A SURVEY OF ASR IN PRECAST BRIDGES IN CALIFORNIA

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ABSTRACT

For decades, the California Department of Transportation (Caltrans) required the use of fly ash to reduce the deleterious effects of Alkali-Silica Reaction (ASR) in concrete. In consideration of possible reductions in early strength gain when using partial substitution of fly ash for cement and in recognition that the quality of precast concrete products such as bridge girders is generally superior to cast-in-place concrete, Caltrans rescinded the requirement for use of fly ash in precast concrete elements in 1999.

To evaluate whether eliminating fly ash was having detrimental effects on precast bridge girders, a study was conducted that comprised of 1) testing aggregate used in the production of precast bridge girders in California for potential ASR reactivity and 2) visual inspection of 120 bridges in California for evidence of ASR. The study found that a number of the aggregates tested had moderate levels of potential ASR reactivity and only a small percentage of the bridges had visual signs of ASR. Recommendations included re-instituting a requirement for fly ash and re-inspection of bridges in the future for ASR.

Keywords: Alkali-Silica Reaction, ASR, Fly ash, Aggregate testing, Petrographic examination, Visual inspection, Precast bridge girders, Caltrans

INTRODUCTION

The California Department of Transportation (Caltrans) for decades required the use of fly ash to reduce the deleterious effects of Alkali-Silica Reaction (ASR) in concrete. However, the precast concrete industry raised concerns regarding the potential for reductions in early strength gain characteristics of concrete when using partial substitution of fly ash for cement, relative to concrete without fly ash. These concerns stemmed primarily from the economic benefits of being able to fabricate precast concrete products on a daily basis; a process that is often highly dependent on the high-early strength gain capabilities of concrete. In consideration of this concern and in recognition that the quality of precast concrete products such as bridge girders is generally superior to cast-in-place concrete, Caltrans rescinded the requirement for use of fly ash in precast concrete elements in 1999.

Caltrans commissioned this study to evaluate whether their decision to not require use of fly ash in precast concrete products is still reasonable. Phase one of the study was comprised of sampling and testing of aggregate used in the production of precast bridge girders for potential ASR reactivity. Phase two of the study was comprised of visual inspection of 120 in-service bridges for evidence of ASR. This paper summarizes the findings and recommendations of this study.

SCOPE OF STUDY

The following tasks were performed:

1. Identify precast plants that produce precast concrete girders for Caltrans projects.
2. Sample coarse and fine aggregates that are used to produce precast girders from the precast plants.
3. Perform ASTM C1260, C1293, and C227 tests on the sampled aggregates to assess their potential for ASR.
4. Develop a list of up to 60 bridges with precast girders that were constructed since 1999.
5. Collect field data via visual surveys of the bridges identified in Item 4 as well as older bridges with precast girders. The visual surveys included photo documentation to enable comparison between conditions present at the time of these surveys and conditions observed in future surveys.
6. Develop a database of the collected field data for use in future evaluations.
7. Prepare a final report summarizing findings and recommendations.

AGGREGATES SAMPLED FROM PRECAST PLANTS

Caltrans provided a list of 14 precast plants that supply a variety of precast products on Caltrans projects. Each plant was contacted and asked if they produced precast concrete girders for Caltrans projects. Eight of these plants indicated that they do produce precast girders for Caltrans. **Error! Reference source not found.**All of these plants are located in California, except for one plant, which is located in Oregon. Coarse and fine aggregates were sampled from each plant. Most aggregate samples were collected from the plants' on-site aggregate stockpiles. In all, twenty-three aggregate samples were collected in 55-gallon drum containers and shipped to a laboratory for testing.

AGGREGATE EVALUATIONS

The twenty-three aggregate samples were comprised of fourteen coarse and nine fine aggregate samples. Each aggregate sample was tested to assess its potential susceptibility to alkali-silica reactivity. The following American Society for Testing and Materials (ASTM) tests were performed:

1. petrographic examinations according to ASTM C295[1], *Standard Guide for Petrographic Examination of Aggregates for Concrete;*
2. accelerated mortar bar tests according to ASTM C1260[2], *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method);*
3. concrete prism tests according to ASTM C1293[3], *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction;*
4. mortar bar tests according to ASTM C227[4], *Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)*.

BRIDGES SURVEYED

One hundred and twenty bridges located throughout California were visually inspected for evidence of ASR in their precast girders. Figure 1 shows the locations of the bridges surveyed. The year of construction of the bridges ranged from 1936 to 2005. Bridges constructed before 1999 were included in the survey to gain information about ASR distress in older precast girders. Figure 2 shows the distribution of the surveyed bridges by year of construction. The bridges varied in size from small, single-span bridges like the bridge shown in Figure 3 to multi-span, multi-lane bridges, like the bridge shown in Figure 4. Most of the precast girders in the bridges were “I” and bulb-T girders. Sixty-five bridges were on an original list of bridges to inspect. Fifty-five additional bridges were added to an “extended” list. Different symbols are used in Figure 1 for bridges on the original list and those on the extended list. The symbols are color-coded to represent the degree of possible ASR cracking observed in each bridge (none, light, moderate, severe).

