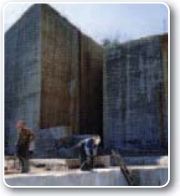
AMERICAN GRANITE CURB PRODUCERS


Granite is one of Earth's most perfect natural materials and in abundant supply.


Granite is quarried in large blocks.


Large blocks are cut into slabs with saws similar to this.


The slabs are cut to the required thickness. A hydraulic splitter is then used to cut these slabs into curbing.


Finished curb is inventoried for immediate shipment.


This granite curb was originally installed over 100 years ago in Milford, New Hampshire. It recently was re-installed due to road improvements and still looks great!

AGCP
American Granite Curb Producers

This two-part study is available free
at www.GraniteCurbProducers.com

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P.O. Box 278
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The strength and durability of granite are due to its crystalline structure.
This structure cannot be duplicated by synthetic curbing products.

AGCP

American Granite Curb Producers

The American Granite Curb Producers announce the results of the most exhaustive tests and analyses ever performed, providing an unbiased comparison of the properties of granite and precast concrete curb.

THE RESULTS ARE IN - AND THE VERDICT IS DRAMATIC AND CONCLUSIVE.

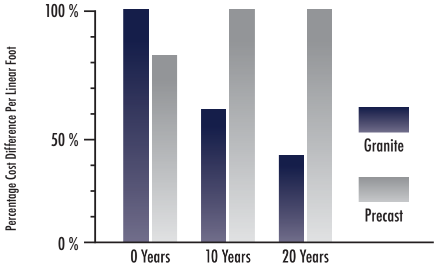
The civil engineering department of the University of Massachusetts has published the results of a joint study conducted with the University of Connecticut and commissioned by the American Granite Curb Producers. The report, A Comparative Analysis of Granite and Precast Concrete Curbing, states the results of comprehensive testing and analysis conducted to determine the relative merits of granite and precast Portland cement concrete curbing. Economic factors, as well as physical characteristics, were carefully examined and documented.

American Granite Curb Producers believes that the results are so striking that every civil engineer, highway department, architect, and contractor should read this study. We are pleased to provide a synopsis in this brochure, which we believe will assist all concerned in reaching a cost-effective curbing solution.


Granite curbing enhances the appearance of every street, highway, and parking lot. Its natural beauty is appreciated for generations.

GRANITE VS PRECAST CONCRETE

Graphic comparison of 20-year period




Concrete curb cannot survive even a short period if it is not backed up by soil. Berm always fails the snowplow test.

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PHYSICAL COMPARISON

The study noted that there are many structures of granite and concrete curb. The range of structural variation in granite, however, is minimal when compared to that of concrete curb. Since it is synthetic, the properties of concrete vary with the materials used and production processes. To provide the most objective comparison, the best available 5000-6000 psi, low slump, air entrained, precast concrete curbing was tested, rather than the inferior poured-in-place concrete. Dimensional granites from quarries in New England and North Carolina were utilized.

The principal factors affecting the life span of curbing are both natural and synthetic. They are loads, impacts, and elements. The strength of the curb to resist loads and impacts decreases with exposure to the elements. Durability typically is defined as the ability of a material to maintain strength and resist breakdown so that it can perform its intended function. There are three principal factors that are considered when evaluating durability: climatic conditions, service and exposure conditions, and maintenance requirements.

The two most significant climatic factors that affect curbing are freezing and thawing. In the tests, both granite and concrete curb were subjected to 360 free/thaw cycles. *Although no change in appearance of the granite was apparent as result of the freeze/thaw cycles, the concrete exhibited a marked deterioration.* This was particularly apparent on corners and edges that were rounded as a result of spalling. Results of the tests indicate that concrete curb will show distress and deterioration after five years in regions that experience around 75 or more freeze/thaw cycles.

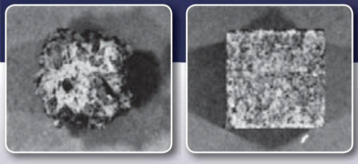
Chemical de-icing agents used on roads can affect the durability characteristics of both concrete and granite, causing weight loss in curbing materials. *Immersion of concrete in various salt solutions was accompanied by a reduction in strength of 25.1% to 74.4%. Reduction in granite was from 0 to 3.41%.* De-icing salts also can cause weight loss in curbing materials. Cyclic salt immersion and drying caused extensive surface scaling in concrete curb, and up to 160 times more weight loss. *The effect on granite was negligible. The tests established that granite is significantly stronger and far more resistant to weathering than concrete curb.* It also can withstand road milling, a commonly used resurfacing technique.

Granite curbing, because of its strength and durability, has an indefinite life span, and can be routinely salvaged and reused. Concrete curb, due to its deterioration and loss of strength, becomes unable to serve the purpose of a curb after a short period of time.


This granite curb was installed eleven years ago and exhibits no sign of damage. The rust stains from snowplow blades demonstrate its unmatched resistance to impact.


This precast curb was installed fifteen months ago and has been damaged by impact. It is highly susceptible to chemical freeze/thaw damage and will continue to disintegrate.


This eleven-month-old berm already is showing damage from compression and impact. Its useful life is almost over.


Concrete (left) and granite (right) were subjected to ammonium nitrate immersion tests. After 40 cycles, concrete lost 50% of its weight - granite lost none.


The effects of impact are obvious in these examples of precast curb installed less than three years ago.

ECONOMIC COMPARISON

To evaluate the two materials from an economic point of view, a life-cycle cost analysis was employed. This procedure considered initial cost, maintenance requirements, life-span, and re-installation. As of 1993, the Federal Highway Administration requires that all states use life-cycle cost analysis as part of the federally mandated pavement management program. Logically, we can expect cities and towns to follow suit as part of their cost reduction programs.

There are three major factors to consider when making an objective cost comparison between granite and concrete curb. These are initial cost, recurring costs, and life expectancy.

To determine the true initial cost, the University of Massachusetts examined the actual delivered and installed price, rather than simply the price of material as purchased from the distributor. At the time of the survey, the material cost of granite averaged about 25% higher than that of concrete curb. Installation prices, which include excavation, compaction, and backfilling, were found to be the same for both materials.

Preventive maintenance and disposal are two recurring costs that can be examined with a high degree of certainty. Properly installed granite curb requires no maintenance. Concrete curb, on the other hand, demands periodic sealing with silicones, linseed oil, plastic, or other materials to extend its life. Such applications have been only moderately successful, and in point of fact are rarely performed. *Since recycling of concrete curb is not economically feasible, it must be removed, disposed of, and replaced.*

The cost of disposal has risen dramatically in recent years, due to the declining availability of disposal space.

Granite has an "indefinite" life expectancy. It can be removed and reset when curb "reveal" (exposed face) is diminished due to resurfacing. Its structural properties allow it to be left in place during road milling operations.

Concrete curbing has no salvage value. Deterioration and breakage, which is very common during removal operations, prevent reinstallation. Installers have acknowledged that breakage of concrete curb during installation is quite common.

Utilizing a life-cycle cost approach is assessing the economic realities of granite versus concrete curb makes it apparent that granite is far more effective that precast concrete. The only perceived advantage of concrete curb is its initial lower cost, which is neutralized by granite's durability, lower maintenance cost, longer life, and the disposal cost of concrete curb. Granite is far less susceptible to damage and needs substantially fewer repairs.

The above char demonstrates total cost comparisons of granite and precast curb over a twenty year period assuming precast is replaced at year ten. Both initial and recurring costs were considered. Replacement of precast curb at year twenty is not included. Detailed charts and discussions of the effect of NPV's are contained in the study.

SUMMARY

The term "cost-effective" is an often-used buzzword that frequently is misapplied. Many times, an uninformed observer uses initial cost as the only factor in determining cost. The short-sightedness of this approach already is evident along the streets, highways, and bridges of states and communities that considered only initial costs in selecting curbing material. In today's and future economies, mid-range and long-range costs factors must be included.

It has been our objective to present the facts in a clear and understandable manner that will enable everyone to arrive at the proper conclusion.

