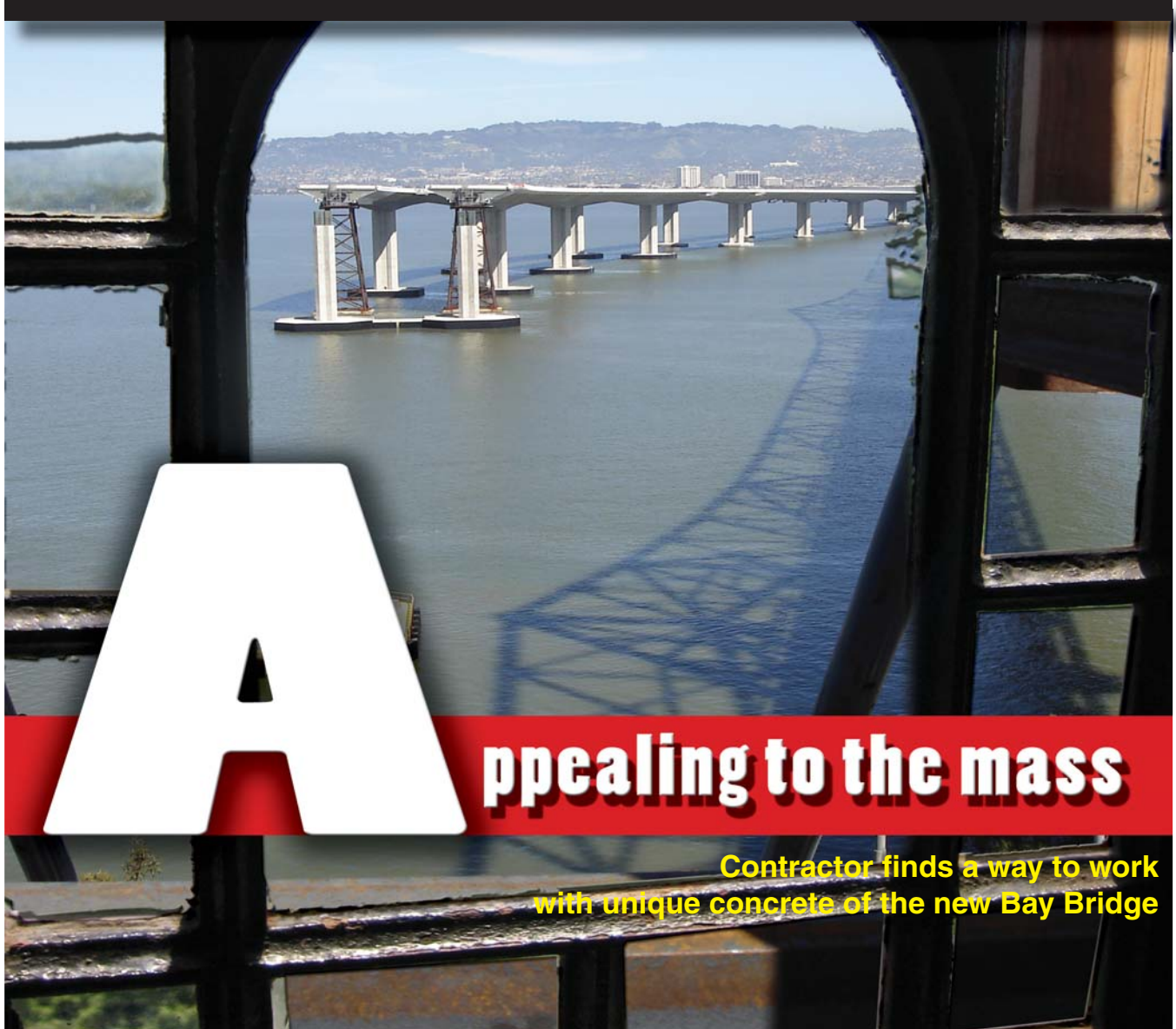


Concrete Progress

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Appealing to the mass

Contractor finds a way to work with unique concrete of the new Bay Bridge

The east span of the San Francisco-Oakland Bay Bridge is now in its seventh year of major construction. The \$5.4 billion project was let as a series of eight major contracts, which ranged in value from about \$50 million to more than \$1.4 billion. These contracts included (from Yerba Buena Island on the west end to Oakland on the east end) the Temporary Bypass, the Transition Structure, the W2 foundation, the self-anchored suspension span (SAS) structure, the E2/T1 foundations, the Skyway and the Oakland Touchdown.

Most of the contracts are now complete, and the bridge is on track to be fully open to traffic in 2013. Currently, the only ongoing projects are the Oakland Touchdown, the SAS, the Temporary Bypass and the Transition Structure. The majority of the bridge is concrete; however, the SAS consists of a 520-ft-tall steel tower and steel deck roadway.

