Concrete Recycling: Reuse of Returned Plastic Concrete and Crushed Concrete as Aggregate

Requested by
Rock Products Committee: Materials and QA Sub Task Group of the Concrete Products Task Group

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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

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Executive Summary

Background

Caltrans is interested in concrete recycling both for environmental and technical reasons. Underutilization of concrete and its components contribute to filling of landfills, increased water usage, depletion of natural resources, increased material transport, and increased greenhouse gas emissions.

Appendix A is a Caltrans presentation that provides an overview of this topic, and two areas described in that overview are the topics of interest for this Preliminary Investigation:

- *Returned plastic concrete* (RPC)—excess portland cement concrete that has not yet hardened.
- *Crushed concrete*—hardened concrete crushed to be reused as aggregate.

From an environmental perspective, about two to eight percent of concrete produced in California is returned, as identified by the California Environmental Protection Agency Climate Action Team (CAT) in 2007 during initial implementation of Assembly Bill 32, the Global Warming Solutions Act of 2006. The CAT team estimated that this correlates to 1.1 million metric tons of carbon dioxide excess per year.

Reuse of fresh returned plastic concrete in particular offers the opportunity to directly reuse the component water, cement, and aggregate and reduce energy use. Importantly, reuse of RPC also means preserving the embodied energy from the manufacture of the original concrete.

Caltrans is interested in learning more about practices, policy and research related to concrete recycling. This Preliminary Investigation is presented in two sections to address the two distinct practices for recycling concrete:

- *Part 1. Returned plastic concrete*—This investigation addresses how RPC is reused in its entirety; it does not address the practice of washing fresh mix to recover aggregate (recognizing that the reuse of concrete aggregates helps conserve natural resources and has wider applications).
- *Part 2. Crushed concrete*—The scope of this investigation includes crushed concrete sourced from demolished pavements and structures as well as crushed new concrete (excess fresh mix allowed to harden and then crushed).

Summary of Findings: Part 1. Returned Plastic Concrete

We could not find evidence of transportation agencies, in the United States or elsewhere, reusing RPC. Although RPC is permitted by public works agencies in California that follow the Greenbook: Standard Specifications for Public Works Construction—typically those in Southern California—our conversations with stakeholders suggest that it is not being used in this capacity. The concrete industry has performed much of the recent work to promote reuse of RPC.

Survey

A survey of state DOTs revealed that among 32 respondents, none allowed the reuse of RPC. Complete survey questions begin on page 8 of this Preliminary Investigation. A follow-up survey of ready-mixed concrete producers conducted by California Construction and Industrial Materials Association (CalCIMA) agreed with Caltrans' survey and showed that reuse of RPC is somewhat common for private work, especially for nonstructural applications; however, there are no documented best practices available that can be built upon.

Interviews and Issues

- We spoke with three Caltrans stakeholders, including both public and private representatives serving on Greenbook committees as well as a representative of the CalCIMA. They shared the understanding, reinforced by an industry survey conducted by CalCIMA, that the Greenbook provisions for reusing RPC were not being used. A CalCIMA representative provided documentation about a Collaborative for Sustainable Transportation and Infrastructure (CSTIC) project that developed a draft protocol for RPC reuse; the protocol is being used to advance the use of RPC with code-setting organizations.
- A number of experts discussed the technical issues associated with reusing RPC. Rick Meininger with the Federal Highway Administration (FHWA) wrote that RPC "can be used under controlled circumstances, but it can be abused also." Colin Lobo with the National Ready Mixed Concrete Association and David Gress with the Recycled Materials Resource Center (RMRC) expanded on this topic, describing the process control challenges that make RPC difficult to reuse for high-performance applications like those in the transportation industry. They discussed the technology of admixtures used to halt and restart the mix hydration process and the applications where these are commonly used.

Resources

Additional guidance on this topic is presented in two sections:

- **Related Specifications and Standards** include the California publications and AASHTO and American Society for Testing and Materials (ASTM) specifications cited in this Preliminary Investigation as well as a guidance publication from the American Concrete Institute (ACI).
- **Research** includes eight citations on this topic ranging from 1988 to 1998; it appears that little research has been done on this area in recent years. These citations address properties and processes for RPC reuse. Some but not all address the use of admixtures. Three of the older research citations are included in the appendices to this report.

