COLORED CONCRETE BRIDGES: CONSTRUCTION AND LIFE-CYCLE COST COMPARISON OF INTEGRAL COLORS AND SURFACE-APPLIED COATINGS

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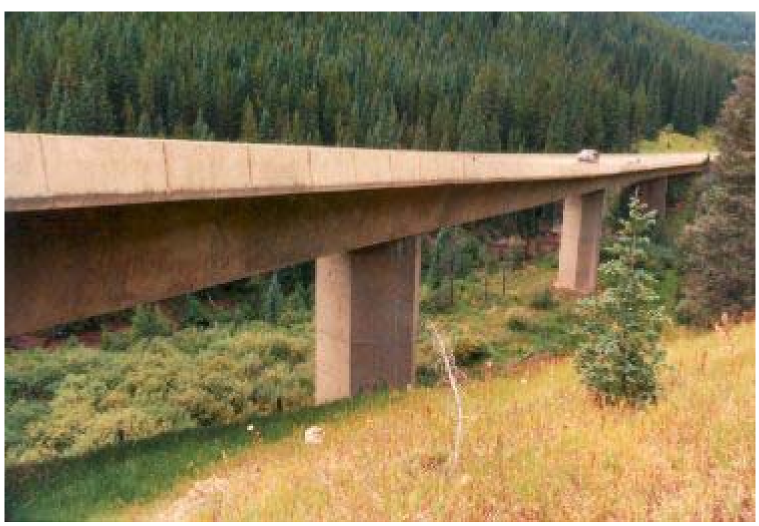
ABSTRACT

A comprehensive approach to high performance concrete and bridge design must include an evaluation of a structure's aesthetics and the durability and economics of its finishes. Color can be used as a bridge design element to establish identity, improve community acceptance and reduce environmental impact. As an alternative to paints and surface-applied coatings, the performance and durability of integrally colored concrete has been well established and it has been used successfully on a growing number of major structures. This analysis suggests that integrally colored concrete is economically competitive with surface-applied finishes, can significantly reduce life-cycle costs, and should be given consideration whenever color is required as part of the aesthetic design of a bridge or other large concrete structure.

Keywords: integrally colored concrete, life-cycle cost analysis, case study, concrete bridges and viaducts, color additives, pigments, aesthetics, environmental impact, finishes, coatings, economics.



The colors in this viaduct on I-70 near Vail, Colorado blend in with the natural colors in the surrounding landscape.

INTRODUCTION

While ordinary gray concrete is acceptable for many structures, a broader palette of colors adds an aesthetic dimension to the design of bridges, viaducts, and other concrete structures. In visually-sensitive areas, for example, color can reduce the environmental impact of a structure by helping it blend into or complement the surrounding landscape. Alternatively, color can be used to make a structure stand out from its surroundings or to enhance its visibility; a technique that can be used to distinguish a "gateway" bridge at the entrance into a city.

In the past, the most frequently used method to color a concrete bridge has been to coat the structure with paint or other surface-applied finishes. An alternative approach is to use integral colors that are mixed throughout the concrete. The performance of integral colors is well established (footnotes 1 and 2) and they have been used successfully on a growing number of major structures (footnote 3).

Black iron oxide was randomly mixed into the concrete used to build the Linn Cove Viaduct, to match the rocks of Grandfather Mountain.

Despite this track record, many bridge designers continue to overlook the potential of integral colors due to concern about cost.

At first glance, this concern may seem well founded. While coatings are applied only to visible surfaces, most of the pigments in integral colors are "wasted" where they are not seen. However, a simple tally of the costs of pigment versus paint does not tell the full economic story. At least three other factors must be considered to weigh their relative cost effectiveness:

1. Integral colors contribute to **overall construction economies**. First, the cost of integral color is at least partially offset by the elimination of coating materials. More significantly, integral colors are added at the same time as other concrete ingredients and have only minimal impact on the labor required to place and finish concrete. In contrast, coatings can require additional labor, scaffolding, and time for surface preparation, priming, and finishing operations.