The bridge is designated as a lifeline structure and is a vital emergency and economic link in the event that a massive seismic event were to occur in the earthquake-prone area. In line with this designation, the bridge was designed to withstand a

1,500-year seismic event and have a 150-year service life.

Various techniques are being used to achieve the planned service life. The large-diameter reinforced-concrete piles that extend through the saltwater are cast in a steel shell that is up to 3¾ in. thick. The majority of the water footings are essentially steel structures that are surrounded by and filled with high-performance concrete. Supplementary cementitious materials (slag cement or fly ash) were required and cementitious contents were generally specified to be 675 per cu yd or higher.

Limited engagements

Many of the placements are massive. The largest of the footings were the W2 footings that support the western end of the SAS structure. Each of these footings was approximately 66 x 66 x 33 ft and was placed in a single placement. The smaller footings also were quite large; the marine footings that support the skyway were 21 ft thick, and the footings of the transition structure on Yerba Buena Island were 5 to 17¾ ft thick. The irregularly shaped columns were up to 18 x 19½ ft in cross section. The E2 cap beam that supports the eastern end of the SAS structure is approximately 200 x 20 x 13 to 18 ft.

To achieve the desired service life, the vast majority of the cast-in-place concrete (including the piles) was deemed to be mass concrete, and a large emphasis was placed on getting the mass concrete right. There were five main requirements for the mass concrete.

First, to limit the potential for delayed ettringite formation, which could shorten the service life of the concrete, the maximum temperature in the concrete was limited to 149°F. This limit was purposely set 9°F lower than the industry-standard maximum temperature limit of 158°F for mass concrete, knowing that the contractors would want to get as close to the limit as possible (to minimize costs for precooling or internally cooling the concrete). This provided a factor of safety to avoid the potential issues that would result in the event that the contractor accidentally allowed the concrete to get a degree or two above the specified limit.

Second, the temperature difference was limited to prevent thermal cracking. Thermal cracking allows chlorides and other

corrosion-causing agents to rapidly access the reinforcing steel, which essentially eliminates the benefits provided by the low permeability of the high-performance concrete. A temperature-difference limit was not specified; however, the specifications stated that thermal cracking was to be prevented. The contractor was allowed to select an appropriate temperature-difference limit. In some cases, the industry standard limit of 35°F was selected. In most cases, however, a performance-based

temperature-difference limit was used. This type of temperature-difference limit specified the thermal stresses remained below the tensile strength of the concrete so that thermal cracking could be avoided.

Third, the temperature difference was limited from the time of placement through the time that the concrete had adequately cooled. This was done to prevent thermal shock (and cracking) of the concrete if the thermal-control measures were discontinued too soon. The specifications stated that the concrete was adequately cool when the hottest portion of the concrete had cooled to within the temperature-difference limit of the average air temperature. This established that the temperature difference could not become large enough to cause cracking of the concrete when thermal-control mea-

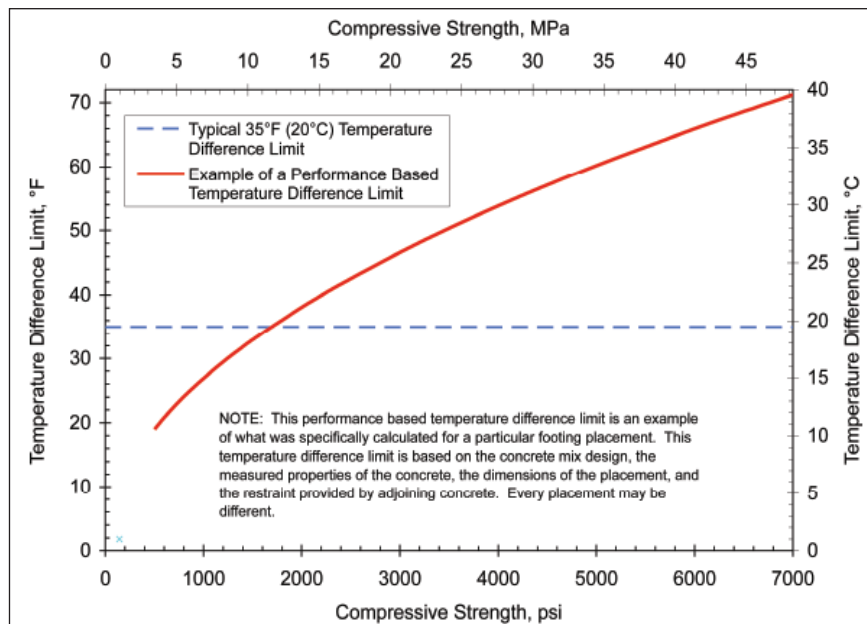
sures were discontinued. This specification requirement unintentionally encouraged the use of embedded cooling pipes to internally cool the concrete, so that thermal-control mea-

asures did not last for weeks.