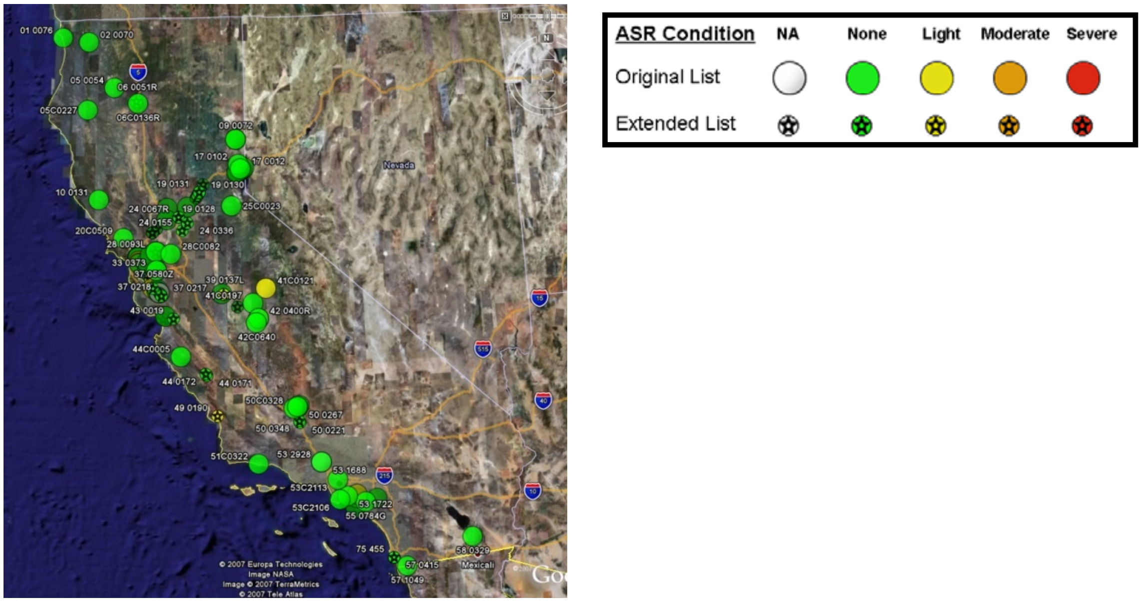

Figure 1. California map showing the 120 inspected bridges and ASR condition of each bridge.

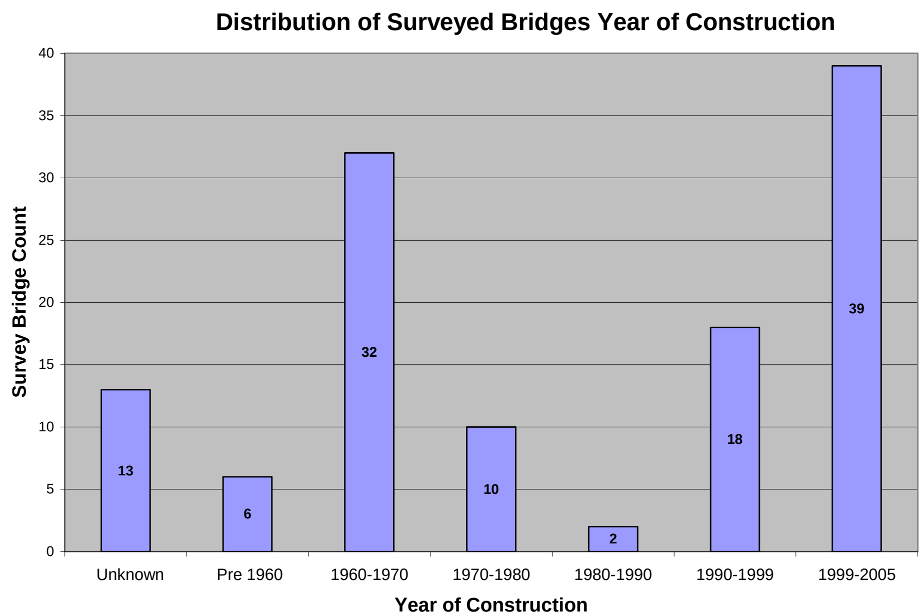

Figure 2. Surveyed bridges grouped by year of construction.

Figure 3. Small, single span bridge

Figure 4. Large, multi-span bridge

ALKALI-SILICA REACTION (ASR)

ASR was first identified as a deterioration mechanism in concrete by Stanton in 1940. Since then, much research and study has been conducted on the causes and the effects of ASR. ACI 221.1R-98[5], *Report on Alkali-Aggregate Reactivity*, summarizes available information on ASR. ASR is caused by the chemical reaction between hydroxyl ions in pore solution of concrete and reactive silica present in many aggregates. The reaction forms an alkali-silica gel, which can expand in the presence of sufficient moisture and cause cracking of the concrete matrix. Three conditions are required for ASR to occur: reactive aggregate, sufficient moisture, and sufficient alkali. The rate of the ASR reaction increases with increasing temperature.