2. In contemporary bridge design, **the volume of concrete can be relatively small in comparison to the surface area of a structure**. Box girders and other hollow sections typically have thin wall sections to minimize the amount of concrete required. This, in turn, reduces the pigment required and makes integral coloring more cost effective.

3. Integral colors provide **life-cycle cost savings** because they are permanent and last the life of a structure. Coatings, by comparison, incur ongoing expense for maintenance. This point is of increasing concern since air quality standards have

mandated reformulation of coatings to eliminate volatile organic compounds; the long term performance of many reformulated coatings has not been demonstrated.

To gain better understanding of these factors, the authors conducted a construction and life-cycle cost study comparing the use of coatings and integral colors in a representative bridge.

DESCRIPTION OF CASE STUDY

The Study is based on a hypothetical structure patterned after a designed in 1995 and constructed over the Mississippi River in St. Paul, MN. The structure includes two parallel concrete segmental box girder bridges approximately 1,250 feet in length. The height of the box girders varies from about 20 feet at pier tables to 8 feet at midspan, and each bridge has a deck just less than 47 feet wide. A selective quantity survey determined the project contains 36,890 cubic yards of concrete and 397,780 square feet of visible surface area.

Color can add a finishing touch to bridge abutments and related structures.

The bridge, as built, was coated with a fluid applied, textured architectural coating system recommended by its manufacturer for structures of this type and complying with Federal Specification TT-C-555b – *Coating, Textured (For Interior and Exterior Masonry Surfaces)*. The coating is applied to parapets, the underside of the box girders, piers, and exposed portions of foundations. After a light sandblasting to remove form release agents, primer and finish coats are applied, a process requiring three visits to all areas. For comparison, the integrally colored concrete bridge uses the same concrete mixtures as the as-built structure, with the addition of color additives complying with ASTM C979 - *Pigments for Integrally Colored Concrete*. Two pounds of colorant are assumed for each 94 pounds of cement, slag and fly-ash specified per cubic yard of concrete. This dosage rate allows for a wide range of concrete colors; additional subtle shades are also available at lower cost. Colorant is placed into ready-mix trucks at the batch plant. It is assumed that the concrete producer uses automated color dispensing equipment since the equipment reduces truck turn-around time at the ready-mix plant and increases quality assurance. It is also assumed that colored concrete work is performed in accordance with published recommendations of

Davis Colors, a leading producer of concrete colors, and applicable ACI guidelines for architectural concrete.

In the integrally colored bridge, controlled sandblasting is assumed on the most visible surfaces of the structure, such as parapets and vertical surfaces of box girders. Controlled sandblasting produces a more uniform concrete appearance by removing the mottling that can appear in the cement paste at the surface of formed concrete. Other surfaces – including the recessed areas on piers and the underside of box girders – have an as-formed finish. As-formed areas will be slightly darker than sandblasted areas, giving an illusion of greater depth to the architectural recesses. While mottling may be more visible in the as-formed areas, it is assumed that this is acceptable since the areas are within the structure's shadow line and are not prominent features. By using as-formed surfaces at selected areas, nearly 24,000 square feet of controlled sandblasting is deducted from the cost of the integrally colored project.

Concrete workability and compressive strength development are not impacted by colorants, so no adjustments are made to labor costs for placing the colored concrete. In addition, colorants have little impact on the sequencing or scheduling of work, except with regards to stripping of forms. From an engineering standpoint, concrete's developed strength dictate when forms can be removed. The architectural standpoint, however, is based on color development. Premature stripping allows evaporation and reduces the water-to-cementitious ratio in the cement paste at the surface of the concrete, resulting in a change in shade. The form set-up requiring the longest time from pouring to stripping on an engineering basis would establish the stripping time for all set-ups on an architectural basis. This, in turn, dictates the time required to construct any particular element. The impact of this would have on the overall work would have to be addressed within the actual construction schedule, taking into consideration the entirety of the project.

Central Avenue Viaduct, Phoenix, Arizona

CONSTRUCTION COSTS

Construction cost models were developed based on national 20-city average construction costs provided by *Engineering News Record* in 2001. Only those elements of the bridge affected by the choice of coloring systems are included in Study, since most of the work remains the same regardless of the system selected. For example, sidewalks and roadway overlays are excluded from Study with the assumption that their coloring, if desired, would be the same regardless of whether the structure is coated or integrally colored.

