Highway Curbing Alternatives: Life Cycle Cost Analysis

Final Report

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ABSTRACT

As government and private developers continue to face challenges to keep initial construction and recurring maintenance costs of roadway curbing within project budgets, there is a strong interest to identify the most cost-efficient curbing alternatives including: (1) pre-cast concrete; (2) slip form concrete; (3) cast-in-place concrete; and (4) granite. To assist in evaluating alternatives, a life cycle cost analysis with a planning horizon of 60 years was employed as a tool to compare both the initial and recurring costs over the life of each alternative. This study expands geographically on earlier studies to include the following states: Connecticut, New Hampshire, Maine, Massachusetts, Rhode Island, Vermont, New York (except NYC), Pennsylvania, Nebraska, Ohio, Virginia, Tennessee, Georgia, North Carolina, South Carolina, New Jersey, Michigan, Maryland, Illinois, Indiana, and Washington, DC. The study also encompasses the provinces of Quebec and Ontario. To account for the impact of geographic location on cost reduction, a life cycle cost analysis is conducted separately for each jurisdiction.

The LCC analysis indicates that when the inevitable replacement of concrete is considered and major costs are taken into account, granite is a more cost-effective curb material than any of the concrete alternatives. The only advantage of using a concrete curb is its lower initial cost. This advantage is negated, however, by granite's durability, longevity, and reusability as well as the relatively low discount rates currently being employed to evaluate public sector investments. It should be emphasized that physical properties make granite a superior curb material, especially in areas with colder climates, where winters, road salt, and plowing are particularly harsh on concrete curb alternatives.

The conclusion that granite is a more cost-effective alternative is further supported by a continuous increase in costs associated with disposing of deteriorating concrete curbs. The disposal crisis presents a troubling and expensive reality that cannot be overlooked. An aspect of the solution to the disposal issue appears to be a general shift toward reusable rather than disposable commodities. Granite curb serves as an excellent example of a reusable commodity. It is the decision of elected officials that will determine whether future generations face ongoing curb replacement expenses or benefit from a supply of long-lasting, durable, and reusable curbs.

The results of the LCC analysis, which include the use of the NPV method along with considerations of curb disposal and damage costs, construction delays for road users, and the aesthetics and the salvage value of granite, demonstrate that granite can be a superior choice compared to concrete alternatives under current economic conditions, especially given that much of the country's infrastructure is burdened by a backlog of deferred maintenance.

BACKGROUND AND STUDY OBJECTIVE

As government and private developers continue to face challenges to keep initial construction and recurring maintenance costs of roadway curbing within project budgets, there is a strong interest to identify the most cost-efficient curbing alternatives including: (1) pre-cast concrete; (2) slip form concrete; (3) cast-in-place concrete; and (4) granite. To assist in evaluating alternatives, a life cycle cost analysis with a planning horizon of 60 years was employed as a tool to compare the initial and recurring costs over the life of each alternative. The objective of this study is two-fold: (1) to update and expand the life cycle cost analysis on granite and precast concrete highway curbing completed in 2022 (*1*), and (2) to develop a one-page summary for each target market (per geographic jurisdiction) that can be shared with sales and marketing staff as a way to reference the key findings of the study quickly. This study expands geographically to include the following states: Connecticut, New Hampshire, Maine, Massachusetts, Rhode Island, Vermont, New York (except NYC), Pennsylvania, Nebraska, Ohio, Virginia, Tennessee, Georgia, North Carolina, South Carolina, New Jersey, Michigan, Maryland, Illinois, Indiana, and Washington, DC. In addition, the study also includes the provinces of Quebec and Ontario. To take into account the impact of geographic location on curbing costs, a life cycle cost analysis is conducted individually for each jurisdiction. The data required for the life cycle cost analysis were obtained through a survey of State DOTs and Provincial Ministries of Transportation, as well as via online publications. This Report includes three major sections: 1) data collection and estimate of average curbing costs; 2) life cycle cost analysis and results; and 3) summary and conclusions. In addition, a "fact sheet" was prepared for each jurisdiction, including a narrative and graphical summary of findings and recommendations. The "fact sheets" are located in the Appendix of the Report.

