Coloring Concrete Bridge Components with Pigments for Integrally Colored Concrete

Cathy Higgins, Dynamic Color Solutions, Inc., Milwaukee, WI

ABSTRACT

This paper is an introduction to using pigments to integrally color concrete bridges. It will start with a description of the classes of products used – particularly iron oxide pigments and how they are used in concrete. It concludes with a presentation of specific issues related to bridge construction including what works well and what does not

Keywords:
Bridge Aesthetics, Pigments, Colored Concrete, Color, Tint, Iron Oxide

Aesthetic issues in bridge construction have centered mainly on shape and form, but texture and color can also play a significant role in the acceptability of the finished project. Color is becoming more of a factor than ever before, particularly for bridges built in a community with participation by the citizens' advisory board. Bridges make an impact on a community. A bridge can be a positive contribution to a neighborhood, particularly when the visual impact, including color, is carefully considered during the design and construction process. As stated by Paul Harbeson, in his "Architecture in Bridge Design" article, "Color has both functional and aesthetic importance in the design of bridge structures. Perception of color is held by some to be a matter of basic, immediate, emotional response. Color is a prime and direct means of transmitting visual information." Frederick Gottemoeller states, "Color and texture are bonuses, sources of enrichment and interest which can enhance a good structural design."

This paper is going to focus specifically on how all of the concrete elements of a bridge can be tinted using pigments designed to integrally color the concrete. In order to properly address the issues specific to bridges with an informed perspective, the basics of integral color for concrete need to be understood.

Materials Used to Color Concrete

Most pigments used to color concrete are iron oxide pigments. They are used because they are:

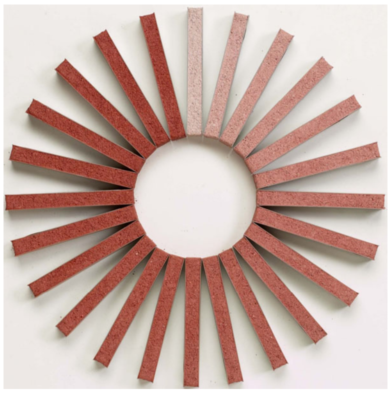
1. available in a wide variety of colors
2. water wettable
3. alkali resistant
4. not water soluble
5. chemically stable
6. light resistant
7. relatively inexpensive

ASTM C979 Standard Specification for Integrally Colored Concrete includes tests for many of these characteristics as well as testing to insure the pigments are within allowable tolerances for total sulfates, that they do not affect time of setting, and do not affect air content or compressive strength of the concrete. All pigments used to integrally color concrete should pass ASTM C979.

Iron oxide pigments can be broken down into two basic classes: Synthetic and Natural. Any concrete pigment can be wholly composed of either natural or synthetic iron oxides, or it can be a blend of the two classes. There are some basic differences between synthetic and natural iron oxides, but in general they all offer good longevity, and color consistency from lot to lot. To describe their differences, it is important to understand some basic pigment concepts first.

Tinting strength is the ability of a pigment to change the color of a given mix – i.e. If a pigment changes the color of a mix substantially with a small addition of color, that pigment is said to have a high tinting strength. The tinting strength of a pigment depends both on the iron oxide content and the fineness of the pigment in question.

Saturation Point is the point at which color intensity stops rising proportionally to the rate of addition of the pigment.



Synthetic Red Iron Oxide Pigment Additions from ¼% to 6% in white cement. Note how the last several samples look virtually the same. This is at or near the saturation point for this pigment.

Synthetic Iron Oxide Pigment is a manufactured product. One way to manufacture a synthetic iron oxide is to use a source of known metal and rust it under very controlled conditions. Synthetic iron oxides can produce intense colors, are relatively expensive, and have high tinting strengths. When making pastel colors, however, they require a very low pigment addition rate, sometimes as low as ¼ to ¾%. The saturation point for synthetic iron oxides is around 5%. Synthetic iron oxides are manufactured in red, yellow, and black shades.