Table 1 shows the estimated prices for colored and uncolored concrete. The higher strength concrete requires additional colorant because pigment dosage rate is related to the amount of cementitious materials in a mix.

Table 1

Concrete Prices per Cubic Yard			
Location	**Mix Design Strength**	**Uncolored Concrete** (For Coated Structure)	**Integrally Colored**
Foundation	4000 psi	$72.81	$92.20
Pier, Pier Table, Box Girder, Deck Closure, Parapet	6000 psi	$93.09	$120.87

Assuming the coating system costs $4.11 per square foot installed and the controlled sandblasting for the integral color costs $1.59 per square foot, initial construction costs are estimated as follows:

Coatings	$ 2,452,000
Integral Coloring	$ 2,391,000
Delta	$ 61,000

This represents a potential 2.5% construction cost savings with integral colors.

LIFE-CYCLE COSTS

The National Highway System Bill of 1995 requires life-cycle cost analysis of major bridge construction projects. With this in mind, life-cycle calculations were performed using *BridgeLLC* software provided by the National Institute of Standards and Technology, NISTIR 6298. Escalation of future costs is calculated at an average of just less than 3% (2.96%) per year inflation and a nominal 7% discount rate for an assumed 4% real discount to provide present-day dollar costs. These values were selected based upon criteria included in the life-cycle analysis program. Table 2 shows the results of the life-cycle cost analysis.

Its designers assume a 100 years service life for the bridge. The coating system is assumed, based upon manufacturer data, to have a 25 years service life and will require re-application three times during the life of the bridge. Costs for re-application are assumed to be identical to the initial application, and include light sandblasting, primer, and finish. While not factored into Study, re-applications of coatings could entail additional costs for traffic management and travel delays while the work is in progress.

While integrally colored concrete is a permanent finish, the Study assumes the bridge will be cleaned at the mid-point of its life to remove accumulated grime. Cleaning is assumed to be performed over both sandblasted and as-formed areas of colored concrete.

With these assumptions, life-cycle costs shown in Table 2 favor a clear advantage for integral colors. Even in scenarios where integral colors are the more expensive option initially, it is still likely that they will become the preferred solution once coating maintenance is evaluated.

Table 2

Finish Life-Cycle Costs*			
Period	**Coatings**	**Integral Colors**	**Delta**
Year 0	$ 817,433	$ 278,387	$ 539,046
Year 25	$ 310,172	0	$ 310,172
Year 50	$ 199,657	$ 46,291	$ 73,366
Year 75	$ 46,161	0	$ 46,161
Total for Structure Life	$1,373,423	$324,678	$968,745
* Shown in Year 0 dollars with costs discounted at 4% per year.			

ANALYSIS BY STRUCTURAL ELEMENT

It is most economical to use colored concrete in bridge components such as box girders and parapets that have a large ratio of exposed surface area to concrete volume. Elements such as foundations, piers and pier tables that have a lower ratio of exposed surface area to concrete volume tend to favor coatings. However, when life-cycle costs are considered, all structural elements except for the compact and massive foundations show the affordability of colored concrete (See Table 3 & Fig.1). An understanding of this will enable designers to make more informed decisions about which structures and which portions of structures are the best candidates for integral coloring.

Table 3

Unit Prices per Cubic Yard By Location							
Location	**Surface Area/ Volume Ratio**	**Initial Costs**			**Live Cycle Costs**		
		Coatings	**Integral Colors**	**Delta**	**Coatings**	**Integral Colors**	**Delta**
Foundations	1.03 SF / CY	$ 77	$ 94	$17	$79	$94	$15
Pier Table	7.77 SF / CY	$ 125	$ 133	$ 8	$144	$135	-$9
Piers	8.60 SF / CY	$ 128	$ 128	$ 0	$149	$130	-$19
Box Girder*	14.27 SF/ CY	$ 152	$ 142	-$10	$186	$145	-$41
Deck Closure*	27.00 SF / CY	$ 204	$ 121	-$83	$269	$127	-$141
Parapet	55.20 SF / CY	$ 320	$ 209	-$111	$452	$221	-$231
* Paved area not included in surface area calculations. Life-cycle costs shown in Year 0 dollars with costs discounted at 4% per year.							