DATA COLLECTION AND ESTIMATE OF AVERAGE CURBING COSTS

The Research Team obtained data on the extent of use, installation, and material costs of four highway curbing alternatives for the 23 jurisdictions mentioned above. In some cases, bid price, the number of projects, and the amount of curb installation data were available online. The sources of data and other information are provided in the list of references at the end of the Report. The Research Team also obtained data directly from State DOT and Ministry of Transportation staff via email and/or by phone. In such cases, the source of the data is also mentioned in the text. The data were collected for the last five years, where available. Each dataset has been reviewed to remove outliers and exclude small projects under 330 ft (100 meters), as cost data for such projects is rarely representative. If raw bid cost data were available, the weighted average cost per linear foot for each year for each alternative was calculated using the following formula:

$$\frac{SUM(C1 * Q1, C2 * Q2, \dots, CN * QN)}{SUM(Q1, Q2, \dots, QN)}$$

where CN is the awarded bid cost in U.S. dollars per linear foot for project N, and QN is the quantity for project N in linear feet. A summary of findings in each jurisdiction is presented below.

State DOTs

Connecticut: An analysis of the data provided by the ConnDOT AASHTOWare staff indicates that from 2019 to 2024 there were almost 45,000 feet of straight granite curb installed with the cost per linear foot including material and installation ranging from $49 to $98 and nearly 70,000 feet of PCC straight curb installed with the cost ranging from $33 to $83 per linear foot. (*1*) Slip-form and cast-in-place curbs during the same five-year period were used on ConnDOT contracts at insignificant quantities and hence were excluded from the analysis. Weighted average values estimated by the Research Team are $49.74 per linear foot for PCC and $69.54 per linear foot for granite. The average cost of both highway curbing alternatives increased by approximately 35%. Granite curb applications have become significantly more popular in recent years compared to the pre-pandemic period. (*1, 2*)

District of Columbia (Washington, DC): An analysis of DistrictDOT data available online shows that from 2019 to 2024, nearly 40,000 feet of straight granite curb were installed, with the cost per linear foot, including materials and installation, ranging from $60 to $90. Additionally, approximately 13,000 feet of PCC straight curb were installed, with costs ranging from $34 to $65 per linear foot. *(3)* Examples of slip form and cast-in-place curbs during the same five-year period were not reported. The Research Team estimates weighted average values of $48 per linear foot for PCC and $75 per linear foot for granite.

Georgia: According to the GDOT Bureau of Office of Engineering Services staff, cast-in-place concrete accounts for 90 to 95 percent of curbing on state highway projects, primarily due to the ease and speed of installation. Granite is installed only on a limited basis for smaller projects in historic areas. The price of cast-in-place curb on nearly a hundred large GDOT projects, with a combined length of installations of about 700,000 feet, ranged from as low as $21 to about $42 per linear foot, with a weighted average of $29.10 per linear foot. Since there was insufficient data to establish an average for granite curbing on GDOT projects, a representative value was calculated based on the weighted averages of other states, and this value was used for the LCC analysis. PCC and slip-form curbs were not used on GDOT projects. *(4)*

Illinois: According to the IDOT Flexureflow database, *(5)* cast-in-place concrete curb and gutter combination accounts for the majority of curbing on state highway projects, while cast-in-place concrete curb, Type B, without the gutter, is installed in about 20% of all projects. There was one project with approximately 2,700 feet of PCC curb installed back in 2020, and no granite curb installations. The cost of the cast-in-place Type B curb on nearly a hundred large IDOT projects, with a combined installation length of about 100,000 feet, ranges from as low as $20 to about $80 per linear foot, with a weighted average of $38 per linear foot. As there was insufficient data to establish an average for granite curbs on IDOT projects, a representative value was calculated based on weighted averages from other states, and this value was used to conduct the LCC analysis. The PCC cost of $50 per linear foot will not be used in the analysis due to its performance similarity and clear cost inferiority relative to the most dominant cast-in-place curb.

Indiana: According to the INDOT — Pay Items List/Unit Price Summaries, (*6*) cast-in-place concrete is accountable for over 90 percent of curbing on state highway projects, primarily due to ease and speed of installation, while no granite curb projects were found. There was one PCC project with about 3,125 feet installed back in 2024. The price of the cast-in-place curb on InDOT projects with a combined length of approximately 475,000 feet ranges from as low as $25 to about $70 per linear foot, with a weighted average of $40.15 per linear foot. As there was insufficient data to establish an average for granite curbing on InDOT projects, the representative value was calculated based on weighted averages of other states, and this value was used to conduct the LCC analysis. The PCC cost of $57.32 per linear foot will not be used in the analysis due to its performance similarity, yet clear cost inferiority to the most dominant cast-in-place curb.

