The Tennant Avenue Bridge

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Introduction

This article initially discusses the events surrounding the changes to the California Department of Transportation's ("Caltrans") specifications for concrete. Next, the article will evaluate the performance of the high SCM replacement mixes recently placed in an actual bridge structure which used these new mixes. Finally, the impact of these high SCM replacement mixes on the overall carbon footprint in the bridge will be compared and contrasted to concrete designed using older specifications.

In 2006, then-California Governor, Arnold Schwarzenegger signed into law Assembly Bill 32 (AB32) which requires California to reduce its greenhouse gas emissions to 1990 levels by 2020. In response to this legislation and other factors, the California Department of Transportation made sweeping changes to their general concrete specifications allowing the use of high replacement percentages of supplementary cementitious materials (SCMs) and reduced overall minimum cement requirements in their concrete mix designs.

Central Concrete Supply Co. Inc., a ready mix supplier in northern California and a subsidiary of US Concrete, has developed a line of low-carbon mixes using EF Technology.™ These mix designs use 50% to 70% less cement through the use of SCMs without impacting initial setting times and constructability of projects. These mixes also have improved strength, shrinkage and permeability properties.

In 2009, Central partnered with Climate Earth, a carbon accounting company, to evaluate the carbon footprint of Central's mixes. Out of this evaluation, a customized carbon calculator was developed which allows Central to determine the carbon footprint for each yard of concrete produced. Using this carbon calculator, Central can compare and contrast the carbon footprint of concrete in individual mixes and in entire projects.

AB32 Scoping Plan and How Caltrans Adopted a Greener Specification

The Kyoto Protocol is an international agreement signed by 37 industrialized countries and the European community to reduce greenhouse gas (GHG) emissions to the 2000 levels by year 2010, to 1990 levels by year 2020 and to 80 percent below 1990 levels by year 2050. It was adopted in Kyoto, Japan, on December, 11 1997 and entered into force on February, 16 2005. The United States did not become a party to the Kyoto Protocol. On June 1, 2005, Governor Arnold Schwarzenegger issued Executive Order S-3-05 mimicking the Kyoto Protocol and directing the Secretary of the California Environmental Protection Agency (CalEPA) to coordinate efforts with several state agencies to achieve those GHG emission reduction goals. In addition, Executive Order S-3-05 directed the CalEPA Secretary to report to the Governor and the State Legislature by January 2006 and biannually thereafter, on the progress made towards meeting those GHG emission reduction targets and on the impacts of global warming to California.

As a result of Executive Order S-3-05, the Climate Action Team (CAT) was created and led by the Secretary of CalEPA. All GHG emitters were grouped into one of 16 subgroups. One subgroup was dedicated to cement and it was led by Caltrans. On September 27, 2006, Governor Schwarzenegger signed into law Assembly Bill (AB) 32, the Global Warming Solutions Act, which adopted the 2020 GHG emissions reduction goal. It also directed the California Air Resources Board (ARB) to develop discrete early actions to be adopted by 2011 and to prepare a Scoping Plan to achieve the 2020 GHG emission reduction goal using technically feasible and cost effective strategies. The Scoping Plan was approved by the ARB Board on December 12, 2008. The Scoping Plan's final recommendations to achieve the 2020 GHG emission reduction from a cement industry perspective, was to develop a California cap-and-trade program in conjunction with other Western Climate Initiative partners to create a regional market system.

The Cement Subgroup of the CAT had active participation from the cement and concrete industries, as well as governmental agencies, environmentalists and academia. Prior to the CAT's final recommendation to adopt a cap-and-trade program, the Cement Subgroup investigated other potential ways to reduce GHG emissions from cement production and concrete consumption. For cement production reduction of GHG, the Cement Subgroup recommended blending supplementary cementitious materials (SCMs) at cement plants, selecting environmentally friendly fuels for cement kilns, using interground limestone, and improving production energy efficiency. Similarly, in order to further reduce GHG associated with cement use, the Cement Subgroup made recommendations regarding concrete consumption. These measures would take place at the batch plant and included blending SCMs at concrete batch plants, optimizing the cement content of concrete mixes, reducing concrete waste and adopting a universal

GHG emission standard to account for GHG emissions associated with transporting cement.

Carbon Footprint Estimates

Climate Earth provides environmental business intelligence (EBI) systems that assign carbon footprints based on financial information. Companies use these systems to monitor their resource utilization and the environmental impacts of products, procurement, suppliers and facilities. Central asked Climate Earth to provide two EBI systems:

> The first system periodically reports Central's total corporate carbon footprint, including all purchased goods and services. Its purpose is to enable Central's executive team to monitor the company's environmental performance and make adjustments based on Central's strategic plan.
>
> The second system is a carbon footprint calculator for individual concrete products. Each concrete mix contains varying amounts of raw materials, including coarse and fine aggregates, portland cement, slag cement, fly ash, chemical admixtures and water. As a result, each mixture of ingredients also has a unique carbon footprint. Climate Earth's web-based carbon footprint calculator shows the total carbon emissions per cubic yard of any mix code. The calculator makes it easy to evaluate footprints for the bidding process, product development, and comparisons to standard concrete mixes.