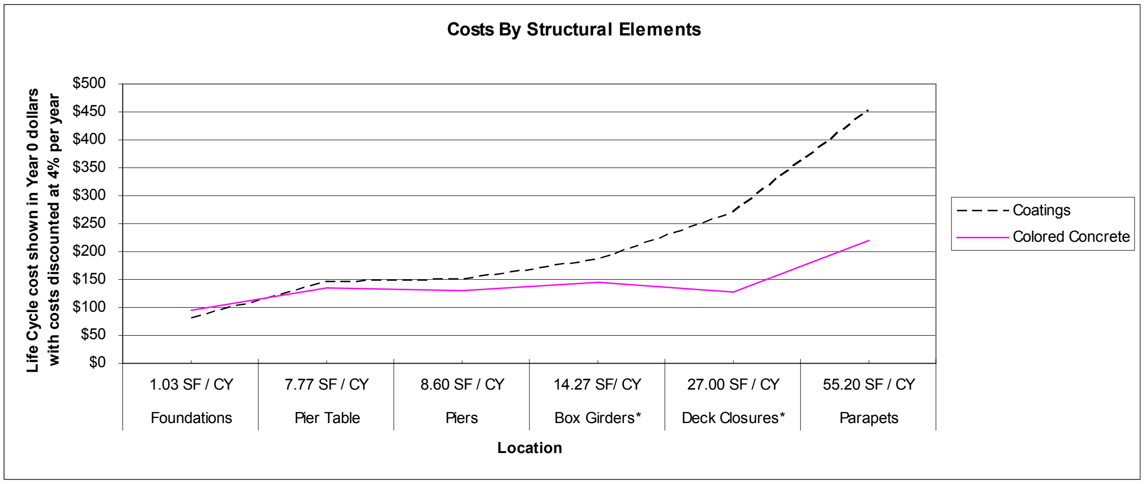


Fig. 1

COMMENTS

This Study is based upon a structure designed with applied coatings in mind. If a structure is designed from the start to maximize the advantages of integral coloring, there may be additional cost efficiencies. For example, textured form liners or additional relief may reduce the need to sandblast surfaces. Additionally, foundations and the lowest portions of piers could be left as-cast to give a darker appearance to the lowest stories, a classical architectural technique which gives visual strength to the base of a structure.

Colored concrete would also allow coloration to extend to the water level beneath the bridge, something that may not be practical with an applied coating.

While this Study considered a cast-in-place structure, a similar methodology can be applied to precast bridges. Well established coloring techniques used to make precast architectural panels can be transferred to the fabrication of precast, prestressed bridge elements. This would allow structural members to be colored in the controlled environment of a factory for even greater quality control.

Vista Canon Bridge, San Diego County

This Study assumes that colored concrete is used throughout structure. Savings may be possible if, at contractor's option, the construction sequence is controlled so that uncolored concrete is used at locations that are not exposed to view, e.g. pier table diaphragms and the paved portions of box girders.

It is difficult to quantify the quality control required to assure that variations within the appearance of colored concrete are kept within an acceptable range. Bridges already demand high levels of care in design, specifications, inspection, and construction management, and the experience of many contractors demonstrates that the additional demands required to assure acceptable concrete appearance can be taken readily and economically in stride. Concrete, whether colored or not, is a natural material and prone to variations in appearance due to many factors. While many designers feel this is part of the aesthetic appeal of concrete, they are advised to view examples of other large concrete structures and to discuss this issue with clients and contractors ahead of time so reasonable expectations can be established. Concerns about variations in appearance can also be addressed through architectural detailing. For example, experience has shown that concrete "blemishes" are less conspicuous if large expanses of concrete are divided into smaller areas through the use of reveals or other architectural features.

A railway overpass in Walluf, Germany.