Typical methods employed to reduce the potential for ASR include use of non-reactive aggregate, limiting the level of alkalis (alkali load) in concrete, and the addition of pozzolans, such as fly ash, to the concrete. Most of the available sources of Class F fly ashes have been shown to be effective in mitigating the potential for expansion due to ASR; however, addition of fly ash can also slow the strength gain of concrete, particularly early strength gain, potentially resulting in reduced production rates at precast plants. Prior to revising the Standard Special Provisions (SSP) Section 8-2, *Portland Cement Concrete* in 1999, Caltrans required pozzolans be added as a 15 to 25 % mass replacement of cementitious materials to all concrete, including concrete used for precast girders. The 1999 revision to the SSP removed this requirement for precast elements such as bridge girders.

PRIOR STUDIES OF PRECAST GIRDERS AFFECTED BY ASR

The Texas Department of Transportation (TxDOT) conducted studies of in-service bridges affected by ASR and Delayed Ettringite Formation (DEF). TxDOT Research Report 1857-1[6] (2000), *Bridges with Premature Concrete Deterioration: Field Observations and Large-Scale Testing*, presented the findings of these studies. The in-service bridges that were part of this study were constructed with precast concrete girders. In the Texas bridges, damage due to ASR and DEF typically occurred at the exterior faces of exterior girders or at locations, such as poorly sealed expansion joints, where the girders were exposed to rainwater. The damage typically consisted of horizontal cracking along the flanges and stems of the girders, as well as some map cracking of the exterior faces and soffits of the girders.

AGGREGATE COLLECTION

The aggregate sampling was conducted over a three-week period. The aggregates were typically kept in stockpiles surrounded by three walls. Each aggregate type was collected in 55-gallon steel drums. As much as practicable, sampling was performed in accordance with ASTM D 75 - 03[7], *Standard Practice for Sampling Aggregate*. Assistance from the plants' front-loaders was required to mix the aggregates. Twenty-three aggregate types were sampled. Table 1 shows the aggregate sizes sampled from the different plants.

Table 1. Aggregate Collection Summary

Plant	Fine	3/8”	1/2”	3/4”	1”	Total
Plant 1	2			2		4
Plant 2	1	1			1	3
Plant 3	1	1	1			3
Plant 4	1			1		2
Plant 5	1	1			1	3
Plant 6	1		1	1		3
Plant 7	1	1			1	3
Plant 8	1			1		2
Totals	**9**	**4**	**2**	**5**	**3**	**23**

MATERIAL EVALUATIONS

The objective of the material evaluations was to assess the potential susceptibility of the collected aggregate to alkali-silica reactivity. For this project, established ASTM tests were performed, which included petrographic examinations according to ASTM C295, accelerated mortar bar tests according to ASTM C1260, concrete prism tests according to ASTM C1293, and mortar bar tests according to ASTM C227. The following sections provide a summary description of the aggregate samples, test methodology, and test results.

SAMPLE DESCRIPTION

The twenty-three samples were comprised of fourteen coarse and nine fine aggregate samples, as previously described in the Aggregate Collection section. The identification and related information of the aggregates are given in Table 2.

Table 2. Identification of Aggregate Samples

ID	Company	Aggregate
1	Plant 6	3/4" Coarse
2	Plant 6	1/2" Coarse
3	Plant 6	Fine
4	Plant 1	3/4" Coarse
5	Plant 1	Fine Sand
6	Plant 1	3/4" Coarse
7	Plant 1	Fine
8	Plant 4	3/4" Coarse
9	Plant 4	Fine
10	Plant 8	Coarse
11	Plant 8	Fine
12	Plant 5	3/4" Coarse
13	Plant 5	3/8" Coarse
14	Plant 5	Fine
15	Plant 7	Fine
16	Plant 7	3/8" Coarse
17	Plant 3	3/8" Coarse
18	Plant 2	1/2" Coarse
19	Plant 2	Fine
20	Plant 2	3/8" Coarse
21	Plant 7	1" Coarse
22	Plant 3	Fine Sand
23	Plant 2	1" Coarse

TEST METHODS

ASTM C295 Test

The samples were first reduced to the appropriate test sizes using the guidelines of ASTM C702[8], *Standard Practice for Reducing Field Samples of Aggregate to Testing Size*. The representative portion of the samples was washed, dried, and sieved according to ASTM C117[9], *Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregate by Washing* and ASTM C136[10], *Standard Method for Sieve Analysis of Fine and Coarse Aggregates*.