Figure 1 shows the total green house gas footprint for Central Concrete Supply Co., Inc. in 2010. Nearly two-thirds of the footprint comes from portland cement, the primary binder in concrete. All of the other raw materials and activities account for the remaining third of the footprint. Central is working to reduce the footprint of each of these components one at a time. The principal focus for the Tennant Avenue project was to reduce portland cement content.

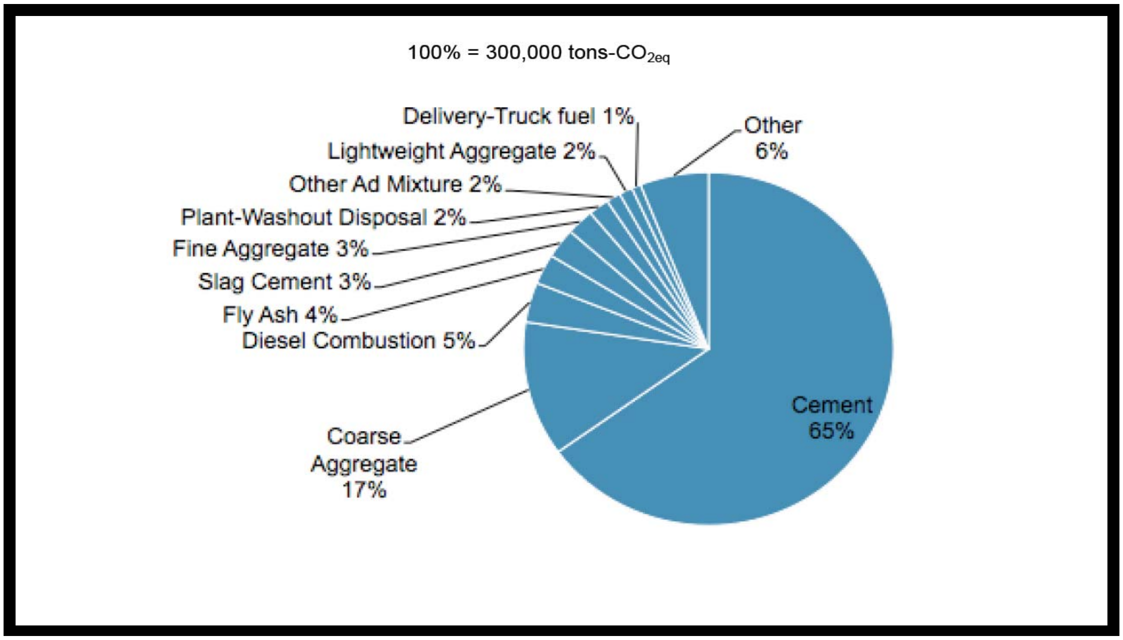

Figure 1. Total Green House Gas Footprint

Performance Review: Tennant Avenue Bridge – Morgan Hill, California

General Information

The size and type of this bridge are typical of a cast in place, box girder overpass structure. The bridge is 267 feet long, 45 feet wide, encompasses two lanes and an 8-foot shoulder. The bridge is flanked on both sides by cast in place barrier rails, which were completed under a separate contract. The bridge sits on 24 inch diameter, encased concrete piles which ranged from 30 to 44 feet deep. The top of the box girder, which is also the driving surface, is 8 inches thick and the bottom of the span is 7 inches thick. A plan and several section views are shown as attachments at the end of this paper.

The bridge is unusual in that was constructed out of concrete with up to 70% replacement of cement with SCMs. This concrete was placed with normal construction practices and the properties of the concrete were enhanced by the addition of fly ash and slag. The high replacement concrete did not dictate any change in the typical construction procedures; the concrete placement, formwork requirements, and stripping times matched those for “ordinary” concrete.

Figure 2. Tennant Avenue Bridge shown from the southwest.

The City of Morgan Hill, California owns the bridge, which was built to Caltrans specifications under Caltrans' supervision. Construction began in the middle of February of 2010 and the bridge was opened to traffic at the end April of 2011.

Table 1 shows the three primary and two incidental mixes used for the project. A total of 1,781.5 cubic yards of concrete were placed in this bridge structure. The SCMs utilized were a type F fly ash and Grade 120 slag cement. The portland cement was an ASTM C150 type II/V.