Synthetic Red Iron Oxide

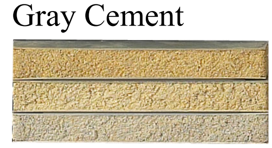
Gray Cement

5%
3%
1%

Synthetic Yellow Iron Oxide

Gray Cement

5%
3%
1%



Synthetic Black Iron Oxide

Gray Cement

5%
3%
1%

Natural Iron Oxides come from naturally occurring ores that are mined around the world. These ores are dried, classified, and pulverized. Natural iron oxides when used to color concrete produce earth tone type colors. Because of their lower tinting strengths, natural iron oxides tend to be used at higher addition rates. It is often easier to control concrete color consistency using natural iron oxides. This is because a small amount of natural iron oxide pigment does not change the color of the concrete dramatically. Therefore, a small change in the amount of pigment used also does not change the color of the concrete dramatically. Natural iron oxides are relatively inexpensive, so even with higher addition rates, they are affordable. The saturation point for naturals is closer to 10%, but except on rare occasions, it is best to stay at a 5% addition or below. Natural iron oxides that are suitable for coloring concrete are available in reds, browns and yellow ochres. Natural black iron oxides exist, but they do not have sufficient tinting strength and therefore are not appropriate for use in colored concrete.

Natural Red Iron Oxide

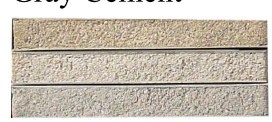
Gray Cement

5%
3%
1%

Natural Yellow Ochre

Gray Cement

5%
3%
1%



There are several other products, in addition to iron oxides, which are used to color concrete. They add more choices to the palette of pigments available to color concrete.

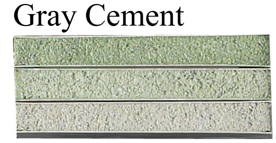
Titanium dioxide, a white pigment, can be used to lighten concrete made with gray or white cement. It will never make concrete made with gray cement truly white, but it will lighten it to a lighter shade of gray. Titanium dioxide is also used in some pigment blends to lighten and brighten them. It is approximately 25-50% more expensive than synthetic iron oxides.

Chromium Oxide is used to color concrete green. It is very durable, but is more expensive than iron oxides. It costs approximately three times as much as synthetic iron oxides. Blue is also available in the form of cobalt oxide. Cobalt blue is extremely expensive. It can be up to twenty times more expensive than synthetic iron oxides. The cost impact of both blue and green, therefore, must be carefully considered when they are to be used in any colored concrete project.

Chromium Oxide

Gray Cement

5%
3%
1%



Cobalt Oxide

Gray Cement

5%
3%
1%

Carbon black is a product that for many years was commonly was used to color concrete. It is proven over time, however, not to be permanent and should no longer be used. It is a very fine material that does not mix well with water. This results in many carbon black particles at the surface initially, but over time most of these particles weather off, which results in a perception of the color "fading." This weathering only occurs on the surface of the concrete, however, so if one was able to break open the concrete and look at the inside color, it would still be dark. This is why carbon black is not recommended for use today. Synthetic black iron oxide, on the other hand, will produce a very stable deep charcoal color and this is the darkest pigment available that is permanent.

Certainly there is a place for each and every one of these pigments, and blends of them, in concrete bridge design and construction. Pigments should be selected by the end color desired. With combinations of all of the pigments, there is a vast array of concrete colors available. No particular class of pigments (with the exception of carbon black) is inherently better or worse than any other, and they can all be used with great confidence and success in bridge construction.

Forms of Pigment

Currently pigment is available in powder, liquid, and granular form. All pigments discussed above are available in powder and liquid form, but only synthetic iron oxides are available in granular form.

Powder pigments have been used in the construction industry for the longest time. They are still the most common form of pigment used by precasters, and ready mix manufacturers. They are the least expensive form of pigments and are typically available in either 50 pound bags or batch size bags as required. Powder pigments have unlimited shelf life when stored properly. It is best to keep them dry, so they don't get lumpy and the bag doesn't disintegrate. For best results, they should to be added early in the batching sequence in order to achieve maximum dispersion and color development of the colored concrete.