Massachusetts: An analysis of the MassDOT Highway Division Construction Price Estimator Database (*7*) for 2020-2025 indicates that there have been almost a hundred completed projects with installations over 330 ft, which include 96 projects with granite (Pay Item 504, granite straight curb Type VA4) curbing and one project with PCC (Pay Item 520.1, straight precast concrete curb, Type VA). The maximum length of the largest, single granite curbing project was 19,300 feet. The only PCC curbing project spanned 6,300 linear feet in length, encompassing resurfacing and related work on Route 7 in Lanesborough, MA. Granite curbing is more widely used on MassDOT highway projects than is PCC, particularly on larger projects. The average low bid price estimated by the Research Team is $31.50 for PCC and $36.25 for granite, which is less than the average prices found during the previous study for the following reasons: (1) the total number of projects with curbing installations almost doubled while the average size of the project more than doubled for granite and increased more than tenfold for the PCC, and (2) during the previous study the data provided by MassDOT may have included some smaller projects which increased the average bid price.

Maryland: According to an analysis by the Maryland DOT Price Index Database of contracts awarded from 2020 to 2024, there were over 50,000 linear feet of concrete curb installations, either cast-in-place or slip form. The average winning bid price for the curb was $54.10 per linear foot. No instances of granite curb installation were found in MDOT contracts. *(8)*

Maine: An analysis of the data provided by MaineDOT staff reveals that from 2020 to 2025, the weighted average winning bid price for a linear foot of granite curb was $56.83, with nearly 50,000 linear feet of curbs installed. During the same period, the weighted average bid price for slip-form concrete curbs was $25.18, with over 60,000 linear feet of straight curbs installed *(9).*

Michigan: An analysis of contracts awarded from 2012 to 2024 by the MDOT Contracts Section Database indicates that the average winning bid price for a linear foot of concrete curb installed using either the cast-in-place or slip-form method was approximately $35. No granite curb contracts were reported during this same period. *(10)*

North Carolina: According to the Let Central database of NCDOT, the average bid price of a cast-in-place concrete curb was $31.60 per linear foot, with over 30,000 linear feet of total installations. During the same period, there was only a single 570 linear foot installation of granite curb, with

no installations of PCC or slip-form curbs. It appears that the most common alternatives for installations on NCDOT contracts are cast-in-place concrete curb and gutter combinations. (*11*)

Nebraska: The NDOT Unit Price and Letting Database from 2021-24 reveals that the average cost of cast-in-place concrete installation was $55.41. No bid information was found in the database for any contracts involving granite, PCC, or slip-form concrete curbs during the same period. (*12*)

New Hampshire: The NHDOT Weighted Average Unit Price Database indicates that for granite curbing, the weighted average was approximately $42 per linear foot, with nearly 83,000 feet installed. According to NHDOT staff, concrete curbing is not used in NHDOT contracts *(13).*

New Jersey: An analysis by the Research Team of the New Jersey Department of Transportation (NJDOT), utilizing the AASHTOWare database from 2021 to 2023, indicates that the average bid price for cast-in-place and slip form curbing was $55.00 per linear foot, while no granite or PCC concrete curb was found on NJDOT contracts. *(14)*

New York: The NYSDOT Weighted Average Item/Bid Price Report (WAIPR) database indicates that the average bid price for PCC curbing was $42.00 per linear foot with insignificant amounts of installations; cast-in-place concrete curb was $40.76 per linear foot with almost 500,000 linear feet installed, while stone granite curb was $67.38 per linear foot with nearly 200,000 feet installed. It should be mentioned that the PCC has been used only on small projects (less than 300 linear feet). (*15*)

Ohio: According to the ODOT Bid Data Reports, cast-in-place concrete is accountable for the majority of curbing on state highway projects, while granite is installed on a limited basis on smaller projects in historic areas. PCC is not used at all. The average bid price per linear foot for cast-in-place ranges from $20 to $70, with a total of approximately 100,000 feet installed. The average bid price for a cast-in-place concrete curb without the gutter was $39 per linear foot. It should be noted, though, that the vast majority of installations include a combination of curb and gutter. (*16*)

Pennsylvania: According to the PennDOT Bureau of Construction & Materials staff, poured-in-place concrete is accountable for the majority of curbing on state highway projects, with the weighted average price of $47 per linear foot, while granite curbs are installed on a limited basis on smaller projects in historic areas. PCC curbs are not used on PennDOT highway projects. (*17*)

Rhode Island: An analysis by the Research Team of the RIDOT Project Management Portal indicates that the average bid price from 2020 to 2024 for granite curbs was approximately $61, with a bid price range of $49 to $90 per linear foot. The pre-cast concrete curb's weighted average cost was about $44, with a range of $30 to $69 per linear foot. (*18*)