Summary of Findings: Part 2. Crushed Concrete as Aggregate

Use of crushed concrete as aggregate for transportation applications is a common practice among departments of transportation (DOTs) but it is not universally permitted, and restrictions vary from state to state. Some issues include performance, processing and material availability.

Survey

One of the summary statements in Caltrans' overview presentation (Appendix A) is that "Caltrans is among the few states which allow recycled concrete aggregates for [portland cement concrete]." The state survey showed that among the 30 state respondents, 10 allowed the use of crushed concrete as aggregate for new concrete pavements. However, only two of these 10 said it was a common practice. Other key survey findings include the following:

- The most commonly permitted applications for crushed concrete are "fill, embankments or noise barriers" and "pavement base or subbase layers." The latter is the most commonly used application.
- Only a few agencies indicated that they allowed the use of crushed concrete for lean base.
- Most agencies noted the same specifications for crushed concrete as with other aggregate types.

- About half of the respondents discussed problems in using crushed concrete as aggregates, including high pH levels related to the alkali-silica reaction (ASR) and groundwater leaching; high absorption of crushed asphalt concrete; and debris and contamination.
- Fewer than half of the respondents have considered expanding the use of crushed concrete as aggregate, with several citing availability as a barrier to expanded use of crushed concrete as aggregate.

Specifications and special provisions are included as Internet links or in a few cases as appendices to this Preliminary Investigation.

Interviews
Our interviews with experts highlighted current and near-term activities to advance the state of the art in this area and promote the practice of using crushed concrete as aggregate.

- David Gress with the RMRC authored a chapter about concrete recycling in a recent RMRC publication on sustainable pavements. He discussed an FHWA effort to promote two-lift concrete paving and described how crushed concrete is well-suited for lower lifts.
- Colin Lobo with the NRMCA and Scott Seiter with Oklahoma DOT described efforts at AASHTO to update the relevant specification (AASHTO MP16, Standard Specification for Reclaimed Concrete Aggregate for Use as Coarse Aggregate in Hydraulic Cement Concrete); initial balloting steps are now in process.
- Mohamed Mahgoub, chair of ACI Committee 555 (Concrete with Recycled Materials), discussed efforts to provide updated guidelines on best practices for recycled concrete aggregate (RCA).

Resources
Additional guidance on this topic is presented in four sections:

- **Specifications and National Guidance** includes several recent publications: RMRC's 2012 manual on sustainable concrete pavements, a 2010 American Concrete Pavement Association (ACPA) fact sheet on concrete containing RCA and a 2009 manual from ACPA on recycling concrete pavements.
- **Research and Case Studies** includes a 2012 article in *Better Roads* addressing ASR, a 2011 National Concrete Pavement Technology Center (CP Tech Center technology deployment plan for using RCA in concrete mix, 2007 research from the NRMCA, FHWA's 2004 case studies on five states and a 1989 NCHRP synthesis report.
- **International Guidance and Research** presents a few instances of crushed concrete used globally—in Australia, New Zealand and Europe.
- **Web Sites** include the alliances, research groups and trade organizations described throughout this investigation.

Gaps in Findings

The inability to identify agencies using RPC does not mean that they do not exist. Though the evidence from the surveys, interviews and Internet searches together suggests that it is unlikely, the nonexhaustive nature of Preliminary Investigations makes it impossible to state this as a certainty. In addition, it was not feasible under the scope of this investigation to conduct surveys of all public works agencies nationwide to learn more about possible RPC reuse outside of the transportation industry. Similarly, though we did not find recent research in the area of RPC, it remains possible that such exists.

Having only heard back from about two-thirds of the states surveyed, it is possible that we did not learn about novel or unique practices related either to RPC or to crushed concrete. In addition, our search for international practices on using crushed concrete provides only a sampling and does not represent the complete picture of this practice abroad. We were informed that new efforts to further investigate RPC were being undertaken by the CP Tech Center, but we were unable to reach Tom Cackler, director of the CP Tech Center.

Next Steps

Based on our correspondence and conversations, it appears that efforts among California industry to advance RPC may have stalled. There may be opportunities to revisit the existing documentation and assess its relevance for Caltrans' purposes.

Regarding crushed concrete recycling, the survey findings indicate that more states may be using crushed concrete for more applications than in past years. Mohamed Mahgoub representing ACI was also eager to connect with Caltrans on this topic.