Liquid color has been used in the United States for over 20 years. It basically consists of the powdered pigments suspended in a water-based dispersion. Liquefying the pigment simplifies the conveying process and therefore allows pigment additions to be automated through the use of dispensing equipment. Dispensing systems can also create verification and documentation of all pigment additions to the concrete mix. Liquid pigment also mixes more readily with the concrete and therefore significantly faster color development and better dispersion of color take place in the mixer. Liquid color costs more than powdered color, but ultimately it helps produce more consistent colored concrete. The use of liquid color in precast and ready mix has been increasing at an every faster rate over the last five to ten years.

Granular pigments are basically powder pigments joined together to make small (bb size) balls. They have been used in the construction industry for less than 10 years. Granules can also be added automatically, and since they are dry, they do not require the addition of any extra water to the mix. As stated earlier, this form of color is only available for synthetic iron oxides, and is used mostly in concrete paver plants and some concrete masonry manufacturing facilities.

Specifying and Cost Impact

The best way to specify color for a bridge project is to start with color samples from a pigment manufacturer or use PCI's Color & Texture Guide. In the specification it is particularly helpful to call out the color of cement to be used, the pigment number and name, and the percentage addition of the pigment. For any bridge project, there must be an approved produced by each of the suppliers of colored concrete, including the prestress concrete manufacturer and the ready mix concrete producer.

The cost of the pigment will obviously be an important factor to consider when coloring a bridge. In a yard of 7 bag mix concrete, iron oxide pigments normally cost approximately $5.00 per yard on the low end to approximately $50.00 per yard on the high end. Because of this wide range of costs, for each bridge project, extra care must be taken to factor pigment costs into the bids for the exact pigment and addition rate specified. This will help prevent any confusion and extra charges during the production and erection of the project.

Quality Control and Production Controls

Good quality control measures must be established when producing any form of colored concrete. On bridges these quality control measures must apply to both the plant cast and the site cast concrete. For each bridge element (i.e. piers, abutments, beams, parapets) a single type and brand of cement should be used. Switching type or manufacturer of cement during a job will cause color variation. Almost all bridges are made using gray cement as the base of their concrete. For bridges where the color consistency is the primary factor, white cement should be considered. White cement is significantly more expensive that gray, but colored concrete made with a white cement base is typically much more uniform in color since white cement is color controlled in the manufacturing process. For this same consistency reason, fly ash and other pozzalonic material should be evaluated carefully and excluded from the specification if there is any question regarding the consistency of the product throughout the entire project.

Pigment additions should normally be kept between 1% and 5% of the weight of the cement in the mix. Color consistency of the concrete at pigment additions below 1% is sometimes difficult to maintain because of the small amount of pigment being mixed into a huge mass of concrete. On occasion, additions of over 5% are appropriate, but 5% is a good target maximum addition rate for pigment.

When producing colored concrete maintaining consistency of all raw materials is essential. Consistent water/cement ratios are also very important. The higher the water/cement ratio, the lighter the concrete will be. The converse is also true. Lower water/cement ratios produce darker concrete. Obviously consistency is the key - from the approved sample through all production.

Patching procedures must also be addressed during the design phase of the bridge project. For prestress beams and other precast elements, the precast concrete manufacturer can experiment at the plant to create a "patch mix" that works with a sample piece. For the poured in place sections, basically the same procedure is desirable. The ready mix concrete producer would need to take an approved sample and have the person who will be responsible for patching experiment to create an approved patch mix and procedure.

The finish of the concrete has a profound impact on the finished color and consistency of all the concrete elements. Integral pigments are not normally a good choice for smooth, off the form finishes. However, with the introduction of self consolidating concrete (SCC), this finish is becoming more viable. Generally, a smooth off the form finish creates color variations at the form face because of differential surface drying of the concrete. SCC creates a denser, smoother, and more consistently colored surface finish. As its use increases, we may see more form finish colored concrete manufactured with good consistent results. In general, integral pigments work best with textured concrete - raked finishes, form liners, retarded, sand blast, or acid etched finishes.