South Carolina: According to the SCDOT Specs and Estimates Engineer, cast-in-place and slip form are the only types of curbs used on state DOT projects, with the selection of specific technology being at the discretion of local jurisdictions and/or contractors. The weighted average

cost of installation is about $38 per linear foot. Neither granite nor PCC curbs are used on recent SCDOT contracts. (*19*)

Tennessee: Based on an analysis by the Research Team of the Construction Division's Price Information Web Portal, the only type of curb used on TDOT contracts is a cast-in-place curb, with a weighted average bid price of approximately $28.50 per linear foot. The weighted average bid price for the PCC curb was $42 per linear foot. However, the PCC curb was last used on TDOT contracts back in 2019 for a single project of just over 200 linear feet, which cannot serve as a good representative value for the analysis. There were no granite curbing projects on TDOT contracts during the last five-year period. (*20*)

Virginia: According to the VDOT Bid Item Price 2-year (2022-2024) Statewide Average Database, the reported bid price of concrete curb is $48.24 per linear foot, without any mention of the size of total installations, number of projects, or specific technology. The VDOT specs indicated that the given type of curb (Concrete Curb CG-2, 6 Inch) could be delivered either as pre-cast or cast-in-place. Granite curbs are not used in VDOT contracts. (*21*)

Vermont: An analysis of VTrans' five-year data (2019-2024) indicates that granite curb has been used on 45 contracts, while concrete cast-in-place has been used on 43 contracts. The average unit cost of a granite curb was $61.82 per linear foot, while the average unit cost for a cast-in-place concrete curb was $56.91 per linear foot. There was a single project where a PCC was used, at $50 per linear foot, without mention of project size. (*22*)

Ministries of Transportation

Ontario: According to Ontario Ministry of Transportation staff, the weighted average reported bid price for concrete curb and gutter is $40.03 per linear foot, based on 91 construction projects between 2021 and 2023, with a total length of installations of almost 250,000 feet. The Ontario Ministry of Transportation specifications indicate that both cast-in-place and slip-form concrete curb and gutter combinations are currently used in its contracts. Granite and pre-cast concrete curbs are not used in Ontario Ministry of Transportation contracts. (*23*)

Quebec: Data analysis conducted by the Research Team of the four-year bid prices from 2021 to 2024 indicates that granite curbs were used on 21 larger contracts with a total of about 43,000 feet; PCC were used on 20 contracts with a total of about 28,000 feet; and cast-in-place or slip-form concrete curbs were used on 175 contracts with the total of almost 500,000 feet. The average unit cost of a granite curb was $52.80 per linear foot (244 CAD/M), while the average unit cost for a PCC concrete curb was $22.72 per linear foot (105 CAD/M), and the cast-in-place or slip-form curb average unit cost was $24.24 per linear foot (112 CAD/M). The raw dataset used for the analysis was provided by the Quebec Ministry of Transport and Sustainable Mobility (Ministère des Transports et de la Mobilité Durable). (*24*)

The price data made available by both ministries was presented in the form of Canadian Dollars (CAD) per linear meter. For the sake of consistency and to facilitate comparison, the data in this section of the Report was converted to U.S. Dollars per linear foot using the following ratios: 1 m

= 3.281 ft and 1 CAD = 0.71 USD. However, in the life cycle cost analysis, as well as in the fact sheets, costs are presented in the native units for each jurisdiction.

A summary of the curbing alternatives used in each jurisdiction, and their respective weighted average unit cost estimates, is presented in Table 1.

Table 1. Weighted Average Cost of Four Curbing Alternatives for Each Jurisdiction

Jurisdiction	Year	Concrete Curbs			Granite Curbs
		Pre-Cast	Slip Form	Cast-In-Place	
CT	2019-'24	49.74			69.54
DC	2019-'24	48.00			75.00
GA	2020-'25			29.10	
IL	2020-'24	50.00		38.00	
IN	2020-'24	57.32		40.15	
MA	2020-'25	31.50			36.25
MD	2020-'24		41.20	41.20	
ME	2020-'25		25.18		56.83
MI	2021-'24		35.00	35.00	
NC	2019-'23			31.60	
NE	2021-'24			55.41	
NH	2019-'24				42.00
NJ	2021-'23		55.00	55.00	
NY	2019-'24	42.00		40.76	67.38
OH	2020-'24			39.00	
PA	2023-'24			47.00	
RI	2020-'24	43.94			60.60
SC	2020-'24		38.00	38.00	
TN	2019-'24			28.50	
VA	2022-'24	48.24		48.24	
VT	2019-'24			56.91	61.82
ON	2021-'23		40.03	40.03	
QC	2021-'24	22.72	24.24	24.24	52.80
Mean Price, US		**41.19**	**38.88**	**41.59**	**58.69**
Mean Price, CANADA		**22.72**	**32.14**	**32.14**	**52.80**

As can be observed from Table 1, the cost per linear foot of the same curbing alternative varies significantly among the various jurisdictions. The variation can be attributed to several factors, including geographic location, labor regulations, roadway classification, project size, availability of curbing material, and local standards.