80-year-old granite curb (left) was compared with precast concrete (center and right) in freeze/thaw tests. The granite was totally unaffected after 450 freeze/thaw cycles. Concrete showed considerable deterioration.


Here, a section of precast curb was completely pulverized by construction equipment at a shopping center.

LifeCycle Cost Comparison

GRANITE AND PRECAST CURBING

Updated by Dr. John Collura, P.E.
Department of Civil Engineering

UNIVERSITY OF MASSACHUSETTS
AT AMHERST

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AGCP
American Granite Curb Producers

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www.americangranitecurb.com
fax 336-786-6984

ECONOMIC COMPARISON

The physical comparison leaves no doubt that granite is the best curbing material available today. Its initial cost is higher than that of precast PCC curb but it has lower maintenance costs. Granite curb also lasts longer than precast PCC and offers other advantages because of its durability. The economical comparison presented in this report will consider this tradeoff between costs and durability. This report is an update and enhancement of a life-cycle cost analysis on granite and concrete curbing performed in 1991 by Dr. John Collura and several other individuals.

Life-cycle Cost

Life-cycle cost analysis will be used to evaluate the economics of granite and precast PCC curbing. Life-cycle cost analysis is a procedure in which initial cost, maintenance requirements, and life span are jointly considered in the evaluation of alternative project designs (1, 2, 3). The present worth of the initial cost and future maintenance and replacement costs are considered rather than just the initial costs. The simplest way to think about present worth is to consider a trust fund in which the initial endowment would be just sufficient to maintain the project during its planned life. The logic of considering all costs, present and future, rather than just initial costs should be readily apparent. Life-cycle cost analysis is a valid means of accomplishing this task. In fact, the U.S. DOT agencies including FHWA require all states to use life-cycle cost analysis as part of federally mandated pavement management programs (4). Present worth (PW) is by definition dependent on the interest rate considered. This interest rate also is known as the discount rate, the rate at which future costs are discounted to current dollars. Discount rates are expressions for our time preferences. A discount rate of 7% implies an indifference between $1.00 today and $1.07 next year.

Another way of looking at this time preference is to consider the common dilemma of choosing between two grades of a product, which have different life expectancies. Many people will pay a higher price for a product that lasts longer. The higher price is obviously paid now to avoid a future replacement expense. Implicit in this decision is a discount rate. Today's premium in price is weighted against a discounted future expense. If experiments were conducted, a range of these implied discount rates would surface. Public investment decisions, however, should be evaluated consistently. For this reason the time preference discount rate is made explicit.

High discount rates weight an expense that occurs in the future much less than the same expense occurring today. A 0% discount rate weights a future expense the same as a present expense. High discount rates favor the low initial cost, but high maintenance alternative because future expenses are weighted less. Low discount rates, on the other hand, favor the initially more expensive, but longer lasting, low maintenance alternative because future replacement expenses are given greater consideration.

This report will use a 7% discount rate consistent with guidelines provided by the U.S. Office of Management and Budget (OMB) and presented on the FHWA Asset Management website (2). It should be noted that many individuals and organizations argue that a lower discount rate should be used. For example, the Portland Cement Association historically has concluded that real discount rates virtually always fall between 0% and 4.5% with typical values being between 1% and 2.5% (5). Moreover, some Federal agencies in their life-cycle analyses currently use lower rates, based on inflation-adjusted Federal borrowing costs. These lower rates, depending on the length of the life cycle, are on the order of 2.5 to 3.2% (2).

Initial Costs

Determining initial costs is a difficult job. Material and labor expenses are usually combined. Lower material costs than those used in this research can be obtained but they are typically for large jobs or exclude overhead for the contractor. Contractors have expenses and these expenses must be included in their prices. It is a mistake to just consider material costs. The city or town is not purchasing a pile of curbing material. It is purchasing delivered, installed, functional curb. A survey including information from local and state bid records as well as private contractors was conducted to determine the material and labor costs of installing granite and precast PCC curbing. Granite curb material cost (VA 4) ranged from a low of $20 per linear foot to a high of $33 per linear foot depending on the state location, type of roadway, size of job, and other factors. The average material and installation cost of precast PCC curb ranged from $21 to $23 per linear foot. Representative values used in the analysis include $22 for PCC and $26.50 for granite VA-4 is a granite curb size specification. This standard designates top and bottom widths as well as tolerances. It is 6" wide at the top. VA-4 was picked because it is the most commonly used type of granite curb and has dimensions similar to typical precast PCC curb. It should be noted that because of granite's strength, thinner (and possibly less expensive) granite curb can be used in many situations. The use of thinner precast PCC curb, however, is not practical. Prices of both granite and precast PCC curb were found to vary with respect to volume. Very large highway jobs cost less per linear foot than small repair jobs. Thus, there are economies of scale in curb construction.

Recurring Costs

There are three recurring costs that can be examined with some degree of certainty. They are preventive maintenance, replacement, and disposal of worn-out curb. Other recurring costs, such as curb damage, are random and prove difficult to quantify. Costs of this nature will be addressed later. Properly installed granite curbing requires no maintenance. Concrete curbing, after proper installation, requires periodic sealing to extend its life. However, this maintenance is seldom, if ever, performed. Consequently, cost figures are unavailable. It is realistic to assume no maintenance will be performed on concrete curbing. This lack of maintenance will be reflected in shorter life expectancy than attainable with ideal care. At the end of its life, the concrete curbing will have to be removed, discarded, and replaced. Recycling of precast PCC curb is not economically feasible at this time because of the labor required to remove reinforced rod. The cost to dispose of deteriorated curb has risen dramatically in recent years. In 1988 the Massachusetts DPW paid, on average, $1.96 per linear foot to remove and discard curb (6). Current prices to remove and discard are approximately $4.86 per linear foot (7). Disposal prices will continue to rise faster than other prices as remaining landfill space becomes more valuable.

Life Expectancy

Granite has an "indefinite" life expectancy. Granite curb can be removed and reset when curb reveal is diminished due to road resurfacing. Granite's structural properties also allow it to be left in place during road milling operations, a popular highway maintenance treatment presently being employed in New England. Road milling is an especially attractive alternative to reconstruction in urban areas. In these locations, road height is limited by the height of building sills and bridges. At some point, additional overlays become impossible. When there is a good base present, road milling is less expensive than tearing up the old pavement and reconstructing the roadway. It also is quicker and permits continued use of the road resurfacing. This factor is especially important for major arterials and collectors. Concrete curbing has no salvage value.

It is subject to breakage during removal operations, which are very common today, given that many state and local highway agencies are implementing large-scale pavement management and maintenance programs.

Typically, curbing is removed, discarded and replaced when its reveal is lost. By this time, it usually has deteriorated to a point where it cannot be reinstalled, even if some life remains and if it could be removed intact economically. Concrete is prone to damage during milling operations because of its low strength and abrasion resistance. Extreme care must be taken to avoid damaging it. This extra care means greater milling expenses. In actual application, a precast PCC curb's useful life often is dictated not by its own life, but rather by the life span of the road. It makes sense to replace deteriorating precast PCC curb while the road is being rehabilitated. If precast PCC does not last as long as the road, curb replacement requires tearing up part of the road. This necessitates patching, which in practice seldom yields quality comparable to original construction. In fact, patching often leads to premature deterioration of the roadway. Two life expectancies of precast PCC will be examined: ten and twenty years.

The twenty-year life expectancy is based on a study by the Rhode Island Department of Transportation (8). This study examined twelve- to fourteen-year-old samples of precast PCC curb and concluded that they should last six to eight more years. This would result in an effective service life of twenty years. It is not known whether this curbing received any preventative maintenance. The twenty-year life span is consistent with the design life of many urban roads. Precast PCC curb normally is replaced in conjunction with reconstruction.

The ten-year life span was included to show what the life cycle cost would be if the precast PCC curb did not last twenty years. Lab testing indicates this possibility should not be ruled out, especially if precast PCC curb is being considered for installation in a region that experiences harsher winters than Rhode Island.