For the actual petrographic examination of the aggregate according to ASTM C295, more than 150 particles on each gradation were petrographically examined, identified, classified, and counted, except for particles that passed the No. 16 sieve or the No. 100 sieve for the coarse and fine aggregate respectively, or when the total particles retained on a given gradation were less than 150. For particles passing the No. 16 sieve or the No. 100 sieve, the amounts of each mineral were estimated. When the total number of particles in a given gradation was less than 150, all particles were identified and counted. Freshly fractured surfaces were made for each particle, when necessary, and were examined under a stereomicroscope at magnifications up to 90X. Powder mounts of particles were prepared, as needed, and were examined using a petrographic microscope at magnifications up to 600X. Grain mount thin sections were fabricated and examined using a petrographic microscope for selected aggregate particles to better assess the compositions of the aggregate. Scanning electron microscopy (SEM) equipped with energy dispersive X-ray analyzer (EDX) was also used in a selected sample to determine the composition of surface coating on aggregate particles.

ASTM C1260 Test

The aggregates were washed, dried, crushed and re-graded according to ASTM C1260 gradation requirement. Three mortar bars were prepared for each aggregate using standard laboratory portland cement based on the mix design requirement of ASTM C1260, cured, and stored in 80ºC 1N NaOH solution. The length changes of the mortar bars were measured periodically up to the age of fourteen days (sixteen days from the age of casting).

Based on ASTM C33[11], *Standard Specification for Concrete Aggregates*, expansions less than 0.10 percent at sixteen days after casting are indicative of innocuous behavior in most cases; expansions of more than 0.20 percent at sixteen days are indicative of potentially deleterious expansion; expansions between 0.10 and 0.20 percent at sixteen days include both aggregates that are known to be innocuous and deleterious in field performance.

ASTM C1293 Test

The aggregates were washed, dried, crushed and re-graded when necessary according to ASTM C1293 requirement. Three concrete prisms were prepared for each aggregate using standard laboratory high alkali cement according to the mix design requirement of ASTM C1293, cured, and stored in 38ºC (100ºF) and 100 percent relative humidity containers. The length changes of the concrete prisms were measured at the age of one, two, and four weeks, and each month thereafter for up to twelve months.

The Na_2O equivalent of the cement (purchased from Lehigh Cement) used was 0.89 percent. NaOH was added to the mixing water to increase the Na_2O equivalent to 1.25 percent, by mass of cement, as required by ASTM C1293. When testing for the coarse aggregates, a standard laboratory non-reactive fine aggregate supplied by Del Mar (Waco, Texas) was used. The aggregate was natural calcareous sand with an average fourteen-day expansion of 0.001 percent via ASTM C1260 test. When testing the fine aggregates, a standard laboratory non-reactive coarse aggregate supplied by Alamo (Gandy, Texas) was used. The aggregate was crushed limestone with an average fourteen-day expansion of 0.009 percent via ASTM C1260 test.

After the test was complete, limited petrographic examination was conducted on selected concrete prisms. Abundant alkali-silica gel was detected in the prisms that exhibited expansion greater than 0.04 percent. For prisms with expansion less than 0.04 percent, no gel or only isolated gel was detected. The petrographic examination confirmed that the expansion observed in the concrete prisms was due to ASR.

Based on ASTM C33, aggregates with expansions equal to or greater than 0.04 percent at one year are considered potentially deleteriously reactive. ASTM C1293 is considered the most reliable procedure among ASTM test methods for evaluation of aggregates for ASR.

ASTM C227 Test

The aggregates were washed, dried, crushed and re-graded according to ASTM C227 gradation requirement. Four mortar bars were prepared, separately in two days, for each aggregate using standard laboratory high alkali portland cement based on the mix design requirement of ASTM C227, cured, and stored in 38ºC (100ºF) and 100 percent relative humidity containers. The length changes of the mortar bars were measured periodically up to twelve months.

ASTM C227 is a test designed to assess the potential reactivity of a cement and aggregate combination. When testing for aggregate’s general potential reactivity, the cement used should have a high alkali content. The cement used in the tests was a high alkali cement from Lehigh Cement with a Na_2O equivalent of 0.89 percent. No additional NaOH was added to the mix to further increase the alkali content of the cement.

Based on ASTM C33, while the boundary between innocuous and potentially reactive combination is not clearly defined, expansion is generally considered deleterious if it exceeds 0.05 percent at three months or 0.10 percent at six months.

TEST RESULTS

The results of the laboratory evaluations are summarized in Table 3 and Table 4, for the coarse and fine aggregates, respectively. Based on the evaluations of the 14 coarse aggregate samples, five samples are considered "potentially reactive," meaning that C1293 testing indicated the aggregate to be potentially reactive, but C295, C227, and C1260 may or may not have indicated the aggregate to be potentially reactive. Two samples are considered "possibly reactive," meaning that C295 and C1260 indicated the aggregate to be potentially reactive, but C1293 indicated the aggregate to not be potentially reactive. Seven samples are considered "innocuous," meaning that in all cases but one, none of the tests indicated the aggregate to be potentially reactive. The one exception, aggregate sample No. 12, was potentially reactive via C295 and C1260, but was not potentially reactive via C1293.

