0-4085-P3

DATABASE FOR PREMATURE CONCRETE DETERIORATION

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Project 0-4085: Preventing Alkali-Silica Reaction and Delayed Ettringite Formation in New Concrete

AUGUST 2004

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Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.	

Preventing Alkali-Silica Reaction and Delayed Ettringite Formation in New Concrete

Database for Premature Concrete Deterioration

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INTRODUCTION

This product is intended to provide guidance to the Texas Department of Transportation (TxDOT) on the type of data that should be collected for new concrete structures and pavements. The information provided herein is based on research performed under TxDOT Project 0-4085, “Preventing Alkali-Silica Reaction and Delayed Ettringite Formation in New Concrete,” a 4 ½-year project, which was completed in August 2004 (see final project report for more detailed information). Since this research projected started in 1999, much progress has been made in better understanding the mechanisms behind alkali-silica reaction (ASR) and delayed ettringite formation (DEF), and guidelines have been developed related to appropriate test methods and specifications. Several of the main findings from TxDOT Project 0-4085 have already been implemented by TxDOT in the form of improved test methods and specifications for ASR and DEF.

The product included herein is aimed at further implementing the key research findings from this project, specifically to collect data and information on concrete mixtures used in new bridges, pavements, and other transportation structures. This product presents the architecture for a database to collect relevant information on materials and mixture proportions used in new concrete. The specific information sought is described herein, along with its importance in regards to ASR and/or DEF. Since the beginning of TxDOT Project 0-4085, TxDOT has been active in developing and populating various materials- and structures-specific databases for both new concrete and existing concrete structures. Because of these ongoing database-related efforts within TxDOT, parallel (and potentially redundant) efforts under TxDOT Project 0-4085 were intentionally limited. However, during the course of the research project, significant information and data on the performance of local Texas materials were generated and collected based primarily on laboratory testing and exposure site performance. Through these efforts, as well as the evaluation of several field structures under TxDOT Project 0-4085 (referred to as TxDOT 4085 for the remainder of this document, for conciseness), the research team has identified what material-related parameters should be collected and evaluated to assure that the long-term durability of TxDOT structures is being realized.

Following are brief discussions on the data that should be collected for the Premature Concrete Deterioration Database (PCDD), with emphasis on the importance of each parameter (e.g., cement chemistry, cement content, etc.) on ASR and/or DEF. After discussing each of the various material and mixture proportion parameters impacting ASR and/or DEF, an overall summary of the key parameters is provided. This synopsis of key parameters is provided in a simple, tabular form in this deliverable, which could then be extracted and integrated into the relevant, active TxDOT databases (e.g., Site Manager).

DATA ESSENTIAL FOR PREMATURE CONCRETE DETERIORATION DATABASE (PCDD)

Below are discussions on the key information and data that should be collected for new concrete used in TxDOT pavements and structures. Some of this information is already commonly collected and stored in TxDOT databases, whereas other information is not currently being sought. The rationale behind the importance of each parameter is briefly discussed, with specific ties to how they may impact ASR and/or DEF.

Material Information

Portland Cement

The chemical and physical properties of portland cement play important roles in both ASR and DEF, and as such, certain key cement-related parameters should be collected as part of the

PCDD. The following cement-related information or parameters should be included in the PCDD:

Type: The type of portland cement (e.g., as per the American Society for Testing and Materials ASTM C 150, ASTM C 1157, etc.) should be collected, along with its designation (e.g., Type I, Type II, etc.). This information is essential for various reasons. The type of cement will reflect the chemical and physical nature of the cement (although specific inputs for key parameters are sought separately, as discussed later); for example, Type II cement has a C_3A content less than 9 percent, and Type V cement has a C_3A content less than 5 percent. The C_3A content has a significant impact on heat development, and thus DEF, and it also directly influences the amount of calcium sulfoaluminate hydrates (monosulfate hydrate or ettringite) that may form in the hydrated cement paste, which are the hydrates that most impact DEF. Research under TxDOT 4085 has shown that Type III cements, with inherently higher C_3A contents and Blaine fineness values, are most prone to DEF, whereas Type V cements are essentially immune to DEF, even if high temperatures are reached during curing. The type of portland cement is also quite relevant to sulfate specifications, and the concern regarding external sulfate attack has increased in recent years. If a blended cement (IP or IS) or a cement based on performance specification (ASTM C 1157) is used, the types of portland cement and fly ash or slag should be identified, as well as the relative proportion of each.