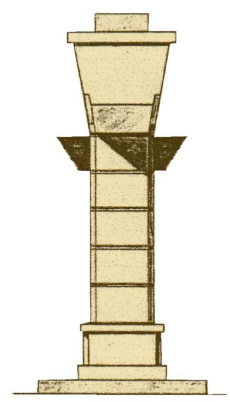
Though some of these procedures are certainly not the norm on an uncolored bridge project, increased attention to detail and good quality control procedures on a colored bridge will yield huge rewards in the appearance of the finished project.

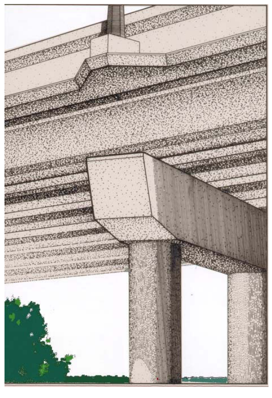
Specifics for Bridges

Over 6,000 bridges have been built each year in the United States since 1960. Any of these bridges that has any concrete on them could be colored. Realistically, only some of those bridges would benefit from being pigmented. The most logical first choices are the bridges that are viewed regularly from all angles by many people. These highly visible bridges are typically located in urban areas, along heavily traveled roadways, or are smaller bridges with lots of pedestrian interaction, including some in recreation areas.

In looking at each bridge element, and what details would lend themselves to the use of colored concrete, the Iowa Department of Transportation "Report of the Bridge Design Aesthetics Team" makes some excellent recommendations (illustrations courtesy of the Iowa DOT). Following is a discussion of each element with at least one detail that would be enhanced by pigmented concrete.

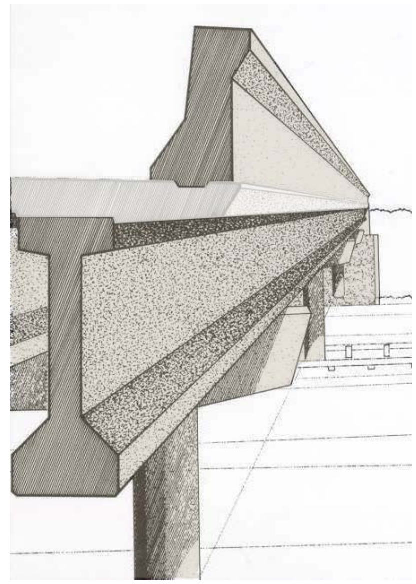
Starting with the substructure, some kind of articulation on piers works very well with pigment. The reveals break up the visual mass of the pier and create enough interest to help mask any small color inconsistencies. The base of the pier can be colored a deeper tone that will help to balance, or "anchor" the bridge.





Detailing the pier cap with a slight slope and not projecting dramatically beyond the beams helps keep the end of the cap be out of direct sunlight. Shading this element helps it blend with the other elements. When it is not recessed and sloped, in the sun this feature looks much brighter than the rest of the elements. This creates an unplanned contrast in color. This detail also shows that the light pole bases in alignment with the piers, and it includes no protruding pier diaphragms.

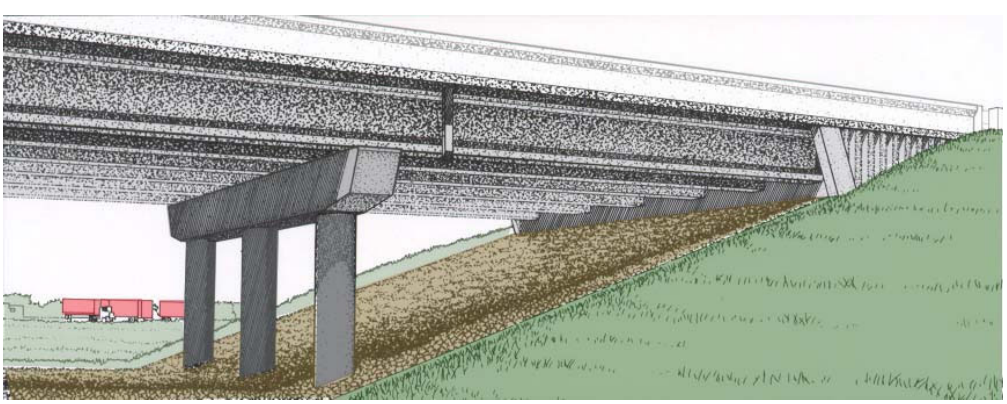
For many bridge applications, only the fascia beams would need to be colored. There are some cases where the interior beams would be seen, and in that case, all of the beams would need to be colored. Light sand blast on the visible elevations of the beams would be an excellent choice for color consistency; in this case only the two faces in view of the traffic would need to be finished.