Table 3. Results of Laboratory Evaluations of Coarse Aggregate

ID	Gradation (ASTM C33)	Petrographic Examination (ASTM C295)	Expansion at the age indicated (%)			ASR potential
			C1260 (14 days)	C1293 (one year)	C227 (one year)	
1	N/A	Potentially reactive	0.433	0.044	0.005	Potentially reactive
2	No. 7	Potentially reactive	0.445	0.047	0.001	Potentially reactive
4	No. 57	Innocuous	0.015	0.012	0.005	Innocuous
6	No. 56 and No. 57	Potentially reactive	0.302	0.040	0.004	Potentially reactive
8	No. 57	Innocuous	0.076	0.006	0.000	Innocuous
10	No. 7	Innocuous	0.076	0.019	0.009	Innocuous
12	No. 57	Potentially reactive	0.274	0.026	0.005	Innocuous
13	No. 8	Potentially reactive	0.174	0.045	0.012	Potentially reactive
16	No. 8	Innocuous	0.045	0.005	0.008	Innocuous
17	N/A	Potentially reactive	0.388	0.030	0.004	Possibly reactive
18	No. 7	Potentially reactive	0.384	0.025	0.011	Possibly reactive
20	No. 89	Potentially reactive	0.096	0.042	0.009	Potentially reactive
21	No. 57	Innocuous	0.037	0.018	0.007	Innocuous
23	No. 56	Innocuous	0.160	0.015	0.003	Innocuous

ID	Gradation (ASTM C33)	Petrographic Examination (ASTM C295)	Expansion at the age indicated (%)			ASR potential
			C1260 (14 days)	C1293 (one year)	C227 (one year)	

The results for the fine aggregate shown in Table 4 revealed three out of nine samples as being potentially reactive and the remaining six samples as being innocuous. Two of the samples considered as "innocuous" were potentially reactive via C295 and C1260, but were not potentially reactive via C1293.

Table 4. Results of Laboratory Evaluations of Fine Aggregates

ID	Gradation (ASTM C33)	C295 Results	Expansion at the age indicated (%)			ASR Potential
			C1260 (14 days)	C1293 (one year)	C227 (one year)	
3	Not consistent	Potentially reactive	0.655	0.056	0.017	Potentially reactive
5	Consistent	Potentially reactive	0.260	0.041	0.001	Potentially reactive
7	Consistent	Potentially reactive	0.284	0.046	0.028	Potentially reactive
9	Consistent	Potentially reactive	0.394	0.026	0.013	Innocuous
11	Consistent	Innocuous	0.124	0.006	0.000	Innocuous
14	Consistent	Potentially reactive	0.286	0.029	0.013	Innocuous
15	Not consistent	Potentially reactive	0.119	0.015	0.005	Innocuous
19	Consistent	Innocuous	0.147	0.022	0.017	Innocuous
22	Consistent	Innocuous	0.204	0.018	0.031	Innocuous

FIELD SURVEYS

BRIDGES SURVEYED

List of Bridges Provided by Caltrans

A list of bridges with precast girders was provided from the Caltrans database. The list contained 54 bridges that were built between 1997 and 2005. The majority of the 54 bridges had precast "I" or bulb-T girders, but one had cast-in-place cable suspended girders.

A second more extensive list containing about 400 bridges was provided, but only a few of those bridges were built with precast girders and were built after 1999. Nonetheless, a number of them were selected, in coordination with Caltrans, to complement the original list and provide additional potential bridges for ASR inspection bringing the total size of the bridge list to 65.

Surveyed Bridges

A total of 120 bridges were surveyed. In addition to the 65 bridges that were on the Caltrans list, another 55 bridges were added to an "extended" list and surveyed for ASR distress. The additional bridges were generally selected to reduce the required travel effort to perform the additional surveys. Some of the bridges had ASR cracking in cast-in-place elements such as columns and abutments but not in the precast girders. The observation of ASR distress was noted, but those bridges were not included in the list of bridges considered to have ASR distress in their precast girders.

METHODOLOGY

The field surveys consisted of visual inspection, primarily of the precast bridge girders, for signs of ASR. Signs of ASR included pattern or map cracking, displacement or movement due to expansion, or exudation of ASR gel. Binoculars or spotting scopes were used to supplement the inspections. The inspections focused typically on the condition of the exterior girders and on girders in locations that were subject to water, such as at poorly sealed deck joints. Photographs were taken to document the conditions observed. Overall and close-up photographs were taken. The photographs were taken relatively systematically, so that in future inspections, the same locations could be more readily re-photographed for comparison purposes. For each bridge, photos were typically taken of the following elements or locations:

1. overall of each elevation
2. end of exterior girders at the abutments
3. exterior face of exterior girders at each support and each mid-span location
4. soffit of deck
5. areas where potential indications of ASR distress were observed
6. notable conditions

The photo locations as well as some field observations were noted on a plan sketch of the bridge. All photos and field observations were recorded in the electronic reports. Caltrans nomenclature was used to designate the abutment, pier, and girder numbers on the plan sketch. All comments on observed conditions refer to the element numbers on the plan sketch. A GPS reading was typically recorded at one abutment location of a bridge.

Data Collection and Reporting System

To provide an effective method of entering, analyzing, and reporting data for the large number of bridges to be surveyed, an electronic data entry system for field data collection was developed.