Table 1. Concrete Mixtures and Quantities Used

Mix Code	Mix Description	Quantity Placed, yd^3
DDJSL9U3	CIDH[1] 675 lbs 50% Cement, 25% Fly Ash, 25 % Slag	384
F01138P8	CDF[2] 88% Fly ash	15
D15SL9EA	Class 1 675 lbs EFV2[3] 50% SCM (25/25)	359.5
D24SL9QA	Class 2[4] 590 lbs 70% SCM (40/30)	1005

S29100EX	3-Sack Sand Slurry 25% Fly ash	18

1. Cast in Drilled Hole, used in the bridge piles
2. Controlled Density Fill, used for backfill
3. Environmentally Friendly™ Version 2, by Central Concrete Supply Co., Inc., to meet Caltrans Section 90, Class 1 Structural Concrete requirements, used in the bridge deck
4. Caltrans Section 90, Class 2, used in the substructure

Compressive Strengths

The required design strength (*f'_c*) for the concrete used in the CIDH piles (Mix DDJSL9US) was 3,650 psi at 28 days. The strength test results are presented here:

Table 2. Strength Test Results for Mix DDJSL9U3			
Average Strength, psi	7 Day	14 Day	28 Day
	3,373	5,187	6,708

The piles were filled in three placements. Slumps were not recorded, nor were the ambient or concrete temperatures documented—however, all properties of the fresh concrete were within Caltrans' requirements.

Mix D24SL9QA was used in the substructure of the bridge and the required design strength (*f'_c*) was 3650 psi at 28 days. Actual strength test results for this concrete mixture are here:

Table 3. Strength Test Results for Mix D24SL9QA			
Average Strength, psi	7 Day	14 Day	28 Day
	2,376	3,536	4,759

The substructure was done in four placements. Slumps at the point of delivery ranged from 3.5 to 4.25 inches. The air temperatures ranged from 56 to 80°F; concrete temperatures were recorded at 65 to 76°F.

Mix D15SL9EA was used for the bridge deck. The required design strength (*f'_c*) was 4,000 psi at 28 days. The deck was done in one placement; slumps and temperatures weren't recorded. The strength test results for this concrete mixture were reported as:

Table 4. Strength Test Results for Mix D15SL9EA			
Average Strength, psi	6 Day	12 Day	28 Day
	2,120	3,060	5,435

Each concrete mixture provided sufficient early strengths for constructability and all exceeded the strength requirements at 28 days.

Rapid Chloride Permeability

Figure 3 is a chart comparing rapid chloride permeability test results from 3 point curves used to develop similar mixes. Four different curves were developed using varying SCM replacements (100% Cement, 25% Type fly ash, 25% fly ash and 25% slag, 30% fly ash and 40% slag). Before the current changes to Caltrans' specification, the structural concrete would have been limited to the 25% replacement with Type F fly ash.

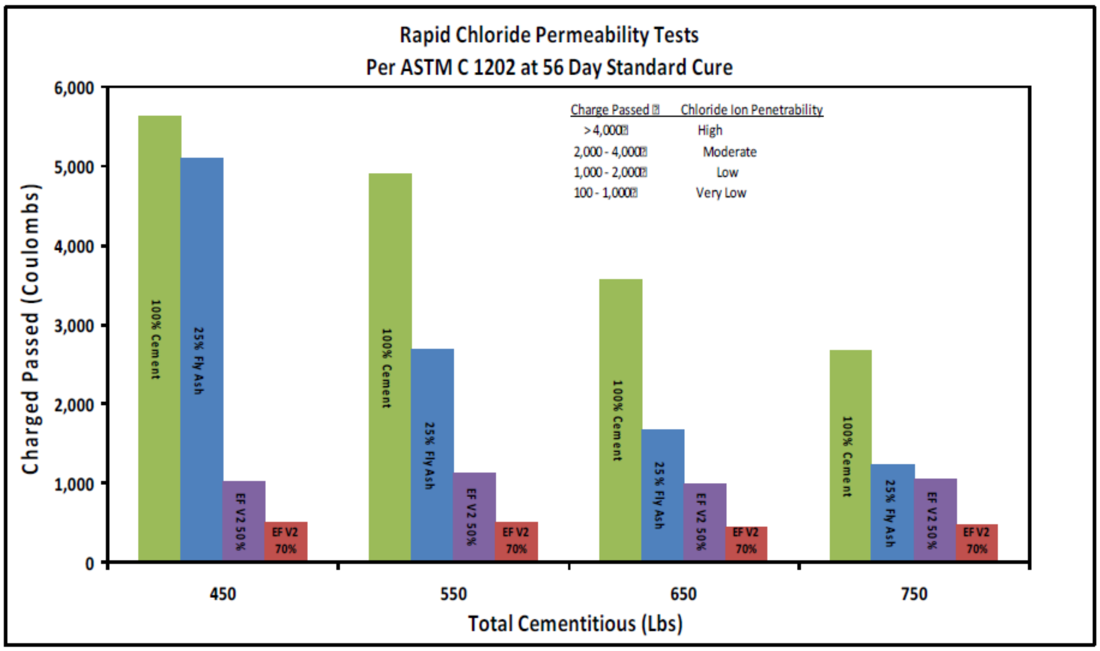

Figure 3. Rapid Chloride Permeability

At the cementitious levels used on this project (590 lbs, 675 lbs), the 50% and 70% replacement mixes have approximately one-third to two-thirds lower permeability values per ASTM C1202 testing. The water content for the mixes in the chart containing 25% fly ash was fixed at 32 gallons (267 lbs) per cubic yard. The ternary blends all had a water content of 31 gallons (258 lbs) per cubic yard.