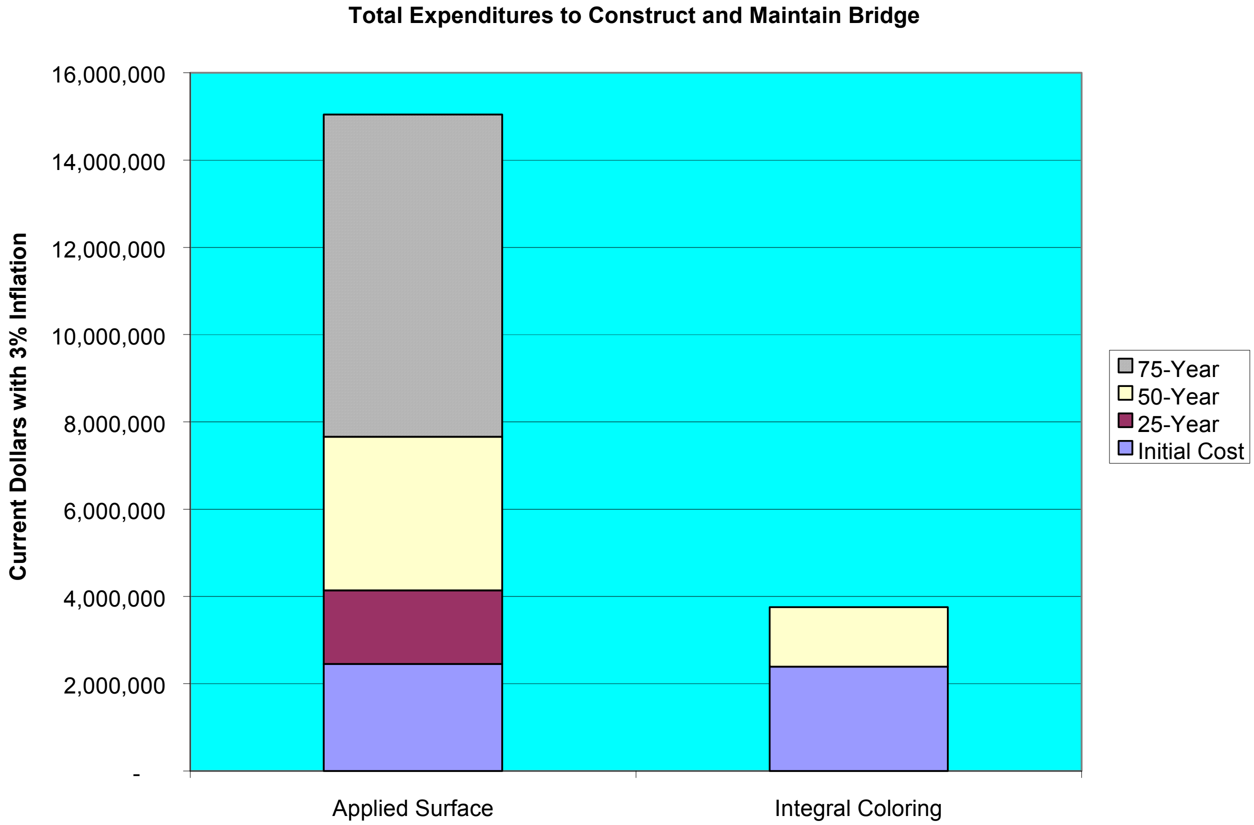
An advantage of integral colors over coatings is that integral colors allow direct observations of structural elements so that damage caused by seismic events, accidents, and the ravages of time are not hidden from view. It should be noted in this regard that the coating manufacturer does not claim that its product protects concrete against water penetration or other environmental conditions that promote premature concrete deterioration.

While we can only speculate about technology 100 years from now, coatings may prove a detriment when it comes time to demolish the structure. At present, there is no effective means of removing heavy buildups of applied coatings for recycling of their chemical content. And while clean integrally colored concrete can be crushed and reused as concrete aggregate or roadway base, concrete with heavy coatings has a lower recycled value. This cost impact has not been included in Study.