LIFE CYCLE COST ANALYSIS

The life cycle cost analysis will employ the net present value (NPV) method, which requires estimates of the initial installation and material costs, recurring costs, curb life expectancy, and an assumed discount rate as discussed below. In addition, the LCC analysis will consider other costs that are difficult to quantify in monetary terms but are important to consider, including curb damage, construction delays to road users, aesthetics, and the salvage value of the curbing.

Initial Costs: The survey of State DOTs and Ministries of Transportation, as well as a review of local, state, and provincial bid records, was conducted to assist in determining the initial costs of four curbing alternatives, as presented above. As shown in Table 1, the average initial curbing costs of granite are generally higher than those of any concrete alternative. The costs, as mentioned above, vary depending on geographic location, local standards, the size of the entire highway project, the amount of curb installation, the availability of curbing material, and other factors. Outlier values are often associated with either very small or exceptionally large highway construction projects. Consequently, these values have been removed during data processing to ensure that the NPV analysis represents typical projects of a size ranging between 330 and 10,000 linear feet.

Recurring Costs: Three recurring costs can be examined with some degree of certainty: preventive maintenance, replacement, and disposal of a worn-out curb. Other recurring costs, such as curb damage repairs, are unpredictable and difficult to quantify. Costs of this nature will be addressed later. Properly installed granite curbing requires no maintenance for the 60-year planning horizon, as indicated by this NPV analysis. On the other hand, concrete curbing requires periodic sealing to extend its lifespan. However, this maintenance is seldom, if ever, performed. Additionally, it is challenging to determine an accurate cost for this type of maintenance. It is realistic to assume no maintenance will be performed on the concrete curbing. This lack of maintenance will result in a shorter life expectancy than would be attainable with ideal care.

At the end of its life, the concrete curbing will have to be removed, discarded, and replaced. Recycling the PCC curb is not economically feasible at this time because of the labor required to remove the reinforced rods, mesh, or cables. Recycling of poured-in-place or slip-form concrete is possible, but it is rarely performed. The cost to dispose of deteriorated curbs has risen dramatically in recent years. Current costs to remove and discard vary significantly between different jurisdictions as well as the size of the project, ranging from about $3 to $9 per linear foot (*7*) on State DOT projects in states for which this analysis is being conducted, depending on the size of the contract and other factors, with a representative value for the NPV analysis of $5. Disposal costs will continue to rise faster than other prices as the remaining landfill space becomes more valuable.

Life Expectancy: Granite's life expectancy well exceeds the time frame of this analysis. The granite curb can be removed and reset when the curb reveal is diminished due to road resurfacing. The structural properties of granite curbs also allow them to be left in place during

road milling operations, a standard highway maintenance treatment. 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 a good base is present, road milling is less expensive than tearing up the old pavement and reconstructing the roadway. It is also quicker and permits continued use of the road during the resurfacing. This factor is especially important for major arterials and collectors.

Concrete curbing typically has no salvage value. It is subject to breakage during removal operations, which are increasingly common today, as many state and local highway agencies implement large-scale pavement management and maintenance programs. It is typically removed, discarded, and replaced when its reveal is lost. By this time, it has usually deteriorated to the point where it cannot be reinstalled, even if some life remains, and it could be removed intact economically. Concrete is prone to damage during milling operations due to its low strength and poor abrasion resistance. Extreme care must be taken to prevent damage to it. This extra care results in higher milling expenses.

In actual application, a concrete curb's useful life is often dictated not by its own life but rather by the life span of the road. It makes sense to replace the deteriorating concrete curb while the road is being rehabilitated. If a concrete curb does not last as long as the road, its replacement requires rehabilitating and possibly rebuilding a section of roadway, which in practice, seldom yields quality comparable to the original construction, but often leads to premature deterioration of the roadway. Two life expectancies of concrete curbs will be examined, ten and twenty years.