AASHTO's efforts to update its standards related to crushed concrete are ongoing. AASHTO's Highways Subcommittee on Materials (SOM) continues initial balloting and evaluation.

Efforts for further investigation and evaluation of the applications and risks associated with use recycle concrete could include the following:

- **Returned Plastic Concrete.** Research could help assess the risks for Caltrans of expanding recycling of concrete materials that are currently wasted or used for lower value products. Research could include:
    - Review of existing specifications (e.g., Greenbook: Standard Specifications for Public Works Construction) and other resources obtained through this Preliminary Investigation.
    - Review of experiences to date in California and elsewhere.
    - Laboratory testing to evaluate strength and performance.
    - Recommendations for testing requirements.

- **Crushed Concrete as Aggregate.** Research could help expand the use of crushed concrete beyond the typical fill applications and take advantage of its superior properties compared with virgin aggregate. These superior properties may allow for reduced thicknesses in base and subbase applications. Other applications, such as use in lean concrete base, may reduce costs. Research could include:
    - Review of existing specifications throughout the country and other resources obtained through this Preliminary Investigation.
    - Review of experiences to date in California and with other state DOTs.
    - Field testing of unbound applications (e.g., base or subbase) to evaluate improved performance compared with virgin aggregate.
    - Laboratory testing in new applications (e.g., lean concrete base, etc.).
    - Recommendations for testing requirements (e.g., ASR, etc.).

Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the individuals listed below:

California

California Construction and Industrial Materials Association
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Standard Concrete Products
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Recycled Materials Resource Center
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National Ready Mixed Concrete Association
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American Concrete Institute
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ASTM International
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Area Operations Manager, Prairie Material
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Part 1. Returned Plastic Concrete – Survey

We worked with Caltrans to develop an online survey of state and provincial pavement material engineers to learn the scope of RPC reuse among transportation agencies. The survey addressed both RPC and crushed concrete; the topic of crushed concrete is addressed in Part 2 of this Preliminary Investigation.

Audience

The survey was sent to all members of the AASHTO Standing Committee on Highways' SOM (http://materials.transportation.org), reaching all 50 states, Washington, D.C., and Puerto Rico. We identified and surveyed contacts in eight Canadian provinces as well.

Survey Text and Questions

The survey introductory text, overview and questions for Part A ("Reuse of Returned Plastic Concrete") are reproduced below.

> The California Department of Transportation is conducting this survey of state and provincial DOT pavement and materials engineers to establish current concrete recycling practices, policies and restrictions. Your participation will help establish trends and best practices related to concrete recycling in the United States and Canada.
>
> Caltrans' Division of Research and Innovation is coordinating this survey and will publish a synthesis report of the survey findings.
>
> Please let me know if you have any questions. Thanks again for taking the time to complete this survey.
>
> Brian Hirt
> CTC & Associates LLC
> On behalf of the California Department of Transportation
> (402) 770-9067
> brian.hirt@ctcandassociates.com
>
> 1. (Required) Please provide your name, title and organization. Your name and title will not be published in Caltrans' final report.
>
> **OVERVIEW**
>
> - Part A of this survey addresses your agency's recycling of **returned plastic concrete** (or **RPC**): the reuse of excess portland cement concrete that has not yet hardened.
> - Part B of this survey addresses your agency's recycling of hardened portland cement concrete that is **crushed and used as aggregate** for new pavement.
>
> **PART A. REUSE OF RETURNED PLASTIC CONCRETE**
>
> These questions center around how your agency recycles plastic concrete mix in its entirety, rather than practices involving washing fresh concrete mix to recover just the aggregate component.
>
> 2. Does your agency allow the reuse of returned plastic concrete (RPC) for transportation applications?
>
> ☐ Yes
> ☐ No

If you answered “Yes,” please answer these follow-up questions. Otherwise, please skip to the bottom of the page and click “continue” to proceed to **Part B** of this survey.

