		Bond and Straub, 1973, p. 51.
	• Urban average	0.72 pounds/capita/day	
(16)	• Demolition solid waste	100 tons per structure	SCS Engineers, 1972.
	• National average	60 tons per dwelling unit	
(17)	• Fresno Region in California*	(see Table 2)	Aerojet General Corp., 1969, p. V-33.

* The ratio of $\frac{\text{Demolition Waste}}{\text{Construction Waste}}$ is generally equal to about 10 in the Fresno Region.

TABLE 1. (Continued)

No.	Predictive Factors	Generation Rates	References
	• Construction and demolition waste as percent of municipal waste	1.5% - 7.2%	
(18)	• Demolition waste	2,255 tons/year/ employee	Combustion Engineering, Inc., 1969.
	• National average		
(19)	• Construction wastes	0.1 times demolition waste	Combustion Engineering, Inc., 1969.

TABLE 2. CONSTRUCTION AND DEMOLITION WASTES IN THE FRESNO REGION

Cities	Total Municipal Waste	Demolition Waste		Construction Waste		Demolition Waste/Construction Waste
	Volume*	Volume	Percentage	Volume	Percentage	Ratio
Kingsburg	4,008	261	6.51	26	.64	10.03
Biola	1,561	54	3.45	5	.32	10.80
Caruthers	4,206	70	1.66	7	.16	10.00
Del Ray	1,739	78	4.48	8	.46	9.75
Fowler	3,809	182	4.77	18	.47	10.11
Kerman	5,710	248	4.34	25	.43	9.92
Laton	1,858	87	4.68	9	.48	9.66
Orange Cove	3,910	280	7.16	28	.71	10.00
Parlier	4,000	147	3.67	15	.37	9.80
Reedley	11,915	617	5.17	61	.51	10.11
Riverdale	2,846	129	4.53	13	.45	9.92
Sanger	13,542	760	5.61	75	.55	10.13
Selma	13,003	594	4.56	61	.46	9.74

* Volume is expressed in tons/year

Source: Aerojet General Corp., 1969.

There are many limitations of these generation rates. First, they have been averaged over an entire state or the nation as a whole. For predictive purposes, generation rate data are needed that discriminate between facility classes, project size, and construction practices. Second, there are large differences in the figures presented in Table 1. For example, Black, et al.(1970) reports a generation rate of 0.18 pounds per capita per day, whereas Jones (1973) estimates a generation rate of 4.65 pounds per capita per day. Unless more empirical research is undertaken, the discrepancy can hardly be resolved.

The rate of 4.65 is high compared to the total national solid waste collection rate of 5.3 pounds per capita per day. If the value of 4.65 is considered accurate, the management of construction/demolition wastes must be given far greater attention than it has received.

The data on construction and demolition waste volumes generated in municipal areas are not adequately reported in literature. One study of the Fresno Region in California reports volumes of construction and demolition wastes from many small communities that generate total municipal solid wastes ranging from 1.5 tons per day to 70 tons per day (Aerojet General Corp., 1969). The data are summarized in Table 2. It is found that the generated construction and demolition waste volumes range from 2 percent to 7 percent of the total municipal solid waste generated annually by these communities. The data consistently show that the demolition waste is about 10 times the weight of construction wastes generated. The data on small communities may be representative of Army posts which often have a great deal of similarity to small communities in terms of population growth and construction activities resulting therefrom. The data presented in Tables 1 and 2 can tentatively be used to predict construction and demolition waste volumes at the Army posts. However, monitoring of solid waste volumes generated by construction and demolition activities should be done at various Army posts in order to verify the prediction criteria.

According to the Combustion Engineering study (1969), the average generation rate of demolition wastes in the U.S. is about 2,255 tons per year per employee. A much higher rate of waste generation has been estimated by Jones (1973). This study suggests that as much as 3,450 tons of solid waste per year per employee are generated by the entire demolition industry.

The estimated generation of solid wastes from construction, remodeling, and demolition activities up to the year 2010 is presented in Figure 1.

Solid Waste Composition

At present, there is a real dearth of reliable information on the composition of construction and demolition wastes in the U.S. (Jones, 1973).

According to the American Public Works Association (Bond and Straub, 1973), construction wastes generated by new construction or remodeling activities are generally composed of:

(1) Scrap lumber

(2) Pipes

(3) Concrete

(4) Other materials

The demolition wastes from the urban renewal projects primarily consist of:

(1) Lumber

(2) Pipes

(3) Concrete

(4) Brick masonry

(5) Asphaltic material

(6) Bat guano/pigeon excreta

(7) Other materials

A recent study sponsored by the National Science Foundation (Jones, 1973) has estimated the composition of solid wastes generated by construction, remodeling, and demolition activities on a national scale. The estimate is based on available data on construction materials flow, assuming an average structural life cycle of 40 years. The composition of solid wastes predicted by Jones (1973) is presented in Table 3.

Another recent survey by Chatterjee (1974) has found the following composition of solid wastes from construction and demolition activities: concrete--69 percent; wood--13 percent; clay--7 percent; steel--8 percent; gypsum products--2 percent; and others--1 percent. The results of the two studies are fairly consistent. As such, the above composition figures may serve as fairly representative predictive criteria.

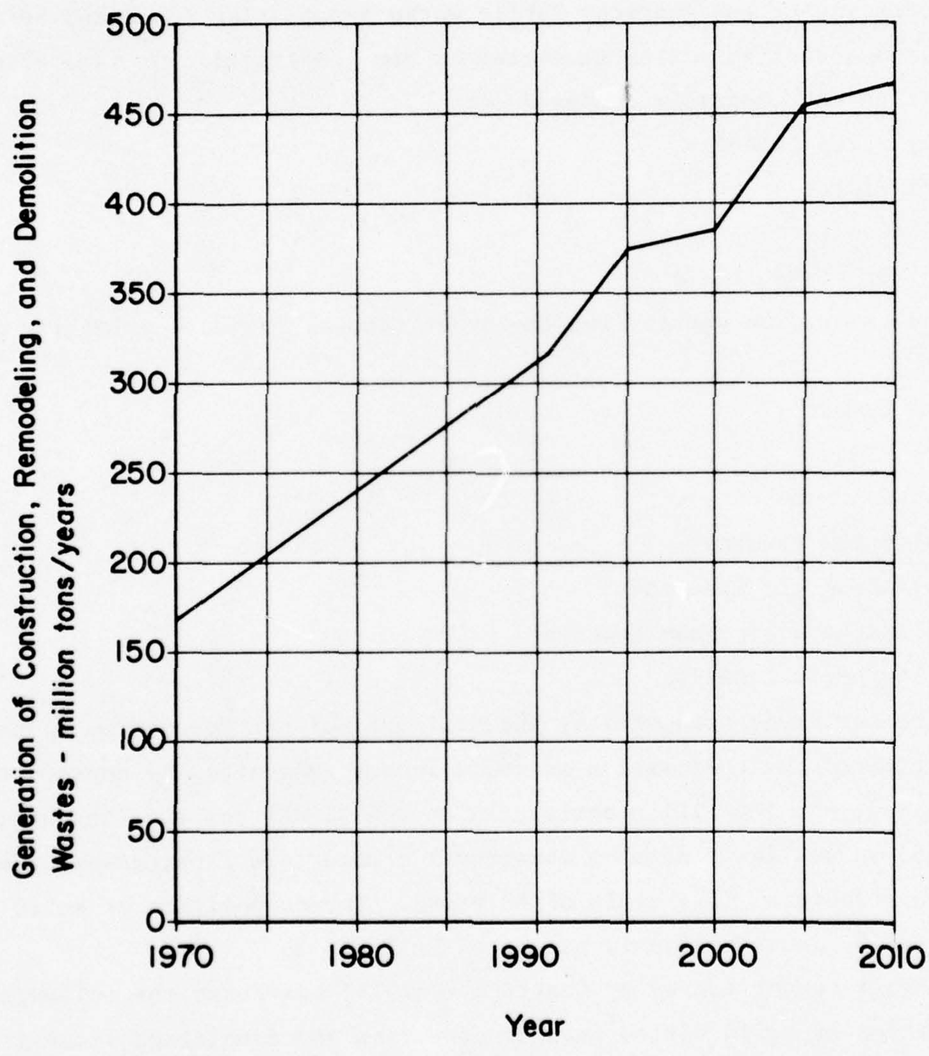

FIGURE 1. PREDICTION OF CONSTRUCTION, REMODELING, AND DEMOLITION WASTES GENERATED IN THE UNITED STATES (SOURCE: JONES, 1973)

TABLE 3. PREDICTION OF CONSTRUCTION, REMODELING, AND DEMOLITION WASTE COMPOSITION IN THE UNITED STATES

Materials	1990	2000	2010
	Percent by Weight	Percent by Weight	Percent by Weight
Concrete	69.77	74.78	76.91
Wood (Total)	13.51	11.10	9.79
Softwood Lumber	12.05	9.19	7.58
Hardwood Lumber	.62	.45	.13
Softwood Plywood	.43	.95	1.44
Insulated Board	.29	.28	.28
Hardboard	.11	.18	.31
Hardwood Doors	.01	.05	.05
Gypsum Products	2.12	2.25	2.29
Clay (Total)	6.86	5.73	4.38
Clay (brick, floor tile, etc.)	5.93	5.09	3.96
Structural Tile	.39	.13	.03
Vitrified Clay Sewer Pipe	.54	.51	.39
Aluminum		.16	.24
Copper		.14	.09
Plastics			.29
Steel	7.74	5.84	6.01
Total Volume	315.34*	385.11*	464.22*

* The total volumes are expressed in million tons per year.

Source: Jones, 1973.

Many hazards may occur from unsafe handling of bulky construction wastes. The demolition wastes, if left unattended, become a dangerous playground for children. A major portion of the construction and demolition solid wastes is inert. However, the wood and metal components can cause significant health hazards as a result of open dumping or open burning. The public health significance of construction and demolition wastes is summarized in Table 4. The relative severity of construction solid waste hazards is shown in Table 5. The order of severity is 5, which is well below that for manufacturing solid wastes.

Little empirical research has been done hitherto to verify the estimated composition of solid waste. The present research program is, therefore, designed to collect data on waste composition from selected Army construction sites. The effort represents a mere beginning in the direction of more precise determination of the composition of construction and demolition solid wastes.

Disposal/Recovery Alternatives

The disposal of solid waste from construction and demolition activities is an important aspect of project management. According to many urban ecologists, "buildings are better considered temporary arrangements than permanent monuments and should be designed to be demolished or dismantled frequently to make way for new structures" (Collins, 1971). Such a policy can work only if methods are developed for reusing materials from demolition activities as raw materials for new construction. The demolition firms, however, need help in developing new technology and new markets needed for economical reuse of solid wastes from construction and demolition projects.

Basically, there are four major methods of solid waste disposal: (1) burying, (2) burning, (3) reuse or salvage, and (4) resource recovery. These alternatives are discussed below.

Burying

Most construction and demolition solid wastes are disposed of by burning or burying (Small, 1971). A recent study of four cities in New Jersey

TABLE 4. PUBLIC HEALTH SIGNIFICANCE OF CONSTRUCTION WASTES

Sources of Wastes	Types of Wastes	Known Public Health Significance
Inert Materials Brick Stone Concrete Wallboard Tile Glass Earth Plumbing fixtures	Ceramics, $CaSO_4$, glass, concrete, stone, brick, plaster, soil, sand	
Wood Plywood Lumber Laths Doors Window frames Structural timber Stumps Trees and trimmings Boxes Crates	Lignin and cellulose	1. Leaching to groundwater of aldehydes, ketones, etc. 2. Cause insects in landfill. 3. Cause hydrocarbon emissions.
Metal Structural shapes Castings Reinforcing bars Cable Nails Sheet metal Plumbing hardware Pipe Tubing Fabricated members Wiring	Fe, Al, Cu, Zn, Brass, Pb, steel	1. May leach to groundwater with acid water causing heavy metal contamination. 2. Asbestos fiber and glass dust are hazards to lung tissue and may be present in incinerator polluted atmosphere. 3. Demolition debris may be aesthetic nuisance if piled on land surface. 4. Surface dumps of demolition debris may harbor rodents, earwigs, and termites, thus producing an environmental, if not a public health hazard. 5. May appear in stack discharges when incinerated.
Miscellaneous Paper Roofing Floor covering Insulation	Rubber, plastics, glass, wool, paper, asbestos, cloth, asphalt, styrofoam	1. Leaching of phenol and organics to groundwater. 2. Asbestos fiber and glass dust are hazards to lung tissue and may be present in incinerator polluted atmosphere.

Source: G. G. Golueke and P. H. McGauhey, 1970.

TABLE 5. SEVERITY OF SOLID WASTE HAZARDS BY MAJOR INDUSTRIAL GROUP

SIC[a]	Industry	Order of Severity
19-39	Manufacturing	1[b]
10-14	Mining	2
40-49	Transportation, Communications, Sanitary Services, Electric, Gas	3
01-09	Agriculture	4
15-17	Contract Construction	5
50-59	Wholesale and Retail	6
60-67	Finance, Insurance, and Real Estate	7
70-99	Services	8[b]

Source: Spindletop Research, Inc., 1971.

(a) The SIC indicates the standard industrial classification of industries developed by the U.S. Bureau of Census.

(b) 1 = Most Severe 8 = Least Severe

shows that the construction and demolition wastes were dumped in sanitary landfills. In Rhode Island many old buildings have been burned, causing serious air pollution problems (Small, 1971).

The capacity of landfills can be greatly enhanced by shredding the wastes prior to disposal. Many different systems are being tested to demonstrate the feasibility of disposing of demolition wastes by shredding and compacting. A hammer shredder is being used in Tacoma, Washington, to improve the economics of sanitary landfill and reduce air pollution due to open burning.

Certain types of construction and demolition wastes can be compacted with a reciprocating ram compactor developed by Kostolich (1967). The machine is designed to handle up to 5,000 tons of solid waste per day.

Burning

Burning of solid waste is generally termed incineration. Incineration of wastes can seriously pollute the air and the environment. Open burning is banned in most states and as such will be discouraged in the future. Controlled incineration of demolition waste is one possible solution, though not the ultimate panacea.

There are many different types of controlled "smokeless incinerators" available for use. One such system is the Air Curtain Destructor which is suitable for use in densely populated residential areas (Anon., 1972c). The partially burned waste particles and odorous hydrocarbons are after-burned by the intense heat without any additional fuel. The system only emits clean, hot gases.

Another non-polluting incinerator is a "portable smokeless incinerator," developed by Camran Corporation in Seattle, Washington (Anon., 1973d). The system is being tested by California Department of Transportation for incinerating construction and demolition wastes.

Salvage and Reuse

There are several alternatives for salvage and reuse of demolition wastes. Certain construction wastes may also be salvaged and reused on the project. The reuse of salvaged materials holds great promise for the future. A recent survey of a major demolition junkyard showed that the following discarded materials were salvaged for sale (Small, 1974):

(1) Old bricks
(2) Wood: doors and windows
(3) Wood: beams
(4) Wood: cabinets
(5) Marble: window sills
(6) Glass fixtures: chandelier, globes, etc.
(7) Aluminum: doors and windows
(8) Steel: beams
(9) Switch boxes
(10) Wiring
(11) Metal: paint cans

Salvage and reuse of steel, aluminum and other metals are possible but are constrained by the economics of a given situation (Darnay and Franklin, 1972).

According to Small (1971), old bricks can be used in building new homes. The waste mortar can be used as a fill material. The leftover wet cement from construction sites can be taken back to the dealer for resale. The wet bags are piled up and covered to keep the cement moist. The cement can be sold for do-it-yourself driveways. Also, the concrete leftovers can be crushed and used as fill material.

The metallic wastes are also easily recycled (Small, 1971). The copper is so expensive that even the scraps can be sold. The cast iron and electric wirings can be sold back to the store.

The waste lumber can be used as framing and bracing materials for new houses (Small, 1971). The packaging materials and wooden crates, generally burnt at site, can be reused or recycled. Plastic pipes,* roofing materials, aluminum siding, and false styrofoam beams can be salvaged and reused. As such, these materials should be designed and manufactured for a longer life span (Small, 1971).

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* The reuse of plastic pipes is possible for inferior uses only. For instance, water pipes can be reused to build sewer lines. However, health standards currently prohibit their reuse on water mains. Also, sterilization of plastic pipes with alcohol or chemicals can be quite expensive.

Resource Recovery

Recovery of wastes is an important strategy for resource conservation and pollution abatement. There are many different alternatives for the recovery of construction/demolition wastes. The major alternatives are:

(1) Recycling of concrete (Buck, 1972)

(2) Building bricks from inorganic wastes (Anon., 1972a)

(3) Making concrete masonry blocks with refuse glass and cement (Phillips, et al., 1972)

(4) Building pavements with waste concrete and glass (Anon., 1972b)

(5) Manufacturing ceramic "Thixite" panels using glass, masonry rubble, and clay (Campbell and Shutt, 1973; MRI, 1974)

(6) Using shredded brush waste as mulch (Kiplinger, et al., undated)

(7) Using wood scraps and sawdust to make kitchen cabinets (Anon., 1973e)

(8) Using "prefabricated" structures* (Small, 1971)

(9) Using aluminum magnet separator system to recover aluminum, iron, and shredded fill material

Concise descriptions and the economics of these alternatives will be developed in the latter part of the study. The economic and process information is generally not presented in detail in available literature. As such, they have been developed by contacting selected operators of these recycling systems.

Disposal/Recovery Costs

There are few, if any, data in the available literature relating to the costs of disposal or recovery of construction and demolition solid wastes. The lack of such data has resulted in inadequate analysis of potential alternatives. Necessary data and predictive criteria will be developed as part of this research program.

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* Prefabrication of structures at the factory allows recycling of various types of wastes generated during fabrication. The wastes may be used at the plant or in another nearby factory. The volume of on-site scrap wood waste is also reduced as a result of prefabrication, since more wastes are generated by on-site fabrication.

CHAPTER II. CONSTRUCTION/DEMOLITION SOLID WASTE MANAGEMENT AT ARMY POSTS

There has been simply no study at all of construction and demolition solid waste management at Army posts. There is thus little documentation of the volumes and composition of solid wastes generated by these activities. Nor is there any reliable data on the costs of managing construction and demolition solid wastes.

The present study represents a first step towards developing reliable and useful information on solid waste characteristics and management costs for selected Army construction and demolition activities. To develop this information, two Army posts were selected by the Construction Engineering Research Laboratory (CERL) for detailed investigation. The posts are Fort Campbell, Kentucky, and Fort Hood, Texas. Both Army posts have many different construction projects currently underway. As such, they provided an opportunity to study generation and disposal of solid wastes for many different classes of facilities.

Data Collection Procedure

Data on construction and demolition solid waste have been collected from the two Army posts, using the following survey procedures:

- Inspection of construction sites
- Interview with site managers

The construction sites were inspected to determine the extent and types of solid wastes being generated by various activities. A visual assessment was also made of the problems relating to collection, transportation, and disposal of solid wastes from construction sites.

The site managers were then interviewed to determine their perceptions of the volume and composition of solid wastes, and their disposal costs. The interview content procedure was determined by careful considerations of facts that could be answered fairly accurately by the site managers. The sequence and substance of questions asked by the investigator are summarized in Table 6. In some cases, a copy of the "Request for Information Form," shown in Table 6, was left with the site managers to enable them to verify the information with the help of their aids and/or subcontractors.

TABLE 6. REQUEST FOR INFORMATION FORM

1. Please state your name, address, and telephone number:

2. What structures are you planning to build:

3. What is the total usable space or covered area (in sq. ft.):

4. What materials will you use and how much:

Concrete	cu. yds.
Wood	cu. yds.
Gypsum Board	sq. yds.
Bricks	cu. yds.
Asphalt Shingles	
Prefinished Panels	

What percent of above materials are wasted on the job to the best of your knowledge:

5. How many truckloads of solid waste are to be disposed of per week to the landfill:

What is the volume of one truckload:

How many weeks will be needed to complete the project:

6. What is the percentage (by volume) of various materials that is present in the waste:

Concrete	%	Packaging Materials (wood, crates, cardboard boxes)	%
Concrete Masonry	%	Wood	%
Bricks	%	Miscellaneous	%
Soil or Earth	%		

7. What is the cost of collection, transportation, and disposal of solid wastes from your construction site:

If you rented one truck for 8 hours, how much solid waste will you collect, transport, and dispose of:

What is the rent (8 hours) of the truck:

What is the cost of all labor (8 hours):

What is the rent (8 hours) of front end loader and other equipment needed:

What is the total cost of collecting, transporting, and disposing of solid wastes for 8 hours:

8. How is the waste disposed of:

9. Do you know other better ways of disposing of solid wastes from construction and demolition sites; give details and costs:

10. Did you do any demolition work at Fort Hood:

What structures did you demolish:

What is the total covered area of the structures: sq. ft.