The twenty-year life expectancy is based on studies conducted by the New York Department of Transportation and by the Rhode Island Department of Transportation (*25, 26*). The twenty-year life span is consistent with the design life of many urban roads. Concrete curb is normally replaced in conjunction with reconstruction.

The ten-year life span is included in the analysis to show what the life cycle cost would be if the concrete curb did not last twenty years. Lab testing indicates this possibility should not be ruled out, especially if the concrete curb is being considered for installation in a region that experiences harsh winter conditions, resulting in a variety of aggressive road treatments. For example, according to the Aspen, Colorado engineering department, granite's estimated useful life is over 60 years, while concrete's is only 10 to 12 years. (*27*) In fact, some studies indicate that while there were cases of prematurely deteriorated concrete curbs after just 3 years past installation, there were also a number of cases when granite curbs were in perfect shape after a century of service. (*25*).

About half of the jurisdictions in this study, including the states of Maine, Michigan, New Hampshire, and Vermont, as well as the Provinces of Ontario and Quebec, experience cold climates (*28*) and hence severe road maintenance conditions. In addition, western Massachusetts, upstate New York, northwestern Pennsylvania, and northeastern Ohio also belong to the same category of cold climate conditions; consequently, the life cycle cost analysis of concrete curbs in all of these jurisdictions should consider the impact of a ten-year lifespan.

Net Present Value Analysis: The analysis considers initial and recurring curbing costs on a linear foot basis over the life of a newly constructed or reconstructed road, and a sixty-year planning horizon is assumed. The analysis will be conducted using discount rates of 5%, 3.5%, and 2% to examine the impact of the discount rate on the estimated net present values of the most popular concrete alternative. It should be noted that these discount rates are higher than the current discount rate being considered by the U.S. Office of Management and Budget (*29*). An illustrative example of the analysis performed for Connecticut, along with a summary of the results of the NPV analysis for each jurisdiction, is presented below.

Connecticut Illustrative Example: Assuming a 5% discount rate advocated by the Portland Cement Association (30) and a PCC curb life of twenty years, costs immediately in year 0 will be $50 (rounded up from ConnDOT weighted average cost of $49.74 for PCC, as shown in Table 1) and $55 ($5 for removal and disposal + $50 for replacement) in years twenty and forty. The net present value (NPV) of these costs is $78.54. The granite curbing can remain in place during the anticipated road milling and rehabilitation in years 20 and 40, so it is assumed there will be no additional costs during the sixty-year planning horizon, and therefore, the NPV of granite is $70 (rounded up from the ConnDOT weighted average cost of $69.54 for granite, as shown in Table 1). Under these assumptions, when considering the inevitable future costs of replacing the deteriorated precast PCC curb, the NPV of the PCC curb is approximately 12% higher than that of the granite curb. However, if the PCC curb lasts only 10 years, its NPV would be about $129.83, compared to granite's $70, making granite a clear choice. Table 2 presents a sample calculation of the Net Present Value (NPV) using a twenty-year life expectancy for the PCC curb, a 5% discount rate, and a sixty-year planning horizon.

Table 2 Precast PCC NPV Calculation at 5% Discount Rate and a PCC Life of 20 Years

Year	Initial Cost	PWF	PW
0	$50	1	$50
20	$55	0.377	$20.73
40	$55	0.142	$7.81
NPV			**$78.54**

Notes: PWF (Present Worth Factor) = 1/(1 + r)^t; where r represents the discount rate and t denotes the time period (in years). PW = PWF × Cost.

When this analysis is conducted at a 3.5% discount rate, which is consistent with several past studies (*1, 31*), the NPV of PCC and granite would be about $91.53 and $70, respectively, as shown in Table 3 for the twenty-year life of PCC, which means that the PCC curb is about 31 % more expensive than granite curb. The NPV of PCC would be almost $160 per linear foot if it lasted only 10 years, which would make it more than twice as expensive as granite.

Table 3 Precast PCC NPV Calculation at 3.5% Discount Rate and a PCC Life of 20 Years

Year	Initial Cost	PWF	PW
0	$50	1	$50
20	$55	0.503	$27.64
40	$55	0.253	$13.89
NPV			**$91.53**

Finally, when a 2% discount rate is used, the NPVs of PCC and granite are $111.92 and $70, respectively, as shown in Table 4 for a twenty-year PCC lifespan, resulting in a PCC curb being about 60% more expensive than a granite curb. If PCC lasted only 10 years, its NPV would be approximately $170 per linear foot, or 2.42 times that of granite.