Analysis

This analysis will consider typical curbing expenses over the life of a newly (re)constructed road. A forty-year planning horizon will be used. Curbing expenses will be examined on a linear-foot basis. Assuming precast PCC curb lasts twenty years and a 7% discount rate, expenses will consist of $22 immediately (year 0) and $26.86 ($4.86 to remove and discard plus $22 to replace) in year twenty. A total of $46.86 will be spent over twenty years. Curb replacement at the end of year forty is not considered. The net present value (NPV) of these expenses is $28.92. The granite curbing can be left in place during projected road milling and rehabilitation in year 20 or so; there will be no other expenses during the forty-year planning horizon. The NPV of granite is therefore $26.50. It is this NPV of present and future expenses that should be considered by public officials – not initial cost. When the inevitable future expense of replacing deteriorated precast PCC curb is considered, granite curb is clearly the less expensive curb material. If precast curb lasted only ten years, its NPV would be $46.20 compared to granite's $26.50. Below is a sample calculation of New Present Value (NPV) using a twenty-year life expectancy of precast PCC curb, 7% discount rate and a forty-year planning horizon. All dollar values are per linear foot.

Precast PCC
Year Expense x PWF = PW
0 $22.00 1.0 $22.00
20 $26.86 0.258 = 6.92
$28.92 NPV

Granite
Year Expense x PWF = PW
0 $26.50 1.0 $26.50 NPV

Notes:
PWF = Present Worth Factor = 1__
(1+ r)t
PW = PWF x expense,
where r = discount rate
t= time period (year)

When this analysis is conducted at a lower discount rate, such as 5%, the NPV of precast PCC and granite would be $32.12 and $26.50, respectively, for the twenty-year life of precast PCC. The NPV of precast PCC would be $54.82 if it lasted only 10 years. The 5% discount rate could be considered a “social discount rate”. This rate considers future citizens more than the 7% discount rate will. Many economists argue that a public official, entrusted with public welfare, should use the lower rate (9). When the 2.5% real, inflation-adjusted discount rate advocated by the Portland Cement Association is used the NPVs of precast PCC and granite are $36.30 and $26.50, respectively, for a twenty-year life span of precast PCC. Precast PCC would cost about 40% more than granite. If precast PCC lasted only 10 years its NPV would be $72.17, more than two and a half times more expensive than granite! This extremely low discount rate is probably idealistic, however. It neglects the financial realities of budgetary constraints.

It should be stressed again that this analysis neglects some costs, which are extremely hard to quantify. These costs are curb damage, construction delays to road users, and aesthetics. Curb damage typically is inflicted on precast PCC curb by rollers, snowplows, and heavy trucks. Granite curb, however, has a legendary resistance to this kind of damage. A very important value, which has been ignored by the economic analysis, is the salvage value of granite. Granite curb was assumed to be worth nothing at the end of the forty-year planning horizon. Granite curb, which was laid at the turn of the century, however, routinely is salvaged and reused. Granite curb laid today will be around for generations. The fact that granite curb is a reusable rather than a disposable commodity, undoubtedly will become more important in the future. The days of plentiful, inexpensive landfill space are over. Recycling rapidly is becoming a necessity. In western Massachusetts, 85 cities and towns that joined a regional recycling facility rather than constructing expensive new landfills were required to adopt mandatory recycling laws (10). Similar arrangements are being adopted across the country. Environmental concern has become a pressing national issue and a structural switch from disposable to reusable commodities is an integral part of the solution.

In summary, the analysis clearly shows how basing expenditure decisions on initial cost without regard to future expenses can lead to high costs over the long run. Public officials cannot afford to ignore the effects today’s investment decisions will have on our children. The infrastructure of northeastern states, like most of the country, has been burdened by a backlog of deferred maintenance (11,12). The situation will not improve if future expenses are ignored during the public works investment decision-making process.

CONCLUSION

The physical comparison clearly indicated that granite is a superior curb material in New England where winters, road salt, and plowing are tough on Portland cement concrete. The economic analysis indicated that when the inevitable replacement of precast PCC is considered, granite curb is a less expensive curb material. The only advantage of using precast PCC curb is its lower initial cost. This advantage is outweighed, however, by granite's durability, longevity, and reusability.

It should be pointed out that many advantages of granite curb did not need to be considered in order to reach this conclusion. The fact that granite curb needs substantially fewer repairs was ignored. The costs of construction delays to motorists where precast PCC curb is torn out and replaced, and savings when using road milling, also were ignored. Additionally, no effort was made to factor in the eyesore posed by deteriorating PCC curb. These uncounted costs only serve to reinforce the conclusions of this report. They also indicate that the installation of granite curb is most desirable where these costs will be greatest – along major urban roads. The conclusions of this report are also strengthened by a continued rise in costs to dispose of deteriorated curb. The disposal crisis is a disturbing, expensive reality that cannot be ignored. Part of the solution seems to be a general trend toward reusable versus disposable commodities. Granite curb is a reusable commodity. The salvage value of granite curb was excluded in the economic analysis. It is their decision that determines whether future generations will be left with continual curb replacement expenses or a stock of durable reusable curb.

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COMPARISON OF GRANITE AND PRECAST CONCRETE CURBING
Cost and Technical Issues

MICHAEL SOCK

April 1999

RESEARCH
& TECHNOLOGY
DEVELOPMENT

Prepared for the
Rhode Island Department of Transportation
by the
Research and Technology Development Section

RHODE ISLAND DEPARTMENT OF TRANSPORTATION

William D. Ankner, Ph. D., Director
James R. Capaldi, P.E., Chief Engineer
Colin A. Franco, P.E., Managing Engineer, R&TD

Executive Summary

This study was undertaken to determine the technical and economic feasibility of using granite curbing as an option within the normal practices of highway construction in Rhode Island. Previous studies have been carried out by various entities, including the RIDOT design section. These were reviewed and referenced where appropriate.

For this endeavor, the R&TD Section began with a literature search and surveys of states and vendors in their usage of highway curbing. A trip to the Fletcher Granite Quarries in Chelmsford was also undertaken to get a first hand look at the curbing operation and logistics involved in the supply of curbing. Through an interview with Mr. Robert Fruggiero, retired RIDOT Materials Engineer, we learned details about the inception of zero slump concrete curbing.

As the technical aspects of granite vs. concrete curbing had been studied and reported on previously, we decided just to overview these and focus our effort on the economics of initial and life cycle costs instead. Needed information was difficult to obtain. However, we did get the same from various sources, such as states, vendors, contractors, and RIDOT records. The life cycle costing was done using conventional formulae, but with three different interest rates. This would give the reader a sense of the life cycle cost over a spectrum of interest rates. Assumptions were made based on prevailing rates, current practices, and engineering judgment. The results indicate no significant difference in the life cycle costs of granite vs. concrete curbing. A major reason for this is that granite curbing shapes have been minimized and streamlined which in turn has led to efficacy in material savings, fabrication, transportation, handling, and installation costs.

The study shows that at lower interest rates the granite is slightly more favorable than concrete, whereas at high rates it is just the opposite. This is true for low, medium, and high volumes of bid quantities.

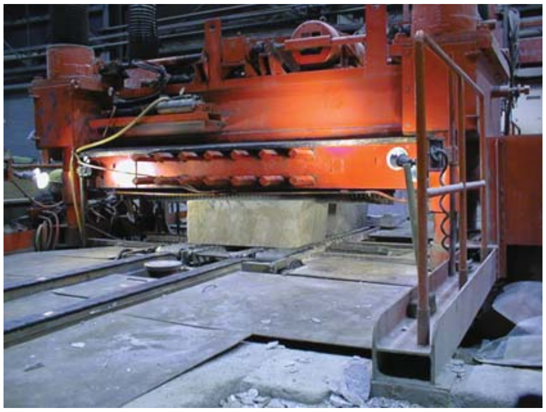
Socio-political factors were not considered in the analysis.

Colin A. Franco, P.E.
Managing Engineer
Research and Technology Development

Objective: Comparison of costs and technical benefits of granite curbing versus zero slump precast concrete. The financial projections were based on estimated costs taken from contract bid items from two projects and General Construction List of Average Unit Prices, a range of interest rates and estimated lives for each material.