3. For which applications is reuse of RPC mixed with new concrete permitted or not permitted by your agency? For which is it commonly used? (Check all that apply)

	Permitted	Not permitted	Commonly used
Sidewalks, curbs or slopes	☐	☐	☐
Footings for lighting, signs or fences	☐	☐	☐
Median barriers	☐	☐	☐
Pipe or pull box filler	☐	☐	☐
Lean concrete base, controlled low strength material or culvert backfill	☐	☐	☐
Low volume roads	☐	☐	☐
High volume roads/highways	☐	☐	☐
Bridge substructures	☐	☐	☐
Bridge superstructures	☐	☐	☐

For applications where RPC is used, on approximately what percentage of projects? (Free response)

4. What are your agency’s limitations of RPC by percent weight into a new concrete mix? (Free response)

5. If your agency allows (or requires) use of admixtures to prevent hydration of RPC intended for reuse, please provide details: What type of admixtures? When are they used or required? (Free response)

6. Please note any batching quality control requirements for the mixing process. (Check all that apply)

☐ Existing RPC may be weighed in-truck and batched with a new concrete mix.
☐ RPC must be put in a holding tank prior to mixing with new concrete.
☐ Our agency’s office of Weights and Measures has specific requirements for the reuse of RPC.

Please provide details on your response. (Free response)

7. Has your agency encountered any problems in reusing RPC for transportation applications?

☐ Yes
☐ No

If you answered “Yes,” please explain. (Free response)

8. Has your agency considered expanding the reuse of RPC (higher allowed percentages or for more applications)?

☐ Yes
☐ No

If you answered "Yes," please describe the outcome of such efforts. (Free response)

9. Please provide links to any state DOT standards or specifications related to the reuse of RPC. (If these are not available online, please email files to brian.hirt@ctcandassociates.com.) (Free response)

10. What guidance for reuse of RPC is there in your state beyond your own agency's (for example, comparable to California's Greenbook: Standard Specifications for Public Works Construction)? (Free response)

Survey Responses

Among the 60 total state and provincial governments surveyed, we received responses from 32 agencies for the portion of the survey related to RPC:

- Alabama DOT.
- Alaska Department of Transportation and Public Facilities.
- Arkansas State Highway and Transportation Department.
- Caltrans.
- Colorado DOT.
- Delaware DOT.
- District of Columbia DOT.
- Florida DOT.
- Georgia DOT.
- Hawaii DOT.
- Idaho Transportation Department.
- Illinois DOT.
- Indiana DOT.
- Iowa DOT.
- Kentucky Transportation Cabinet.
- Louisiana Department of Transportation and Development.
- Maryland State Highway Administration.
- Michigan DOT.
- Nevada DOT.
- New Hampshire DOT.
- New Jersey DOT.
- New Mexico DOT.
- New York State DOT.
- Ohio DOT.
- Oklahoma DOT.
- Pennsylvania DOT.
- South Carolina DOT.
- Texas DOT.
- Utah DOT.
- Virginia DOT.
- Wyoming DOT.
- British Columbia Ministry of Transportation and Infrastructure.

In response to Question 2 (Does your agency allow the reuse of returned plastic concrete (RPC) for transportation applications?), all 32 respondents answered "No."

As a result, no further survey answers were provided for questions 3 through 9. A few agencies provided additional feedback to the final few questions of this section of the survey.

10. What guidance for reuse of RPC is there in your state beyond your own agency's (for example, comparable to California's Greenbook: Standard Specifications for Public Works Construction)?

- ACPA engineering bulletin, "Recycling Concrete Pavements." (Colorado)

11. Please provide any additional comments you may have about your agency's use of RPC.

- RPC is not really addressed either way for use or non-use in any of our specifications or procedures. (Alabama)
- FHWA and the CP Tech Center are working on developing engineering standards for the use of RPC. This will be a very beneficial resource for all DOTs. (Colorado)
- Maryland State Highway Administration currently does not use RPC. However, we would like to obtain the results of your survey for future consideration. Thank you for the opportunity to participate. (Maryland)

The ACPA citation is discussed in **Resources** on page 35 of this investigation. We followed up with FHWA and the CP Tech Center based on Colorado's feedback, as noted in **Interviews** beginning on page 12 of this investigation.

Follow-up Industry Survey

After delivery of the initial draft of this Preliminary Investigation in August 2012, CalCIMA conducted a follow-up national survey of ready-mixed concrete producers. CalCIMA's survey questions appear in Appendix B to this Preliminary Investigation, and the results as provided by CalCIMA appear in Appendix C.

Like Caltrans' survey, CalCIMA's did not find any reuse of RPC by state agencies. It also appears to show that reuse of RPC is fairly common for private work, especially for nonstructural applications, such as site work and foundations. For more information about this survey, please contact Charley Rea with CalCIMA; Rea's contact information appears in **Contacts** on page 6.