Source: The specific source of cement used in TxDOT applications should be collected, including the plant where the cement was produced and the date of production and delivery. Tracking the source of cements is essential, especially as cement shortages have prompted the increased import of overseas sources.

Chemical Composition: Although there are ranges of different oxides and compounds in portland cement that impact ASR and DEF, one must be pragmatic in requesting and collecting only the most important characteristics; otherwise, the PCDD would be too much of a burden for contractors, materials suppliers, and TxDOT engineers. It is anticipated that this information would be obtained from mill sheets from the given cement plant. A note of caution: reliance on these mill sheets can be problematic as they often represent running or monthly averages.

Further, when considering the information contained on a mill sheet, it should be noted that the amount of each cement compound (C_3A, C_4AF, C_3S, C_2S) is based on rough estimates from Bogue's equations, which are now known to be inaccurate in many cases, especially when estimating the amount of C_3A in a given cement. Regardless of these challenges and deficiencies in cement chemistry data, namely the relevance and accuracy of the mill sheets, this data is essentially all that is available for a given cement for a given job. The most critical information that should be collected includes:

- ***Alkali Content*** – the alkali content of portland cement, expressed as Na_2O_e or equivalent alkali content, has a major impact on both ASR and DEF. The effect of alkali content on ASR is fairly intuitive—for a given mixture and cement content, higher alkali contents increase the likelihood of ASR by increasing the pore solution pH, increasing the solubility of reactive silica, and increasing overall reactivity of the system. As discussed later, the Na_2O_e of a given portland cement is not, in and of itself, an accurate indicator of ASR potential, but rather it is the total alkali loading of the concrete mixture (alkali content of the cement multiplied by the cement content, expressed in lbs/yd^3) that ultimately governs ASR potential. Conventional wisdom, prior to around 10 years ago, was that simply specifying a low-alkali cement (Na_2O_e less than 0.6 percent) would ensure durability, but it is now widely understood that it is the overall alkali loading of the concrete mixture that actually influences durability. TxDOT has already recognized this fact and has based its ASR specification on limiting the alkali loading of plain concrete to 4 lbs/yd^3, regardless of the alkali content of the cement. As discussed later, this prescriptive limit on total alkali loading for plain concrete is generally effective in curbing ASR, but the results of TxDOT 4085 clearly show that some aggregates (e.g., Jobe-Newman from El Paso) suffer excessive expansion and cracking at alkali loading below this limit. It is thus imperative that the PCDD addresses this concern by tracking mixtures that have been designed based on Option 1 of the original Special Item 421, which prescribed this 4 lbs/yd^3 limit for plain concrete. Confirming the presence of additional aggregates that react below this alkali threshold through this

PCDD will strengthen the case for either eliminating this prescriptive option or lowering the alkali threshold to a more conservative value (e.g., 3.0 to 3.5 lbs/yd^3).

The effects of cement alkalinity on DEF are also quite important, although not quite as obvious. In general, higher cement alkali values tend to exacerbate DEF. First of all, higher alkali cements tend to solubilize certain cement compounds (and gypsum), thereby increasing the rate and heat of hydration of portland cement. This results in a rapid formation of calcium silicate hydrates (C-S-H), and the resultant higher temperatures, if they exceed about 160 ^{o}F, can lead to the incongruous dissolution of ettringite, with the liberated aluminates and sulfates becoming *trapped* in the rapidly forming C-S-H. This process sows the seeds for subsequent DEF, where ultimately the sulfates and aluminates are released by the C-S-H, react with monosulfate hydrate, and form ettringite, which can expand and crack the concrete. Thus, higher alkali cements, through their role in early hydration, play a key role in DEF.