Background: Approximately twenty-five years ago, RIDOT stopped using granite curbing as a standard, with the exception of bridge projects. The primary motivation was cost, as precast concrete, the replacement, was cheaper to purchase and install. Granite had the advantage of long life and the capability of being reused, but it was very expensive and because of the massive size and irregular shape, very difficult to install. However, trimmed granite is still specified for bridges, due to its superior durability and the critical need for protection of the decks. At the current time, improved processes for quarrying and shaping the granite have both lowered the cost and made it possible to produce more dimensionally controlled pieces. This in turn lowers the installed cost of the granite curbing, to the point where it is nearly competitive with precast concrete. There are granite suppliers within 100 miles, but there has been interest shown from a supplier as far away as Canada. It is therefore believed that it is time to re-examine the use of granite as a standard for curbing.

Granite Quarrying and Shaping



Concrete Casting:

Procedure: The present worth of each system was taken using the installation cost per linear foot. Added to that was the remove and dispose cost for concrete (with the interest calculated over the expected useful life of the curbing) or the remove, stockpile and reset cost of the granite, also per linear foot. This was done over a sixty year time frame and only straight curbing was examined. The technical issues were reviewed by examining available literature and test reports and based on general knowledge of concrete and granite.

Assumptions: The three initial costs for the granite were taken to be: \$11, \$12 and \$14[1] per linear foot and \$6 per foot to install. The initial costs for concrete were taken to be: \$13.50, \$14 and \$15[1] per linear foot. The costs are for large (over 5000 feet), medium (between 1000 and 5000 feet) and small (under 1000 feet) installations for each material, respectively. The cost is assumed to change only with inflation. The interest rates used were 3, 6 and 9 percent, to allow a reasonable range for comparison. The remove, stockpile and reset cost of granite was assumed to be \$7 per linear foot and the remove and dispose cost for concrete was assumed to be \$2 per linear foot. The life of granite curbing is projected to be over one hundred years and the life of concrete is assumed to be twenty years. The projection for this study is over sixty years. A loss of ten percent for breakage for the remove, stockpile and reset operations was allowed for the granite. It is possible that the concrete may still be usable after twenty years (in condition adequate for a remove and reset operation), but that is considered unlikely.[2]

Cost Analysis:

Case I (example):

Granite initial cost (GIC): \$17 per linear foot (including installation)
Granite remove and reset cost (GRR): \$7 per linear foot
Concrete initial cost (CIC): \$13.50 per linear foot
Concrete remove and dispose cost (CRD): \$2 per linear foot

Rate of return (i): 3%
Present worth factor over twenty years for given interest rate (PWF20i): 0.5537
Present worth factor over forty years for given interest rate (PWF40i): 0.3066

Granite:

Over sixty years, the cost of the granite will include the initial cost (once), replacement of broken pieces (two times at 10%) and remove and reset (twice, at 20 years and then 40 years hence). Therefore, the present worth cost for granite curbing (PWG) would be:

[\$17, Initial cost]+[\$0.94, present worth of 10% breakage replacement in 20 years]+[\$0.52, present worth of 10% breakage replacement in 40 years]+[\$3.87, remove and reset cost in 20 years]+[\$2.15, remove and reset cost in 40 years]=***\$24.48 per linear foot***

Concrete:

Over sixty years, the cost of the concrete will include the initial cost (three installations, at time zero, 20 years and 40 years), and remove and dispose (twice, at 20 years and then 40 years hence). Therefore, the present worth cost for concrete curbing (PWC) would be:

[$13.50, Initial cost]+[$7.47, present worth of the installation cost in 20 years]+[$4.14, present worth of the installation cost in 40 years]+[$ 1.11, present worth of remove and dispose cost in 20 years]+[$0.61, present worth of remove and dispose cost in 40 years]=***$26.83 per linear foot***

Similar analyses were performed for other rates and initial costs to obtain the costs shown in the table below.

Table 1 - Life Cycle Cost as a Function of Rate of Return and Quantity

	i=3%	i=6%	i=9%	i=3%	i=6%	i=9%	i=3%	i=6%	i=9%
GIC †	17.00			18.00			20.00		
GRRC †	7.00			7.00			7.00		
CIC †	13.50			14.00			15.00		
CRD †	2.00			2.00			2.00		
PWF20$_i$	0.5537	0.3118	0.1784	0.5537	0.3118	0.1784	0.5537	0.3118	0.1784
PWF40i	0.3066	0.0972	0.0318	0.3066	0.0972	0.0318	0.3066	0.0972	0.0318
PWG †	24.48	20.56	18.83	25.57	21.60	19.85	27.74	23.68	21.89
PWC †	26.83	19.84	16.76	27.76	20.54	17.36	29.62	21.95	18.57

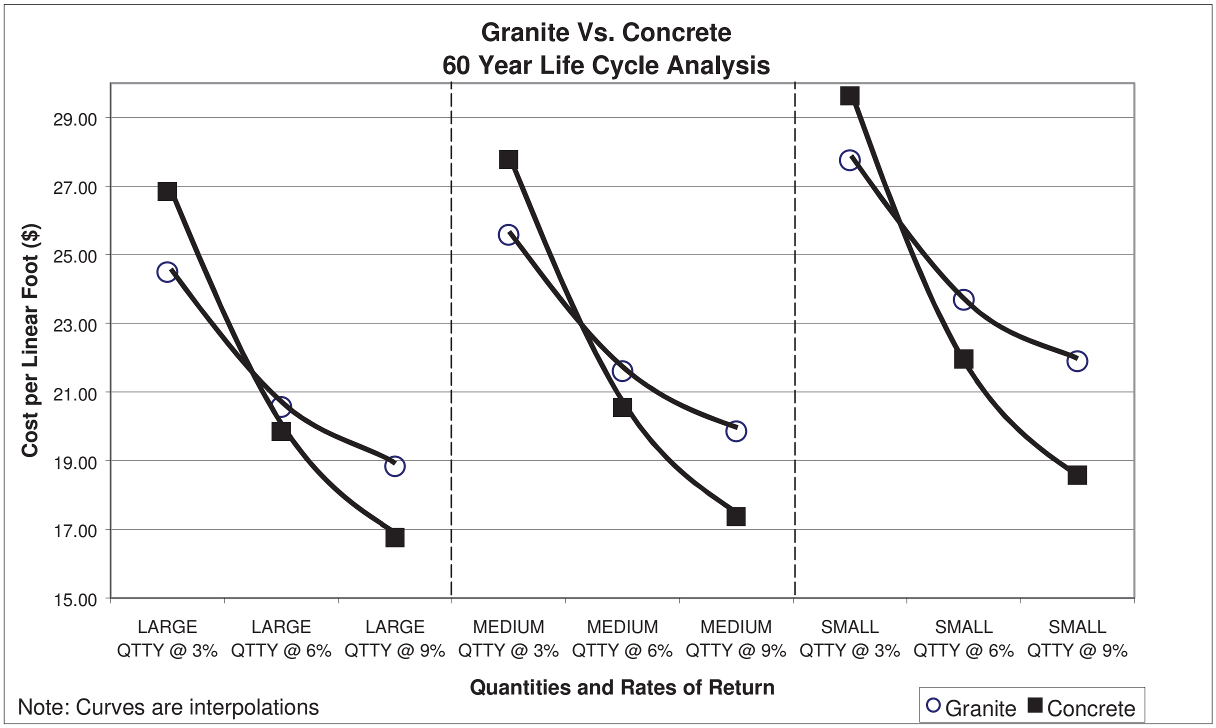
† dollars per linear foot

Material Properties - Technical Analysis:

The durability of the granite in comparison to the concrete is the main issue in terms of performance. It is generally accepted (and testing bears out) that although low w/c concrete is resistant to freeze/thaw deterioration, granite is virtually unaffected. Erosion and wear can be an issue over the long term, but again, the properties of granite in this regard are far superior to that of concrete. Since it is assumed that the granite will be reset after removal and the concrete will be disposed of, breakage of the granite can affect costs. But care in handling the granite will minimize any losses and it is a very strong material, capable of being subjected to a certain degree of rough treatment without fracturing. Placement of the granite is not the consideration that it was, since current means of production produce pieces that have consistent geometric shapes with dimensions that are sufficiently controllable to provide adequate ease in setting. However, since precast concrete curbing is a manufactured product, its tolerances can be determined very precisely, with great repeatability.