The main objectives of the data collection system were:

1. Easy entry of information in the field.
2. Entry of photo information and linking of photos to specific data.
3. Mapping of bridge locations:
4. For planning bridge surveys, route planning, etc.
5. For presentation of survey results, and linking to photos and reports.
6. Ability to add future surveys to system.
7. Complete, generate and check survey reports in the field:
8. Virtually eliminate collection of field data on paper.
9. No need to retype collected information later in the office.
10. Ability to edit and re-generate reports later if needed.
11. Easily print formatted reports.
12. Perform analysis on the database survey data and generate summary reports.

The completed system is illustrated in Figure 5 and includes four main components:

1. Field data collection using a Tablet PC, digital camera and other field equipment.
2. A database system for storing collected information and other available bridge information.
3. A mapping application for summary data presentation and for planning purposes.
4. Electronically generated reports for presenting the collected survey data in a uniform format.

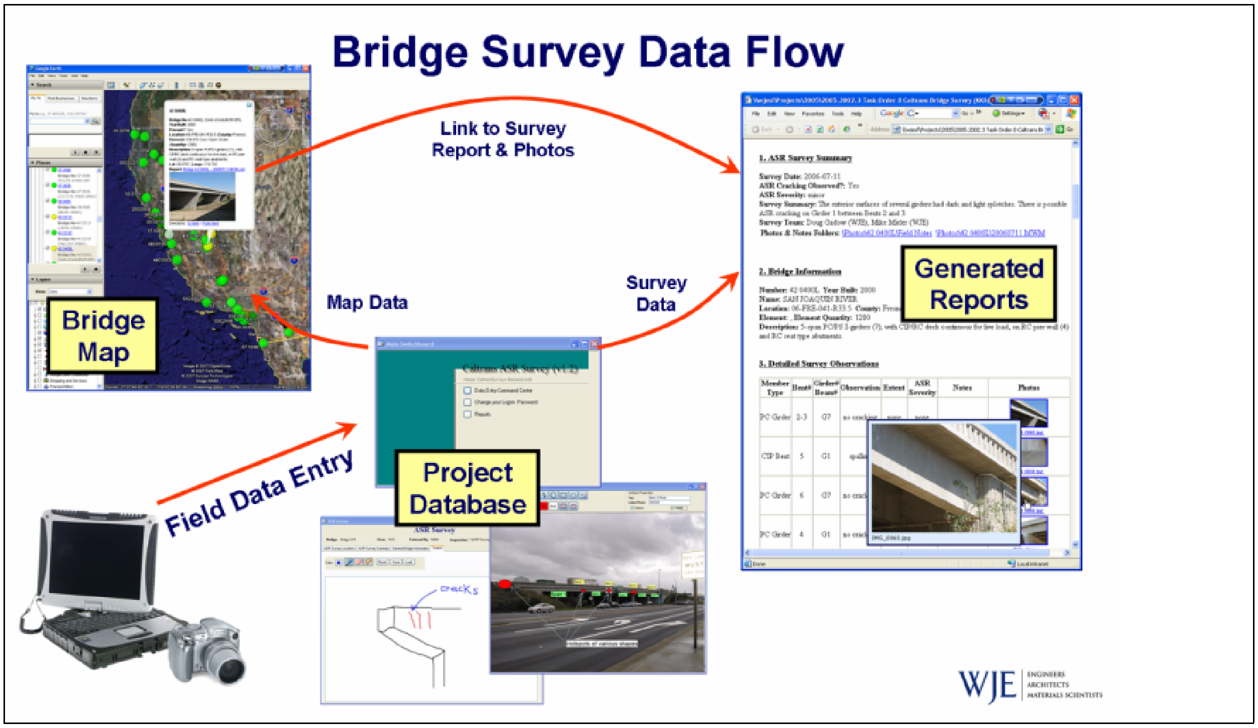

Figure 5. Diagram showing the flow of data from field data collection to report generation.

RESULTS

One hundred and twenty bridges located throughout California were visually inspected for signs of ASR distress in their precast girders. The field surveys were conducted over a three-month period, from 21 May to 23 August 2006. Fifteen of the 120 (13%) bridges were identified as having possible ASR distress in their precast girders. For all 15 of these bridges, the observed ASR distress in the precast girders was characterized overall as minor and was observed typically at isolated locations at the exterior face of an exterior girder. At the isolated locations with possible ASR cracking, the degree of ASR cracking ranged from minor to moderate. Two of the 15 bridges were constructed after 1999. Figure 6 and Figure 7 show the distribution of ASR occurrence in the surveyed bridges according to year of construction and county. Photos of precast girders showing possible ASR distress are provided in Figure 8 and Figure 9.

During the field surveys, ten bridges were identified as having ASR distress in areas such as abutment walls and bents although these elements were not surveyed as thoroughly as the girders. A number of the bridges had cast-in-place elements with moderate levels of ASR cracking. At one bridge, the moderate level of ASR cracking was widespread and occurred on all of the rain-exposed surfaces of the cast-in-place girders and anchorage blocks as shown in Figure 10 and Figure 11.