The two paragraphs above describe separately how cement alkalinity can lead to ASR or DEF. In reality, most cases of DEF are actually found in combination with ASR, where ASR occurs first, thus dropping pore solution pH (through the inclusion of sodium and potassium in the ASR gel) and triggering the release of sulfates and aluminates from C-S-H. This *one-two punch* is greatly exacerbated by high-alkali cements, as the potential for both durability problems is locked in at early ages. Prior to TxDOT 4085, little was known about the interactions between ASR and DEF and their interdependence on certain material properties, such as cement alkalinity. Further, limited emphasis was placed on trying to delineate the causes of ASR, DEF, or combinations thereof; however, through the research performed under TxDOT 4085, the underlying mechanisms of distress are now much more clearly understood, making it possible to clearly identify which parameters most impact PCD and which ones should be included in the PCDD.

- ***C_3A Content*** – The C_3A content of portland cement has a major impact on DEF for two main reasons. First, C_3A contributes the most heat of any of the main cement compounds, and thus, the higher the C_3A content of the cement, the more heat that will be produced, thereby increasing the likelihood that the temperature threshold for DEF will be exceeded. Second, the more C_3A in the cement, the higher the proportion of calcium sulfoaluminate hydrates (monosulfate or ettringite) in the hydrated cement paste. In a nutshell, more C_3A means more *fuel for the fire* for DEF, as well as external sulfate attack.

- ***Sulfate Content*** – The sulfate content of portland cement represents the total of sulfates present in the clinker, plus the amount of sulfate added in the form of gypsum (or hemi-hydrate). It is primarily important for DEF, where the sulfates ultimately react to form either monosulfate hydrate or ettringite. It has been proposed over the years that *over-sulfated* cements may lead to DEF, even if temperatures do not exceed 160 ^oF, the so-called “ambient temperature DEF theory.” However, this theory has now been dispelled, and it is now clear that even cements with excessive sulfate contents will not cause DEF unless the concrete undergoes a high temperature excursion during curing. Nevertheless, given the direct impact of sulfate content on the amount of monosulfate hydrate or ettringite that can form, and given that sulfates are trapped in rapidly-forming C-S-H during the early hydration stage, later to be released to trigger DEF, it is prudent to include this parameter in the PCDD.

Physical Properties: In addition to the chemical characteristics described above, the physical characteristics of portland cement can play an important role, primarily in DEF. The important physical characteristics of cement and physical properties of paste/mortar made from the subject cement that should be collected in the PCDD include the following:

- ***Fineness*** – The fineness of portland cement, expressed as a Blaine surface area (m^2/kg), has a significant effect on early strength gain and heat of hydration, and thus it can play a key role in DEF. For a given cement, the higher the Blaine value, the more heat will be produced in the early stages. Generally, Type III cements, which exhibit the highest Blaine values, are used for precast operations or occasionally for rapid repair applications. Cements with higher Blaine values will generally have a higher sulfate content, as the added sulfate (e.g., gypsum) is needed to slow down the early hydration and to meet the requirements for optimal sulfate content under ASTM C 150.

- ***Compressive Strength*** – All cements produced according to ASTM C 150 are tested for compressive strength by measuring the compressive strength of 2” x 2” mortar cubes cast using the subject cement, in combination with standard Ottawa sand (as per ASTM C 109). These strength values appear on the cement mill sheets for various test ages. Based on work performed under TxDOT 4085 and collaborations with Dr. Michael Thomas (University of New Brunswick), cements that exhibit 1-day compressive strengths (under ASTM C 109) greater than about 3000 psi are most prone to DEF, as these cements typically possess some combination of the following properties: higher C_3A contents, higher alkali contents, and higher Blaine fineness values. Thus, by tracking the 1-day compressive strengths of cements used in Texas in the PCDD, valuable information can be collected on a parameter that tends to be a good, general indicator of DEF susceptibility.