Summary:

From the present worth analysis, it can be seen that the granite is less expensive when interest rates are low. Since it is assumed that the precast will be replaced every twenty years, the longer the period of the analysis, the greater life span of the granite will improve its competitiveness. Granite weathers better than concrete, although a good mix will generally show only moderate scaling over a twenty year period and will resist freeze/thaw. Finally, granite is considered aesthetically more pleasing than concrete, although the value of that is less tangible. Note that it would be necessary to



Note: Curves are interpolations

perform another analysis for a case where a significant amount of radius curb is used.

Commentary – Francis Manning:

One consideration that could affect the type of curb is the concept of the permanent roadbed. Alterations in alignment and grade have necessitated, every twenty years or so, rebuilding most entire pavement structures. For several reasons, we are now reconstructing more roads in place. This could make feasible a permanent roadbed, i.e., a strong, permeable, well-drained, subsurface capable of lasting scores of decades. Riding surfaces would still have to be maintained, resurfaced, and replaced at appropriate intervals, but the granular structure below the metaled asphalt or portland cement concrete surface would not have to be touched. It would make sense to consider the curb, embedded in the subbase, part of the permanent roadbed. But only indefinitely durable granite could with assurance be expected to last at least two pavement replacement cycles.

References:

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1. Rhode Island Contract Nos. 9730 and 9822 , Proposal Items and General Construction List of Average Unit Prices

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Life Cycle Cost Study for Sustainable Hardscape Design
Exterior Stone Paving

Executive Summary

"When the cost model is considered along with physical characteristics, one can conclude that granite is the best overall choice."

Current trends within the public and private sectors of design and construction reflect the deliberate effort to maximize the total value and minimize the total cost or the Life Cycle Cost for a given product. Call it the "big picture" method of product selection. Architects and consumers are searching for the best products at the lowest prices knowing that "best value and cheapest" do not often coexist within one product. Exterior pavers are a perfect example of this perpetual search, where the best value and cheapest do not coexist. The objective with those facts in mind is superior product selection considering current costs and overall sustainability or endurance of the product over its life.

Using the "big picture" method, this study establishes a cost/value model, which includes the initial material, installation and maintenance costs as well as life span for granite, limestone and precast concrete pavers. Material and installation costs are easily defined through suppliers and contractors, while maintenance costs and life span are largely a function of the product selected. Absorption and resistance to abrasion and chemical resistance are critical factors that influence maintenance and durability. The summation of all aspects can make the architect and consumers choice of material much easier.

The initial cost for installed natural stone exceeds that of precast concrete. However, when the costs for maintenance and replacement are included, the "big picture" has a different look. In climates where freezing moisture is a consideration, water absorption is a major consideration. Materials with lower water absorption rates will experience less cracking during freeze/thaw cycles. Granite outperforms the other materials by a significant margin with an absorption rate of 0.2% versus 4.5% for limestone and 6% for precast. In areas with high foot traffic, a high abrasion resistance is important. Again, granite is superior to the other two. Typical abrasion resistance for granites is 7 times better than limestone and 5 times better than precast. Product resistance to chemicals is an important consideration for staining and degradation due to exposure to acids used in cleaning and/or pollution. Granite is composed of mainly silicate materials, which resist staining and acid attack. Limestone and precast are primarily composed of calcite, which is susceptible to staining and dissolves readily in weak acid.

When the cost/value model is considered along with physical characteristics, one can conclude that granite is the best overall choice. While granite outperforms limestone and precast concrete in each of the sustainability categories (maintenance, physical characteristics, life span), it is important to recognize again that "the best value and the cheapest do not coexist within one product." In this instance you do get what you pay for—the additional initial investment required for granite is returned easily by a factor of two over its longer life span (50 years versus 20 years), due to its superior materials chemistry.

7502 Greenville Ave.
Suite 800
Dallas, Texas
75231 USA
tel. 972/437-4200
fax. 972/437-4562
general@cdc-usa.com

Life Cycle Cost Study for Sustainable Hardscape Design - Exterior Stone Paving

Rodney Harvey
Associate, Curtain Wall Design and Consulting, Inc.
Dallas, TX 75231

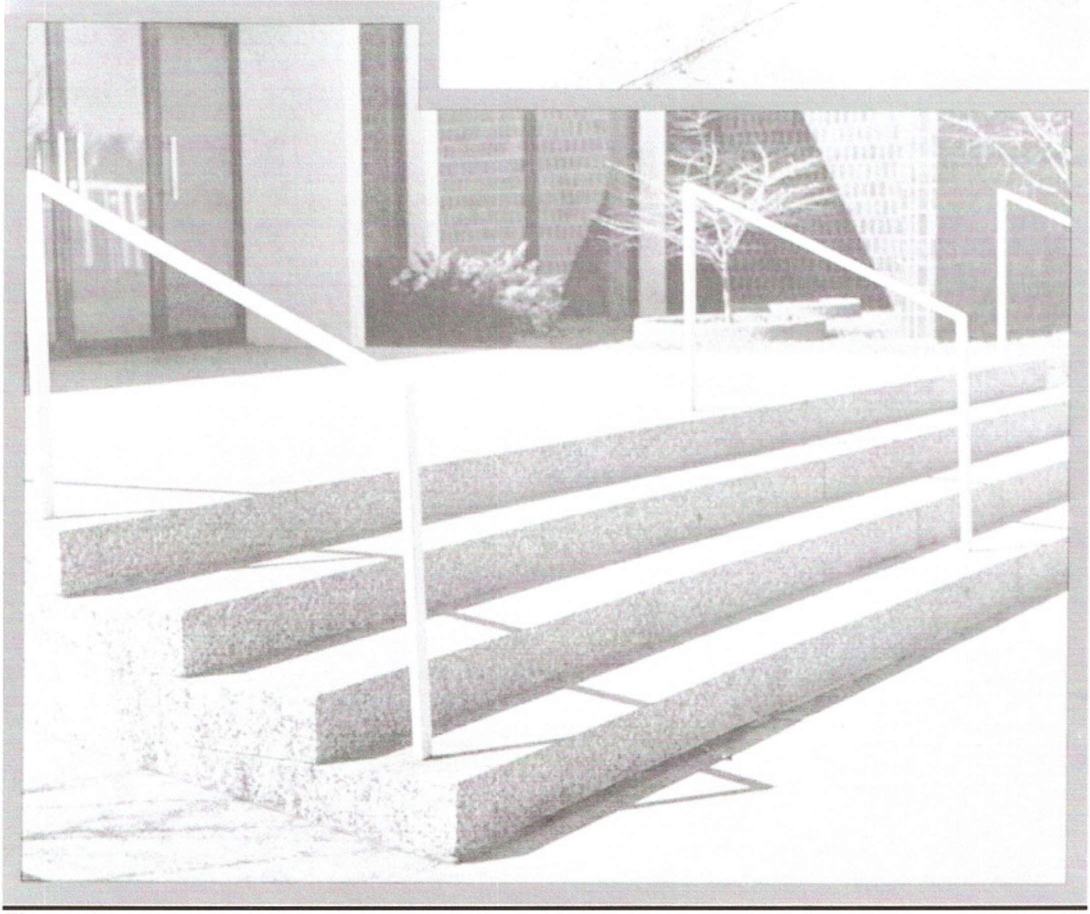

Figure 1 – Sustainable hardscape design incorporating cubic granite

Purpose

Life Cycle Costing (LCC) is most often utilized in building design energy conservation measures as required by the governing authorities responsible for code enforcement or design review on projects in a given region. The basic premise for the economic analysis is the subjective study of materials and procedures which will have an impact on proposed or future costs. Hardscape design using realistic LCC will result in superior product selection for an individual project with optimal performance over the life of the product.