What equipment did you use:

What demolition wastes did you generate and how many truckloads was it:

Concrete

Trees and wood

Steel

How long did it take to collect and dispose of solid wastes from the site:

The majority of the site managers were fairly enthusiastic in providing the needed information. Most managers appeared to overestimate their waste generation rates and disposal costs in order to defend their claim of burgeoning disposal costs. However, on the whole, the data were satisfactory, since they were found to be consistent with the rates of material usage and figures reported.

Fort Campbell

The Fort Campbell Army post is located in the state of Kentucky, approximately 50 miles north of Nashville, Tennessee (Figure 2). The post has a resident population of 24,000 and an effective population of 40,000. The effective population includes all resident population and 1/3 of the nonresident population working at the post.

The solid waste generated at the Army post, on an average, is 22,000 cubic yards per month.* The solid waste is collected in a loose form and weighs about 100 tons per day, assuming a density of 200 pounds per cubic yard.** This represents a waste collection rate of 8.5 pounds per capita per day.

There are two major small towns in the vicinity of Fort Campbell. The towns are: Clarksville, Tennessee, and Hopkinsville, Kentucky. The city of Clarksville had a population of 31,719 in 1970 and is increasing at a rate of 4.4 percent per year. The present (1974) population of the city is 37,500 persons. The city of Hopkinsville, on the other hand, had a population of 21,250 in 1970 and has been increasing at a rate of 0.92 percent per year. The present (1974) population of the city is 22,100 persons. The solid waste collection rate for both cities is in the order of 6 pounds per capita per day. The solid waste collected at Clarksville is about 115 tons per day, and at Hopkinsville, it is about 70 tons per day.

There are four major construction activities currently underway at Fort Campbell. The location of these facilities is shown in Figure 3.

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* The data have been furnished by Robert Anderson, Deputy Facilities Engineer at Fort Campbell, Kentucky.

** Bond, R. G., and C. P. Straub (1973), p 25.

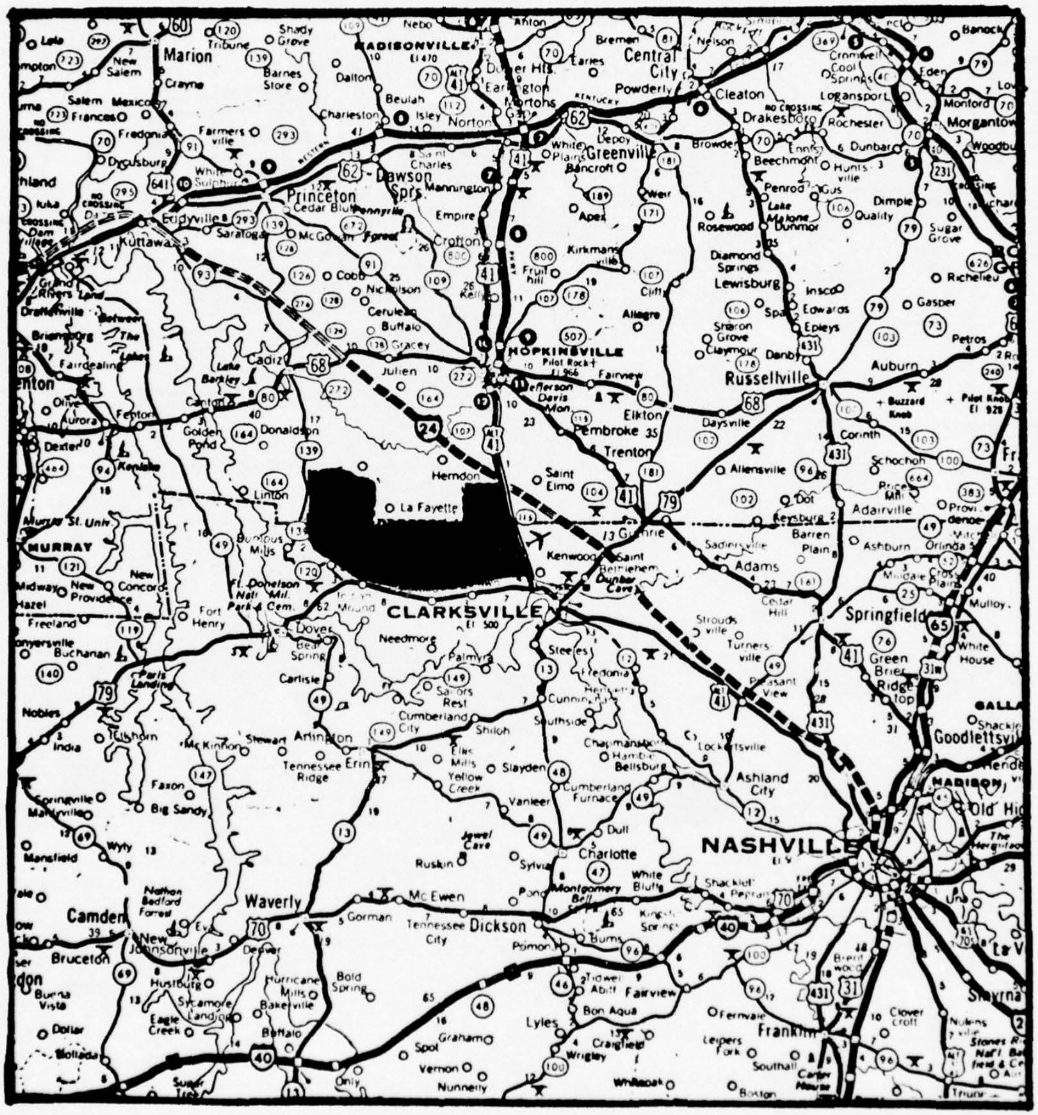


FIGURE 2. LOCATION OF FORT CAMPBELL, KENTUCKY

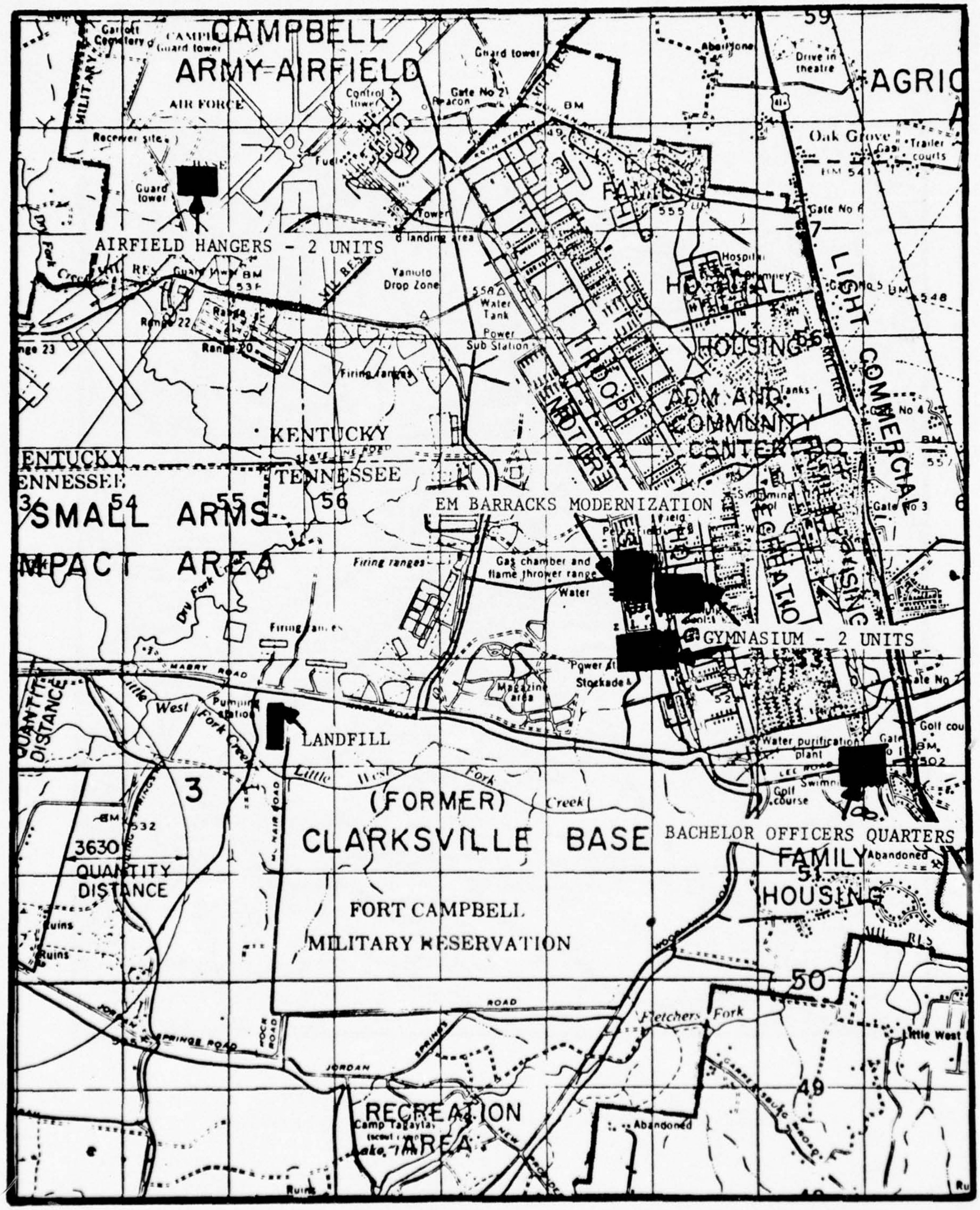


FIGURE 3. CONSTRUCTION SITES AT FORT CAMPBELL, KENTUCKY

The solid wastes from the existing construction projects are transported to and disposed of at the landfill located near the Little West Fork Creek on the McNair Road.

The characteristics and disposal costs of construction and remodeling solid wastes are summarized in Table 7. The summary information has been developed based on raw data collected by interviewing site managers at the four construction projects in June 1974.

Fort Hood

Fort Hood is a military installation located west of Killeen, Texas, along Highway 190. The post is 65 miles north of Austin and about 60 miles south of Waco (Figure 4). Fort Hood is the free world's largest armor post and covers an area of 340 square miles. The resident population of the post is 54,000, and the post supports about 110,000 people in the area.

The solid waste disposed of at the Army post in 1973 was about 225 tons per day. It had a loose density of 200 pounds per cubic yard.* This represents a waste collection rate of 9.3 pounds per capita per day.

Killeen is the largest city in the vicinity of Fort Hood. The town is located adjacent to the Army post and is entirely dependent on the post for its economic sustenance. The 1970 population of the city was 35,507; it has been increasing at a rapid rate of 5.2 percent per year. The present (1974) population is 42,900. The solid waste collection rate for the city is about 6 pounds per capita per day (Bond and Straub, 1973). Therefore, the solid waste collected by the city of Killeen is 128 tons per day.

There are six major construction and demolition projects currently underway at Fort Hood. The location of these facilities is shown in Figure 5. The solid wastes from these construction sites, as a rule, are trucked to and disposed of in a landfill located on the northwest side of the post. The domestic and other post solid wastes are dumped in a separate landfill in the vicinity.

The characteristics and disposal costs of construction, remodeling, and demolition solid wastes are summarized in Table 8. In all, only two

* The figure was provided by Major R. Sevcik of Fort Hood, Texas.

TABLE 7. CONSTRUCTION/DEMOLITION SOLID WASTE CHARACTERISTICS AND DISPOSAL COSTS AT FORT CAMPBELL, KENTUCKY

Construction Sites	Facility Parameters			Solid Waste Quantities				Composition of Solid Wastes			Major Costs of Waste Management*	
	Facility Class	Facility Size**	Construction Type	Duration (Days)	Volume (Cu. Yds.)	Weight (Tons)	Gen. Rate (Tons/Day)	Waste Components	% Volume	% Weight	Cost Element	$/Ton
(1) Airfield Hangars (two hangars, pavement, runways etc.)	Operational Facilities	4.0 acres $6.5 million	Concrete and steel frame	240	225	375	1.60	Concrete	50	56	Capital Cost	7
								Concrete Masonry	--	--	Labor Cost	10
								Wood	10	8	Total Estimated Cost	17
								Packaging Materials	5	2	Perceived*** Contractor Cost	15
								Steel Scraps	2	8		
								Soil	30	24		
								Miscellaneous	3	2		
(2) Bachelor Officer's Quarters (BOQ) (Two story, 6 units)	Troop Housing	0.9 acres $1.8 million	Concrete (1st floor) and wood frame (2nd floor)	340	8,150	1,100	3.25	Concrete	2	2.5	Capital Cost	7
								Concrete Masonry	1	0.5	Labor Cost	10
								Wood	22	10.5	Total Estimated Cost	17
								Soil	74	86		
								Miscellaneous	1	0.5	Perceived*** Contractor Cost	75
(3) EM Barracks Modernization (27 buildings)	Troop Housing	25.0 acres $12.1 million	Remodeling and renovation	480	38,500	5,200	11.0	Concrete	21.5	35	Capital Cost	6
								Wood	60	35	Labor Cost	9
								Sheet Rocks & Tiles	7.5	10	Total Estimated Cost	15
								Steel Scraps	2.4	10		
								Soil	6	7		
								Miscellaneous	2.6	3	Perceived*** Contractor Cost	50
(4) Gymnasium (2 units)	Community Facilities	1.0 acres $1.3 million	Concrete and steel frame	320	8,112	4,000	12.0	Concrete	7	10	Capital Cost	6
								Packaging Materials	15	7	Labor Cost	9
								Soil	75	80	Total Estimated Cost	15
								Miscellaneous	3	3	Perceived*** Contractor Cost	5

* The wastes are trucked to a post landfill in all cases, except for airfield hangars whose wastes were used to fill a local ditch.

** The facility size is expressed in terms of total floor area and *total facility cost*.

*** Perceived contractor cost is the cost of waste management as reported by the contractor. In most cases, this cost is different from the cost estimated by the Battelle researchers based on data furnished during site interviews.

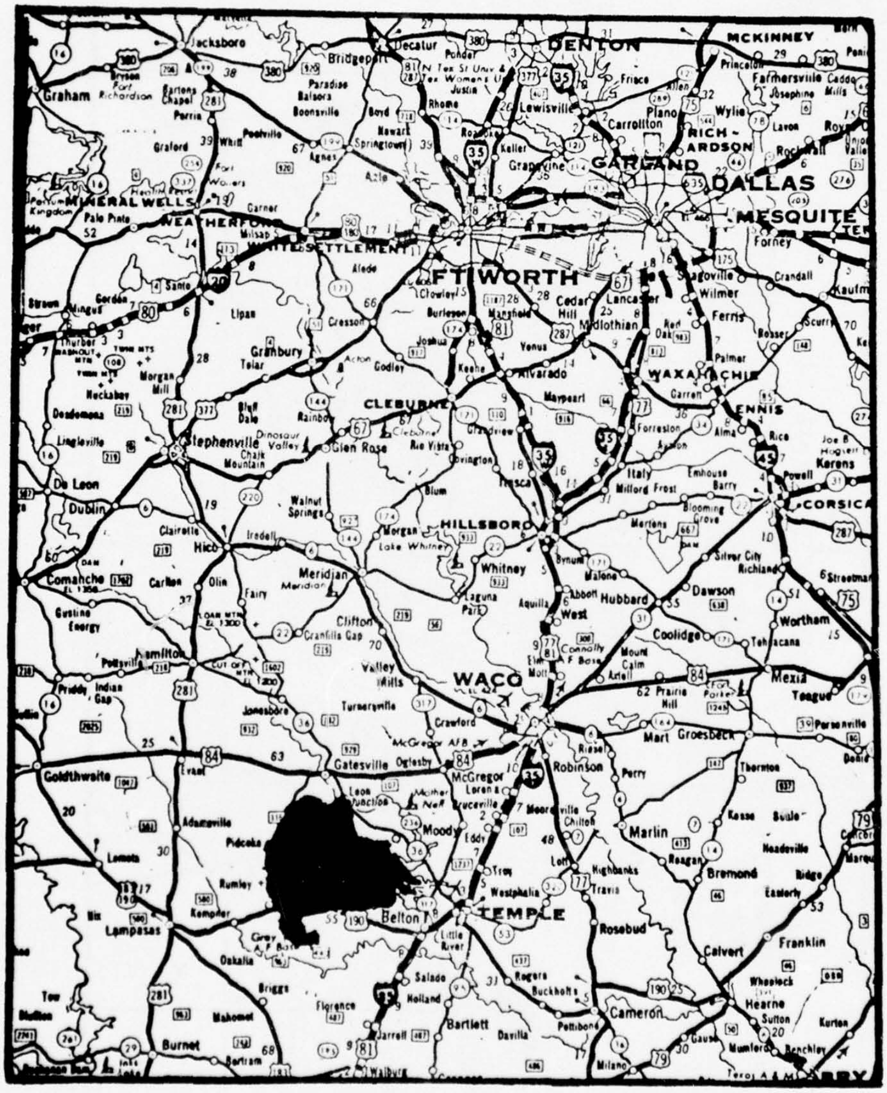


FIGURE 4. LOCATION OF FORT HOOD, TEXAS

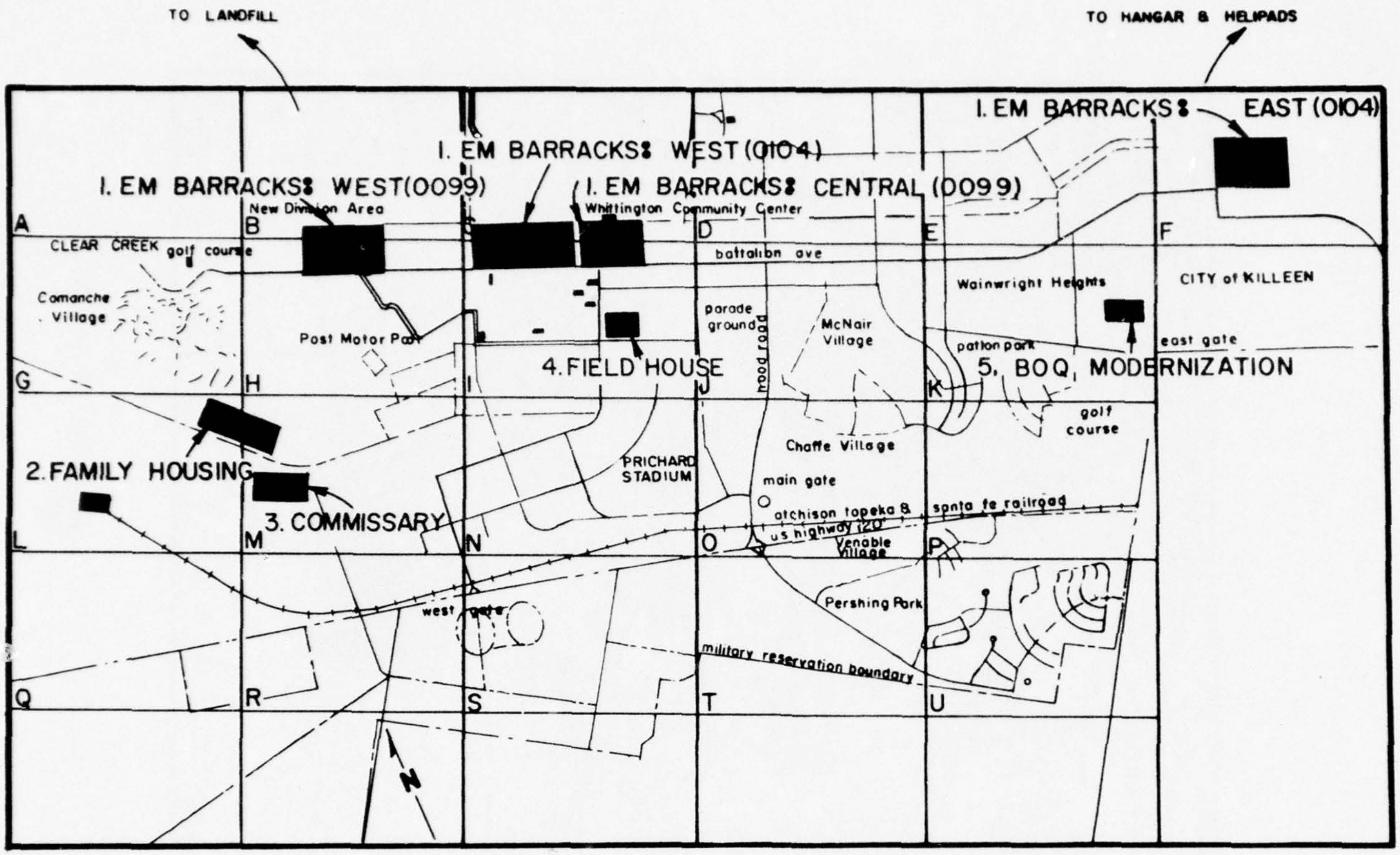


FIGURE 5. MAP OF FORT HOOD SHOWING LOCATIONS OF EXISTING CONSTRUCTION SITES

TABLE 8. CONSTRUCTION/DEMOLITION SOLID WASTE CHARACTERISTICS AND DISPOSAL COSTS AT FORT HOOD, TEXAS(a)