Supplementary Cementing Materials (SCMs)

The state of Texas has been a national leader for many years in the use of SCMs in concrete pavements and structures. Below are discussions on the data and information that should be collected and stored in the PCDD for fly ashes and other SCMs, such as slag and silica fume, with specific reference to how these key parameters impact ASR and/or DEF. With the trend towards ternary blends (two SCMs plus cement) or even quarternary blends (three SCMs plus cement) in North America, it should be noted here that the information and data described below for individual SCMs should be collected for any and all SCMs used in a given mixture. The information sought for SCMs, as described next, deals only with the inherent characteristics of the SCMs and not the dosages used in a given mixture; information on dosages of SCMs is sought separately, as described later in this document (under *Mixture Proportions*).

Fly Ash

The use of fly ash—both ASTM C 618 Class F and ASTM C 618 Class C fly ash—has been prevalent in Texas for many years. In recent years, there has been a general trend towards the use of Class F fly ash, rather than Class C fly ash, for suppressing ASR, as it has been shown under TxDOT 4085 and in a range of other studies, including internal TxDOT research, that Class F fly ash is more effective than Class C fly ash in suppressing ASR. Class C fly ash can still be used effectively to suppress ASR, but generally higher dosages are needed, when compared to Class F fly ash. For some highly-reactive aggregates, dosages in excess of 35 to 40 percent (by mass replacement of cement) are needed for Class C fly ash, which sometimes makes it less feasible from a constructibility point of view (e.g., low early strengths) or from a specification compliance point of view (note TxDOT does not generally allow more than 35 percent fly ash in structural/pavement concrete). Research under TxDOT 4085 has shed light on the mechanisms responsible for the reduced efficiency of Class C fly ash, with significant data from accelerated laboratory tests and outdoor exposure blocks. Capturing data from field structures through the PCDD will help strengthen the understanding of how fly ash controls ASR and/or DEF in field structures, and this field experience can be linked to the laboratory data generated under TxDOT 4085. The following are the most important information and data that should be collected for fly ashes in the PCDD:

Type: In the United States, fly ashes are classified using ASTM C 618 based on the sum of the oxides SiO_2 + Al_2O_3 + Fe_2O_3, with no specific reference to CaO content. However, if one examines closely the ASTM C 618 classification scheme and calculates how the CaO content fits in with the aforementioned oxide summation, it ends up that the approximate cut-off point between a Class F fly ash and a Class C fly ash can be found at a CaO content of 20 percent; thus, fly ashes with CaO contents less than 20 percent can be considered to be Class F fly ashes, and those with CaO contents above 20 percent are Class C fly ashes. As described in the TxDOT

4085 final report, this cut-off point is quite convenient when one considers the effects of CaO content on the ability to control ASR-induced expansion. Somewhere between about 20 and 22 percent CaO, there is a marked change in behavior of fly ashes, with a significant decrease in fly ash efficiency as this threshold range is crossed. It is generally observed that as the CaO content increases above this range, more fly ash is needed to control expansion. For example, only 20 percent (mass replacement of cement) of a low-calcium fly ash (CaO = 10-15 percent) might be needed to control expansion for a given highly-reactive fly ash, whereas an excess of 35 percent of a high-calcium fly ash (CaO = 25-30 percent) would be needed to control expansion for the same aggregate. Collecting data on the fly ash type (F versus C) is a convenient and simple method of tracking behavior of these two classes of fly ash that tend to differ significantly in their ability to control ASR. As described next, specific values of CaO for fly ash will be sought separately to develop a more quantitative link between CaO content and ASR suppression. This information will also be helpful when considering DEF, although the findings of TxDOT 4085 show that Class C fly ashes are more effective in controlling DEF than they are at controlling ASR. This is likely due to the fact that both Class F fly ash and Class C fly ash contain a fairly high amount of Al_2O_3, which affects the early hydration process and tends to lessen the potential for DEF.

Source: The PCDD should track the source (power plant and distributor) of the fly ashes used in TxDOT applications. Because Texas has several major coal-burning power plants, the vast majority of the fly ash used comes from within Texas. Only a small percentage of fly ash used in Texas comes from outside the state, but this information should be tracked as well.