Objectives

1. Evaluate material, installation and maintenance costs associated with granite, limestone and precast concrete paving.
2. Establish a scientific basis for evaluation of each material subjected to similar environmental and serviceability factors.
3. Estimate and compare annual and total life cycle costs for each type of paver.

Methodology

Cost data for labor and materials for each maintenance activity predicted over the study life cycle period was obtained from:

- Various granite, limestone and precast concrete suppliers, fabricators and installers
- Stone maintenance professionals
- Architects, Contractors and Engineers Guide to Construction Costs, 2002 Edition

A scientific basis for evaluation of each material can be established by isolating key characteristics of the physical properties which dictate a long service life.

Material and Installation Costs

Market data and published construction material costing data indicates limestone and precast paving are the lowest cost alternatives to granite for initial installation. While granite and precast pavers can be grouped on the basis of shipping, handling and installation methods limestone carry as much as a 10% premium due to additional handling precautions and breakage allowances.

Maintenance Costs

Stone maintenance (cleaning) addresses the aesthetic quality of a paving installation. Exposure to environmental pollutants, foot traffic, contaminated runoff water from adjacent structures, and natural weathering impact the outward appearance and often the structural integrity of stone paving.

Although stone cleaning addresses the aesthetic quality of paving, the durability of a selected product should also be considered prior to performing this maintenance. The physical properties of limestone and precast concrete indicate that these materials are predisposed to experience surface loss, increased rates of decay and potential structural damage due to cleaning cycles. Granite, however, is a much more resilient material. With these facts in mind, the cost of scheduled maintenance and eventual replacement cost due to a reduction in service life should be considered.

The maintenance schedule used in the following comparison model(s) is hypothetical. Actual recommended maintenance procedures and schedules for the materials listed will vary subject t location, foot traffic volume and specified project requirements.

Sunset Red Granite paving – Assume basis of 10,000 square feet of 1 1/4" thick, flamed or honed finish granite.

Common maintenance schedule:

- Annual cleaning of surface
- Major Reapplication of sealer and repointing of joints at 5 to 10 year intervals

Monthly Maintenance: Stone inspection
Annual Maintenance: Stone cleaning

Total installed cost:	$390,000.00 ($39/s.f.); 50 year anticipated service life
Annual Maintenance:	$ 4,000.00 (.40/s.f.)
Major Maintenance:	$ 24,000.00 (.40+$2/s.f.)

Leuders limestone paving – Assume basis of 10,000 square feet of 2" thick, smooth finished limestone paving.

Common maintenance schedule:

- Annual cleaning of surface
- Major Reapplication of sealer and repointing of joints at 2 to 5 year intervals

Monthly Maintenance: Stone inspection
Annual Maintenance: Stone cleaning

Total installed cost:	$330,000.00 ($33/s.f.); 20 year anticipated service life
Annual Maintenance:	$ 4,000.00 (.40/s.f.)
Major Maintenance:	$ 24,000.00 (.40+$2/s.f.)

Precast concrete paving - Assume basis of 10,000 square feet of 2" thick, 7,000 psi, smooth finished precast concrete paving.

Common maintenance schedule:

- Annual cleaning of surface
- Major Reapplication of sealer and repointing of joints at 3 to 5 year intervals

Monthly Maintenance: Stone inspection
Annual Maintenance: Stone cleaning

Total installed cost:	$250,000.00 ($25/s.f.); 20 year anticipated service life
Annual Maintenance:	$ 4,000.00 (.40/s.f.)
Major Maintenance:	$ 24,000.00 (.40/s.f.+$2/s.f.)

Scientific Basis for Comparison

Consideration of the anticipated service life of each product is critical in the comparison and/or justification of the initial costs of installation. Three key indicators/predictors of the anticipated service life as well as the sustainability of the installed unit are absorption, hardness and chemical resistance.

Absorption

Water absorption rate or porosity of a given paving material is a significant indicator of the viability of the stone to meet the project requirements. High absorption rates (over 3%) in architectural paving materials are undesirable due to the adverse affects on the appearance, structural integrity and overall service life of the paver. The impact of a high absorption rate on a material will likely include one or more of the following:

- *Staining* – In populated areas water is typically a vehicle for pollution, minerals, chemicals and etc. Absorption of water indicates absorption of staining agents as well.
- *Stone size changes* – actual dimensional changes which can increase stress concentrations at joints.
- *Freeze/Thaw fractures* - When exposed to sub-freezing temperatures (below 32 degrees farenheit), water absorbed into a stone may freeze, expand then consequently weaken and spall or crack the stone. Joint sealant or mortar will also be impacted by this event. Hardscape material with water absorption ***under 3%*** is considered frost (freeze) resistant. Note the condition of the granite (left) and precast pavers (right) under the same environmental and traffic conditions in Figure 1.1 below.

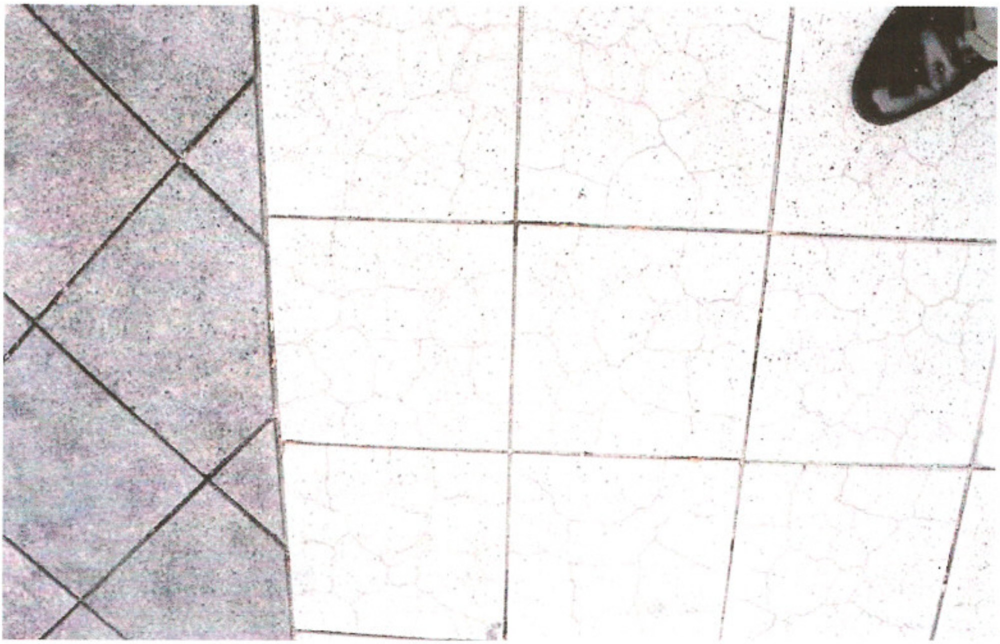

Figure 1.1

- *Efflorescence* – a crystalline deposit of water-soluble salts and minerals on the surface of masonry. Sources include brick, tile, concrete masonry units, concrete, cement, mortar as well as other materials used wall construction.
- *Rising moisture/ rising damp discoloration* - a condition in which the stones appear darker due to water wicking into the stone by capillary action from a water source along one or more edges of the stone, such as at the base of a building. This occurrence is prevalent where masonry extends below grade. Mildew, mold and algae growth may also occur.
- *Exfoliation* - spalling, powdering, or chipping due to weathering and/or chloride-based de-icing products used on paving systems which amplifies the impact of freeze-thaw cycling.

See Table 1, **Absorption,** for a comparison of the paver types in this study.

Aesthetic quality and service life are key components in the selection criteria of sustainable architectural hardscape materials. The absorption rate of a given material is one of three key indicators of the sustainability of the finish, color and structural integrity of the paver. As a general rule, with higher water absorption and porosity, and lower density, the stone tends to be less durable and less stain resistant, and more susceptible to frost, salt and chemical deterioration.