Construction Sites	Facility Parameters			Solid Waste Quantities				Composition of Solid Wastes			Major Costs of Waste Management	
	Facility Class	Facility Size(b)	Construction Type	Duration (Days)	Volume (Cu. Yds.)	Weight (Tons)	Gen. Rate (Tons/Day)	Waste Components	% Volume	% Weight	Cost Element	$/Ton
(1) Field House (Gymnasium)	Community Facilities	1.4 acres $2.2 million	Concrete Masonry Construction	430	2,718	2,750	6.4	Concrete	16	30	Capital Cost	6.0
								Concrete Masonry (including bricks)	33	50	Labor Cost	9.0.
								Bricks	--	--	Total Estimated Cost	16.5
								Wood	12	8	Perceived(d) Contractor Cost	25.0
								Packaging Materials	17	9		
								Miscellaneous	22	3		
(2) EM Barracks	Troop Housing	18.7 acres $24.3 million	Brick/Concrete Masonry Construction	100	9,000	11,028	110	Concrete	5	8	Capital Cost	4.3
								Concrete Masonry	55	62	Labor Cost	4.3
								Bricks	10	13	Total Estimated Cost	10.6
								Wood	5	3	Perceived(d) Contractor Cost	8.2(c)
								Packaging Materials	15	7		
								Soil & Earth	5	6		
								Miscellaneous	5	1		
(3) Commissary	Community Facilities	3.0 acres $4.1 million	Concrete Masonry Construction	50	1,600	1,827	36.5	Concrete	1	2	Capital Cost	5.8
								Concrete Masonry	70	87	Labor Cost	8.1
								Wood	5	3	Total Estimated Cost	13.9
								Packaging Materials	10	5	Perceived(d) Contractor Cost	28.6
								Soil & Earth	2	2		
								Miscellaneous	12	1		
(4) Family Housing (1000 units)	Family Housing	151 acres $19.5 million	Brick/Concrete Masonry Construction	350	11,860	15,107	44	Concrete	10	15	Capital Cost	5.7
								Concrete Masonry	3	3	Labor Cost	7.8
								Bricks	3	4	Total Estimated Cost	13.5
								Wood	4	2	Perceived(d) Contractor Cost	10.0
								Packaging Materials	2	1		
								Soil & Earth	70	74		
								Miscellaneous	8	1		

(a) There is no land cost involved since the land for disposal is available at the Army post.

(b) The facility size is expressed in terms of total covered area and total project cost.

(c) The construction and demolition wastes are trucked and disposed of in an open dump. The wastes are compacted by a bulldozer in the landfill. The compaction cost is not paid by the contractor.

(d) Perceived contractor cost is the cost of waste management as reported by the contractor. In most cases, this cost is different from the cost estimated by the Battelle researchers based on data furnished during site interviews.

demolition activities have been studied, both at Fort Hood. The summary information has been developed based on raw data furnished by the site managers during an on-site interview in August 1974.

Regulation of Open Dumping

Regulations have been established to control open dumping in Kentucky and Texas. The construction and demolition solid wastes are generally disposed of by open dumping at the Army post. As such, these regulations are relevant to the Army construction/demolition activities.

The state of Kentucky requires a state permit in order to establish, construct, operate, maintain, or use a solid waste disposal site or facility. The permit is administered by the Department of Natural Resources and Environmental Protection Agency under the revised statutes Chapter 224 of the Kentucky Environmental Protection Law.

The Texas Industrial Solid Waste Order No. 71-0820-18, issued by the State Water Quality Board, requires a state certification to own or operate a disposal site for commercial purposes. As such, the Army posts do not require this certification. However, current public hearings may alter this situation.

Yet, the Army posts may not be required to obtain state permits in the future. The U.S. Court of Appeals ruled on June 5, 1974, that the Clean Air Act does not require Federal facilities to obtain state air pollution control permits (Commonwealth of Kentucky vs. Ruckelshaus). However, the U.S. Army facilities are compelled to comply with the substantive requirements of the state permit policy and implementation plan.

As such, it is essential that the Army take necessary measures to ensure compliance of its open dumps with state standards. The preliminary examination of the two Army post's open dumps showed that they are not fully in compliance with the standards. During future investigation, attention should be paid to the recovery of resources from these waste piles.

Analysis of Data

The data presented in Tables 7 and 8 are graphically plotted in order to relate the volume of solid waste to the parameters of facility size like covered area and facility cost. Also, the cost of waste management is related to the rate of waste generation. The relationships are shown in Figures 6, 7, and 8. These relationships are based on limited data and should be improved and refined further through additional data collection and measurement work.

In Figure 6, there are no data points below 0.9 acres of floor area. As such, the exact nature of the plot cannot be defined. However, two possible extreme plots of solid waste volume for floor areas less than 0.9 acres are shown by dotted lines. Future research must attempt to define the exact nature of the plot in this zone. Also, for floor areas greater than 110 acres, the exact nature of the plot is not known; the dotted curve is a mere extrapolation of the lower trend. Figure 6 also shows that the volume of solid wastes for airfield and hangers is about 1/10 of other vertical structures like barracks, family housing, etc. Figure 7 shows a similar relationship between solid waste volume and cost of facility.

The cost estimates presented in Tables 7 and 8 and Figure 8 are based on the following assumptions:

- The wastes are collected at least once a week from each construction site. The estimated costs are therefore averaged over a week.
- The collection and pickup of small volumes of wastes (less than 40 TPD) are done manually, using labor, hand carts, and hoppers.
- The collection and pickup of wastes of larger volumes (greater than 40 TPD) are done mechanically, using front-end loaders and a truck.
- The labor cost is usually about $3 per person per hour.
- The wages paid to a truck driver are usually about $10 per person per hour.
- The wages paid to a front-end loader driver are usually about $15 per person per hour.
- The rent of a truck is generally $10 per truck per hour. The volume of a truck is generally 5 cubic yards.
- The hopper or a storage bin can usually be rented for $5 per hopper per day.
- A front-end loader can be rented for $15 per loader per hour.
- A truck can usually transport wastes to the landfill about four times a day. This assumes that the landfill is located about 5 miles from the site. On both the Army posts, this distance is less than 5 miles.

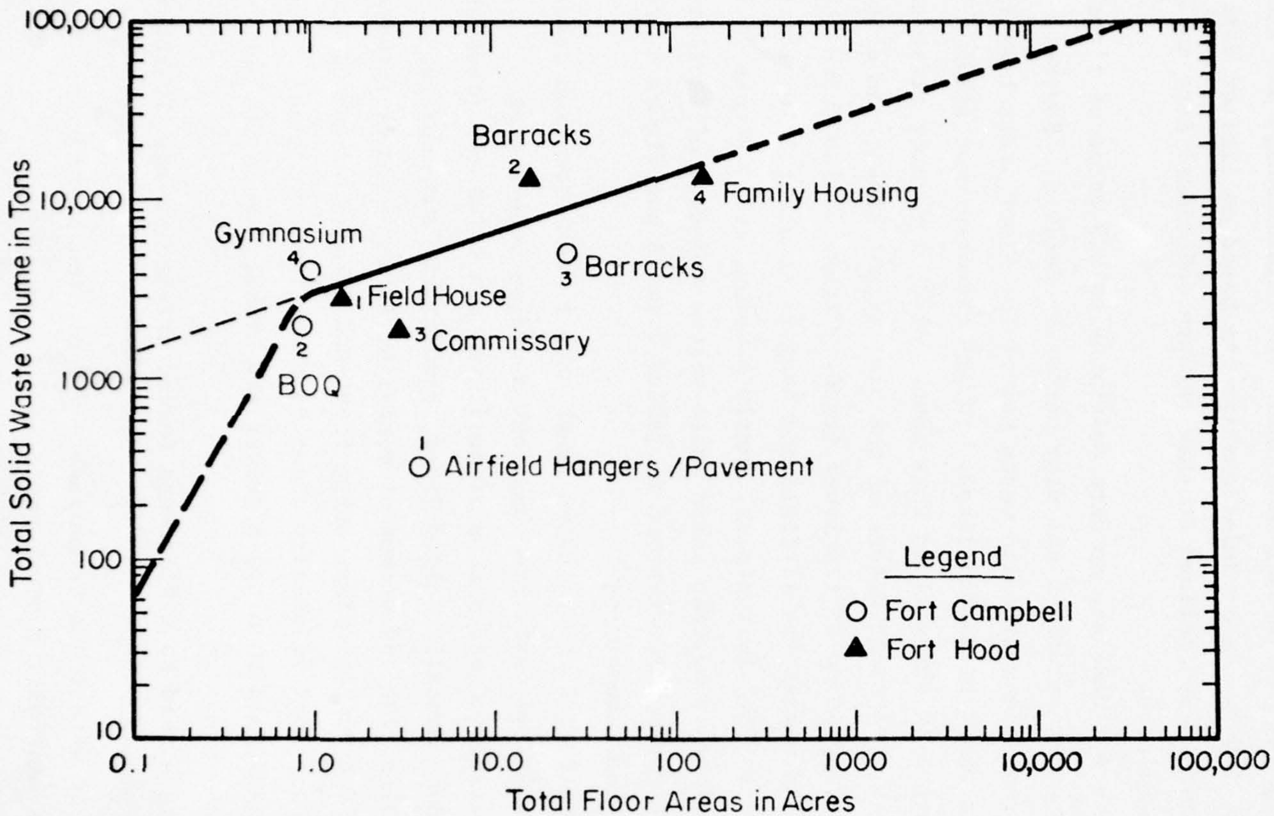


FIGURE 6. TOTAL SOLID WASTE VOLUME VERSUS FLOOR AREA RELATIONSHIP

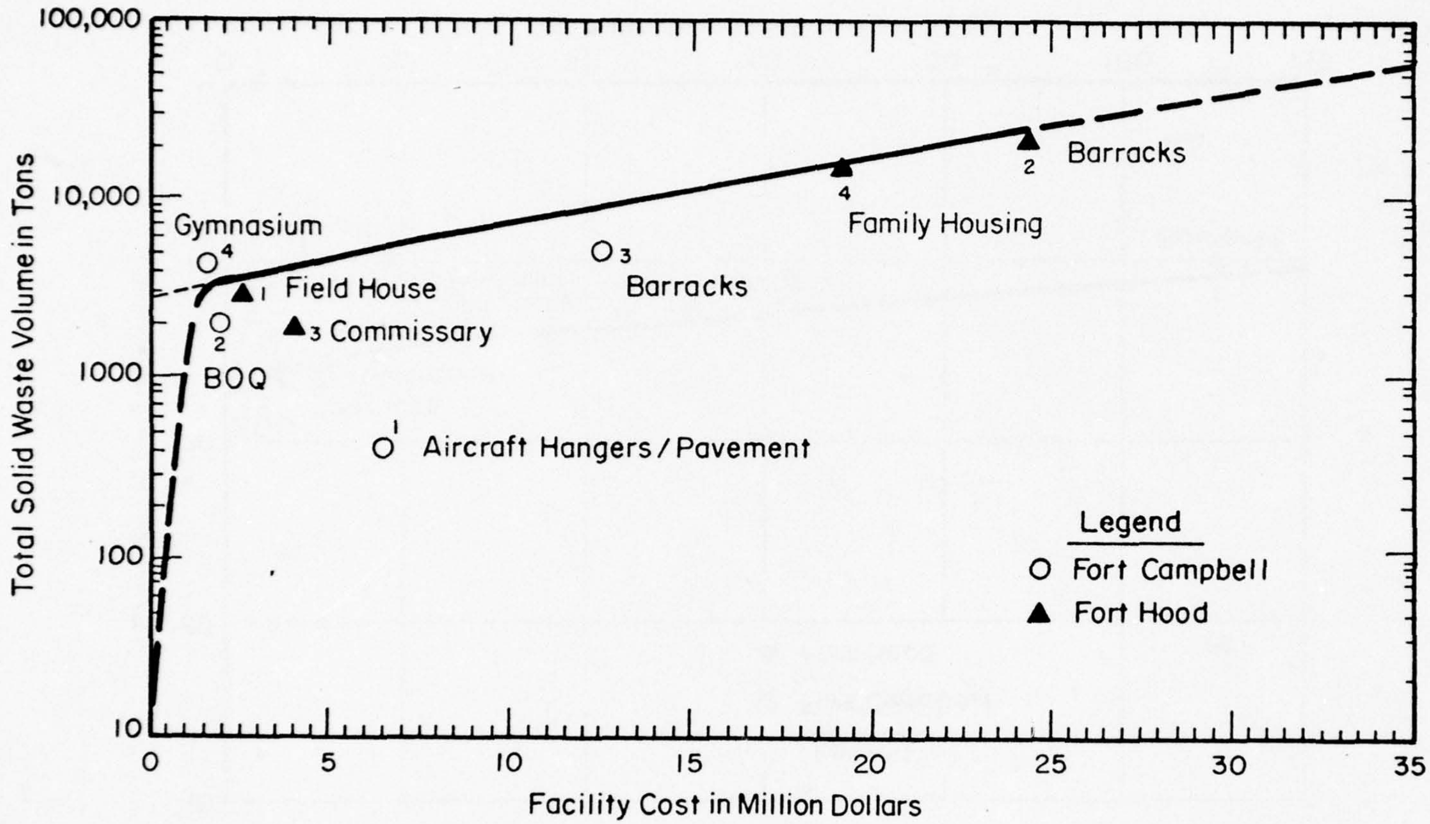


FIGURE 7. TOTAL SOLID WASTE VOLUME VERSUS FACILITY COST RELATIONSHIP

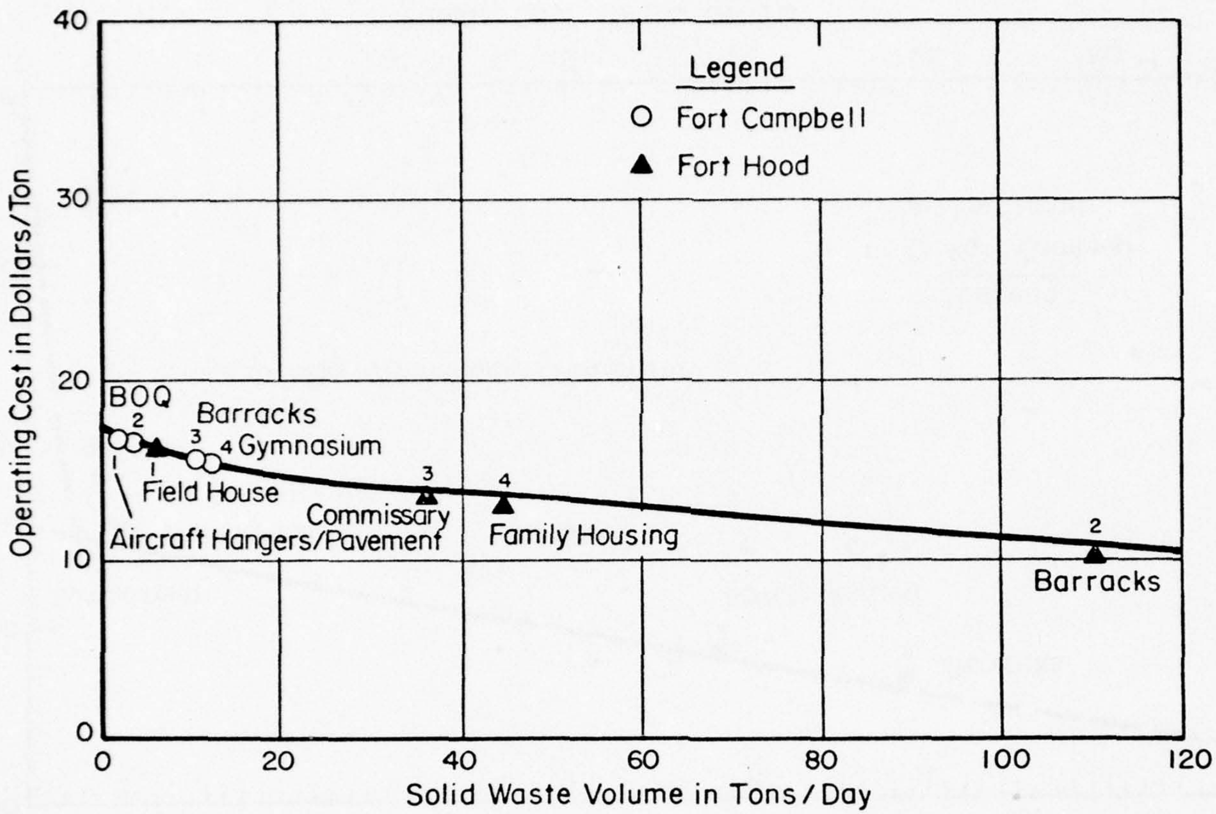


FIGURE 8. SOLID WASTE MANAGEMENT OPERATING COST VERSUS VOLUME RELATIONSHIP

• The cost of maintaining a landfill is usually quite nominal, i.e., about $2 per ton. No precise data were furnished by the post officials on the cost of landfill operations.

• On an average, it takes about 15 minutes to load a 5-cubic-yard truck using a small "Bob Cat" front-end loader. A large loader takes less time--about 8 to 10 minutes. Furthermore, it takes about 30 minutes to pick up and gather 5 cubic yards of sparsely scattered solid wastes from a construction/demolition site.

• The land for disposal is generally provided at no cost by the Army.

Conclusions

The data collected and analyzed in this section represent a pioneering effort to study the construction and demolition solid wastes at selected Army posts. Useful observations regarding this study are summarized below:

• In the absence of better data, the information presented in Figures 6, 7, and 8 may be used to generally indicate waste volumes and management costs.

• The waste composition data for various facilities are shown in Tables 7 and 8, which may be used for purposes of planning and prediction.

• Further investigation and measurement of solid waste volumes are needed to establish reliable solid waste generation rates.

• Further data collection and analysis may be devoted to the development of statistical formulas that relate waste generation rate and management costs to potential facility variables.

• Investigation of selected Army post open dumps should be made to ensure compliance with state standards and recovery of wastes.

CHAPTER III. ASSESSMENT OF WASTE MANAGEMENT ALTERNATIVES

Many different categories of wastes are generated by various construction operations (See Table 9). Basically, there are three major types of disposal alternatives for construction and demolition wastes: (1) waste-to-landfill alternatives, (2) incineration, and (3) resource recovery. Specific disposal alternatives, identified during this research program, are summarized in Table 10.

In addition, the assessment methodology and details of specific alternatives are described in the following subsections.

Methodology

The basic assessment methodology for each disposal alternative involves development of a brief profile on the technical and economic aspects of a given process. The technical aspect describes the basic process, equipment, and operational characteristics of each disposal alternative. The economic aspect documents, in some detail, the various capital and operating costs involved in using these alternatives. Other relevant factors to be considered in the selection of disposal alternatives are discussed briefly in the subsections on "Advantages and Disadvantages."

The profiles on each disposal alternative are presented in the following sections.