CaO Content: The CaO content of fly ash has a major impact on ASR, as described above (under *Type* of fly ash) and a somewhat lesser impact on DEF. For fly ashes used in TxDOT applications, the CaO content should be collected as part of the PCDD. This information will also prove useful in the long term if the PCDD is extended to include external sulfate attack. High-CaO ashes tend to be less effective in suppressing external sulfate attack than low-CaO ashes, and in fact, some high-CaO ashes actually reduce sulfate resistance (compared to a control without fly ash), mainly because of the presence of C_3A, free lime, and sulfates in the fly ash as the CaO content drifts above about 21 to 23 percent. Interestingly, these high-CaO ashes still tend to be quite effective in suppressing DEF, mainly because of the presence of Al_2O_3 in the ash.

Total Alkali Content: Although it is standard practice in North America to report both the available alkalies and total alkalies for a given fly ash, research under TxDOT 4085 and other joint projects with Dr. Michael Thomas and Dr. Benoit Fournier have clearly demonstrated that the "available alkalies" reported on fly ash data sheets have very little relation to the actual availability of alkalies in real concrete. As such, recent efforts within ASTM have sought to remove available alkalies as a performance indicator. Therefore, for the PCDD, it is recommended that only the total alkali content of fly ashes be recorded. For the fly ashes typically used in Texas, the total alkali contents are quite low, less than about 3 percent, and for such fly ashes, there is very little impact on ASR. For some Midwest ashes, with total alkali contents greater than 6 or 7 percent, the contribution of alkalies to the pore solution of hardened concrete can be significant, exacerbating the potential for ASR.

Al_2O_3 Content: As previously discussed, the Al_2O_3 content of fly ashes (and other SCMs) appears to have a significant effect on DEF for concretes that experience high temperature excursions during curing. In other words, the presence of Al_2O_3 from SCMs tends to be beneficial in preventing DEF, even when temperatures exceed 160 ^{o}F in the first days after placement. Although the Al_2O_3 content of fly ash has little impact on ASR, it is still worth tracking because of its importance in relation to DEF.

Ground-Granulated Blast Furnace Slag

Ground-Granulated Blast Furnace Slag (GGBFS) is one of the most commonly used SCMs worldwide and has recently been used more in Texas, spurred by the El Paso district and recent use in the Dallas/Forth Worth area. GGBFS is an effective material in reducing heat of hydration of concrete, reducing permeability, and improving durability with respect to ASR, DEF, and sulfate attack. It is likely that the use of GGBFS will continue to increase in Texas, especially as the trend continues towards more stringent specifications aimed at reducing heat generation and improving long-term durability. Unlike fly ash, which tends to vary tremendously from one source to another, GGBFS is fairly uniform in its chemical and physical characteristics. For the purpose of this PCDD, it will suffice to simply keep track of the type (Grade 100 or Grade 120) and amount of GGBFS used in concrete structures. If future sources of slag were to change significantly with regard to chemical characteristics, physical properties, or performance, the PCDD should be revised to gather additional information regarding GGBFS. The following are the most important information and data that should be collected relating to GGBFS for the PCDD:

Type: GGBFS is classified according to ASTM C 989 as Grade 80, Grade 100, and Grade 120. Grade 120, the most reactive in terms of hydration and strength gain, is the most common of the three in North America, followed by Grade 100. Grade 80 is rarely encountered in the North American market. Whenever GGBFS is used for TxDOT applications, the Grade (as per ASTM C 989) should be recorded and stored in the PCDD.

Source: The PCDD should track the source (supplier) of GGBFS used in TxDOT applications. GGBFS is processed (granulated, ground) mainly in the Eastern part of the U.S., and distribution terminals are then set up regionally to handle the slag distribution.

Silica Fume

Silica fume is a highly-reactive SCM that has seen only limited use in TxDOT applications. Silica fume is not very effective in suppressing ASR when used in dosages typically found in transportation applications (e.g., 6 to 8 percent by mass replacement of cement), and it is also not very effective in suppressing DEF when used at these dosages. However, silica fume works very well when combined with slag or fly ash in ternary blends. The specific sources of silica fume are quite limited, and as such, the properties (amorphous silica content greater than 90 percent, surface area greater than 15,000 m^2/kg) vary little from one distributor to another. As such, only the type and source of silica fume are needed for the PCDD, as described below:

Type: Silica fume is produced according to the specifications in ASTM C 1240. There are both chemical and physical limits placed on silica fume within this ASTM standard, and there is very little variation between North American sources. In addition to noting in the PCDD that the silica fume meets ASTM C 1240, the form of silica fume should be listed. Silica fume is nowadays available almost exclusively as a densified, dry product, but it has over the years been available as a wet, slurried product (mixed with about 50 percent water and a dispersant to attempt to keep the solid particles in suspension).