Part 1. Returned Plastic Concrete – Interviews and Issues

California Stakeholders

Although RPC is not being reused among state DOTs, as shown in the survey results, the reuse of RPC for public works projects in California is authorized and encouraged by California Public Resources Code, Section 16000-16004 (Appendix D). This document references California's Greenbook: Standard Specifications for Public Works (the relevant section, 201-1.2.6, Reclaimed Concrete Material, is Appendix E). Both publications are cited in **Resources** on page 18 of this Preliminary Investigation.

Caltrans wished to know the extent of RPC reuse in California, and we spoke with three California stakeholders who suggested that very little use was being made of these provisions.

Los Angeles County

Erik Updyke, Co-chair of the American Public Works Association Greenbook Committee

We spoke with Erik Updyke, who felt strongly that the concrete suppliers were much more likely than public works agencies to have the information we were seeking about the extent of RPC use in Southern California. He said that he would be surprised if more than a small fraction of public works agencies knew about the RPC provisions in the Greenbook. He suggested we speak with Ken Sears, chair of the Concrete Ad Hoc Task Force of the Greenbook Committee. (See following interview.)

Standard Concrete Products

Ken Sears, Chair of the Concrete Ad Hoc Task Force of the Greenbook Committee

At Erik Updyke's suggestion, we followed up with Ken Sears, who indicated that he would be surprised if any producers were using the Greenbook RPC provision at all. The Concrete Ad Hoc Task Force has been discussing this topic at length recently, and he explained that if RPC were being used in Southern California, the Ad Hoc Committee would almost certainly know about it because of the cross section of producers, vendors, suppliers and industry consultants represented on the committee who have provided feedback. He explained that the group had identified a number of challenges related to the existing provision, which appear to be discouraging its use. Some of these challenges apply both to crushed concrete aggregates as well as RPC:

- The provisions in the Greenbook allow for a relatively low volume of recycled materials in a mix: no more than 15 percent of total reused materials (including both plastic concrete and crushed concrete aggregate). For a 10-yard load of concrete, that is 1.5-yard maximum of reused materials.
- Ready-mixed concrete producers typically do not have the means to verify the quantities of RPC as required in the provisions. It requires a considerable capital investment to be able to do this as required.
- For crushed concrete turned into an aggregate, many ready-mixed concrete producers do not have the additional storage facilities or silo capacity if the material is not used immediately. This too requires an investment.
- The use of recycled materials can be allowed or prohibited unilaterally by each local agency. The investment required to enable the RPC or crushed concrete aggregate is difficult to justify when these materials may or may not be used depending on each individual project specification. Sears believes that a top-down mandate requiring the use of these materials would be more likely to meet with success than bottom-up support of the practice by industry.

California Construction and Industrial Materials Association
Charley Rea, Director of Communications & Policy, CalCIMA

At Ken Sears' suggestion, we spoke with Charley Rea of CalCIMA, who provided results of an informal CalCIMA survey of its members on this topic, reproduced below. These results did not reveal practices by other state DOTs related to RPC reuse, and they affirmed the statements made by Sears on the limitations of the Greenbook provisions for public works agencies.

Question 1. Practices by other State DOTs or countries, regarding use of returned plastic concrete.

- *It is my understanding the practice of batching fresh concrete on top of returned plastic concrete is utilized in some states, including Ohio. The applications where this is embraced are non DOT and non-high performance concrete projects. The practice is also not used with concrete requiring air-entrainment. The returned plastic concrete is weighed for estimating the amount of concrete in the mixer for volume conversions and calculations to determine the amount of fresh concrete to be batched on top of the estimated returned concrete. The known empty weight of the concrete mixer with a full tank of fuel and full water tanks would be the tare weight used to extrapolate the amount of returned plastic concrete left in the drum. The use of the recycled/fresh concrete blend would govern the amount/percentage used. If the returned concrete was a 5 sack 2000 psi mix it would not be resold for 6 sack 3000 psi. If a truck was returned with 5 yards of 5 sack 2000 psi concrete and an upcoming job required 10 yards of 6 sack 3000 psi, they would consider batching 5 yards of a 7 sack or higher cement content mix on top to make a composite mix that would satisfy the cement content and the required in-situ concrete's compressive strength. Additional use of measured and recorded chemical admixtures such as normal water reducers, retarders and hydration stabilizers are incorporated into the composite mix based on age (hours) of the initial concrete, temperature of the plastic concrete, travel time to the next project and ambient temperature.*

- *Producers in Canada generally work with proprietary mix designs based typically on performance criteria which encourages and supports the innovation and added cost associated with recycle/reclaiming and re-use of the various "left over concrete" components. For example, the use of high solids slurry (the cement and water paste left over from screening out aggregates) becomes an advantage in performance based mix designs ... reduced virgin cement and often adjusted set characteristics (for example, faster set times to offset the use of accelerators in winter).*

Question 2. What are the practices in California for non-public work regarding returned plastic concrete?