Waste-To-Landfill Alternative

Waste to landfill is a major disposal alternative for construction and demolition wastes. This study of selected Army posts shows that it is the most common disposal alternative. There are two major types of landfill that are utilized for the disposal of construction/demolition solid wastes. These are separate open dumps and sanitary landfills.

Separate Open Dumps

Separate open dumps are extensively used for the disposal of construction and demolition wastes. About 13 percent of the construction

TABLE 9. CONSTRUCTION WASTE CATEGORIES

Operation	Sub-Operation	Wood	Veg.	Paper	Metal	Concrete	Masonry	Bitumen	Rock	Soil	Other
		Waste Categories									
Site Assessment And Exploration			X	X	X						
Site Survey and Layout		X	X	X	X						
Site Access	Land	X	X		X	X		X	X	X	
	Water	X			X	X			X		Rubber
	Air		X						X	X	
Site Support Facilities	Asphalt Plant							X	X		Sediment Cutback
	Quarrying								X		Sediment
	Aggregate Production								X		Sediment Dust
	Concrete Production	X		X	X	X			X		Sediment Dust Cement Fiberglass
	Foundry and Metal Shop			X	X				X		
	Carpentry Shop	X		X	X						
	Service and Maintenance			X	X						Glass Plastic Cloth
	Quality Control Laboratory	X		X	X	X	X	X	X	X	
	Sawmill	X		X	X						Plastic Nylon Twine
	Personnel Support Facilities	X		X	X						Glass Plastic Garbage Cloth
	Sewage and Runoff Disposal Facilities										Sediment
Site Clearing	Vegetation Removal		X								
	Existing Structure Removal	X			X	X	X	X	X		
	Fencing	X			X	X					
Site Excavation and Grading	Earthmoving								X	X	
	Surface Runoff Control		X		X	X	X		X	X	Plastic Jute Sediment

TABLE 9. (Continued)

Operation	Sub-Operation	Waste Categories									
		Wood	Veg.	Paper	Metal	Concrete	Masonry	Bitumen	Rock	Soil	Other
	Groundwater Control				X	X	X		X	X	Grout Sediment Plastic
Structures Fabrication	Building Materials	X		X	X	X		X			Burlap
	Roads	X			X	X	X	X	X		Glass
	Railroads	X			X	X			X		Glass
	Bridges	X		X	X	X			X		Dust Sediment Twine Plastic Styrofoam
	Tunnels	X		X	X	X	X	X	X	X	Dust Twine Plastic Styrofoam Sediment
	Dam	X		X	X	X		X	X	X	Dust Sediment Grout Glass Twine Styrofoam Plastic
	Waterways	X	X	X	X	X		X	X	X	Glass Twine Plastic Styrofoam
	Buildings	X		X	X	X	X	X	X	X	Glass Plastic Rubber Caulking Porcelain Glass wool Fiberglass Asbestos Carpet Twine Styrofoam
Landscaping			X	X	X	X		X	X	X	Burlap Glass Twine Plastic
General				X	X						Rubber Glass Plastic Styrofoam

Source: Prylon & Schanche, 1973.

TABLE 10. SUMMARY OF SELECTED WASTE MANAGEMENT ALTERNATIVES

Name of Process	Process Description	Cost Information: Capital Cost $/Ton	Operating Cost $/Ton	Revenues $/Ton	Net Operating Cost, $/Ton	Remarks
Waste-to-Landfill Alternatives	(1) Separate Open Dumps	0.40	0.50 to 0.90	--	--	This alternative may cause serious environmental problems.
	(2) Sanitary Landfill	0.80 to 2.00	1.50 to 3.00	--	--	This is a safer alternative, but it results in waste of resources.
Incineration	Waterwalled incinerator burns combustible solid waste to reduce volume to 10 to 30 percent	13,000 ($/Ton/Day)	2.50 to 6.00	2.00 to 4.00	0.50 to 2.00	This alternative converts wastes to energy; however, use of this system depends on the composition of available wastes.
Pyrolysis	Thermal conversion of the organic waste to burnable gas	10,000 to 18,000 ($/Ton/Day)	9.50 to 13.50	1.50 to 4.50	8.00	The process is still experimental; it also requires a large organic waste component.
Thixite Process, Lakewood, Colorado	(1) Crushed glass, concrete and bricks are mixed with certain proportions and fired at a temperature of 1500° F. Capacity: 242,000 panels/year	6.00 million (entire plant)	17.60	20.60	3.00 (Profit)	Operation still experimental. A prototype plant will be developed soon.
	(2) A tile making equipment for conventional brick manufacturer (See Appendix C)	10.00 thousand (Equipment installation cost)	0.45 per sq. ft. tile	2.00 per sq. ft. tile	1.55 per sq. ft. tile (Profit)	Operation still experimental. A prototype plant is being developed in San Francisco, California, and Albuquerque, New Mexico.
Waste-to-Bricks Process--Tekbricks (Lake Park, Georgia)	It includes a pulverizer, a mixer, a high-pressure mold. Complete automation. Capacity: 25 million bricks per year	1.90	13.00	15.00	2.00 (Profit)	A plant is in operation in Atlanta, Georgia. Should be studied for possible implementation in future.

TABLE 10. (Continued)

Name of Process	Process Description	Cost Information: Capital Cost $/Ton	Operating Cost $/Ton	Revenues $/Ton	Net Operating Cost, $/Ton	Remarks
Ecological/Recycled Pavements	Crushed waste concrete and glass can be mixed in proper grading and proportion with bituminous binder or cement and water to produce an excellent paving material	--	2.50 to 10.50 per sq. yds. pavement	--	--	Experimental system. Has been tested in one prototype operation.
Wood Waste-to-Energy Alternative	Hydrogenation of wood to low-sulfur oil	NOT AVAILABLE YET			Expected to be Profitable	A prototype will be tested shortly.
Mulching	Brush and wood wastes can be shredded to form topsoil and seeding mulch	600 ($/Ton/Day)	4.00	5.00	1.00 (Profit)	Certain technical problems of using wood waste as mulch need to be resolved.
Pulverizer	Stationary shredder for bulky wastes. Capacity: 100 Ton/Hour	0.95 million (entire plant)	2.84	--	--	Assumes one shift operation. This is one of the most economic pulverizers available for use.
Handling of Special Waste	Containerized disposal into landfills	--	0.25 per gallon	—	--	Possible to share existing hazardous waste disposal facility or a sanitary landfill.
Integrated Management	(1) Union Electric supplementary fuel system	6,000 ($/Ton/Day)	6.05	5.45	0.60	Recycling of wasted resources makes it a profitable venture.
	(2) Bridgeport, Conn., supplementary fuel and dry separation processes	27,000 ($/Ton/Day)	11.00	4.00	7.00	If the cost of collection and disposal is less than $7 per ton, such systems can be profitable and make more effective use of resources.

and demolition wastes consist of wood and related products that are combustible. As such, operation of separate dumps is generally accompanied by continuous or periodic burning.

Open dumps usually require small capital and operating costs. The cost of dumping is expressed as

$$DC = LC + OC$$

where

DC is the cost of dumping (\$/ton)

LC is the land cost (\$/ton)

OC is the operating cost.

The land required for open dumping is usually more than that required for sanitary landfills. The waste is generally compacted before being sent to a sanitary landfill. For an average mixed construction waste, the land cost is determined by the following formula:

$$LC = 0.31 \times \frac{6}{D} \times \frac{L}{1200}$$

where

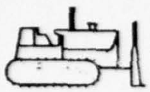
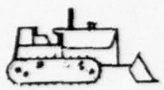
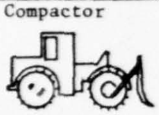
D is the average depth of fill in feet

L is the cost of land in \$/acre.

The land cost is about 31 cents per ton when land is purchased for \$1200 per acre and the average depth of fill is 6 feet.

The operating cost consists of equipment, power, and labor costs. The equipment cost generally varies with the type of equipment used. The various types of equipment and their capabilities in landfill operations are summarized in Figure 9. Also, Table 11 shows the variations in the capital cost of this equipment. The power and labor costs for this equipment may also vary.

The operating cost generally ranges between 10 to 50 cents per ton (Staff of Research and Education Association, 1973). For the highest cost combination of equipment, labor, and power costs, the operating cost can be about 25 cents per ton. On the other hand, the cheapest combination of these factors results in the lowest operating cost. However, the average operating cost of a separate open dump is about 15 cents per ton. This is a small fraction of the total cost of collection and disposal estimated for the Army posts.

	Solid Waste		Cover Material			
	Spreading	Compacting	Excavating	Spreading	Compacting	Hauling
Crawler Dozer 	Excellent	Good	Excellent	Excellent	Good	Not Applicable
Crawler Loader 	Good	Good	Excellent	Good	Good	Not Applicable
Rubber-Tired Dozer 	Excellent	Good	Fair	Excellent	Good	Not Applicable
Rubber-Tired Loader 	Good	Good	Fair	Good	Good	Not Applicable
Compactor 	Excellent	Excellent	Good	Excellent	Excellent	Not Applicable
Scraper 	Not Applicable	Not Applicable	Good	Excellent	Not Applicable	Excellent
Dragline 	Not Applicable	Not Applicable	Excellent	Fair	Not Applicable	Not Applicable

Source: Glysson, et al., 1972. Reprinted with permission.

FIGURE 9. RATINGS FOR LANDFILL EQUIPMENT CAPABILITIES

TABLE 11. SANITARY LANDFILL EQUIPMENT PRICES (OCTOBER 1974)

Type	Operating Weight (lbs)	Storage Volume (cu yds)	Blade Size (feet-inches)	Approximate Price (Dollars)
Track/Crawler Loader	12,400	0.75 - 1.25		18,000
	16,700	1.50 - 1.75		25,600
	18,000	1.25 - 1.75		28,000
	27,000	2.00		37,000
	33,000	2.25		47,000
	50,000	3.25		72,000
	52,000	3.00		60,000
Track/Crawler Dozer	11,000		6'8"	16,300
	14,500		7'6"	24,000
	16,000		8'	26,000
	30,000		9'10"	62,000
	45,000		11'	78,000
	48,000		11'9"	70,000
	69,000		13'	116,000
	70,000		12'7"	98,000
	92,000		14'6"	165,000
	140,000		17' or 20'	230,000
Wheel/Rubber-Tired Loader	20,000	2.00		36,000
	22,000	2.50		37,000
	26,000	3.00		47,000
	37,000	4.00		70,000
	37,000	3.00		70,000
	41,000	4.50		80,000
	51,000	5.00		86,000
Wheel/Rubber-Tired Dozer	40,000		14'	65,000
	66,000		14'	112,000
	80,000			150,000
	144,000			190,000
Compactor	30,000	4.50		58,000
Scraper	34,350	9.00		54,000
	30,000	11.00		64,000
	46,500	15.00		85,000
	51,100	15.00 - 21.00		110,000
	90,000	24.00 - 33.00		185,000
Draglines	35,000	0.75 - 1.25		63.700
	52,000	1.00 - 1.75		77,600
	67,000	1.25		85,000
	97,000	2.50		130,000
	250,000	5.00		255,000

<u>Advantages and Disadvantages</u>. The advantage of a separate open dump is that it is the cheapest disposal alternative for small volumes of solid wastes. Also, since the construction wastes contain little or no toxic leachates, open dumping is safe from the standpoint of groundwater pollution.

However, the disadvantages of an open dump are many. Some of these are:

(1) Requires substantial land

(2) May cause serious fire hazard

(3) May cause health hazard

(4) May be unsightly

(5) May cause mal-odors

(6) May affect neighboring property values

(7) May cause serious air pollution problems

Generally, the disadvantages of an open dump greatly outweigh the advantages. Hence, they are not usually recommended.

<u>Sanitary Landfills</u>

Improvements over open dumping have resulted in two basic types of landfilling. These are:

(1) Sanitary landfills

(2) Modified sanitary landfills

Sanitary landfills place earth covering over solid wastes on a daily basis. On the other hand, the modified sanitary landfills apply earth covering on solid wastes only occasionally.

The construction and operation of the various types of sanitary landfills have been discussed in detail in the following texts:

(1) Staff of Research and Education Association, "Pollution Control Technology," 1973, pp 492-501.

(2) Charles Vigh, "Sanitary Landfill Location and Design," 1973.

(3) Brunner, D. R., and D. J. Keller, "Sanitary Landfill Design and Operation," U.S. Environmental Protection Agency, 1972.

According to the Environmental Protection Agency (1974), the following factors should be taken into account in selecting the location of landfills:

(1) Public opposition

(2) Proximity to major highway routes

(3) Local and state speed limits

(4) Load limitations on public highways

(5) Bridge capacities

(6) Underpass limitations

(7) Number of stop lights and major intersections encountered

(8) Railway gates and intersections

(9) Haul distance (in hours)

(10) Local traffic pattern and congestion

(11) Detours, existing and proposed

(12) Large valleys, rivers, or other physical obstacles separating the landfill from major sources of waste

(13) Special events (like fairs, ball games, seasonal events, etc.)

(14) Recurring natural events (like annual flooding, excessive snowfall, drifting, mud slides, etc.)

The cost of sanitary landfills depends on the following factors:

(1) Land Cost ← (LC)

(2) Planning and Design Costs (PDC)

- Solid waste survey
- Site investigation
- Design, plans, specifications, etc.
- Permit application

(3) Site Development Costs (SDC)

- Land development (clearing, landscaping, drainage, etc.)
- Access roads
- Fencing and signs
- Grading
- Watermains
- Protection from groundwater pollution

(4) Facilities Cost (FC)

- Office
- Equipment maintenance sheds
- Personnel facilities
- Utilities
- Scale house
- Weight scales
- Yard lighting

- Apron pavement
- Repair equipment

(5) Equipment Costs (EC)

- Bulldozers
- Scrapers
- Graders
- Trucks
- Tractor/mower

(6) Operating Cost (OC)

- Personnel
- Planning and design
- Facilities maintenance
- Equipment operating expenses
- Equipment maintenance and repair
- Equipment rental, depreciations, or amortization
- Cover material cost
- Insurance
- Administration and overhead

The total cost of sanitary landfills (SLC) is expressed by the following formula:

$$SLC = C + OC$$

where

C is the Capital Cost in dollars/year

OC is the Operating Cost in dollars/year.

The capital cost (C) is given by:

$$C = LC + PDC + SDC + FC + EC$$

The capital is generally recoverable or repayable at 10 percent interest over 20 years. The corresponding annual amortization factor (AF) is about 0.1594. An additional 40 percent debt service reserve (DSR) may be charged to ensure that the revenues are higher than the theoretical debt service payments. A formula that converts capital cost in terms of dollars per ton (CT) is expressed as follows:

$$CT = \frac{C \times AF \times DSR}{S} = \frac{0.23}{S}$$

where

AF is 0.1594

DSR is 1.4

CT is Capital Cost in dollars/ton

S is the volume of solid wastes in tons/year

Representative cost data for predicting capital and operating costs of sanitary landfills are shown in Table 12. The capital and operating costs are broken up into four major components to assist planners in allocating funds for effective management of landfill projects. The cost data for small (Site 1), moderate (Sites 2 and 3), and large (Site 4) size landfills are presented in Table 12. The Site 3 landfill is more expensive compared to Site 2, since Site 3 involves an expensive system for groundwater pollution control.

Incineration

Modern incineration consists of controlled burning of solid waste in a closed chamber at a high temperature. The wastes are batch fed or continuously fed into the agitating grates leading to a primary combustion chamber. The burned exhaust gas and fly ash are released to a secondary combustion chamber to be burned at a temperature of 1500 to 1800° F. The burned gas is then passed through a settling chamber, a gas-cleaning device, and an exhaust stack.

Process

There are two basic types of incinerators generally in use today:

(1) Refractory-walled incinerator

(2) Water-walled incinerator

A refractory-walled incinerator consists of a combustion chamber lined with refractory walls and ceilings. The lining restricts the rate at which the material can be burned since it is dependent on the rate at which heat can be safely removed without causing damage to the incinerator. The desired cooling can be achieved by a high throughput of air that results in increased

TABLE 12. CAPITAL AND OPERATING COSTS OF SANITARY LANDFILLS

	Site 1 30 TPD		Site 2 500 TPD		Site 3 600 TPD		Site 4 2,500 TPD	
	Initial Cost ($1,000)	$/Ton	Initial Cost ($1,000)	$/Ton	Initial Cost ($1,000)	$/Ton	Initial Cost ($1,000)	$/Ton
Planning and Design	3	0.03			90	0.19	225	0.20
Site Development	22	0.22	430	0.16	400	0.84	970	0.20
Facilities	14	0.14	150	0.06	100	0.21	73	0.10
Equipment	50	1.25	350	0.54	246	0.52	240	0.40
Capital Cost	89	1.64	930	0.76	836	1.76	1,508	0.90
Debt Service		0.68		0.32		0.72		0.35
Operation Cost		0.25		0.20		0.20		0.15
Maintenance Cost		0.25		0.20		0.20		0.15
Total Cost		2.82		1.48		2.88		1.55

Source: U.S. Environmental Protection Agency (1974).

particulate pollution and requires more expensive air pollution control equipment. Due to these deficiencies, the refractory-lined incinerators have become totally obsolete.

The water-walled incinerator consists of a furnace whose walls are made of vertically arranged metal tubes connected side by side with metal fins. The boiler packages are located in the back passages of the incinerator to convert heat into steam. The volume of gas entering the air pollution control equipment in this case is about 25 percent of that for a refractory-lined unit. These incinerators require high-energy-drop scrubbers or electrostatic precipitators for air pollution control. The Chicago Northwest Incinerator tests have shown that these incinerators can meet the Federal particulate standard which is 0.08 grains per standard cubic foot. A suitable incinerator has the following key elements:

(1) A combustion chamber
(2) Metal grate
(3) Air blower
(4) Receiving and storage area for solid waste
(5) Firing system
(6) Fans and blowers
(7) Air pollution control system
(8) Exhaust stack
(9) Non-combustible ash-handling system
(10) Wastewater treatment process

A properly designed incinerator can reduce the volume of waste to as much as 10 to 30 percent of its original volume. The burned residue and non-combustibles are sent to a landfill or are separated by mechanical or magnetic devices for recovery of useful metals and other by-products.

Economics

The cost of incineration is based on data from several plants built between 1972 and 1973. The capital cost of water-walled units varies from $12,000 to $15,000 per ton of installed capacity. Operating cost data for water-walled incinerators are scarce. However, the figures appear to be comparable to refractory-lined incinerators. The operating cost of incinerators depends on the size of unit and the percent of capacity being used.

A 910 kgm per day typical conventional refuse incinerator in Chicago costs $6.60 per ton. A 1000 TPD incinerator in New York costs about $4.80 per ton. A new water-walled incinerator of similar capacity costs $2.40 per ton. The Washington, DC, incinerator has an average cost of about $3 per ton.

Comments

Pyrolysis is thermal degradation of organic substances in an oxygen-deficient atmosphere. The concept is currently under development by nearly 12 different private and public organizations in the United States. The available pyrolysis systems are: the Garret System, the Union Carbide System, the Torrax System, the Monsanto System, the LandGard System, the Battelle Gasification System, etc.

Construction wastes do not contain a high concentration of organic substances; as such, the pyrolysis systems may not apply to these wastes. The capital cost of pyrolysis systems varies between $10,000 and $18,000 per ton of daily capacity. The operating costs are expected to be in the range of $9.50 to $13.50 per ton. The revenues received from the sale of products may reduce the operating costs to as much as $8.50 per ton.

Advantages and Disadvantages

Generally, construction and demolition wastes are not incinerated, since they have a low content of combustibles. However, when a large number of trees are cut at a construction site, they may be disposed of by burning. At most Army posts, there are many small and medium-sized incinerators and numerous coal- and oil-fired boilers. It is, therefore, desirable to consider incineration of wood and other combustible wastes from construction sites in the coal-fired incinerators or boilers to recover energy from solid wastes. It is important to combine the elements of "separation" and "salvage" into a complete recycling system as an alternative to many expensive on-site incineration processes.

Production of Thixite* Panels

A new process has been developed to produce Thixite panels from waste concrete, bricks, and glass. This process avoids the problem of contaminated glass which has made glass recovery somewhat impractical (Campbell and Shutt, 1973). For areas with no nearby glass plants, it is uneconomical to salvage glass by hauling long distances for recycling.