Source: The PCDD should track the source (supplier) of silica fume used in TxDOT applications. Silica fume is supplied by several of the large admixture companies, and in fact, most of these offerings originate from the same base source of silica fume.

Other Supplementary Cementing Materials

If SCMs other than fly ash, GGBFS, or slag are used in TxDOT applications, the type, source, and amount of the material should be entered into the PCDD. The two most likely SCMs to be used in coming years will be ultra-fine fly ash (UFFA) and calcined clay (e.g., metakaolin).

Chemical Admixtures

The only chemical admixtures that have been used in concrete in recent years to suppress ASR are lithium-based compounds, primarily lithium nitrate. This product has been used more as a post-treatment for existing structures, primarily through topical applications. This PCDD focuses only on new concrete, and as such, the information to be collected should focus only on its use as an admixture, as described next:

Lithium Nitrate

Although a range of different lithium compounds has been used over the years, only lithium nitrate is commercially available today as an admixture. It has been used very little in Texas to date, mainly because of its relatively high cost (compared to SCMs, etc.). If lithium compounds are used for TxDOT applications in the future, the following information should be collected for the PCDD:

Type: The type of lithium-based admixture should be recorded in the PCDD. The most common formulation on the market today is a 30 percent $LiNO_3$ solution. Other formulations, such as LiOH, have been used in the past, but the nitrate-based formulation is preferred as it is safer to handle and does not increase the pore solution pH, as is the case for other lithium compounds.

Source: Lithium-based admixtures are distributed by several of the larger admixture companies. The distributor should be recorded in the PCDD, and if the actual manufacturer of the product is known, it should also be noted.

Aggregates

A large proportion of the concrete aggregates in Texas are potentially reactive with regard to ASR. Fortunately, TxDOT has taken an aggressive stance in dealing with ASR, first assuming that all aggregates were reactive (and thus subject to ASR specifications) and now only requiring mitigation measures for aggregates that are considered reactive, based on laboratory testing. Through this process, a fair amount of laboratory data have been generated on most, if not all, of the aggregate sources in the state, and this information will be an essential component for the PCDD. The following aggregate-related data and information should be collected for the PCDD:

Type: The type of aggregate, coarse or fine should be denoted, along with the TxDOT size designation. It should also be noted whether the fine aggregate is manufactured or natural and whether the coarse aggregate is a gravel or crushed stone.

Source: The producer code number and pit/quarry name should be recorded in the PCDD.

Laboratory ASR Data: Any available laboratory data for the aggregates used in a given TxDOT application should be recorded in the PCDD, including the type of test performed (ASTM C 1260, ASTM C 1293, etc.) and the expansion value (14 days for ASTM C 1260, 1 year for ASTM C 1293). TxDOT has generated significant ASTM C 1260 data on aggregates throughout the state, and research at The University of Texas at Austin (UT Austin) under TxDOT 4085 generated extensive data on a range of aggregates using ASTM C 1260, ASTM C 1293, and outdoor exposure blocks. The collection and analyses of the laboratory data for aggregates will perhaps be the most important component of the PCDD as it will allow for the correlation between standard laboratory tests and long-term field performance. This will be especially important because TxDOT 4085 identified several Texas coarse aggregates that pass ASTM C 1260 but fail the more accurate ASTM C 1293 and exposure block testing. Tracking the performance of these aggregates in the field will help better elucidate the pros and cons of accelerated laboratory tests, and if more aggregates are found to behave in this fashion (pass ASTM C 1260, fail ASTM C 1293), serious consideration should be given to modifying the existing test methods and specifications within the state. Other accelerated test methods, such as the Chinese mortar bar test, are currently being evaluated at UT Austin, and if the alternate test(s) are found to be better indicators of field performance and are ultimately adopted by TxDOT, the data generated for subject aggregates should be recorded in the PCDD.