- *Plants do not currently have the capacity to measure left over concrete as required per the Greenbook and as such cannot take advantage of re-use of left over concrete. Lack of capital means there are not likely to be plant expansions in the near future that will allow for the measurement and re-use.*

- *The Greenbook allows for up to 15% of a 2000 psi returned concrete to be batched on top of and sold for the same psi. However, the Department of Weights and Measures in the State of California does not allow the practice, due to there not being a way to accurately record the exact volume of returned concrete added to fresh concrete, and include this on a weigh ticket. The current weigh master laws, ethics, and industry accepted "standards of business" deter and make the practice of using returned plastic concrete unfavorable. The common practice at this point in time is to use any returned plastic concrete at the batch plant or material yard and/or in making construction blocks, molds, or foot pavers. Some concrete plants have aggregate reclaimers while*

- *For non-public work, it is job specific for allowance depending on what the LEED goals, requirements and allowances are for specific projects. Not sure if other suppliers are able to utilize returned plastic concrete. Some plant facilities may have a reclaiming receptacle for returned concrete which separates the coarse and fine aggregate.*

Question 3. What can be done to increase use of returned plastic concrete?

- *Any process recommendations would have to ensure the plant's current operations are not interrupted. Any additional measures would impact the plant's current ability to produce at current volume requirements.*

- *Caltrans has made and continues to make some advancement in their specifications to produce better concrete. They have changed from allowing minimal percentages of approved pozzolans to now mandating the use and encouraging higher percentages of SCM to be incorporated into their concrete. Caltrans needs to consider allowing performance based concrete to be used in substitution for their prescription or recipe designed concrete. They need to have clear demarcations in their specifications for "performance based specifications", "prescriptive" and "green or sustainable based concrete specifications". Allowing the industry to optimize their own individual percentages of fine and coarse aggregates and removing the minimum and maximum allowable cementitious and supplementary cementitious materials may prove to be a financial as well as a life cycle cost benefit to the State. Measurable metrics, including compressive and flexural strength, air entrainment, and slump testing can still provide the compliance proof the state is receiving the performance characteristics and quality for their projects when allowing performance based concrete to be utilized.*

Rea also discussed and provided documentation about a draft protocol for RPC reuse developed from the United States Environmental Protection Agency (U.S. EPA) Region 9's Collaborative for Sustainable Transportation and Infrastructure. CSTIC is an action-based collaborative dedicated to increasing the sustainability of infrastructure, based on lifecycle materials management view.

Project 2010-1, titled "Developing a Protocol and Running a Demonstration Test for Increasing the Beneficial Use of Plastic 'Returned Concrete,' " focused on reusing plastic concrete on other jobs. Project participants included the American Concrete Institute, Central Concrete, Inc., the NRMCA and U.S. EPA Region 9.

As described in a summary document (Appendix F), the protocol "will propose the measurements, verifications, documentation and limitations that will allow the average batch concrete company to use returned plastic concrete in levels above the typical 0-15%, while preserving adequate assurances of performance." The project was successful in developing a draft protocol for RPC reuse. A draft protocol, "Standard Practice for Same Day Recycling of Returned Plastic Ready-Mixed Concrete," was developed (Appendix G), and it provides scenarios both for same-day and overnight reuse. The protocol is being used to advance the use of RPC with code-setting organizations such as ASTM, state agencies, and other organizations.