Recent developments have made the recovery of glass, concrete, and bricks from demolition wastes potentially feasible (Midwest Research Institute, 1974). This is in contrast with the past research and development work which focused on the use of reclaimed glass, concrete, and bricks for highway paving. The Colorado School of Mines has developed a "vibrocast construction material," called Thixite, which is 94 percent solid waste. The Thixite Corporation in Lakewood, Colorado, manufactures and markets this product.

Although Thixite was originally developed as a means of using waste glass, it utilizes other solid wastes generated by demolition projects. Bricks, concrete, stones, slags, and other siliceous materials together with waste glass are used to produce Thixite.

The Thixite may be used for a variety of purposes. These include panel flooring, wall paneling, paneling window sills, and paving of parking lots, patios, and fences.

Process

Thixite manufacturing plants use common equipment and processes of the ceramic industry. The raw materials are crushed, ground, and sorted into fractions of different particle sizes. The fractions are combined in appropriate proportions with a small amount of water, vibrocast into the desired size and shape, and fired at relatively low temperatures. The mixture contains a minimum of 13 percent finely ground glass (which acts as a binder), 6 percent clay, and the remaining 81 percent may be crushed concrete or bricks.

---

* Registered trademark of Thixon Corporation.

The nature of the used waste largely determines the surface texture and appearance of Thixite. Ceramic dyes can be added to produce a variety of colors. Finished pieces can be sandblasted to various depths, smoothed, and polished.

Depending on the amount of glass and the nature of the non-glass, the properties of the finished Thixite may vary slightly. The samples tested so far show that the compressive strength and water absorption characteristics are better when high strength concrete waste is used.

Economics

The estimated costs of producing Thixite are based on limited data. The costs are presented in terms of capital and operating costs for an annual production of 242,000 panels. The capital costs are shown in Table 13 and operating costs in Table 14. The overall economics of building panel production are shown in Table 15, which shows a net annual profit margin of 17 percent.

Production costs, however, vary with the region and the level of production. The regional variations in the unit operating costs are shown in Table 16. The variation in the operating cost with the level of production is shown in Figure 10.

Advantages and Disadvantages

There are two major advantages of producing Thixite. First, Thixite provides a means of utilizing much of the solid wastes generated by demolition projects. Not only does it utilize waste glass, but also other wastes like concrete, bricks, rubble, etc. Second, since the process utilizes many different types of solid waste, separation and cleaning of solid wastes are not needed for recovery.

At present, the production of Thixite has been confined to Denver, Colorado. Plans exist to expand the system to several metropolitan areas. Until this is done, it will not be economical to transport solid waste over long distances to Thixite plants. Furthermore, a sufficient supply of solid waste should be available within a small area to supply a plant. A market

TABLE 13. ESTIMATED CAPITAL REQUIREMENTS FOR THIXITE PROCESS (ANNUAL PRODUCTION - 242,000 PANELS)

Amortized Investment		
Engineering, Research, and Development	$ 350,000	
Startup	1,000,000	
TOTAL AMORTIZED INVESTMENT		$1,350,000
Fixed Investment		
Structures and Improvements	600,000	
Machinery and Equipment		
Production	1,450,000	
All Other	900,000	
Total Machinery and Equipment	2,350,000	
TOTAL FIXED INVESTMENT		2,950,000
Recoverable Investment		
Land	200,000	
Working Capital	1,500,000	
TOTAL RECOVERABLE INVESTMENT		1,700,000
TOTAL CAPITAL REQUIREMENT		$6,000,000

Source: Midwest Research Institute, 1974.

TABLE 14. ESTIMATED OPERATING COSTS FOR THIXITE PROCESS
(ANNUAL PRODUCTION - 242,000 PANELS)

Direct Production Costs		
Labor	$3,750,000	
Materials	804,000	
Variable Overheads	1,250,000	
TOTAL DIRECT COST		$5,804,000
Indirect Costs		
Fixed and General Overhead	1,200,000	
Capital Charges	975,000	
TOTAL INDIRECT COSTS		2,175,000
TOTAL MANUFACTURING COST		$7,979,000
UNIT COSTS	Per Panel	Per Sq Ft
Direct Production Cost	$24.00	$0.600
Indirect Cost	9.00	0.225
TOTAL UNIT COST	$33.00	$0.825

Source: Midwest Research Institute, 1974.

TABLE 15. THE ECONOMICS OF BUILDING PANEL PRODUCTION
(ANNUAL PRODUCTION - 242,000 PANELS)

Net Sales Receipts (at $1.25 per square foot)	$12,100,000
Total Manufacturing Cost	7,979,000
Net Profit Before Taxes	4,121,000
Less Income Taxes	2,060,000
Net Profit After Taxes	2,061,000
Total Capital Requirement	6,000,000
Profit Margin (profit/sales)	17.0%
Capital Turnover Rate (sales/capital)	2.02 times
Return on Total Capital (profit/capital)	34.3%

Source: Midwest Research Institute, 1974.

TABLE 16. REGIONAL VARIATIONS IN UNIT OPERATING COSTS

Region	Cost Per Panel ($)	Cost Per Sq. Ft. ($)
New England	30.60	0.765
Middle Atlantic	33.21	0.831
East North Central	35.60	0.890
West North Central	32.38	0.810
South Atlantic	30.93	0.774
East South Central	29.65	0.742
West South Central	30.73	0.768
Mountain	33.45	0.837
Pacific	36.27	0.907
Average U.S.A.	32.54	0.814

Source: Midwest Research Institute, 1974.

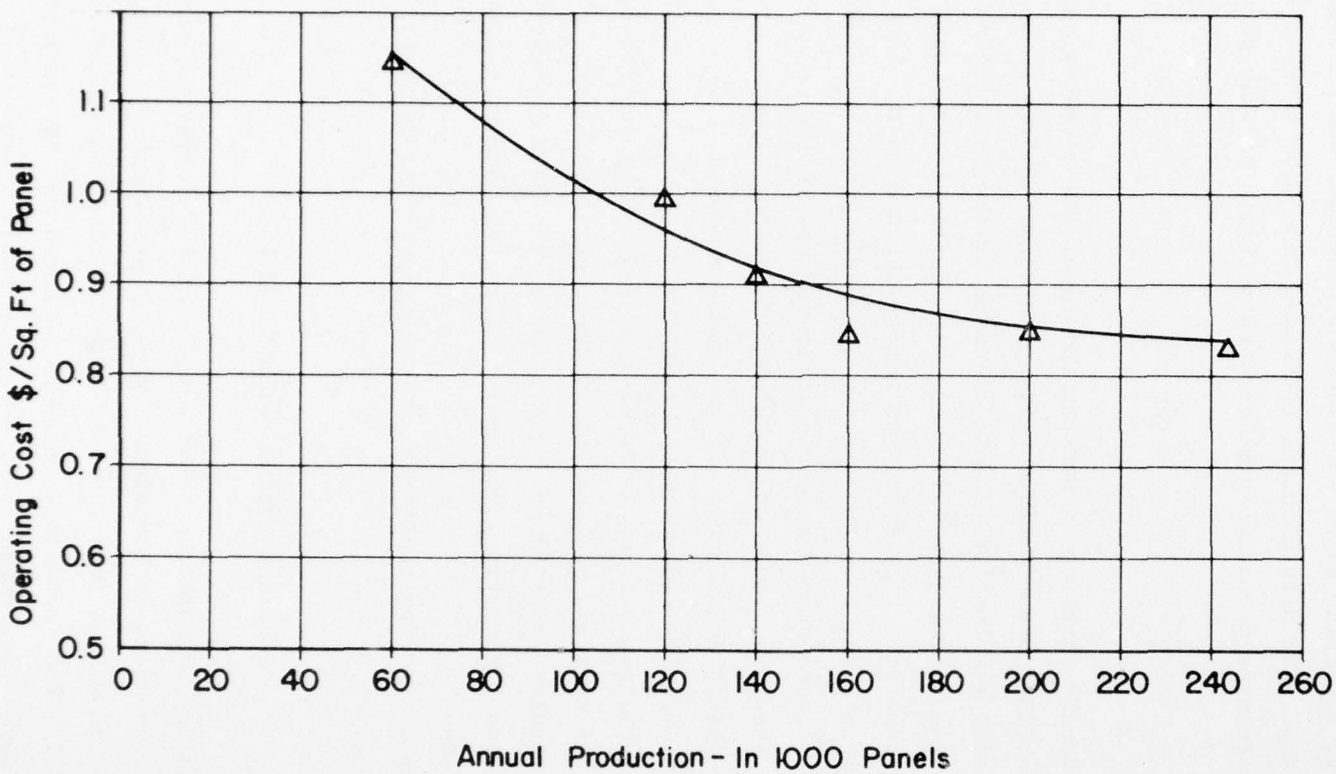


FIGURE 10. VARIATION IN OPERATING COST FOR THIXITE PANEL PRODUCTION

Source: Based on data presented in Midwest Research Institute, 1974.

for finished product is also needed in close vicinity. In addition, a relatively large initial investment ($6 million) is required to begin production.

Recently, a Thixite plant in Lakewood, Colorado, was closed for some unknown reason. The data on plant operation should be studied in the future to determine potential problems and pitfalls of this process.

Comments

The Thixon Corporation in Denver, Colorado, has recently started a new venture with a San Francisco brick manufacturing firm to produce 2 feet x 2 feet x 1 inch tiles made of waste bricks, porcelain, china clay waste, industrial slags, fly ash, mine tailings, and waste glass. Concrete wastes are not preferred as aggregates due to the lack of hardness. However, concrete may be used as fine fill material in this process. The waste material used should have the following properties:

(1) It should not melt at or below 1500°F.

(2) It should not produce any gas when processed.

(3) The material should be non-reactive.

The process requires a total investment of $10,000 by a brick manufacturer. The cost of tiles produced is about 45 cents per square foot. The selling price is generally about $2 per square foot. The Thixon Corporation is also working with an Albuquerque, New Mexico, firm for commercial implementation of the process.

Appendix C provides additional information on the Thixite tile production process.

Waste-to-Bricks Process--Tekbricks

The Tekology Corporation (Palisades Park, New Jersey), a subsidiary of Certain-teed Products Corporation, has developed a process that converts inorganic solid wastes into low-cost high-standard home-building bricks (Anon., 1972). The technology has been patented and is available for license to firms interested in disposing of solid waste with reasonable profit.

Process

The basic waste-to-brick manufacturing process involves the following steps:

(1) Separate inorganic waste materials obtained from construction/demolition activities.

(2) Pulverize them into aggregates of less than 3/8 inch.

(3) Dry mix waste aggregates with Portland cement (usually 90-96 percent of the mix is waste aggregates depending on grain size).

(4) Add water and a proprietary chemical epoxy binder.

(5) Loosely pack the moist mixture in a high-pressure mold and subject it to a pressure of 6000 psi, which causes a binding chemical reaction.

(6) Discharge the formed bricks, stack them on pallets, and "cure" (dry) for a minimum period of 24 hours.

The composition of the input waste materials should meet the specifications summarized in Table 17. The concrete and vitrified clay waste from construction and demolition sites can be pulverized to meet these requirements. The potential manufacturers of these grinders are listed in Table 18. The resulting bricks withstand about 3000 psi compression and have an ultimate strength of over 5000 psi.

Economics

According to John Belt, the Licensing Officer of the Certain-teed Products Corporation, Valley Forge, Pennsylvania, the economics of Tekbrick process are extremely encouraging. The cost data for a 25-million-bricks-a-year plant are shown in Table 19. The capital cost for different capacity plants may be estimated on the basis of data shown in Figure 11.

Recommendations

It is recommended that the Army undertake the following measures to investigate the use of these bricks:

(1) Undertake a systematic testing program to evaluate the claims of Tekology Corporation.

TABLE 17. WASTE SPECIFICATIONS FOR TEKBRICK PLANTS

Particle Size	<3/8 inch
Fineness Modulus	2.6
Organic Material	<3 percent

Sieve Number	Percent Retained
4	4.8
8	11.8
16	15.8
30	19.0
50	17.1
100	14.0
Pan	17.5

TABLE 18. MANUFACTURERS OF GRINDERS, CUTTERS, CRUSHERS, MILLS, PULVERIZERS, AND SHREDDERS

Industrial and Municipal
Allis-Chalmers
Alpine American Corporation
Beloit Corporation
Beloit-Passavant Corporation
Denver Equipment Division
Dresser Industries, Inc.
Eidal International Corporation
Entoleter, Inc.
Fuller Company
GEOS Corporation
The Heil Company
The Hobart Manufacturing Company
Jeffrey Manufacturing Company
Joy Manufacturing Company
Koppers Company, Inc.
The Perolin Company, Inc.
Perry Products Company
Williams Patent Crusher & Pulverizer Company

TABLE 19. ECONOMICS OF TEKBRICK PROCESS

Production Rate (minimum)	25 million/year
Weight of a brick	8 pounds
Intake of wastes	43 TPH 350 TPD
Capital Cost	
Tekbrick Process[(a)]	$ 1.2 million
Pulverizer	$ 0.7 million
Total	$ 1.9 million
Operating Cost[(b)]	
Tekbrick Process	
In $/1000 bricks	$35
In $/ton waste	$10
Pulverizer[(c)]	
In $/ton waste	$ 3
Total[(d)]	
In $/ton waste	$13
Revenues	
Total Sales in $/Ton Waste	$18
Total Revenues in $/Ton waste	$15
Net Profit	
In $/Ton Waste	$ 2
Percent Profit	$15

(a) The capital cost of Tekbrick Process includes hoppers, chemical tank, scale, mixers, mold, hydraulic press, and stacking space. The pulverizer is included in the package. The costs are based on data from a recently constructed plant in Atlanta, Georgia, designed with complete automation.

(b) Assume an economic life of 20 years.

(c) The labor cost has been excluded, since the Tek Process labor will be able to handle the pulverizer too.

(d) Other cost factors may be added if necessary. For example: colored bricks cost $11 per 1000 bricks more; "rock facing" texture costs $8-10 per 1000 bricks more.

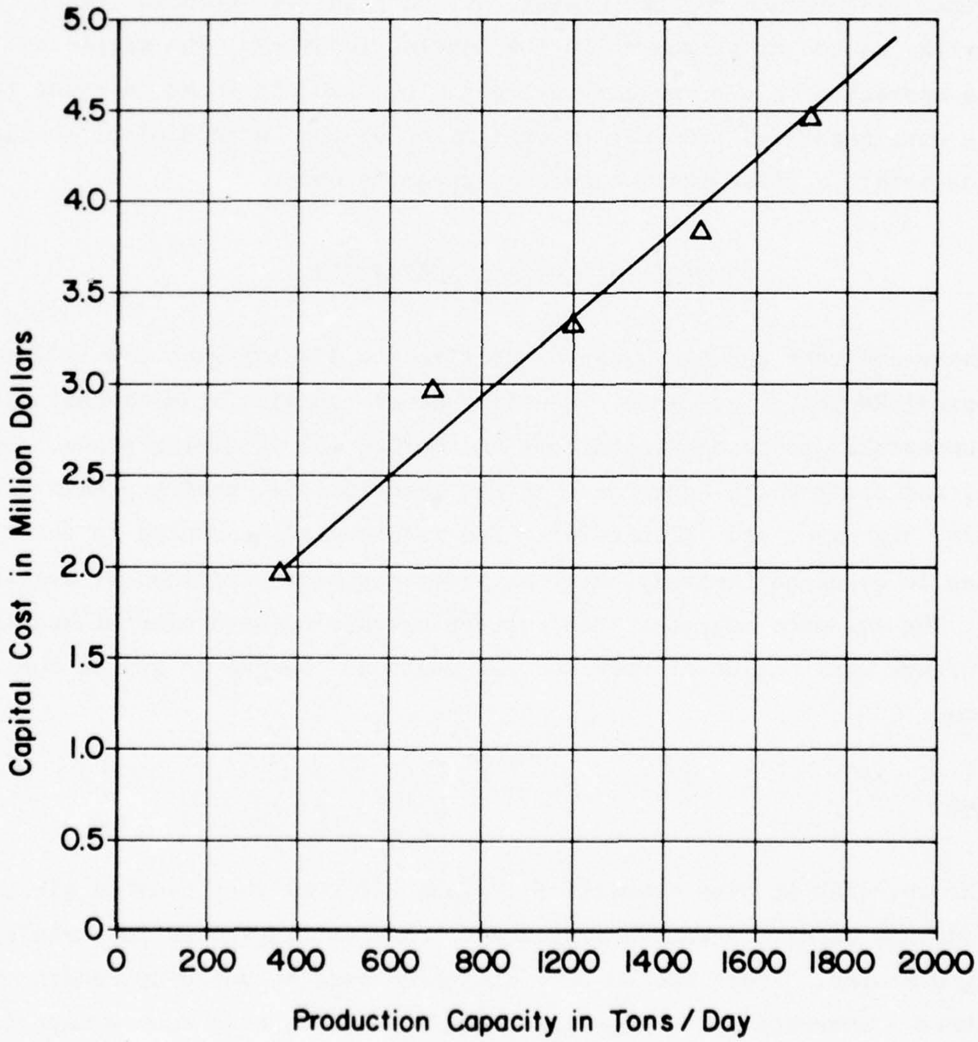


FIGURE 11. CAPITAL COST VERSUS PRODUCTION CAPACITY RELATIONSHIP FOR TEKBRICK PLANTS

(2) Make necessary changes in building codes to allow the use of such materials that pass specified tests.

(3) Undertake research to develop techniques to reduce the weight of these waste-to-brick products (the bricks weigh about 8 pounds instead of the usual 5 pounds). Also, the Tekblocks are 16 inches x 8 inches x 8 inches and weigh 20 pounds.

Recently, the Nassau waste-to-brick plant in the Bahamas went out of business. The reason for the closure of the plant was reduced demand for bricks caused by slowdowns in the housing industry. The waste-to-bricks operation, a new and marginal activity, was abandoned in order to reduce over-capacity. Further investigation of the Georgia plant should be made before a pilot test of such a system is made.

Ecological/Recycled Pavements

Waste concrete and glass can be utilized to develop what are called Ecological/Recycled pavements. The literature contains studies that have been undertaken to assess techniques and methods of utilizing glass, concrete, and other waste aggregates as raw materials for paving parking lots, streets, highways, etc. (Table 20). The information presented in these studies is based on limited, one-time assessments of experimental systems only. The evidence suggests that further private or governmental studies and further utilization of recycled pavements are needed to assess these systems.

Process

The research studies summarized in Table 20 show that crushed glass and concrete materials can be recycled for use as aggregates in asphaltic paving mixtures. Stone wastes have also been used in building concrete pavements. Concrete waste aggregates can be used as base course materials, too. However, there has been no utilization of waste concrete as raw material for fresh concrete mix in the United States (Buck, 1972). Crushed refuse glass has been substituted for about 30 percent of natural aggregates in portland cement (Phillips, 1972). The characteristics of recycled concrete produced from waste concrete are shown in Table 21.

TABLE 20. STUDIES OF ECOLOGICAL/RECYCLED PAVEMENTS

Type of Process	Investigator	Process Description	Results	Reference
Crushed stone to porous pavement	Franklin Research Institute Philadelphia, Pennsylvania	A half-acre parking lot at Woodlands, Texas, was paved with a mixture of 2.5 inches of gap graded asphaltic concrete with 3/8-inch aggregate over 12 inches of crushed stone and 24 inches of sand.	The porous paving costs $7.20 per square yard as compared to $10.23 for conventional paving. Major cost savings are associated with elimination of curbs and drains.	Anon., 1974.
Crushed glass and waste concrete to bituminous pavement	Royal Oak Beautification Council, Royal Oak, Michigan	A 1.2-acre municipal parking lot was paved with a 1.5-inch bituminous coal binder containing 25% glass and 25% waste concrete crushed to 3/8 inch, 44% of 3/4-inch stone aggregate, 5.5% asphalt, and 1% hydrated lime for adhesion between glass and asphalt. The bituminous coal binder was topped by a 1-inch wearing surface consisting of 50% glass, 43% sand, 6% asphalt, and 1% lime.	The mix is similar to regular asphalt and the pavement is stronger than ordinary bituminous concrete and has a greater skid resistance. Cost of paving is about $2.50 per square yard.	Anon., 1972.
Fly ash (from on-site incinerators to concrete)	Chicago Fly Ash Company Chicago, Illinois	Fly ash is utilized for making concrete products, such as concrete slabs, concrete bricks, etc.	The company sells over .5 million tons of concrete products made from fly ash annually.	Personal Communication, 1973.
Refuse glass to portland cement concrete	American Cement Corporation Riverside, California Environmental Control Glass Containers Corporation Fulleston, California	Study was performed to determine short-term and long-term engineering properties resulting from a direct substitution of refuse glass for natural aggregate in the production of concrete masonry blocks.	Problems involved in using waste glass in portland cement products can be overcome, and the use of glass in concrete and masonry blocks seems feasible.	
Crushed waste concrete to concrete	U.S. Army Engineer, Waterways Experiment Station Vicksburg, Mississippi	Discarded concrete driveway wastes and concrete beams were crushed to form coarse aggregates. The aggregates were mixed with sand, cement, and water. The mix was used to make test blocks.	The tests showed that waste concrete, not contaminated by sulfates, can be used as concrete aggregates. The characteristics of recycled concrete are shown in Table 21. Concrete from demolished buildings may contain sulfates from plaster and gypsum boards. Technical and economic feasibility of such use should be tested.	Buck, 1972.