Mixture Proportions

The information described so far has focused only on the inherent properties of the constituent materials used in TxDOT concrete. However, it is just as important to collect information on the proportions of these materials used in concrete, as described below:

Portland Cement Content – The portland cement content should be noted in the PCDD for all concrete mixtures. This data would be linked to the previously described information about the subject cement, such as cement alkali content, fineness, etc. The cement content is particularly important for plain concrete (without SCMs) containing reactive aggregates—in this case, the contractor would have opted for Option 6 (or the old Option 1 in the previous version) in Item 421, in which he is limited to 4 lbs/yd^3 of cement alkalies (expressed as Na_2O_e). Thus, the cement content must be known and multiplied by the alkali content of the cement to determine the alkali loading of the concrete. Keeping track of the total alkali loading in concretes cast in accordance with Option 6 will be very important in the long run, as at least one aggregate in the state has been found to be reactive at alkali loadings lower than this threshold limit. If more aggregates are found that behave in this fashion, it would be prudent to consider lowering the alkali threshold level for plain concrete to a more conservative value (e.g., 3 to 3.5 lbs/yd^3). It is also important to record the cement content, because it can be used after the fact to calculate the heat of hydration of various structural elements using ConcreteWorks. This software program has already been used to evaluate existing structures to determine if excessive temperatures were reached during hydration that could have locked in the potential for DEF.

SCM Content – The amount of each SCM used in a given concrete mixture should be recorded in the PCDD. This information will be linked to the information provided on each of the SCMs (i.e., CaO content, total alkalies, etc.) and will also be linked to the specific mitigation option selected, according to Item 421.

Aggregate Content – The proportions of fine and coarse aggregate should be collected for the PCDD. This is especially important when considering that some aggregates show a pessimum effect, meaning that at a certain aggregate/alkali ratio, the mixture will expand significantly, whereas at other aggregate/alkali ratios, the mixture may be quite durable.

Lithium Nitrate Dosage – If lithium nitrate is used in TxDOT concrete, the dosage of admixture should be recorded (expressed as volume of 30 percent solution and also expressed as gallons of solution per lb of Na_2O_e). The current TxDOT ASR specification allows for a prescriptive dosage of lithium equal to 0.55 gallons of 30 percent lithium nitrate solution per lb of Na_2O_e in the portland cement. However, research under TxDOT 4085 clearly shows that this dosage does not work for all aggregates; in fact, about half the aggregates tested at UT Austin require more than this manufacturer's recommended dosage. Thus, tracking the dosages used in field concrete will help provide linkage between the laboratory evaluations and long-term field performance. It has been proposed under TxDOT 4085 that the prescriptive use of lithium compounds be removed from TxDOT ASR specifications in lieu of performance testing using ASTM C 1293 (2-year expansion limit of 0.04 percent). It should be noted that work under TxDOT 4085 showed that lithium nitrate can suppress DEF in heat-cured mortar and concrete, and this is another reason why lithium might be used in future applications.

Water Content – The water content (based on SSD aggregates) should be tracked for all TxDOT mixtures, allowing for the calculation of w/c (or w/cm) ratio for each mixture. The potential for ASR and DEF are both reduced through the use of lower w/cm ratio concretes, although past work has shown that the main effect is simply delaying the onset of degradation (by lowering the rate of ion and water movement in concrete).

Specifications

For all concrete structures or pavements tracked in the PCDD, the specifications by which the job had to comply should be noted. Specifically, it should be noted if any of the following specifications were adhered to for the given application:

ASR Specifications – For aggregates deemed to be reactive, the contractor is required to follow one of eight mitigation options, seven of which are prescriptive and one which is based on performance-testing using ASTM C 1260. The specific option selected should be noted in the PCDD, and if the option selected was Option 8 (ASTM C 1260 testing with intended materials), the data for that test should be recorded. The data generated under this section will be especially important as it will provide valuable data and information on how contractors are addressing ASR. Further, the data generated will help shed further light on some of the features of the specifications that deserver further attention of modifications, such as the 4 lbs/yd^3 limit on alkalies for plain concrete, the prescriptive dosage of lithium, and the appropriateness of ASTM C 1260 when testing aggregates that produce erroneous results under this testing regime.