Summary of Issues in California

Based on our research and the feedback discussed above, the following items outline the current challenges and limitations to reuse of RPC in California:

- **California Public Resources Code.** Section 16003 of the Public Resources Code (Appendix D) authorizes use of RPC for private and public work, but it does not require the state to use RPC.
- **The Greenbook.** Section 201-1.2.6 of Greenbook (Appendix E) provides a method to use RPC, but is limited in that it only allows 15 percent RPC and requires the truck to be emptied. This requires additional steps, processes, equipment, and plant space for small amounts of recycled material. So while the Greenbook does allow reuse of RPC, at this time it is difficult to implement the processes spelled out in the Greenbook.
- **State of California Division of Measurement Standards** (http://www.cdfa.ca.gov/dms). This California state agency has determined that estimated weights— such as the estimated weight of RPC left in a truck—are not permitted. As a result, RPC must be removed from a truck to be weighed, which is a limitation on the reuse of RPC.
- **California Building Code** (http://publicecodes.cyberregs.com/st/ca/st/index.htm). The state's uniform building code requires a concrete truck to be emptied. To the extent this is a default code, it also represents a limitation on use of RPC.

National Experts

Federal Highway Administration

Rick Meininger, Research Civil Engineer

As suggested by Colorado's response to the online survey, we followed up both with FHWA and the CP Tech Center on efforts to address reuse of RPC. Lee Gallivan at FHWA put us in touch with Rick Meininger of the Turner-Fairbank Highway Research Center. Meininger responded by email:

> *I think Returned Plastic Concrete can be used under controlled circumstances, but it can be abused also. I suggest that [CTC] contact the National Ready Mixed Concrete Association, and perhaps also the California Association and some of the admixture suppliers as well to find out what industry research has been done and what practices may be sanctioned by specifiers when special admixtures and appropriate engineering controls are used. Research has been done that has allowed the holding of plastic concrete for long periods—even overnight—when special stabilizing admixtures have been used.*

National Ready Mixed Concrete Association

Colin Lobo, Senior Vice President, Engineering

We spoke with Colin Lobo, who said that he is not aware of any national or international standards that address or permit the use of returned plastic concrete; it is not mentioned in either AASHTO M157, Standard Specification for Ready-Mixed Concrete, or ASTM C94, Standard Specification for Ready-Mixed Concrete (cited in **Resources** beginning on page 18 of this Preliminary Investigation). The ASTM subcommittee responsible for C94 has an active task group that is developing revisions to address the reuse of RPC. It might be that a separate standard will need to be developed, like ASTM C1602 was developed for use of nonpotable water. Lobo also mentioned efforts in California to establish an RPC protocol. (CalCIMA provided further details on this effort; see above.) An initial draft from this effort was forwarded to the ASTM task group for its consideration.

The NRMCA has done research in the past on reusing RPC in different quantities, and with and without hydration stabilizing admixtures, to understand how it changes the property of the concrete mix. Lobo provided a number of research references, which are listed in **Resources** on page 19 of this Preliminary Investigation. These include international studies from Europe and Japan.

Lobo described the challenge in controlling the large number of variables related to the reuse of RPC. These include quantity, composition, temperature and age. Typically RPC would not be used in new mix to meet the requirements of pavements and bridge decks because these types of applications require a higher level of quality and uniformity, and there are concerns related to the relative unpredictability of properties of concrete containing RPC. RPC is used in a controlled and predictable manner by some ready-mixed concrete producers for residential or commercial foundations and footings where it meets performance requirements well. In these applications the ready-mixed concrete company has to establish internal guidelines and policies on how RPC must be controlled and provide restrictions on its use.

Lobo indicated that it is possible that concrete containing RPC may be used in mass concrete elements or the substructure of transportation structures where the quality requirements of concrete are not very critical and it can be determined that the concrete meets the requirements of the specification and can be delivered with some degree of uniformity from batch to batch.

Lobo noted that there is typically a small amount of old concrete in a new batch (noting that states outside of California do not require drums to be washed), and this small amount has a negligible effect on performance. A yard or more of old concrete can start having an impact on the properties of the new mix. Typically these are effects on setting time and strength, though these can be managed when the effects are known and can be controlled. Hydration stabilizing admixtures may or may not be used when RPC is used for nontransportation applications.

Recycled Materials Resource Center

David Gress, Assistant Director, RMRC, and Professor of Civil Engineering, University of New Hampshire

We spoke with David Gress, who said that the use of RPC batched into a new mix is common for private applications, such as home foundations, and performs adequately for that lower-value purpose. He said this kind of mix would not be appropriate to use for pavements, which require high performance, strength and durability. He explained that using concrete after the commonly specified limit of 90 minutes of being mixed with water can result in significantly lower quality. Reusing older RPC is definitely problematic, and without very close quality control of timing and batching, it would result in clumps of set concrete being randomly dispersed in the new mix, resulting in compromised quality (strength and durability).