Hardness/Abrasion Resistance

Abrasion resistance is a property of stone that should be tested per ASTM (ASTM C241) to provide an indication of the stone's wearing qualities where exposed to foot traffic. Resistance to scratching and durability in foot traffic areas are largely dependent upon the hardness of the minerals that make up the stone. The hardness of a mineral is oftentimes defined by use of Moh's Scale of Relative Hardness, developed in 1822 by the Austrian Mineralogist Friedrich Moh. This scale lists 10 minerals in ascending order of scratch resistance:

1. Talc
2. Gypsum
3. Calcite
4. Fluorspar
5. Apatite
6. Feldspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

This scale can be further expanded by adding other minerals or common materials with scratch resistance that is similar to those minerals originally cited by Moh:

1. Talc, Sulpher
2. Gypsum, Amber
2½ Fingernail
3. Calcite, Coral (3-4), Pearl (3-4)
3½ Copper penny
4. Fluorspar, Fluorite, Rhodochrosite
5. Apatite, Turquoise (5-6)
5½ Opal, Steel knife blade
6. Feldspar
6½ Hardened steel file, Common window glass
7. Quartz, Garnet, Beryl
8. Topaz
9. Corundum
10. Diamond

It should be noted that the above scales are of "relative" hardness, and not linear. As example, there is significantly less difference between 7 and 8 on the list than there is between 9 and 10. What the scale does tell us is that a mineral that can be scratched with a fingernail has a hardness of less than 2½. A mineral that can be scratched with a pocketknife, but not with a penny, has a hardness of between 3½ and 5½. Abrasion resistance contributes to long service life in high traffic areas of public buildings. A minimum abrasive resistance of 12 is recommended for commercial floors, stair treads, and platforms subject to heavy foot traffic. See Table 1 for a comparison of the paver types in this study.

Table 1. – Physical properties for different paver types

Stone Type	Absorption (wt%)	Bulk density (g/cm^3)	Compressive strength (MPa, dry)	Flexural strength (MPa, dry)	Hardness	Abrasion resistance	Thermal Expansion 10^{-6}/°C (REF 10)
					Mohs, H	Taber index, H_a	
Granite	0.17	2.6–2.7	80–310	8–18	5–7	90–160	5-11
Limestone (medium-	4.47	2.2–2.6	20–230	4–20	2–3	6–28	2-6

dense)							
Precast* Concrete	6.0	2.0–2.6	20–240	4–12	2–7	5–40	2-12

* - Product specific test data not available. See Figure 1.2 for example of product performance.

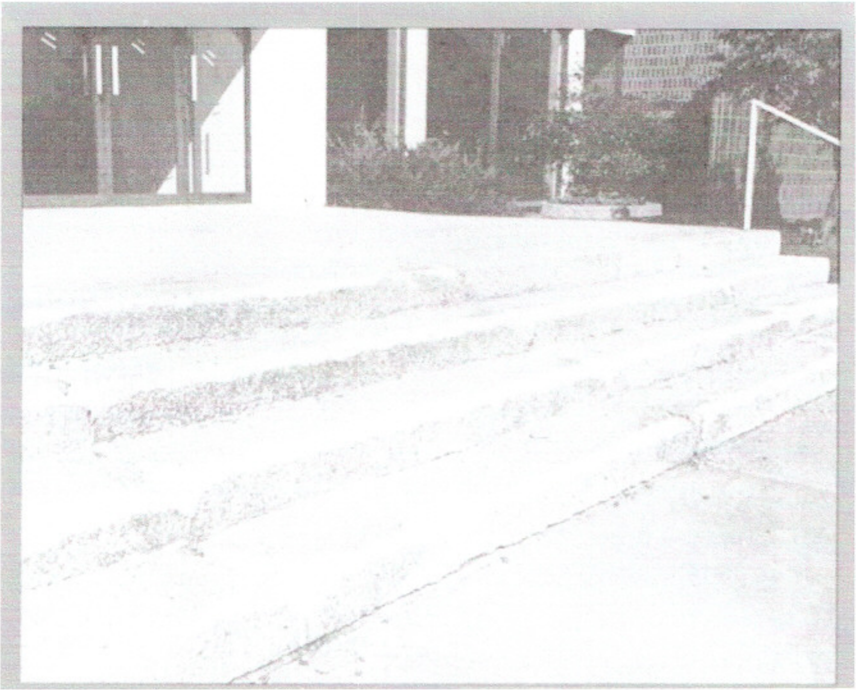

Figure 1.2

Chemical Resistance

Chemical resistance with respect to hardscape materials can be divided into two logical exposure categories, direct and indirect.

- **Direct Exposure** - Examples of direct exposure are chemicals used in cleaning and maintenance which are applied directly onto masonry surfaces. These chemicals are intentionally applied and most often at pre-specified concentrations and pressures.

- **Indirect Exposure** - Acid rain or acid precipitation is an example of indirect exposure. Chemical pollutants comprised of acidic components present in rain, snow, fog, dew or dry particles are deposited unintentionally or indirectly onto masonry surfaces.

Granite is primarily composed of silicate minerals, like feldspar and quartz, which are resistant to acid attack. Limestone and marble are primarily composed of the mineral calcite (calcium carbonate), which dissolves readily in weak acid; in fact, this characteristic is often used to identify the mineral calcite.

Acid precipitation affects stone primarily in two ways: dissolution and alteration. When sulfurous, sulfuric, and nitric acids in polluted air react with the calcite in marble and limestone, the calcite dissolves. In exposed areas of buildings and statues, we see roughened surfaces, removal of material, and loss of carved details. Stone surface material may be lost all over or only in spots that are more reactive. See Figure 1.3 below for example of limestone paver directly adjacent to granite stair tread. Note the surface loss and condition of stone edges.

Figure 1.3

The extra acidity in rain comes from the reaction of air pollutants, primarily sulfur oxides and nitrogen oxides, with water in the air to form strong acids (like sulfuric and nitric acid). The main sources of these pollutants are vehicles and industrial and power-generating plants. (USGS)

Total Life Cycle Cost Comparison

	Granite	Limestone	Precast
Total Installed Costs Amortized over anticipated life	$7,800	$16,500	$12,500
Annual Maintenance Amortized over anticipated life	$4,000	$4,000	$4,000
Major Maintenance Not including beginning and ending interval	$1,440	$2,400	$2,400
Life Expectancy**	50 years	20 years	20 years
Annual Cost	$13,240	$22,900	$18,900

** - Likely service life expectancy of limestone and precast paving units as established by the Building Research Establishment. See table below.

Class of use	Service life Expectancy without wear	Approx. total number of people walking over one particular stone
Intensive (airport, shopping mall)	20 Years	500,000,000
Medium(office)	20 Years	5,000,000

Building Research Establishment
Garston Watford WD2 7JR

References:

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2. Marble and Stone Slab Veneer, Masonry Institute of America, 1989
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Measures of Sustainability

Overview / Embodied Energy / Operating Energy / Exergy / Durability / Externalities / Ecological Footprint / Eco-Labeling / Life Cycle Assessment

Embodied Energy

Embodied energy in building materials has been studied for the past several decades by researchers interested in the relationship between building materials, construction processes, and their environmental impacts.

What is embodied energy?

There are two forms of embodied energy in buildings:

· ***Initial embodied energy;*** and
· ***Recurring embodied energy***

The ***initial embodied energy*** in buildings represents the non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction. This initial embodied energy has two components:

Direct energy the energy used to transport building products to the site, and then to construct the building; and

Indirect energy the energy used to acquire, process, and manufacture the building materials, including any transportation related to these activities.

The ***recurring embodied energy*** in buildings represents the non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building.

As buildings become more energy-efficient, the ratio of embodied energy to lifetime consumption increases. Clearly, for buildings claiming to be "zero-energy" or "autonomous", the energy used in construction and final disposal takes on a new significance.