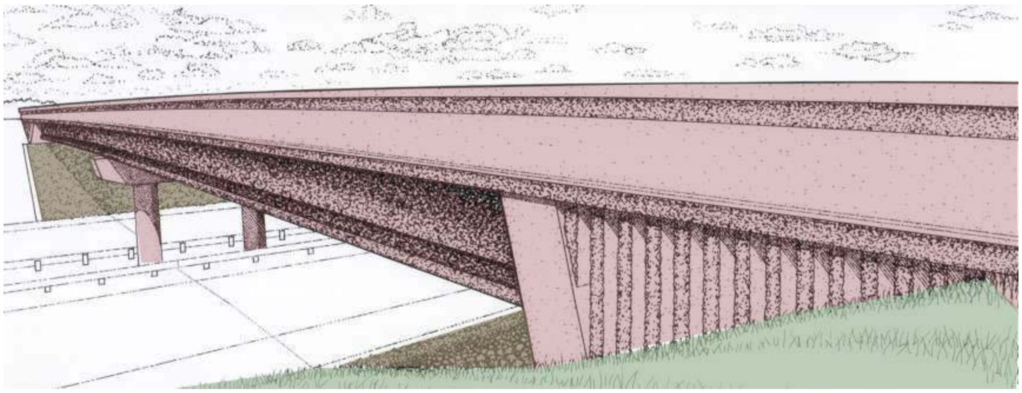
Also shown in this detail is an over hanging deck with a beveled edge. The beveled edge on the deck will decrease the effect of a band of contrasting color created by the uncolored deck. For continuity of the roadway, it is assumed that the deck would not be pigmented.

Parapets also offer the opportunity to use pigments. For any bridges on roads with restricted speed, lots of architecturally beautiful pigmented parapets can be considered. For higher speed roads, where impact resistance is key, a parapet detail as above gives an appealing view of the parapet and again, texture and shape help add to a consistent appearance.

Depending on the color scheme of the entire bridge the uncolored deck can be designed to be an intentional feature of the bridge. If, for example, the base of the piers were a deep charcoal color, the piers themselves could be a slightly lighter charcoal color, the beams could be deep gray with a sand blast finish, the deck could be left uncolored and the parapets tinted a lighter gray than even the uncolored deck (by using a pigment that lightens the concrete). This would create an interesting, and aesthetically pleasing color combination for any bridge.



Finally, the abutments can also be colored, and would be greatly enhanced with some kind of texture that could be created by the use of a form liner. This example shows a fractured ribbed pattern on the abutment, which breaks up the mass and is interesting and attractive.



Most of the suggested details above illustrate ways to break large masses of concrete into smaller visual pieces, or to create light and shadow effects. These two techniques alter the typical flat, smooth surfaces that are used in bridge designs today. In addition to being more pleasing aesthetically, they help mask slight inconsistencies that commonly occur in gray cement form finished concrete. This backdrop of texture and detail will produce an outstanding canvas onto which integrally colored concrete elements can be applied resulting in a stunning bridge project

While reviewing bridge design awards and evaluating bridges that evoke the greatest visual impact, the "monumental" bridge almost always comes to mind. These bridges deliver the maximum impact when viewed from afar. What tends to be most remarkable about this class of bridges, aesthetically, is their form. However, 80% of all bridges built are 150 feet long or less (according to the National Bridge Inventory). If future bridge designers focus on the aesthetics of these smaller structures that have such a profound impact on our local communities, and they use the elements of color and texture available to them, they will certainly be able to make a positive impact on our neighborhoods for years to come..

References:

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