TABLE 21. CHARACTERISTICS OF RECYCLED CONCRETE

	Mix Characteristics						Concrete Characteristics			
Mixture Number	Coarse Aggre-gates(a)	Fine Aggre-gates(b)	Water-Cement Ratio	Air Content (Percent)	Slump (Inches)	Cement Content (lbs/cu yds)	Workability	Concrete Strength (90-day) pounds/in^2	Frost Resistance DFE_{300}	Percent Length Increase in 90 Days at Constant Temperature/ Moisture
1 control mix	Chart gravel	Natural sand	0.49	5.5 to 6.5	2 to 3	461	Good	5060	3	0.015
2	Crushed driveway concrete	Natural sand	0.49	5.5 to 6.5	2 to 3	461	Same as Mix 1	3880	23	0.016
3	Crushed driveway concrete	Crushed concrete fines	0.49	5.5 to 6.5	2 to 3	508	Less than Mix 1	4280	28	0.019
$ control mix	Lime-stone	Natural sand	0.49	5.5 to 6.5	2 to 3	508	Good	5320	62	0.001
5	Crushed concrete beam	Natural sand	0.49	5.5 to 6.5	2 to 3	498	Same as Mix 1	4660	45	0.002

(a) The fine aggregate grading requirements are: Sieve Size/No. 3/4 in. 1/2 in. 3/8 in. 4
Cumulative Percent Passing: 97-100 63-69 30-36 0.3

(b) The fine aggregate grading requirements are: Sieve No. 4 8 16 30 50 100 200
Cumulative Percent Passing: 100 82-88 61-70 40-50 16-26 5-9

Economics

The ecological/recycled pavement studies have been experimental in nature; therefore, no "operational" cost data are available. However, a tentative cost analysis suggests that these new techniques may be comparable, or possibly less expensive, than existing methods of building concrete pavements. For example, Franklin Research Institute reports that porous pavements cost about $7.20 per square yard, which is cheaper when compared to $10.23 per square yard for conventional paving (Anon., 1974). The bituminous mixture of crushed glass and waste concrete aggregates produces a pavement that is stronger and has greater skid resistance than ordinary bituminous concrete pavement (Anon., 1972). The cost of such a pavement ranged between $2 and $8 per square yard.

Advantages and Disadvantages

Principal advantages of ecological/recycled pavements, using crushed glass and waste concrete, include the utilization of solid wastes as raw materials and reduced need for disposal of solid waste. The resulting pavements may also possess better physical properties, such as drainage and skid resistance than ordinary paving materials. The major disadvantage of ecological/recycled pavements is the requirement that the waste materials be free of impurities (especially sulfates). Also, wastes should be available in sufficient volume to insure economic feasibility. Certain restrictive waste specifications for various recycling alternatives are shown in Table 22.

Wood Waste-to-Energy Alternative

The U.S. Bureau of Mines has recently developed a useful process to convert wood and other organic wastes to low-sulfur oil at its Pittsburgh, Pennsylvania, Energy Research Center. The process has exciting possibilities and will be tested at a pilot plant being constructed at Albany, Oregon. It is anticipated that the use of about 10 percent of the nation's wood waste could produce seven billion barrels of oil per year (Solid Waste Report, 1974).

TABLE 22. CONCRETE WASTE CHARACTERISTICS FOR SELECTED RECYCLING ALTERNATIVES

Recycling Alternatives	Waste Characteristics
Fill material	• High concrete content • High brick content • Small organic content like wood • Smaller size of debris
Concrete aggregate	• Adequately tested hardness • Near urban center where aggregates are in short supply
Parking lots	• Crushed concrete aggregates • Glass • Bituminous binder • Used in a Detroit suburb • Wearing surface (25% glass; 25% concrete crushed 3/8 inches; 44% stone aggregate 3/4 inches; 5.5% asphalt; 1% hydrated lime

The Albany pilot plant is being built by the MAECON Construction Company, Los Angeles, California, under a contract from the Bureau of Mines.

Process

The process involves treatment of wood wastes with carbon monoxide and steam under high temperature and pressure. This hydrogenation process produces a high-quality, low-sulfur oil suitable for use by power plants. At first, only wood wastes from lumbering operations will be used in the Albany pilot plant; later other wastes like paper, garbage, and livestock manure will be utilized.

The Albany plant is expected to have a capacity of 3 tons per day (input wood waste) and will produce 6 barrels of low-sulfur oil.

Economics

No cost data are available at this time. It is anticipated, however, that the operating costs will not exceed the revenues received from the sale of the oil.

Mulching

Mulch is a covering over the surface of a soil that prevents evaporation of water and growth of weeds. Mulch consists of wood chips, straw, hay, wood fiber, sawdust, peat moss, and humus. Generally, the specifications preclude the use of secondary materials as mulch. Trees and other slash cleared from forested land can be processed into chips and applied as mulch during seeding operations (SCS Engineers, 1972). The wood debris from demolition projects may also be used in this manner. A current practice of seeding highway right-of-way areas consists of spraying a mixture of wood fibers, seed, fertilizer, and water. The longer wood fibers are superior for seeding; as such, the wasted wood fibers can be used for this purpose.

Smaller trees (less than 4 inches in height) and brush can be shredded to produce a topsoil mulch for shrubbery and flower beds. Leaves, grass, etc., can be ground to produce humus fertilizer.

Mobile shredders can be utilized for mulching tree and brush wastes. However, the use of recovered wood for mulching may not be a viable alternative. The reasons are:

(1) Recovered wood is unattractive as a mulch.

(2) Recovered wood as mulch will present fire hazards.

(3) Recovered wood can be contaminated; as such, it may harm the soil.

Economics

A mobile shredder can be purchased for a low capital investment of $600 (Thompson and Hamilton, Inc., 1974). The operating cost of such a shredder is about $4 per ton. Detailed information on larg shredders is presented in the section on Pulverizers.

Pulverizer Systems

Systems designed to recover or utilize construction/demolition wastes require size-reduction of waste before processing. To accommodate these recovery systems, Jeffrey Manufacturing Company, Columbus, Ohio, has developed size-reduction or pulverizer systems capable of shredding most construction/demolition wastes. In addition, there are several other pulverizer systems, as shown in Table 23.

Process

A pulverizer system consists of four basic units:

(1) A waste receiving hopper

(2) A conveyor for carrying wastes to the feeder

(3) A pulverizer with a feeder

(4) A conveyor for carrying shredded wastes to a recovery/utilization system

A typical refuse pulverizing system is shown in Figure 12.

The pulverizers or shredders vary in terms of "sorting" or "presizing" requirements as a result of design capacity. The lower capacity pulverizers

TABLE 23. COSTS OF AVAILABLE PULVERIZER SYSTEMS

Name of the Process	Process Description	Cost Information				Special Characteristics
		Capital Cost Million $	Operating Cost $/Ton	Revenues $/Ton	Net Operating Cost $/Ton	
CSWMP Project, Tacoma, Washington	Shredder for bulky wastes. Capacity: 40 TPH Horsepower: 800 Type: Williams hammermill	0.65	6.34			
Williams Hammermill, St. Louis, Missouri	Bulky waste size reduction. Capacity: 35 TPH Horsepower: 800 Type: Williams hammermill	0.50	12.00			Convict labor was used. Cost would be reduced by 50 percent with better labor, and keeping unprocessable items out of the machine.
Hazemag Crusher, Buffalo, New York	Bulky waste size reduction Capacity: 11 TPH Type: Model No. SAP 5/M	0.35	9.37 (non-combustible waste) 6.24 (mixed waste)			Mixed waste contained wood which is easier to shred.
Municipal Shredder, Madison, Wisconsin	Size reduction of municipal waste. Capacity: 15 TPH plus 8 TPH Type: Heil Tollemache hammermill/Gondard hammermill	0.32	3.90			The shredder operates two shifts per day and processes 280 TPD.
Jeffrey Pulverizer, Columbus, Ohio	Stationary shredder for bulky wastes. Capacity: 10 TPH	0.33	7.64			One-shift operation has been assumed.
Jeffrey Pulverizer, Columbus, Ohio	Stationary shredder for bulky wastes. Capacity: 100 TPH	0.95	2.84			One-shift operation has been assumed.

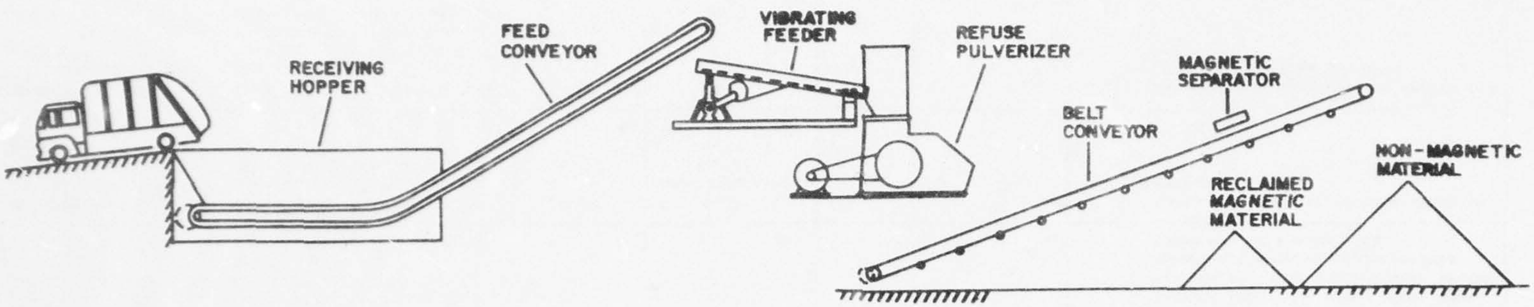


FIGURE 12. A TYPICAL REFUSE PULVERIZING SYSTEM

Source: Jeffrey Manufacturing Company, 1974.

require a large amount of sorting and vice versa. The approximate specifications for capacity vis-a-vis feeder opening are shown in Table 24.

A typical "portable" shredding unit has a capacity of 5 to 10 TPH. It is capable of handling small construction/demolition items such as bricks, planks, and boards up to approximately 8 feet long.

On the other hand, a typical "stationary" shredder has a capacity of about 40 TPH and is capable of handling non-reinforced concrete blocks of 3-feet x 3-feet x 4-inch size, bricks of 12-inch size, and timber about 8 feet long.

Economics

The costs involved in developing and operating pulverizer systems are known to vary greatly with capacity and hours of daily operation. The costs of selected pulverizers are shown in Table 23. Using available data on Jeffrey Shredders, the economics of capital and operating costs of typical 10 TPH and 100 TPH systems have been developed. The costs are presented in Table 25. Using simple economic concepts and crude cost estimates of intermediate capacities, capacity-cost relationships have been developed for capital and operating costs as shown in Figures 13, 14, and 15. These are useful relationships for estimating costs of potential pulverizers.

Advantages and Disadvantages

The advantages of pulverizers are as follows:

(1) Shredders of various capacities are available according to the need.

(2) Portable shredders are available and can be transported easily from one site to another.

(3) Shredders can be adapted to existing waste recovery/utilization systems.

The disadvantage is that some sorting or pre-sizing may be necessary prior to the shredding process.

TABLE 24. APPROXIMATE SPECIFICATIONS FOR REFUSE PULVERIZERS

Model Number	Feed Opening Width In Inches	Approx. Capacities in Tons per Hour	Approx. H.P.
432 (a)	32	7	100
548 (a)	48	15	250
748	48	25	400
766 (b)	66	35	1000
770 (c)	70	35	500
990 (c)	90	55	750
913 (b)	102	75	2000

Capacities shown are for continuous operation, based on a regular, steady feed. Alternate under- and over-feeding and other factors can adversely affect through-puts (and power consumption).

Capacities are based on a nominal 3 in. and below product from unsorted refuse at approx. 280 lb./cu. yd.

(a) Pre-sorting to reduce large, uncrushable items is necessary.

(b) For special applications such as reduction of large items only.

(c) Bulky feeds--When reducing bulky refuse only to a nominal 12" product prior to incineration, machine capacity can be increased by approx. 12-1/2%.

TABLE 25. ECONOMICS OF JEFFREY PULVERIZER

Cost Item	Cost of 10 TPH System	Cost of 100 TPH System
CAPITAL COST		
Pulverizer and Conveyor	$130,000	$600,000
Buildings	137,000	280,000
Scale	7,000	14,000
Front-End Loader	16,000	16,000
Packer Trucks (2)	40,000	40,000
TOTAL	$330,000	$950,000

Cost Item	Cost of 10 TPH System ($/Ton)	Cost of 100 TPH System ($/Ton)
OPERATING COST (assuming one-shift operation)		
Labor	3.50	0.50
Amoritization	2.80	1.00
Power	0.30	0.30
Lighting	0.20	0.20
Water	0.02	0.02
Gas heat	0.10	0.10
Hammer wear	0.15	0.15
Mill maintenance	0.08	0.08
Small equipment	0.07	0.07
General supplies	0.10	0.10
Front-end loader operation	0.04	0.04
Transportation to landfill	0.28	0.28
TOTAL	7.64	2.84