Table 4 Precast PCC NPV Calculation at 2% Discount Rate and a PCC Life of 20 Years

Year	Initial Cost	PWF	PW
0	$50	1	$50
20	$55	0.673	$37.01
40	$55	0.453	$24.91
NPV			**$111.92**

Figure 1 illustrates the results of the NPV analysis across various discount rates and PCC life scenarios over a 60-year planning horizon, with a weighted average cost of $50 per linear foot for PCC and $70 for granite. The analysis indicates that granite consistently represents a better option in terms of NPV. When accounting for other significant costs not considered in the NPV analysis, it becomes even clearer that granite is the superior choice, as discussed further in more detail in the section below.

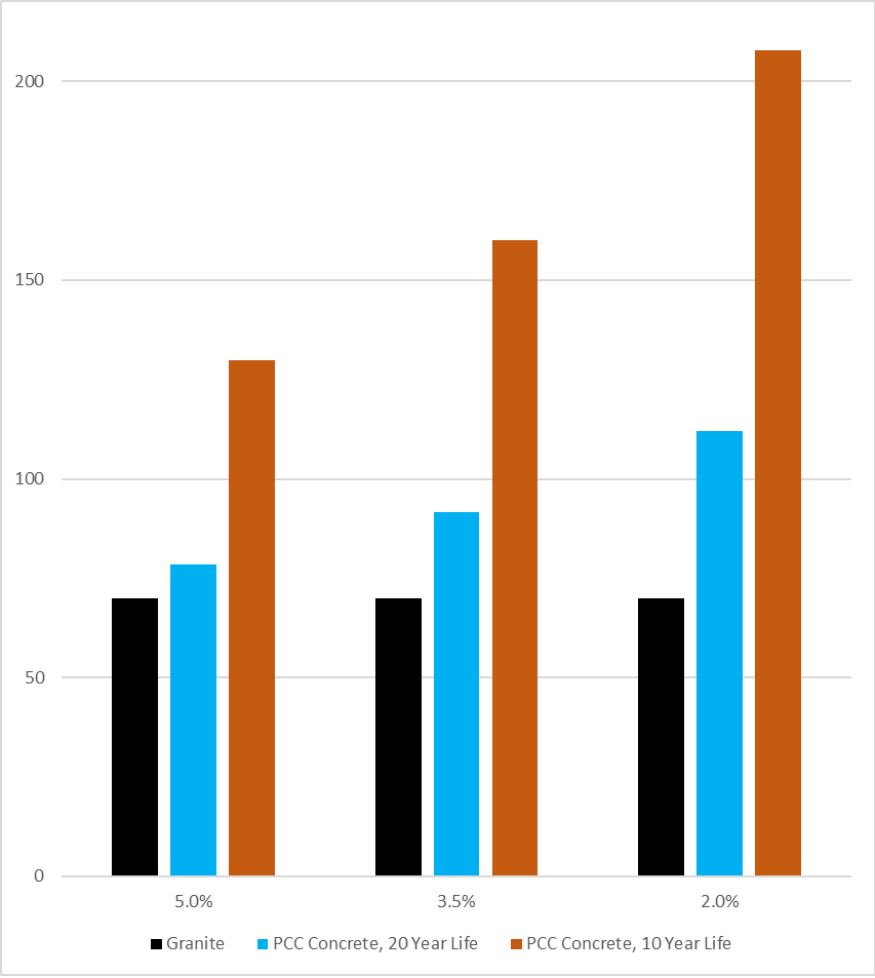

Figure 1. NPV in USD per LF of the Granite and PCC Curbs under Different Discount Rate Scenarios

A summary of the results of the NPV analyses for other jurisdictions is presented in Table 5.

Table 5 Results of the NPV analyses in USD per LF at 2% Discount Rate, 60-Year Horizon

Jurisdiction	Concrete Curbs			Granite Curbs
	Type	20 Year	10 Year	
CT	PCC	112	170	70
DC	PCC	108	200	75
GA	CIP	67	127	**59**
IL	PCC	86	161	**59**
IN	PCC	91	170	**59**
MA**	PCC	72	134	36
MD	SF/CIP	93	173	**59**
ME*	SF	59	111	57
MI*	SF/CIP	80	150	**59**
NC	CIP	69	133	**59**
NE	CIP	123	227	**59**
NH*	-	-	-	42
NJ	SF/CIP	123	227	**59**
NY**	PCC	93	173	67
OH**	CIP	89	165	**59**
PA**	CIP	106	196	**59**
RI	PCC	99	185	61
SC	SF/CIP	86	161	**59**
TN	CIP	65	123	**59**
VA	PCC	108	200	**59**
VT*	CIP	127	235	62
ON*	SF/CIP	-	-	**-**
QC*	PCC	55	103	53

Notes: All values are rounded to the nearest USD. Values for granite in bold font are estimated based on Northeast U.S. averages. Concrete Curb Types: **PCC** – Pre-Cast Concrete; **SF** – Slip Form; **CIP** - Cast-In-Place. * Jurisdictions that experience cold climates and hence severe road maintenance conditions. ** Severe road maintenance conditions in some areas.