	EMBODIED ENERGY	
MATERIAL	**MJ/kg**	**MJ/m3**
Aggregate	0.10	150
Straw bale	0.24	31
Soil-cement	0.42	819
Stone (local)	0.79	2030
Concrete block	0.94	2350
Concrete (30 Mpa)	1.3	3180
Concrete precast	2.0	2780
Lumber	2.5	1380
Brick	2.5	5170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5890
Particle board	8.0	4400
Aluminum (recycled)	8.1	21870
Steel (recycled)	8.9	37210
Shingles (asphalt)	9.0	4930
Plywood	10.4	5720
Mineral wool insulation	14.6	139
Glass	15.9	37550
Fiberglass insulation	30.3	970
Steel	32.0	251200
Zinc	51.0	371280
Brass	62.0	519560
PVC	70.0	93620
Copper	70.6	631164
Paint	93.3	117500
Linoleum	116	150930
Polystyrene Insulation	117	3770
Carpet (synthetic)	148	84900
Aluminum	227	515700

NOTE: Embodied energy values based on several international sources - local values may vary.

How is it measured?

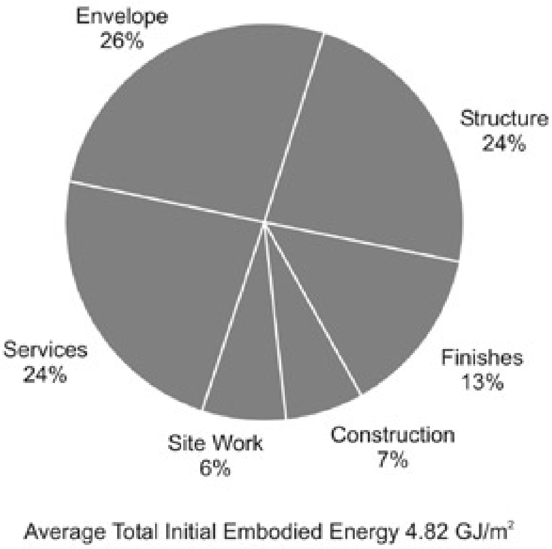
Typically, embodied energy is measured as a quantity of non-renewable energy per unit of building material, component or system. For example, it may be expressed as megaJoules (MJ) or gigaJoules (GJ) per unit of weight (kg or tonne) or area (square metre). The process of calculating embodied energy is complex and involves numerous sources of data. Refer to the Related Resources + References page for further information on embodied energy.

Implicit in the measure of embodied energy are the associated environmental implications of resource depletion, greenhouse gases, environmental degradation and reduction of biodiversity. As a rule of thumb, embodied energy is a reasonable indicator of the overall environmental impact of building materials, assemblies or systems. However, it must be carefully weighed against performance and durability since these may have a mitigating or compensatory effect on the initial environmental impacts associated with embodied energy.

How much embodied energy is typically found in buildings?

The amount of embodied energy in buildings varies considerably. Initial embodied energy consumption depends on the nature of the building, the materials used and the source of these materials (this is why data for a building material in one country may differ significantly from the same material manufactured in another country). The recurring embodied energy is related to the durability of the building materials, components and systems installed in the building, how well these are maintained, and the life of the building (the longer the building survives, the greater the expected recurring energy consumption).

Research carried out by Cole and Kernan(1) using a model based on Canadian construction of a generic 4 620 m2 (50,000 ft2) three-storey office building with underground parking, considered three different construction systems (wood, steel and concrete), and yielded the following results for average total initial embodied energy. (Note: Data were averaged for the three construction systems as the overall differences between the building types were not significant.

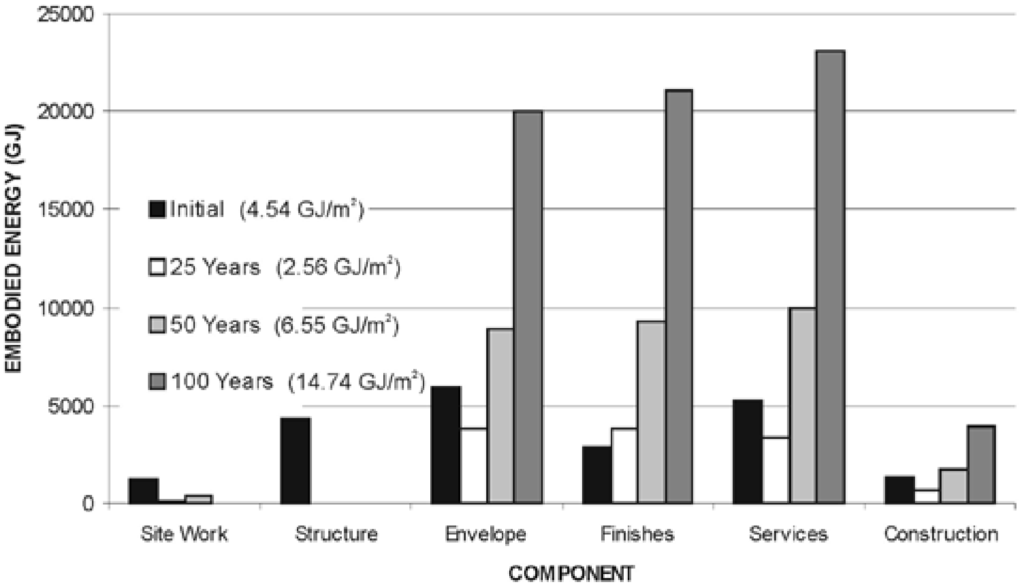


Breakdown of Initial Embodied Energy by Typical Office Building Components Averaged Over Wood, Steel and Concrete Structures [Cole and Kernan, 1996].

The building envelope, structure and services contribute fairly equally and account for about three-quarters of total initial embodied energy. The finishes, which represent only 13% of the embodied energy initially, typically account for the highest increase in recurring embodied energy. Embodied energy may not be significantly different between building systems (e.g., wood versus steel versus concrete), however, the environmental impacts associated with one material versus another can be dramatically different.(2)

It is interesting to consider the relationship between site work (6% of initial embodied energy) and services (24%). The reallocation of embodied energy, and hence project budget, from conventional services to the site management of stormwater, for example, may have a negligible effect on initial embodied energy, but the impact on recurring embodied energy may prove significant. Additional benefits downstream of the building at the community infrastructure level should also be considered. This points to one of the shortcomings of embodied energy analysis, which typically ends at the property line and is somewhat unwieldy in dealing with a broader context.

When recurring embodied energy in buildings is considered, yet more interesting relationships are revealed from the work of Cole and Kernan. First, to the credit of civil engineers, the structures of buildings normally do not expend recurring embodied energy, lasting the life of the building. By year 25, however, a typical office building will see an increase of almost 57% of its initial embodied energy due mostly to envelope, finishes and services. By year 50, recurring embodied energy will represent about 144% of the initial embodied energy, and it was projected that by year 100, this proportion would rise to almost 325%. This relationship is a direct result of what is referred to as ***differential durability***, where the service lives of the various materials, components, and systems comprising the building differ dramatically. The current preoccupation with lower first costs in buildings reveals its disregard for sustainability when viewed from a building life cycle perspective.



Comparison of Initial to Recurring Embodied Energy for Wood Structure Building Over a 100-Year Lifespan [Cole and Kernan, 1996].

Is embodied energy a useful measure?

Embodied energy can be a very useful measure provided it is not viewed in absolute terms. The initial embodied energy of various materials, components and systems can vary between projects, depending on suppliers, construction methods, site location and the seasonality of the work (e.g., winter heating). The recurring embodied energy is difficult to estimate over the long term since the non-renewable energy contents of replacement materials, components or systems are difficult to predict. For example, how energy intensive will glass be 100 years from now? However, as buildings become more energy efficient and the amount of operating energy decreases, embodied energy becomes a more important consideration. There also exist strong correlations between embodied energy and environmental impacts. But it is widely acknowledged today that embodied energy represents one of many measures and should not be used as the sole basis of material, component or system selection.

The next section deals with Operating Energy as a measure of sustainability.

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FOOTNOTES:

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2.Comparing the Environmental Effects of Building Systems, Wood the Renewable Resource Case Study No.4, Canadian Wood Council, Ottawa, 1997.