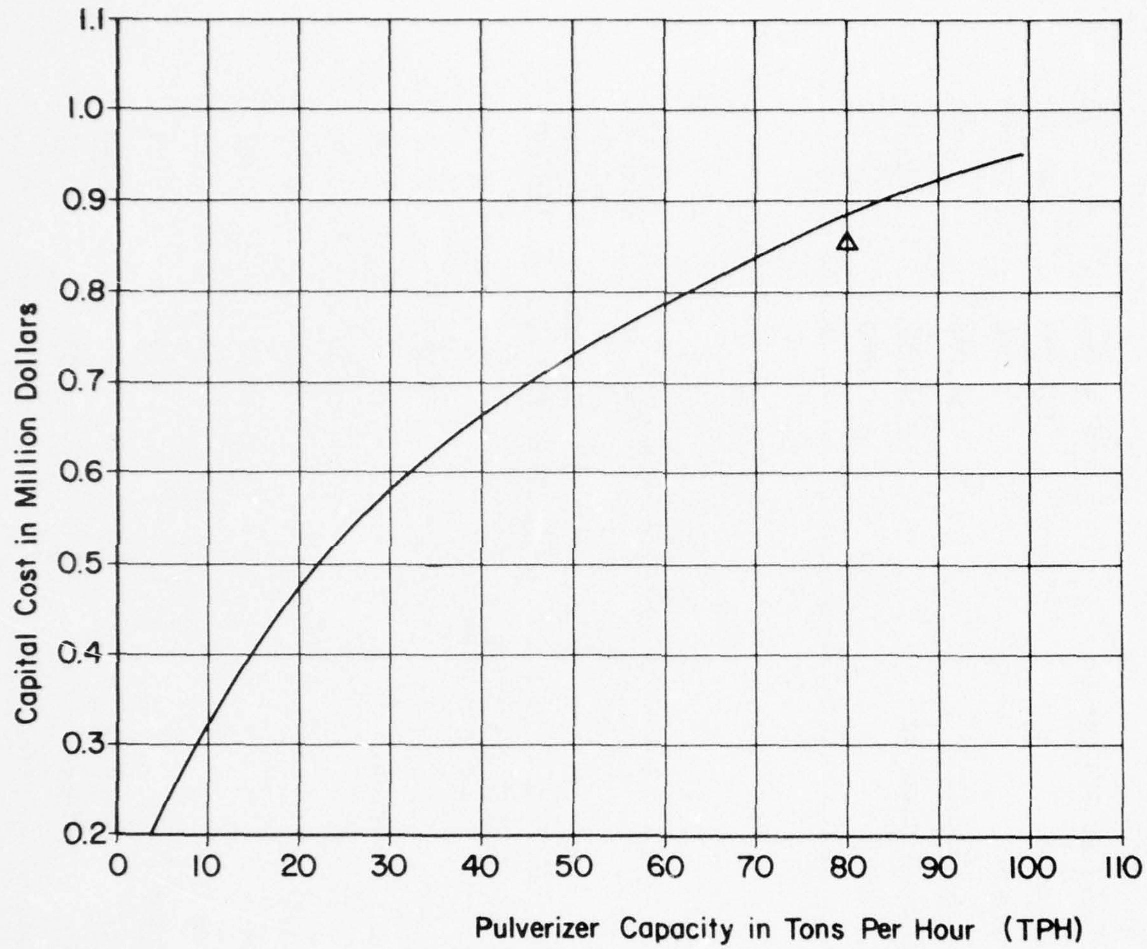


FIGURE 13. CAPITAL COST VERSUS CAPACITY RELATIONSHIP FOR WASTE PULVERIZERS

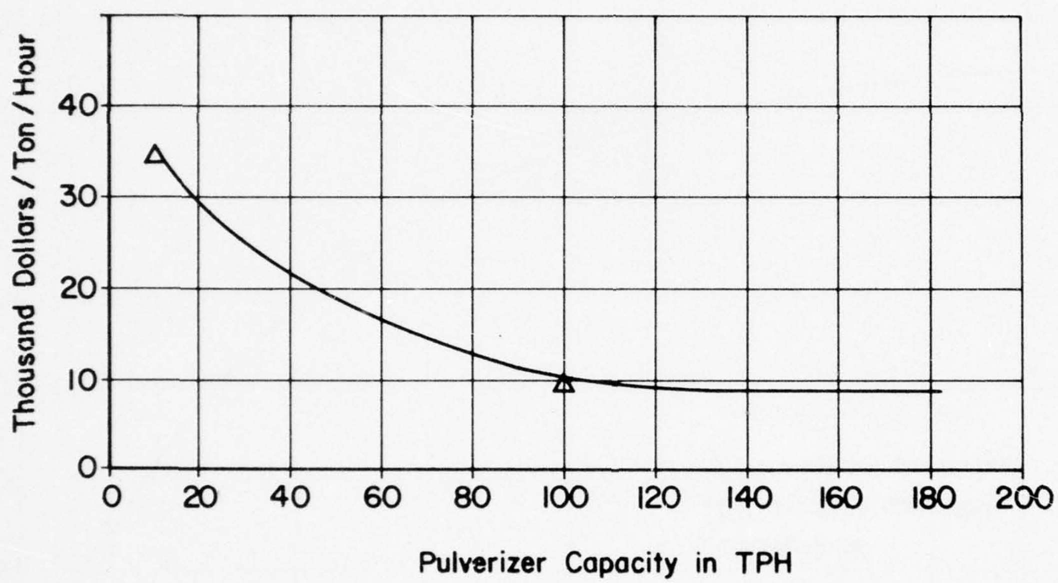


FIGURE 14. UNIT CAPITAL COST VERSUS CAPACITY RELATIONSHIP FOR PULVERIZERS

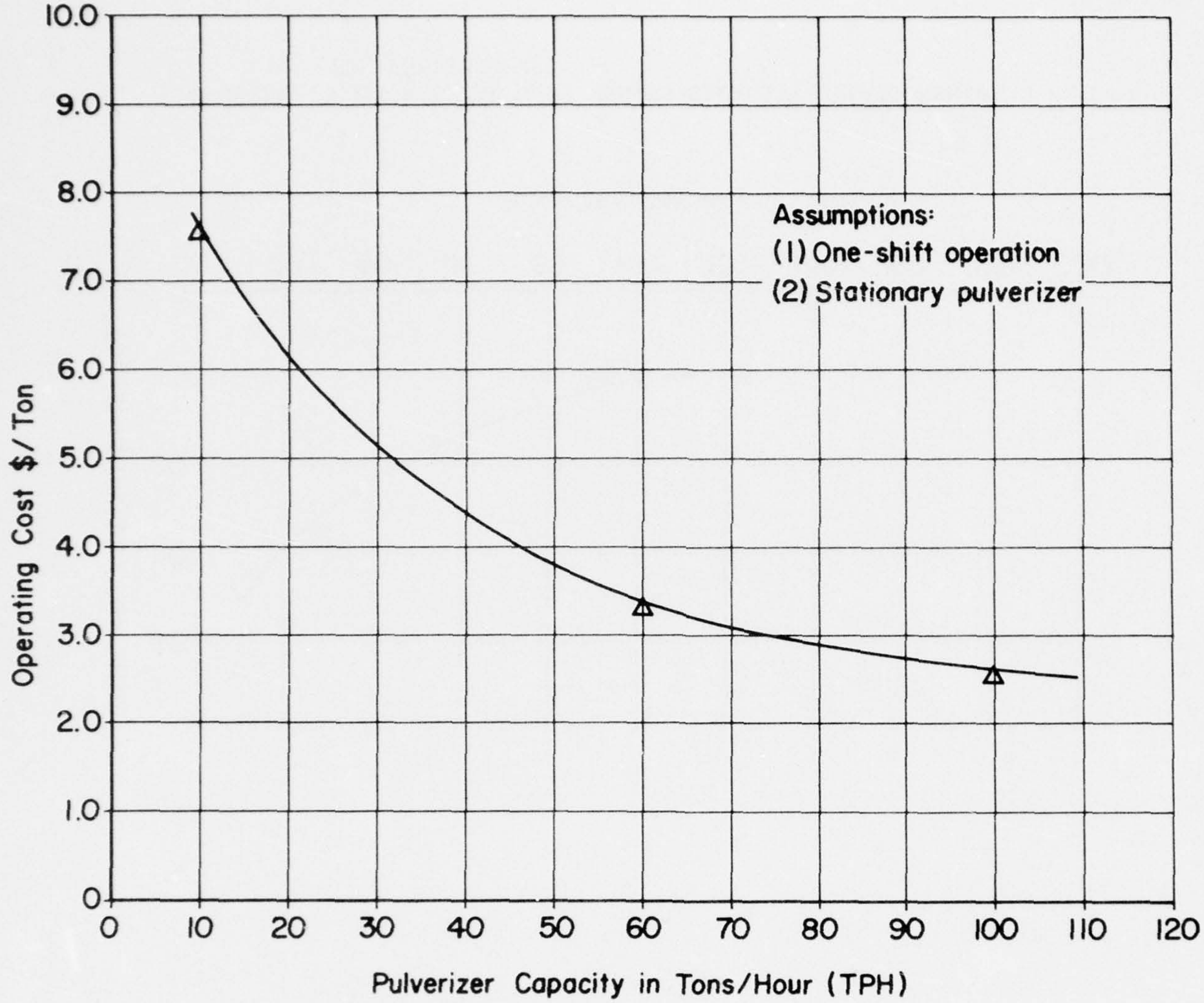


FIGURE 15. OPERATING COST VERSUS CAPACITY RELATIONSHIP FOR WASTE PULVERIZER

Handling of Special Wastes

There are a few special wastes generated by various construction activities. These are:

(1) Paper sacks, with cellophane lining

(2) Asbestos insulation

(3) Paints

(4) Pesticides

Generally, the paper sacks are disposed of in a landfill or are incinerated. The asbestos insulation is seldom used in construction. The paints are generally consumed from 5-gallon cans; as such, they can be partially wasted if unused. Pesticides are usually brought in large mobile tanks and are taken back after use without any waste. Clearly, paints and paint cans are the only special wastes of some hazardous nature that require proper disposal.

The paints can be disposed of either to an existing hazardous waste disposal facility or may be chemically fixed for disposal in a landfill. The disposal of special wastes by environmentally safe methods costs about \$0.11 to \$0.50 per gallon. The costs are based on service cost charged by major hazardous waste disposal contractors like Rollins Environmental Services, Approved Chemical Treatment, Inc., etc. The environmentally safe methods generally consist of chemical fixation and disposal to a landfill with groundwater monitoring facilities. Since construction wastes do not generally contain major hazardous wastes, detailed consideration of hazardous waste disposal has not been made.

Integrated Management

Integrated management involves utilization and disposal of construction and demolition solid wastes in conjunction with other solid wastes from the post and from adjacent municipal and industrial systems. This is an important, and perhaps the only, realistic alternative for the disposal of solid wastes when the volume of construction/demolition solid wastes is less than 500 tons per day. The integrated management should also be considered when the present level of construction activity is expected to continue for less than 10 years.

The analysis of selected waste recycling systems shows that when the volume of construction wastes is less than 500 tons per day, it may be desirable to combine the construction wastes with other solid wastes for purposes of recycling. For a total waste volume of 500 tons per day or more, it is possible to design an integrated solid waste management system for the specific composition and condition of the waste.

There are only a few major integrated resource recovery systems being developed in the U.S. Details of three such systems are shown in Table 26. In developing these systems for solid waste containing large volumes of concrete, designers must consider incorporating specific processes for utilizing concrete waste. Some of the potential concrete utilization processes have been discussed in this section.

However, when the mixed solid waste has a large proportion of municipal wastes, it is more appropriate to consider the recycling systems summarized in Tables 27 and 28. The basic process and economic information relating to these systems are presented in these tables.

The justification for waste recycling vis-a-vis disposal is fairly well established by available data. For instance, comparison of electricity consumption shows that recycling systems may require at least 25 percent less energy than production from virgin materials (Table 29). Also, the electricity needed for the separation of solid waste is below the energy content of average municipal solid waste (Table 30). The relative energy consumption ratio for throwaway containers vs. returnable containers indicates a significant energy saving resulting from container recycling (Table 31).

Clearly, the integrated recycling of wastes can be an economic and energy-efficient alternative for managing solid wastes in a given region.

Segregation of Construction Waste

The major components of construction waste are: (1) concrete, (2) bricks, (3) wood, (4) packaging materials, and (5) soil. Separation of these waste components is important for recycling or recovery of wastes. The waste separation may be done either at the source or by processing of mixed wastes. The major separation approaches are segregation at source and separation of mixed waste.

TABLE 26. PROPOSED INTEGRATED RESOURCE RECOVERY SYSTEMS IN THE U.S.

Location	Estimated Capital Cost Million $	Sponsor	Contractors	Service Area	System Capacity (Tons/Day)	Processes	Output	Estimated Operation Cost $/Ton	Construction Plan	REMARKS
1. Bridge-port,(a) Connecticut	48.00	Connecticut Resource Recovery Authority, Bridgeport Conn.	(1) Garrett Research and Development Corp., Inc. LaVerne, Calif	192 sq. mi. 400,000 persons Covers Bridgeport, Fairfield, Monroe, Stratford, Trumbull, and Westport cities	1,800	(1) ary fuel system: 80 percent refuse plus 20 percent #6 fuel oil (2) Dry separation processes	(1) Steam/electricity: 10 percent of the energy needs of the region (2) Ferrous scrap--80,000 TPY (both) (3) Aluminum--4,000 TPY (4) Glass--40,000 TPY (5) Residue--5 percent of waste	11.0 (Total) 7.0 (Net)	2 years: completion by July, 1976.	M.R.J. Bush, Hartford, Conn. Tax revenues: $1.0 million
2. Berlin,(a) Connecticut	32.00	Connecticut Resource Recovery Authority, Bridgeport, Conn.	(1) Combustion Equipment Assoc. Inc., New York	192 sq. mi. 465,000 persons Covers Berlin, New Britain, Newington, etc.	1,800	(1) Organic waste to Eco-Fuel II system	(1) Eco-Fuel II (powder refuse fuel) (2) Ferrous Scrap (3) Aluminum (4) Residue	11.0 (Total) 7.0 (Net)	2 years: completion by July, 1976.	M.R.J. Bush, Hartford, Conn. Tax revenues: $0.06 million
3. Hemp-stead,(a) New York	44.60	City of Hempstead, New York	(1) Hempstead Resource Recovery Corp., New York City	130 sq. mi. 400,000 persons	2,000-3,000	(1) Black Clawson Fiber-claim process (2) 100 percent refuse fuel system--Nashville type	(1) Steam (400,000 lbs/hour) to generate electricity for 15 percent of Hempstead's demand (2) Ferrous metals--40,000 TPY (3) Color-sorted glass--23,000 TPY (4) Aluminum--5,000 TPY	5.70 (Net) 11.30 Present disposal cost	2.5 years	$15 million state funds cannot be used, since the city does not own the system.

(a) Solid Waste Report, Vol. 5, No. 1, May 27, 1974, pp. 101-103.

TABLE 27. ECONOMICS OF SOLID WASTE RECYCLING SYSTEMS
(IN DOLLARS PER TON OF WASTE)

Process or System	Cost of Operation*	Current Technology: Credits for Recycled Resources**: Ferrous Metal	Other Metals	Glass	Compost	Cellulose Fiber	Energy	Total Credits	Net Cost	Optimistic Technology: Total Credits	Net Cost
Conventional incineration	10-20						3	3	7-17	3	7-17
Above, with residue separation	11-22	1	2	1			3	7	4-15	10	1-12
Supplementary fuel system (St. Louis)	5	1					3	4	1	6	-1††
Pyrolysis‡‡‡	7-10	1	2	1			3	7	0-3	10	-3†† - 0
Compost	7-10	1	2	1	3-5			7-9	-2††-3	14	-7†† - -4
Fiber recovery (Black Clawson)	10-14	1	2	1		4†††		8	2-6	25	-15†† - -11
Rust engineering	8-12‡	1	2	1		4-5‡‡		8-9	-1††-4	25	-17†† - -13

* For plants processing 500 to 1,000 tons/day of waste.
** Steel at $10/ton; other metals at $200/ton; glass at $10/ton; compost at $5 to $10/ton.
† Steel at $30/ton; other metals at $200/ton; glass at $20/ton; compost at $14/ton; cellulose fiber at $50/ton (0.35 ton/ton waste).
†† Negative numbers indicate a credit.
††† Based on 0.18 tons fiber/ton waste; fiber value $20 to $25/ton.
‡ For 500 tons waste only.
‡‡ Based on 0.28 ton fiber per ton waste; fiber value $16/ton.
‡‡‡ See page 67 for explanation.

Source: Large, 1973, Reprinted with permission.

TABLE 28. COMPARISON OF SOLID WASTE RECOVERY PROCESSES

Name	Process	Principal Products	Other Products	Capacity (TPD)	Development Status	Anticipated Costs of 1000 TPD Systems: Capital Cost ($/TPD)	Operating Cost ($/Ton)	Revenue ($/Ton)	Net Cost ($/Ton)
			ENERGY RECOVERY						
Union Electric (St. Louis, Missouri)	Supplementary fuel system	Steam, electricity	Ferrous metals	650 (24 hrs)	Demonstration plant	6,000	6.05	5.45	0.60
Montreal Incinerator	Incinerator plus boiler	Steam	Scrapmetal, Ash	1,200	Plant completed in 1970	12,500	7.00	3.50	3.50
Issy-Les-Moulineaux (Paris, France)	Incineration and steam recovery	Steam, electricity	--	1,500	Plant completed in 1965	15,300	7.70	2.88	4.82
Munich Incinerator (Munich, Germany)	Incineration and steam recovery	Electricity	Metal	1,056	Plant completed in 1969	15,400	13.96	7.00	7.00
			MATERIAL RECOVERY						
Black Clawson (Franklin, Ohio)	Fibreclaim hydrapulping, separation, and fluid-bed combustion	Paper, fibers	Iron, aluminum	50	Demonstration plant 1971	14,500	12.00	7.00	5.00
U.S.B.M. (College Park, Maryland)	Incinerator residue recovery	Metals	Glass	250	Pilot plant	1,725	1.83	15.76	-13.93
Raytheon System (Lowell, Mass.)	Incinerator residue separation	Iron	Aluminum, zinc, copper, glass, aggregates	250 (8 hrs)	Under construction, 1974	13,000	10.80	11.20	- 0.40 (profit)
			PYROLYSIS						
Garrett (San Diego, California)	Pyrolysis and separation	Oil	Char, glass, iron	200 (24 hrs)	Under construction, 1976	20,000	8.23	5.10	3.13
Monsanto (Baltimore, Maryland)	Landgard pyrolysis and separation	Steam, metals	Char, aggregates	1,000	Under construction, 1974	15,400	10.50	4.35	6.15
NTTC System (Nashville, Tennessee)	Waste incinerator plus steam boiler	Steam chilled water	--	720	Under construction, 1974	24,000	9.50	6.00	3.50

TABLE 29. COMPARISON OF ELECTRICITY CONSUMPTION IN PRODUCTION: VIRGIN MATERIALS vis-a-vis RECYCLING

	Total 1970[a] Production (10^6) (tons)	Percent of[a] Production From Old Scrap	Electricity Coefficients Existing[b] Methods (kwh/ton)	Electricity Coefficients 100%[c] Recycle (kwh/ton)
Steel	132	26	750	515
Aluminum	4.0	4	16,700	350
Paper	52.5	18	1,050	780

(a) Dr. Hirst's references are 1970 Minerals Yearbook, U.S. Bureau of Mines, and Statistical Abstract of the United States, U.S. Bureau of the Census, 1972 edition.

(b) "Electricity Use Coefficients for Existing (1967) Methods Obtained From Bureau of the Census and Fortune Magazine," ("1966 Input/Output Coefficients").

(c) Hirst refers to "Patterns of Energy Demand in Steelmaking," Rand Corporation Report WN-7436-NSF, 1971; "Energy Expenditure Associated with the Production and Recycle of Metals," Oak Ridge National Laboratory Report (NSF-EP-24); and personal communications with Robert Hunt, Midwest Research Institute, April 1972. The coefficient for steel assumes that 50% of recycled scrap is processed in electric arc furnaces and 50% in basic oxygen furnaces. All three values in this column include 50 kwh/ton for miscellaneous purposes.

Source: Eric Hirst, Oak Ridge National Laboratory.

TABLE 30. ELECTRICITY REQUIREMENTS FOR SEPARATION OF SOLID WASTE[a]

	kwh Per Ton of Waste
Black Clawson Method	150
Franklin Institute Method	13
Bureau of Mines Incinerating Residue[b]	10- 20
Junked Automobile Shredding	25- 60
Average Value from EPA	20- 40

(a) Eric Hirst, Oak Ridge National Laboratory, Private Communications with the Black Clawson Company and the Franklin Institute Research Laboratory; and "Recovery and Utilization of Municipal Solid Waste", Report SW-10C, U.S. Environmental Protection Agency, 1971.

(b) "Incineration Yields About 10 Million BTU or 1000 kwh of Electricity Per Ton of Waste" at the Union Electric Company in St. Louis, Missouri.

AD-A034 419 BATTELLE COLUMBUS LABS OHIO F/G 13/2
PREDICTIVE CRITERIA FOR CONSTRUCTION/DEMOLITION SOLID WASTE MAN--ETC(U)
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TABLE 31. RELATIVE ENERGY CONSUMPTION--THROWAWAY VERSUS RETURNABLE BEVERAGE CONTAINERS

Container Type					
Throwaway	Returnable	Quantity	Beverage	Returnable Fills	Energy Ratios[a]
Glass	Glass	16 oz.	Soft drink	15	4.4
Can	Glass	12 oz.	Soft drink	15	2.9
Glass	Glass	12 oz.	Beer	19	3.4
Can	Glass	12 oz.	Beer	19	3.8
Paper	Glass	1/2 gal.	Milk	33	1.8
Plastic[b]	Plastic	1/2 gal.	Milk	50	2.4

(a) Without remelting (discarded bottles and cans are not returned for remanufacture).

(b) High-density polyethylene.

Segregation of construction wastes at the source is an important possibility. No formal study of waste segregation at construction sites has been done in the past. Also, during the present study, no specific investigation has been made to determine the potential for waste segregation at the source. However, some judgmental appraisal of waste segregation potential has been made on the basis of observations at selected Army post construction sites.

It has been found that waste materials generated at a construction site over certain periods are of distinct types. For instance, during construction of wooden frames, wood wastes are generated in large quantities which can be accumulated in a separate pile for reuse. Concrete waste can also be accumulated in a separate pile and transported to a recycling point. Separate waste piles can, thus, permit segregation of wastes at the source.

Economics of separate waste accumulation at a construction site are not clear at this time. The feasibility of these alternatives should, therefore, be assessed in the future.

Separation of mixed waste is another major alternative. There are several practical methods of separating mixed wastes. These methods are:

(1) Inertial separation

(2) Gravity separation

(3) Electric or magnetic separation

(4) Chemical or thermal separation

Inertial separators use the principle of inertia to separate mixed wastes of different density. Three major inertial separators are shown in Figure 16. Gravity separators include zig-zag air classifier, heavy-media or sink/float separation, tabling, jigging, etc. (Dale, 1974). It appears that these two methods may be applicable to the separation of mixed construction wastes.

Other separation methods like the electric or magnetic separation and the chemical separation are generally not applicable to mixed construction wastes. However, more investigation is needed to determine their applicability to mixed construction wastes.

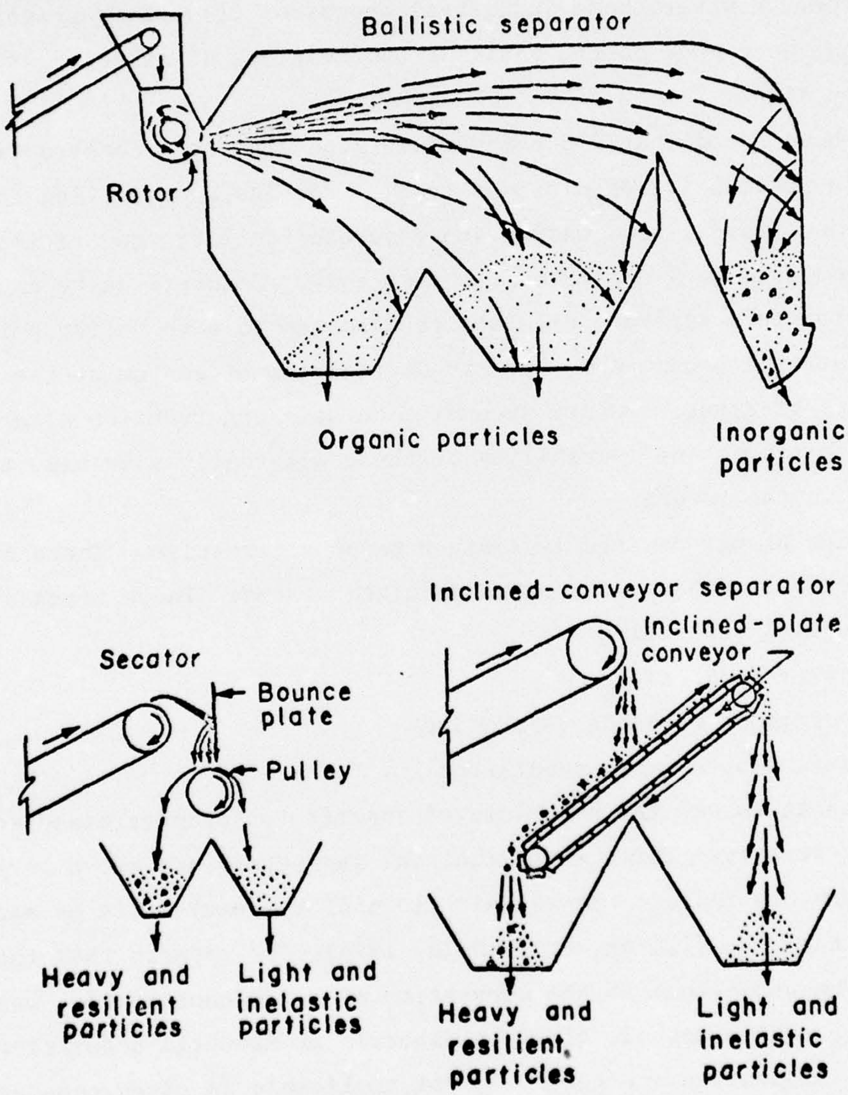

FIGURE 16. THREE MAJOR INERTIAL SEPARATORS

Source: Wiley, 1963. Reprinted with permission.