As can be observed from Table 5, while the types of the most popular concrete curb alternatives and their cost per linear foot vary significantly among jurisdictions, granite remains the most cost-effective curbing alternative under a 2% discount rate for all 10-year or 20-year concrete life scenarios. The analysis was not conducted for two jurisdictions: New Hampshire, as no concrete curb alternatives were found on NHDOT contracts over the last decade, and for Ontario, as its standards only called for a curb and gutter combination, which can only be achieved by slip-form or cast-in-place concrete alternatives, without any apparent granite equivalent.

Other LCC Costs and Environmental Impacts: The NPV method is a valuable tool, but is not sufficient on its own to fully evaluate the relative costs of granite curbing compared to concrete alternatives. This is because the NPV analysis, as presented above, does not account for costs such as concrete curb damage, construction delays for road users, aesthetics, and the salvage value, all of which favor granite.

Curb damage is typically inflicted on the concrete curb by rollers, snowplows, and heavy trucks. Granite curb, however, has a legendary resistance to this kind of damage, as depicted in Figure 2. The granite curb, which was laid more than a hundred years ago, is routinely salvaged and reused. The granite curb laid today will be around for generations. The fact that granite curbs are reusable, rather than a disposable commodity, will undoubtedly become more important in the future. As the days of abundant and inexpensive landfill space come to an end, recycling is becoming increasingly necessary. 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 (*32*). Similar arrangements are being adopted across the country. Environmental concerns have become a pressing national issue, and a structural switch from disposable to reusable commodities continues to be an integral part of public infrastructure investments.

Figure 2 Prematurely Deteriorated PCC Curb vs a Century-Old yet Visibly Intact Granite Curb (Source: Denver Blog at Reddit.com and Oaklandunderfoot.com)

While the NPV method employed in the analysis incorporated the cost of discarding concrete (and acknowledged the consequence of not requiring the need to recycle old granite and consume scarce land at recycling and landfill facilities), the analysis does not address other environmental impacts associated with alternative curbing materials. These other impacts relate to, for example, sustainability, climate change, energy consumption, and carbon emissions associated with the mining, manufacturing, and transportation of curb materials. To further compare alternative curbing materials in terms of their environmental impacts, a more detailed, quantitative, and qualitative evaluation would be necessary. Such an evaluation could attempt to assess these impacts using monetary and non-monetary quantitative metrics, as well as possibly various qualitative criteria.

SUMMARY AND CONCLUSIONS

The LCC analysis indicates that when the inevitable replacement of concrete is considered and major costs are taken into account, granite curb is clearly a more cost-effective curb material. The only advantage of using a concrete curb is its lower initial cost. This advantage is negated, however, by granite's durability, longevity, and reusability as well as the relatively low discount rates currently being employed to evaluate public sector investments (*29*). In addition, it should be emphasized that a physical comparison clearly indicates that granite is a superior curb material, especially in areas with colder climates, where winters, road salt, and plowing are particularly harsh on concrete curb alternatives.

The conclusions of the LCC analysis are also strengthened by a continued rise in costs associated with disposing of a deteriorated curb. The disposal crisis is a disturbing, expensive reality that cannot be ignored. Part of the solution to the disposal problem seems to be a general trend toward reusable versus disposable commodities. Granite curb represents a good example of a reusable commodity. It is the decision of elected officials that determines whether future generations will be left with continual curb replacement expenses or a stock of long-lasting, durable, and reusable curbs.

The results of the LCC analysis including the use of the NPV method coupled with the consideration of costs of curb damage, construction delays to road users, aesthetics, and the salvage value of granite show that granite can be the superior choice over concrete alternatives under current economic conditions especially when the infrastructure of most of the country has been burdened by a backlog of deferred maintenance (*33*).

Finally, in light of rising environmental concerns associated with sustainability, climate change, energy consumption, and carbon emissions related to the mining, manufacturing, and transportation of curb materials, it is recommended that a more detailed quantitative and qualitative environmental assessment be carried out using both monetary and non-monetary metrics.

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