CONCLUSION

On an initial cost basis, the cost of integral colors is 97% that of coatings, shaving approximately $61,000 off the $2,451,790 price of coating the bridge. When maintenance costs are added to the equation, integral colors are only 25% of the cost of applied finishes based on projected expenditures, as shown in Figure 2.

Figure 2



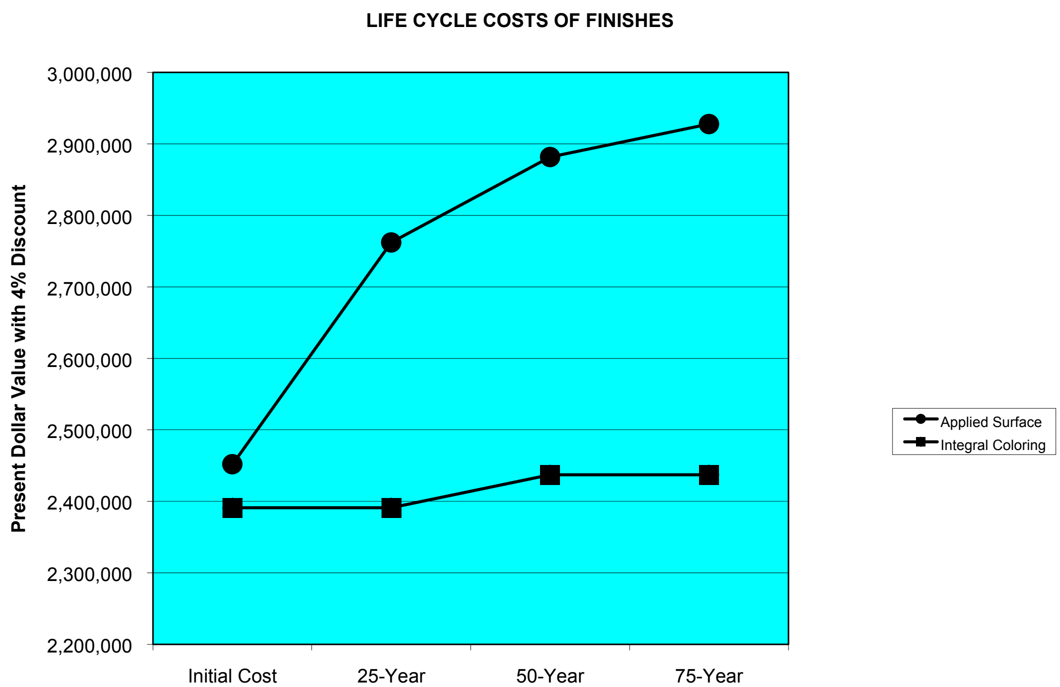
Life-cycle costs shown in Figure 3 demonstrate that integral color is the more economical finish not only at the time of construction, but throughout the structure's life. Considering the time value of money, the costs of the two alternatives are as follows:

Coatings	$2,927,780
Integral Colors	$2,437,160
Delta	$ 490,620

This represents a potential 17% life-cycle cost savings with the use of integral colors.

Portal to tunnel on Highway 3 in Hawaii

Figure 3



A decision to use coatings requires the future maintenance expenditure of over $12.5 million in today's dollars. If this were to be funded at the present time, an investment of $475,990 would have to be set aside to meet future obligations. In contrast, future expenditures for colored concrete would amount to $1.4 million and would require only $46,290 set aside to meet future obligations.

While each proposed project must be considered on its own merits, this Study suggests that integrally colored concrete is competitive with surface applied finishes, can significantly reduce life-cycle costs, and should be given consideration whenever color is required as part of the aesthetic design of a bridge or other large concrete structure.

REFERENCES

1. Paris, Nick and Chusid, Michael, "Color in Concrete: Beauty and Durability", *Concrete International*, January 1999,

2. Paris, Nick and Chusid, Michael, "Colored Concrete: Paving the Way for Beauty", *Concrete International*, Jury 1999.

3. Chusid, Michael, "Colored Concrete Reaches New Heights", *Concrete Products*, January 2003.

4. A version of this paper was first published in *Concrete International*, June 2003.