CHAPTER IV. CONCLUSIONS AND RECOMMENDATIONS

This study basically expands on the current state of the art of construction solid waste management. Chapter I summarized the available information on solid waste generation rates, waste composition, disposal alternatives, and disposal costs. The available data on waste generation rates and composition were found to be inadequate for the prediction of construction solid wastes at Army posts. As such, further investigations were made to quantify the rate and composition of construction solid waste at selected Army posts. The results of these investigations were reported in Chapter II.

Disposal alternatives examined in this report included burying, burning, salvage, and resource recovery. These alternatives were discussed in some detail in this report. Several potential resource recovery alternatives were identified and analyzed. No reliable cost data were found in the available literature; therefore, an effort was made to develop cost information on disposal alternatives currently being used at selected Army posts. The data obtained from existing landfill operations were summarized in Chapter II.

Based on data collected for this study, specific relationships were developed for predicting the volume, composition, and disposal cost of solid waste generated by construction of different types of facilities. The relationships were based on limited data, but may be used for predicting the volume, composition, and disposal cost only selectively (See Chapter II).

The data presented in Chapter II do not cover any major Army demolition activities. As such, the relationships do not apply to demolition activities. Also, these relationships must be verified by actual measurement, data collection, and statistical analysis.

In Chapter III, selected waste management alternatives were assessed in detail (See Table 10). The waste management alternatives considered were:

- Waste-to-Landfill Alternatives
- Incineration
- Production of Thixite
- Waste-to-Bricks Process--Tekbricks
- Ecological/Recycled Pavements

- Wood Waste-to-Energy Alternative
- Mulching
- Pulverizer Systems
- Handling of Special Wastes
- Integrated Management

Detailed analysis of the alternatives indicated that selected resource recovery alternatives, like production of Thixite panels, waste-to-bricks process, and recycled pavements, could be superior to landfilling or incineration of construction wastes. Use of pulverizers was found to be beneficial for resource recovery as well as economic landfilling.

Handling of special wastes from construction activities generally does not pose a major problem in solid waste management. Large volumes of special wastes can be disposed of in a nearby hazardous waste landfill.

When the volume of construction solid waste is small compared to the municipal and industrial solid waste in the region, it may be economical to consider integrated management of solid wastes. The information on processes, capital/operating costs, revenues, and other critical decision factors relating to the above alternatives was presented in Chapter III. This information can be useful in analyzing future construction programs and selecting effective disposal alternatives.

No detailed assessment of salvage has been presented in this study since salvage is not a major factor affecting construction solid waste management. Salvage is of much greater importance in demolition work; as such, it should be studied in greater detail in future demolition study.

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APPENDIX A

SOURCES OF DATA AND INFORMATION

The following are the sources that were contacted to develop necessary data for this study.

Fort Hood, Texas

Construction Site	Contact
Field House (Gymnasium)	Mr. Kasch Kasch Brothers, Inc. P.O. Box 427 Clarksville, Tennessee (817) 685-6484
EM Barracks	Bill Prillman Jim Yoder Algernon Blair, Inc. P.O. Box 759 Killeen, Texas 76541 (817) 562-7266
Commissary	Zapata Warrior Constructors P.O. Box "Q" Killeen, Texas 76541 (817) 526-9957
Family Housing Units	Jack Cooper Hunt Construction Company P.O. Box 169 Killeen, Texas 76541 (817) 526-4003
Overall Site Supervision	Joe Jarrell Jim Berryman Bob Ray U.S. Army Corps of Engineers Fort Hood, Texas (817) 685-3609

Fort Campbell, Kentucky

Construction Site	Contact
Airfield Hangars	Ray Harvey Construction Superintendent Algernon Blair, Inc. P.O. Box 93 Fort Campbell, Kentucky (502) 798-5060
Bachelor Officers' Quarters	Bill Lackson Construcciones Werle P.O. Box 176 Oak Grove, Kentucky (502) 798-4252
EM Barracks Modernization	Bill Britton Construction Superintendent Tenco Construction Co. Athens, Alabama 53611 (502) 798-6866
Gymnasium	Joseph S. Grubich Fortec Contractors P.O. Box 427 Clarksville, Tennessee (502) 798-4233
Overall Site Supervision	Larry Mathews U.S. Army Corps of Engineers P.O. Box 427 Clarksville, Tennessee (502) 798-7222

Other Sources of Information

Type of Information	Contact
Volume and composition of construction wastes	Mr. Swisler (Statistics) 469-6691 Bill Shannon (Architect) 469-7355 Dan Lane (Single Family Operations) 469-5557 Department of Housing and Urban Development 60 East Main Street Columbus, Ohio 43215

Type of Information	Contact
Sources of data	Mr. Allen Bibliography/Reference Library Department of Housing and Urban Development Washington, DC
Volume and composition of solid wastes	Mr. Ben Gillespie Director of Public Relations Browning-Ferris Industries, Inc. Houston, Texas (713) 741-1540
	Corporate Headquarters SCA Services, Inc. Boston, Massachusetts (617) 423-4100
Waste volume, composition, and management alternatives	Dick Powers SCA Services, Inc. Great Lakes Regional Office Chicago, Illinois (312) 279-0710
Concrete recycling	Alan D. Buck U.S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi
Aluminum recycling	Dr. Robert F. Testin Director of Environmental Planning Reynolds Metals Company Richmond, Virginia
Waste volume, composition, and management alternatives	Waste Management, Inc. Oak Brook, Illinois 60521 (312) 654-8800
Construction/demolition waste studies at MIT	Professor Myle S. Holley, Jr. Department of Civil Engineering Massachusetts Institute of Technology Cambridge, Massachusetts 02139
Demolition waste volumes, composition, and salvage operations	S. G. Loewendick & Sons, Inc. 1890 West Main Street Columbus, Ohio (614) 253-8601

Type of Information	Contact
Demolition waste volumes and composition	Mr. Murphy Terrell T&W Wrecking 434 Mt. Vernon Avenue Columbus, Ohio (614) 252-9375
	Craig & Sons, Inc. 468 South 22nd Avenue Columbus, Ohio (614) 258-0615
Recycling of brick and concrete wastes--Tekbricks	Mr. James R. Ryan Mr. John Belt Financial Analyst Tekology Corporation Bergen and Edsall Boulevards Palisades Park, New Jersey 07650 (201) 944-2221 (201) 947-0825
Use of wood as primary/supplementary fuels	Mr. R. H. Dowhan 1000 Prospect Hill Road Windsor, Connecticut 06095 (203) 688-1911
Recycling of waste masonry	Mr. Neil English Executive Director International Masonry Institute 823 15th Street, N.W. Washington, DC 20005 (202) 783-3908
Recycling of bricks	Mr. Bob Anderson Assistant Chief Engineer Brick Institute of America McLean, Virginia (703) 893-4010
Research underway to recycle glass as concrete aggregates	Mr. Tom Redmond Manager, Research and Development National Cement Masonry Arlington, Virginia (703) 524-0815
Recycling of bricks	Mr. Gene Yarborough Acme Brick Co. 2821 West Seventh Street Fort Worth, Texas 76107 (817) 332-4101

Type of Information	Contact
Rubber recycling (no useful information)	Mr. Stewart Clary Chief Compounder of Reclaimed Rubber Goodyear Tire 1144 Market Street Akron, Ohio 44316 (216) 794-2121
Waste disposal and recycling	Mr. Gene Wiengerter Executive Director National Solid Waste Management Association Washington, DC (202) 659-4613
Recovery and disposal of wastes	Dr. J. D. Mackenzie, Professor University of California Los Angeles, California (213) 825-4241
Disposal of waste	Mr. Bruce Hendricks Browning Ferris Fannin Banks Building Houston, Texas 77025 (713) 741-1540
Separation of wastes by aluminum magnet	Mr. Bert Hildebrand, Manager Materials Recycling Systems Combustion Power Company 1346 Willow Road Menlo Park, California 94025 (415) 324-7744
Recovery of wastes	Mr. Peter Vardy Institute of Waste Technology Waste Management Inc. 900 Jorie Boulevard Oak Brook, Illinois (312) 654-8800
Recovery of masonry and wood waste	Mr. Roy Ferrari Ferma Corporation Mountain View, California (415) 961-2742
Recovery of wastes	Mr. Wade St. Clair Director of Information National Center for Resource Recovery Washington, DC (202) 223-6154

Type of Information	Contact
Cost of collection and disposal	Mr. J. C. Thim Cleveland Wrecking Company 1400 Harrison Street Cincinnati, Ohio (513) 921-1160
	Mr. Richard Jackson Angelo Wrecking Company 375 W. Park Avenue Columbus, Ohio 43223 (614) 279-9700
Shredding of waste	Mr. Hank Peterson Jeffrey Manufacturing Company 100 East Broad Street Columbus, Ohio 43216 (616) 421-3123
Conversion of masonry rubble and glass to thixite	Mr. Bob Merritt, Researcher Colorado School of Mines Research Institute P.O. Box 112 Golden, Colorado 80401 (303) 279-2581
	Mr. Rick Barrow Director of Public Relations Glass Containers Mfg. Institute 1800 K Street, N.W. Washington, DC 20006 (202) 872-1280
Thixite panels	Mr. Cliff Shutt Thixon Corporation 2186 S. Holly Street Suite 3 Denver, Colorado 80222 (303) 757-0422
Conversion of rubber tires to fuel oil	Dr. John W. Larsen University of Tennessee Knoxville, Tennessee (615) 974-5070
Crushing of refuse	Mr. Gilbert M. Schuster Director of Public Works City of Tacoma Tacoma, Washington

Type of Information	Contact
Shredding of wood for particle boards	Kelbro Corporation Sacramento, California (916) 452-5841
Cost of shredding	Mr. August Braun, Sales Manager Williams Patent Crusher and Pulverizer Company 813 Montgomery Street St. Louis, Missouri (314) 621-3348

APPENDIX B

DENSITY OF WASTE COMPONENTS

The construction and demolition wastes contain many different components. Each component has a different density, i.e., weight per unit volume. The density figures used for various calculations in this study are as follows:

Components	Density (Pounds/Cu. Foot)
Concrete	
Concrete Masonry	105
Concrete Blocks	140
Bricks	
Clay Bricks	120
Soil	
Clay	100
Others	
Wood	50
Cardboard	40
Steel Scraps/Conduits	480
Asphalt	100
Plastics	60

APPENDIX C

CHARACTERISTICS OF THE THIXITE TILE PRODUCTION PROCESS

Product Description

Use

Thixite ceramic tile can be used for interior walls and floors and exterior walls and paving, including patios. With its low absorption (technically, it could be referred to as vitreous), high strength, and hard-wearing characteristics, it is particularly suitable for such uses as entranceways, shopping malls, etc.

Material Composition

Thixite tiles are made from 94 percent recycled, process ceramic and glass waste. All raw materials are carefully chosen for quality before entering the cleaning and processing plant. Manufacture of the tile is done in a unique way which allows large tiles (2 ft. x 2 ft. x 1 in.) to be made in any shape with extremely high dimensional accuracy. The firing schedules of the kiln are unique in that the consumption of energy is as low as one-tenth of that used in the manufacture of some conventional tile. Table C1 provides detailed product properties.

Finishes

Thixite is never glazed. Its exceptional physical characteristics and unique and distinctive appearance make glazing unnecessary.

TABLE C1. DETAILED PRODUCT PROPERTIES

1. Physical Properties	ASTM	T31	T94
Density (lb.cu.ft.)		132	140
Wt. per 1' x 1' x 7/8" Tile (lb.)		9-1/2	10-1/4
(a) Crushing Strength (psi)	C133-55	10,050	13,500
(a) Modulus of Rupture (psi)	C133-55	1,500	1,900
(a) Porosity-Apparent Porosity (%)		16.9	2.38
True Porosity (%)		18.5	8.39
(a) Water Absorption:	C 67-66		
24-Hour Test (%)		2.47	1.34
5-Hour Test (%)		5.78	
Saturation Coefficient		0.45	0.56
(b) Freeze-Thaw Test-% Loss	C67-Method B	0.055	N.A.
(c) Thermal Expansion (in/in/°F)		5.0×10^{-6}	4.7×10^{-6}
(c) Resistance to Wear (Taber Test)	C501-71	20	61
(c) Adhesion to Mortar; 3/8" Joint:			
Bond Shear Strength (psi)		390	485
Bond Tensile Strength (psi)		195	135
Est. of Failure (%) Bond		70	50
Mortar		27	25
Product		3	25
2. Chemical Properties			
(c) Ink Test	C126-71	Light Stain	Medium Stain
(c) Acid Solubility (% loss in sulphuric acid)	C279-72	6.2	2.0

(a) Tests completed by "Colorado School of Mines Research Institute."

(b) Tests completed by "NAHB Research Foundation, Inc."

(c) Tests completed by "Commercial Testing Laboratory."

Textures

Thixite has an attractive brushed texture for external applications. It can also be ground and polished for specialized interior uses.

Colors

Although only two standard colors are available today, a wide range of other colors are available on special order.

Size and Shape

The basic product is available in three tile sizes: 2 ft. x 2 ft. x 1 in., 2 ft. x 1 ft. x 1 in., and 1 ft. x 1 ft. x 1 in. Other sizes and thicknesses are available upon request. Similarly, a wide range of shapes (curved and straight) are available, also upon request.

Special Applications

Thixite is available as hearthstones, swimming pool coping, windowsills, and other special products.

Special Features

Thin grout joint or butt joints can be made. Large tile size results in reduced installation costs with fewer joints.

Method of Installation

Preparatory Work

Surfaces to which Thixite tiles will be applied should be sound, clean, and free from curing compounds, coatings, oil or grease, paint, or any other coatings which might prevent proper bond of mortar setting beds. Wall surfaces should be plumb and true to within 1/8 in. in 8 ft.-0 in. Floor surfaces should be level to within 1/4 in. in 10 ft.-0 in. and sloped properly to drains where drains occur.

Methods

In general, installation of Thixite tiles should conform to the installation details of the ANSI Standards, as applicable: A108.3-1967, "Quarry Tile and Pavers Installed in Portland Cement Mortars."

Thixite tiles may also be installed by employing thin-bed setting techniques using dry-set portland cement mortars or epoxy mortars. Installations shall conform to the ANSI Standard A108.5-1967, "Installation of Ceramic Tile with Dry-Set Portland Cement Mortar" and the current Tile Council of America's Handbook for Ceramic Tile Installation, as applicable.

"Marble set" and "Slate set" methods can also be employed for installing Thixite in vertical surfaces.

Cleaning and Maintenance

Thixite needs no maintenance other than washing in the event of dirt accumulation.

Guarantee

Thixon Corporation guarantees Thixite products for the life of the installation, under normal usage, against any defects in the physical and chemical properties of their products, and will replace, without charge, any product deemed defective by an authorized representative of the company.

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US Army, Europe
ATTN: AEAEN

Director of Facilities Engineering
APO New York 09827

DARCOM STIT-EUR
APO New York 09710

West Point, NY 10996
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ATTN: Library

HQDA (SGRD-EDE)

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-FEB
ATTN: DAEN-FEP
ATTN: DAEN-FEU
ATTN: DAEN-FESA
ATTN: DAEN-FEZ-A
ATTN: DAEN-MCZ-S
ATTN: DAEN-RDL
ATTN: DAEN-ZCE
ATTN: DAEN-PMS (12)
for forwarding to
National Defense Headquarters
Director General of Construction
Ottawa, Ontario K1A0K2
Canada

Canadian Forces Liaison Officer (4)
U.S. Army Mobility Equipment
Research and Development Command
Ft Belvoir, VA 22060

Div of Bldg Research
National Research Council
Montreal Road
Ottawa, Ontario, K1A0R6

Airports and Const. Services Dir.
Technical Information Reference
Centre
KAOL, Transport Canada Building
Place de Ville, Ottawa, Ontario
Canada, K1A0N8

British Liaison Officer (5)
U.S. Army Mobility Equipment
Research and Development Center
Ft Belvoir, VA 22060

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Ft Belvoir, VA 22060
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US Army Foreign Science & Tech Center
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ATTN: Far East Office

Ft Monroe, VA 23651
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ATTN: ATEN-FE-E
ATTN: ATEN-FE-U

Ft Lee, VA 23801
ATTN: DRXMC-D (2)

Ft McPherson, GA 30330
ATTN: AFEN-FED

USA-CRREL

USA-WES
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5th US Army
ATTN: AFKB-LG-E

6th US Army
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US Army Engineer District
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Philadelphia
ATTN: Library
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Baltimore
ATTN: Library
Norfolk
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ATTN: Chief, NAOEN-D
Huntington
ATTN: Library
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ATTN: Chief, SAWEN-E
Charleston
ATTN: Chief, Engr Div
Savannah
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ATTN: Chief, SASAS-L
Jacksonville
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Mobile
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ATTN: Chief, SAMEN-C
Nashville
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Memphis
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Detroit
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St. Paul
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ATTN: Chief, NCCED-H
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ATTN: Chief, ED-B
ATTN: Chief, ED-D
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New Orleans
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Little Rock
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Tulsa
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Fort Worth
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ATTN: SWFED-MA/MR
Galveston
ATTN: Chief, SWGAS-L
ATTN: Chief, SWGCO-M
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Los Angeles
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San Francisco
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Sacramento
ATTN: Chief, SPKED-D
Far East
ATTN: Chief, Engr Div
Japan
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Portland
ATTN: Library
Seattle
ATTN: Chief, NPSEN-FM
ATTN: Chief, EN-DB-SE
ATTN: Chief, NPSEN-PL-WC
ATTN: Chief, NPSEN-PL-ER
Walla Walla
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ATTN: Library
ATTN: NPADE-R
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North Atlantic
ATTN: Library
ATTN: Chief, NADEN-T
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ATTN: MEDED-T
South Atlantic
ATTN: Chief, SADEN-TE
ATTN: Library
Huntsville
ATTN: Library (2)
ATTN: Chief, HNDED-CS
ATTN: Chief, HNDED-ME
ATTN: Chief, HNDED-SR
Lower Mississippi Valley
ATTN: Library
ATTN: Chief, PD-R
Ohio River
ATTN: Library
ATTN: Chief, Engr Div
North Central
ATTN: Library
ATTN: Chief, Engr Planning Br

US Army Engineer Division
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ATTN: Chief, MRDED-T
Southwestern
ATTN: Library
ATTN: Chief, SWDED-TH
South Pacific
ATTN: Chief, SPDED-TG
ATTN: Laboratory
Pacific Ocean
ATTN: Chief, Engr Div
ATTN: Chief, PODED-MP
ATTN: Chief, PODED-P
North Pacific
ATTN: Chief, Engr

Facilities Engineer
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Ft Campbell, KY 42223
Ft Hood, TX 76544
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Ft George G. Meade, MD 20755
Ft McPherson, GA 30330
Ft Sam Houston, TX 78234
Ft Lewis, WA 98433
USAECOM
Ft Monmouth, NJ 07703
DSCPER
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Ft Eustis, VA 23604
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CAC&FL
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AMC
Dugway, UT 84022
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Ft Lee, VA 23801
Ft Gordon, GA 30905
Ft McClellan, AL 36201
Ft Knox, KY 40121
Ft Leonard Wood, MO 65473
Ft Sill, OK 73503
Ft Bliss, TX 79116
HQ, 1st Inf Div & Ft Riley, KS 66442
HQ, 5th Inf Div & Ft Polk, LA 71459
HQ, 7th Inf Div & Ft Ord, CA 93941

AF/RDXT
WASH DC 20330

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Bolling AFB, DC 20332

AF Civil Engr Center/XRL
Tyndall AFB, FL 32401

Little Rock AFB
ATTN: 314/DEEE (Mr. Gillham)

US Naval Oceanographic Office
Code 1600-Library
WASH DC 20373

Naval Facilities Engr Command
ATTN: Code 04
Alexandria, VA 22332

Port Hueneme, CA 93043
ATTN: Library (Code L08A)
ATTN: Morrell Library

Washington, DC
ATTN: Building Research Advisory Board
ATTN: Transportation Research Board
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Defense Documentation Center (12)

Engineering Societies Library
New York, NY 10017

W. N. Lofroos, P. E.
Dept of Transportation
Tallahassee, FL 32304