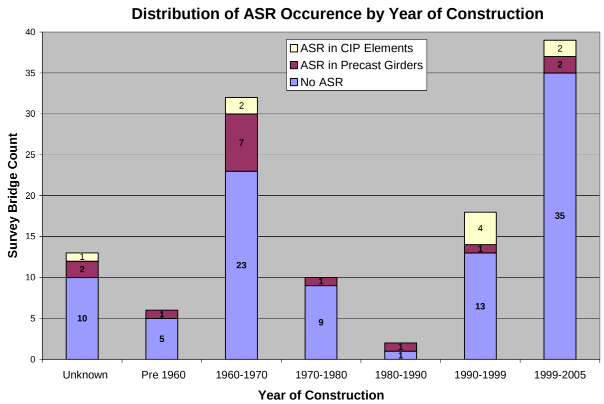

Figure 6. ASR occurrence in the surveyed bridges by year of construction.

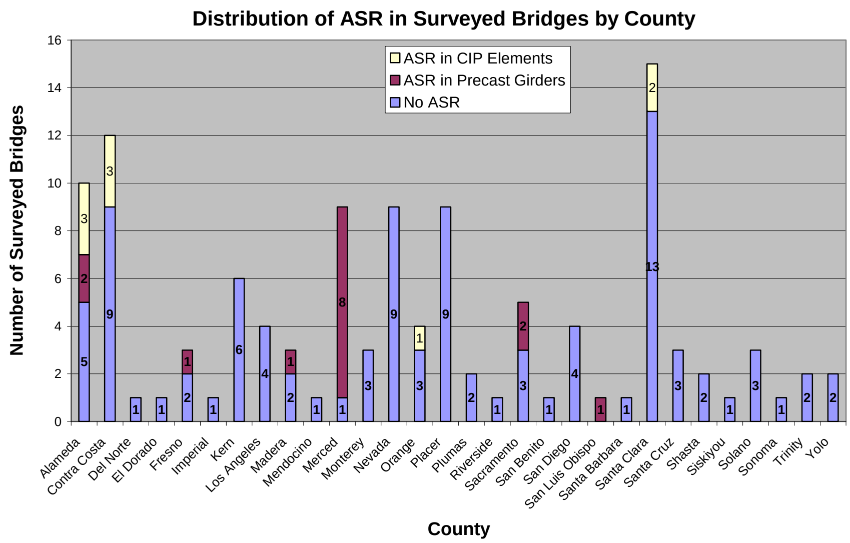

Figure 7. ASR occurrence in the surveyed bridges by county.

Figure 8. Cracking at girder end


Figure 9. Cracking at bottom of girder


Figure 10. Cracking in CIP girder


Figure 11. Cracking in CIP anchorage

EVALUATION

Very few (13%) of the 120 bridges surveyed had signs of possible ASR distress in their precast girders and in those 15 bridges, the distress was characterized as minor. As for bridges constructed in 1999 or later, only two of the 39 bridges (5%) had possible ASR distress. At this time, the precast girders constructed in 1999 or later are performing well. However, since ASR distress takes a number of years to develop and since the bridges constructed in 1999 or later had at most been in service for seven years at the time of these inspections, these bridges should be re-inspected for ASR distress in the future to evaluate the long-term performance of their precast girders.

CONCLUSIONS

The purpose of this study was evaluate if the 1999 Caltrans decision to no longer require fly ash or other supplemental additives in precast bridge girders has resulted in ASR distress in precast girders constructed since 1999. Phase one of the study was comprised of sampling and testing of aggregate used in the production of precast bridge girders for potential ASR reactivity using ASTM test methods C295, C1260, C1293, and C227. The aggregate testing included twenty-three aggregate samples, consisting of 14 coarse and nine fine aggregate samples, collected from eight precast plants that currently supply precast girders on Caltrans projects. Phase two of the study was comprised of visual inspection of 120 in-service bridges for evidence of ASR to identify evidence of potential ASR distress in the precast concrete girders.

Because ASR distress can take years to develop, it is difficult to definitively assess, at this time, whether the decision to no longer require fly ash or other supplemental additives to mitigate ASR has resulted in an increase of ASR distress in precast girders. However, based on the aggregate testing and the field surveys of bridges, the following conclusions have been developed:

1. Ten aggregate samples are deemed to be potentially reactive, depending on the method of evaluation, and thirteen samples are deemed innocuous. As described in the Materials Evaluation section, results of the C295 and C1293 methods were more heavily weighted in the characterization of the aggregate’s potential reactivity than the C1260 and C227 methods.

2. Fifteen (13%) of the 120 bridges surveyed had signs of possible ASR distress in their precast girders, with all ASR distress observed characterized overall as minor.

3. Two of the 39 bridges (5%) constructed since 1999 exhibited possible ASR distress, in the form of cracking, in the precast girders.

4. Ten of the 120 bridges surveyed exhibited evidence of possible ASR distress in elements other than precast girders, such as non-precast girders, abutment walls and bents.