Shrinkage

The drying shrinkage potential for various concrete mixtures was measured by the ASTM test method 1202, as modified by the Structural Engineers of Northern California (SEONC). Shrinkage test results for a typical straight cement mix, 15% fly ash replacement, 50% slag replacement and ternary blends at 550 lbs total cementitious materials. Predictably the straight cement mix has the highest drying shrinkage at all ages. The 50% slag mix is identical to the portland cement mix and the ternary blends have significantly lower shrinkage potential.

Figure 4. Drying Shrinkage

Heat of Hydration

Much of the concrete placed in this bridge substructure can be considered mass concrete where the maximum internal temperatures from the heat of hydration may be of concern. The 70% SCM replacement mix has a lower initial heat of hydration curve, which reduces the potential for micro-cracking due to thermal stress that could significantly reduce the service life of the concrete structure.

Carbon Footprints for Concrete Mixes

Table 5 describes the calculated CO_2 footprints for each of the concrete mixtures used in the Tennant Avenue Bridge. Predictably, the structural concrete mixes have higher carbon footprints than the other mixes.

Table 5. Total Carbon Footprint			Actual Mixes used on Tennant Avenue		*Old Section 90 Mixes*	
Mix Code	Mix Description	Quantity Placed, yd³	Lb CO_2eq, per yd³	Total lb CO_2eq	*Lb CO_2eq, per yd³*	*Total lb CO_2eq*
DDJSL9U3	CIDH[1] 675 lbs 50% Cement, 25% Fly Ash, 25 % Slag	384	406	155,904	*502*	*192,768*
F01138P8	CDF[2] 88% Fly ash	15	130	1,950	*130*	*1,950*
D15SL9EA	Class 1 675 lbs Fly Ash 25%	359.5	504	181,188	*504*	*181,188*
D24SL9QA	Class 2[4] 590 lbs 70% SCM (40/30)	1005	283	284,415	*450*	*52,250*
S29100EX	3-Sack Sand Slurry 25% Fly ash	18	249	4,482	*249*	*4,482*
Total lbs of CO_2eq				627, 939		*832,638*

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Contrasting Carbon Footprint

By comparison, the traditional Caltrans ("old") Section 90 mixes used 15% to 25% fly ash replacement and did not allow ternary blends of cement, GGBFS, and fly ash. The carbon dioxide equivalents for the "old" Section 90 mixes using 25% fly ash replacement are shown above in italics.

The carbon footprint of the bridge structure using Caltrans new Section 90 specifications is reduced by 204,699 lbs CO_2eq or 102.3 tons CO_2eq. This represents a 25% reduction compared to mixes that would have been done just a year or two ago. The bridge could have had an even lower carbon footprint if a 50% replacement mixed had been used for the pavement, rather than the usual 25% replacement mix. An additional 38,000 lbs CO_2eq could have been saved using a 70% replacement mix in the drilled shafts. The additional reduction would have been approximately 74,000 lbs CO_2eq or 37 tons CO_2eq, or an additional 9% reduction in overall carbon footprint.

Summary

The Tennant Avenue Bridge is a typical overpass that one may see throughout the United States. Its construction wasn't unique; that is, no changes were made to its construction schedule to compensate for the reduced carbon footprint. The carbon footprint was reduced 25% compared to traditional mixes and may well have been further reduced. The specifications by which the concrete mixes were allowed to be used represent a dramatic change that provides a glimpse into the future sustainable design and construction of the infrastructure.

Project Participants

Owner – City of Morgan Hill
Designer – Mark Thomas and Company, Inc.
CM – CSG Consultants, Inc. (for Caltrans)
GC – Top Grade Construction
Concrete Sub – Viking Construction
Concrete Sub foundation – Malcolm Drilling
Concrete Supplier – Central Concrete Supply Co., Inc.

Acknowledgements

Frankie Ridolfi, Climate Earth
Lynette Rotairo, PE, CSG Consultants, Inc.
Po Chen, PE, Mark Thomas & Company, Inc.
Moises Caballero, Central Concrete Supply Co., Inc.
Tarek Khan, FACI, BASF Corporation