Mass Concrete Specifications – It should be noted in the PCDD when a given structure was subjected to the new mass concrete specification. This specification limits the temperature of fresh concrete, the maximum temperature generated in the structure, and the gradient in temperature between core and surface. The precautions taken by the contractor to meet these specifications should be noted, and if ConcreteWorks was used to pre-design the mixture, the predicted values for maximum heat and maximum thermal gradient should be recorded. Also, if available, the thermal data from the actual concrete placement should be collected, as it is required as part of the specification compliance.

Precast Concrete Temperature Limits – It should be noted in the PCDD when a given precast girder was required to meet the new temperature limits placed on precast elements. These temperature limits, based on the findings for TxDOT 4085 and other related work, require that the maximum temperature of precast elements not exceed 150 ^{o}F (for plain concrete) or 170 ^{o}F (for concrete containing SCMs). This information will be quite useful to track in that concrete cured below these temperatures should be immune from DEF, based on TxDOT 4085 findings.

Job-Specific Inputs

The following information should be collected for each job that is tracked in the PCDD:

Job Number and Location

The specific job or project number should be recorded, along with information on the location of the job.

Scheduling Information

The schedule for the job should be recorded, with particular information provided on the dates of the construction/fabrication of the concrete structure or pavement being tracked in the PCDD.

Contractor Information

Information on the contractor responsible for the job should be noted in the PCDD.

Concrete Supplier Information

The concrete supplier and his/her plant(s') location should be noted in the PCDD.

Special Exposure Conditions

Some concrete structures or pavements may be subjected to certain exposure conditions that may exacerbate the potential for ASR and/or DEF. If the following exposure conditions are expected, it should be recorded in the PCDD:

Exposure to Deicing Chemicals

If it anticipated that the concrete will be exposed to deicing chemicals, it should be noted in the PCDD. This can be quite critical for both ASR and DEF, as research has shown that ASR reactivity can be increased in the presence of deicing salts, and that scaling of heat-cured concrete can be exacerbated by the use of deicing salts. If known, the type and approximate amount of deicing salts to be used should be noted.

Exposure to Marine Environment

If concrete structures being tracked in the PCDD are to be exposed to a marine environment, it should be noted in the PCDD. Exposure to a marine environment may exacerbate ASR by increasing the pore solution pH within the concrete.

SUMMARY

This document has described the key information and data that should be collected under the PCDD. For convenience and to aid in the implementation into existing TxDOT databases, a tabular summary is provided in Table 1, highlighting the specification information and data that should be collected in the PCDD.

Table 1 – Summary of Information and Data to be Collected in the Premature Concrete Deterioration Database (PCDD)

(see text for more detailed information on data/information sought and relevance to ASR/DEF)

ITEM	SUB-ITEM	INFORMATION/DATA	DETAILS
Material Information			
	Portland Cement	Type	
		Source	
		Chemical Composition	Alkali Content
			C_3A Content
			Sulfate Content
		Physical Properties	Fineness
			Compressive Strength
	Fly Ash	Type	
		Source	
		Chemical Composition	CaO Content
			Total Alkali Content
			Al_2O_3 Content
	GGBFS (Slag)	Type	
		Source	
	Silica Fume	Type	
		Source	
	Other SCMs	Type	
		Source	
	Lithium Nitrate	Type	
		Source	
	Aggregates	Type	
		Size Designation	
		Source	
		Laboratory ASR Data	ASTM C 1260
			ASTM C 1293
			Other
Mixture Proportions			
	Portland Cement Content		
	SCM Content		
	Aggregate Content		
	Lithium Nitrate Dosage		
Specifications			
	ASR Specifications		
	Mass Concrete Specifications		
	Precast Temperature Limits		
Job-Specific Inputs			
	Job Number		
	Location		
	Schedule		
	Contractor Information		
	Concrete Supplier Information		
Special Exposure Conditions			
	Deicing Chemicals		
	Marine Environment		