5. The data collection system and database developed for all 120 bridges establishes a baseline condition for each bridge that can be used to facilitate future ASR surveys.

DISCUSSION/RECOMMENDATIONS

One of the primary tasks of the study was to recommend, in consideration of the inventory of aggregates known to be used for fabrication of precast girders, changes to Caltrans' specifications that may be warranted to appropriately mitigate the potential for ASR in precast bridge girders. Since it is relatively early in the life of bridges constructed since 1999 to accurately gauge the long-term performance of the precast girders with respect to ASR distress, reliance on the results of the visual bridge surveys alone for assessing the appropriateness of the current specification requirements would be misleading. However, considering the findings of the visual observations, comprehensive aggregate evaluations, and findings from other known investigations related to ASR in structural bridge elements, it is our opinion that the current specification requirements are not providing sufficient protection against ASR in precast bridge girders.

Based on a literature review of States' Departments of Transportation (DOT) specifications performed under another study for Caltrans, as well as our experience with other DOTs, it is a commonly held belief by the DOTs that the quality of concrete used in precast girders is generally better than cast-in-place concrete and often significantly exceeds the design requirements. This is due in part to the controlled environment typically afforded in precast plants and because of the relatively high release-of-tension compressive strength requirements for precast girder concrete; attainment of the specified release strength early enough to allow for turning of the casting beds on a daily basis, generally requires over-designing the concrete mix relative to the 28-day design strength. This practice frequently results in actual 28-day strengths that well-exceed design strength requirements, and the "surplus" strength is often correlated to increased durability.

While the potential durability benefit of having a more dense concrete matrix afforded by uniform mixing, good consolidation, and high strength concrete is recognized, such characteristics do not necessarily reduce the potential for ASR. For example, highly cementitious mixes result in a relative increase in the total alkali load of the concrete, which can serve to significantly increase the potential for ASR, even when using "low" alkali cement. In fact, years of investigations and continuing research by TxDOT since the mid 1990's have clearly demonstrated that precast concrete girders fabricated with reactive aggregate are susceptible to distress caused by ASR (TxDOT Research Report 1857-1[6]).

The testing performed on the twenty-three coarse and fine aggregate samples obtained from precast plants essentially indicated that ten of the samples are potentially reactive, depending on the method of evaluation. Eight of the ten samples exhibited expansions, via C1293, that classify the aggregate as potentially reactive. C1293 is recognized by the industry as being the most reliable method for assessing performance of aggregate in concrete relative to potential ASR. Based on these findings, potentially reactive aggregate is presently used in the fabrication of precast bridge girders in California.

Considering the above information, the conditions required for development of ASR in bridge girders exist. Based on the present specification requirements, the only protection against ASR is the required use of low alkali cement. However, as previously discussed, use of low alkali cement alone does not necessarily ensure against ASR as the potential for ASR varies by both the total alkali load and the reactivity of the aggregate. In other words, a highly reactive aggregate may cause expansion even in a low alkali cement environment, and low alkali cement, in sufficient quantity, can result in an overall high alkali load. In conclusion, potentially reactive aggregate and concrete mixes with high cement factors are both potential detrimental factors in the fabrication of bridge girders in California.

Based on the above findings, the following recommendations have been developed:

1. Future surveys of the bridges contained in the database should be made on a periodic basis to assess the progression of previously documented distress conditions and to identify new distress. This is particularly important for the bridges constructed post-1999 so that the potential and rate of distress can be better evaluated and quantified.

2. Core samples should be removed from bridge girders identified with possible evidence of ASR and should be petrographically tested using ASTM C856.

3. For aggregate known to be non-reactive as determined by accepted testing methods and/or field experience, required use of mitigating measures for ASR such as fly ash is not warranted.

4. For aggregate known to be potentially reactive and to be exposed to an alkali load sufficiently high to cause ASR, mitigation measures should be employed. This requires assessing the potential reactivity of the aggregate and calculating the total alkali load of the concrete.

5. If the potential for reactivity of the aggregate is unknown, mitigating measures should be employed unless the total alkali load is low enough that ASR is not likely to occur.

REFERENCES

1. ASTM C295, "Standard Guide for Petrographic Examination of Aggregates for Concrete," V.04.02
2. ASTM C1260, "Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)," V.04.02
3. ASTM C1293, "Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction," V.04.02
4. ASTM C227, "Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)," V.04.02
5. ACI 221.1R-98, "Report on Alkali-Aggregate Reactivity"
6. TxDOT Research Report 1857-1 (2000), "Bridges with Premature Concrete Deterioration: Field Observations and Large-Scale Testing"
7. ASTM D 75, "Standard Practice for Sampling Aggregate," V.04.02
8. ASTM C702, "Standard Practice for Reducing Field Samples of Aggregate to Testing Size," V.04.02
9. ASTM C117, "Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregate by Washing,", V.04.02
10. ASTM C136, "Standard Method for Sieve Analysis of Fine and Coarse Aggregates," V.04.02
11. ASTM C33, "Standard Specification for Concrete Aggregates," V.04.02