Fourth, temperature sensors were required in every mass concrete placement. Temperature sensors were required near the center of the placement and at one or more locations near the exterior surface of the concrete. Some leeway was allowed in the actual locations of the temperature sensors; however, surface sensors were to be within 2 to 3 in. from the surface of the concrete and the center sensor had to be at

the hottest location in the concrete. When cooling pipes were installed, the center temperature sensor location was to be adjusted so that it was in the hottest portion of the concrete (equidistant between the cooling pipes, near the center of the placement but in the area with the largest cooling pipe spacing). Temperature data was to be downloaded, examined and provided to Caltrans daily. At the completion of thermal control

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for each placement, a summary report that compared temperature and temperature differences to the limits and to the thermal modeling was to be provided. If limits were exceeded, steps were to be taken so the same problems did not occur on a future placement. If the thermal modeling was completely inaccurate, the modeling was to be updated so that it could be used as a planning tool for the contractor.

Fifth, a detailed thermal-control plan was to be provided. The thermal-control plan was to be based on modeling of temperatures and temperature differences in the concrete placement. The thermal-control plan had to describe in detail the placement and concrete mix design; all aspects of the thermal modeling including assumptions and results; measures to control temperatures and temperature differences including installation and removal of the formwork and insulation; cooling pipe layout and operation; temperature sensor equipment, layout and operation; and specific corrective measures that would be followed to address excessive temperature or temperature differences if they should occur.

CTLGroup worked with a majority of the contractors involved in the project to develop their thermal-control plans and aided in the selection of the most appropriate and cost-effective means of thermal control. Since most of the placements were different, there was no "one-size-fits-all" approach. In all cases, the first step was to select an appropriate mass concrete mix design. In general, the appropriate mix design had the lowest temperature rise possible while still meeting the requirements of the specifications and the schedule. For some placements, the cementitious materials consisted of 40% Class F fly ash or 50% slag cement. In other cases, lower SCM dosages were selected. Many different concrete mix designs were used, including normal-weight concretes, lightweight concretes, high-strength concretes and self-consolidating concretes.

Depends on the performance

Based on the third mass concrete requirement, most contractors opted to use a performance-based temperature difference limit (PBTDL). The concept of PBTDL is based on information in ACI 207 documents, other literature and CTLGroup experience. In essence, a PBTDL provides a measurable limit so that the in-place thermal stresses can be controlled to not exceed the in-place tensile strength of the concrete surface. This allows the temperature-difference limit to be specifically tailored to the properties of the concrete and the geometry of the placement. A PBTDL can be used to minimize thermal cracking, to optimize thermal-control measures and to reduce potentially long construction times that are associated with mass concrete. To help reduce the time of construction, maturity or other means to estimate the in-place strength of the concrete are often used with a PBTDL. For many of the placements that have occurred to date on the bridge, especially those with cooling pipes, the use of the PBTDL allowed thermal control to be completed in less than one week. Had a 35°F temperature-difference limit been used, the time of thermal control would have been at least two to four times longer.



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When a PBTDL was used, concretes with low coefficients of thermal expansion were selected. For the early placements, this involved prescreening and pretesting aggregates from several sources. The mineralogy of the aggregate determines its coefficient of thermal expansion. In general, basalts and limestones have the lowest coefficient of thermal expansion. Granites also have a reasonably low coefficient of thermal expansion. Siliceous aggregates, such as cherts and quartzites, have the highest coefficient of thermal expansion. The cost effectiveness of the aggregate versus the benefit that it provided also was judged. In addition, since the PBTDL maps the temperature-difference limit to the in-place strength of the concrete, the concretes were designed to achieve a high strength-to-temperature-rise ratio. This generally involved optimizing air contents, minimizing water contents and achieving slump through the use of admixtures. Again, the cost effectiveness was weighed against the benefits and the benefits of other approaches to achieve the same results.

The mass concrete placements to date on this bridge have been challenging, as is the overall construction of this history-making structure. The strong emphasis on placing the mass concrete properly will contribute to the aim that the service life is not jeopardized during construction by excessive problems or shortcuts. The innovative mass concrete specifications allowed the desired goals to be achieved without excessive inflation in the schedule and costs. As with all projects, there have been some issues with higher-than-planned temperatures and temperature differences; however, the issues have been minor and were not repeated on multiple placements. ●

Gajda has been with CTLGroup, Skokie, Ill., for more than 16 years.

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