Gress discussed another reuse process for RPC: a treatment process for taking a concrete apart into its components of coarse aggregate, sand and cement. The cement fraction can be chemically put to sleep with admixtures, processed by concentrating the recycled paste fraction until the specific gravity is again ideal, and then chemically awakened and used as a portland cement substitute in new concrete. Gress said that this process too requires exceptional quality control to ensure proper control of water in the reclaimed cement paste. To learn more about this process, Gress suggested we contact the major admixture companies (BASF, W.R. Grace and Sika). This process is commonly used for new concrete when it has to be transported long distances before placement.

Gress was unaware if or how RPC was being reused in Europe. He suggested that we contact European-owned BASF for information.

National Concrete Pavement Technology Center at Iowa State University
Peter Taylor, Associate Director, CP Tech Center

As suggested by Colorado DOT, we contacted the CP Tech Center for more information about efforts to further investigate RPC. Peter Taylor directed us to contact Tom Cackler, director of the CP Tech Center. We were unable to reach Cackler for more details.

Part 1. Returned Plastic Concrete – Resources

Complete citations for specifications and standards referenced in **Interviews and Issues** beginning on page 12 are presented here. In addition, we have included related research about RPC, including initial findings shared by Caltrans and those mentioned or provided by Colin Lobo of NRMCA. Research in this area is not very recent; the latest citations date to the late 1990s.

Related Specifications and Standards

California Public Resources Code, Section 16000-16004, State of California, undated, (Appendix D).
http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=15001-16000&file=16000-16004
These paragraphs state California legislature's intent to encourage the use of recycled concrete as defined in the 2003 edition of the Greenbook. The language defines requirements for fully informing users when recycled materials are used and provides for the Department of Transportation and the Department of General Services to restrict use of recycled materials.

2009 Greenbook: Standard Specifications for Public Works Construction, BNi Building News, 20129.
http://www.bnibooks.com/shopexd.asp?id=6224
From the web site: The Greenbook is designed to aid in furthering uniformity of plans and specifications accepted and used by those involved in public works construction. … The Greenbook consists of six parts: General Provisions, Construction Materials, Construction Methods, Alternate Aggregate Materials, Pipeline System Rehabilitation, and Modified Asphalt Products.

Section 201-1.2.6, Reclaimed Concrete Material, is Appendix E to this Preliminary Investigation.

Related Resource:

> According to the Greenbook web site, http://www.greenbookspecs.org, more than 200 other cities, counties and agencies in the South California area have adopted it as their standard for public works construction specifications.

Environmental Management for the RMC Industry, National Ready Mixed Concrete Association, 2009.
http://my.nrmca.org/scriptcontent/BeWeb/Orders/ProductDetail.cfm?pc=2PEMRM
From the web site: The document describes best industry practices for water management, air quality management, admixture, chemical and fuel storage issues, noise management, hazardous waste management, best management practice for fleet maintenance shops, plant aesthetics, plant closures, environmental security and sustainability issues.

Related Resource:

> Caltrans' Office of Structural Materials advised that information relevant to this Preliminary Investigation appears on page 59 of this publication. The report is available for purchase, and the agency's Materials and QA Sub Task Group may be able to provide the complete report to others within Caltrans.

AASHTO M157, Standard Specification for Ready-Mixed Concrete, 2011.
https://bookstore.transportation.org/item_details.aspx?ID=1818
The abstract notes that this specification covers ready-mixed concrete manufactured and delivered to a purchaser in a freshly mixed and unhardened state as hereinafter specified. Neither this standard nor its ASTM equivalent addresses RPC.

ASTM C94, Standard Specification for Ready-Mixed Concrete, 2012.
http://www.astm.org/Standards/C94.htm
This is the ASTM equivalent to AASHTO M157 for nonhighway projects. Per the ASTM web site, a revision is in process for this standard specification to address returned concrete:

> **Work Item: ASTM WK11029—Revision of C94/C94M–05 Standard Specification for Ready-Mixed Concrete**
> http://www.astm.org/DATABASE.CART/WORKITEMS/WK11029.htm
> The stated rationale for this work item is to "address returned concrete." According to this web page, work was initiated in 2006, and the status is currently listed as "draft under development." Michael Pistilli is the ASTM technical contact for this work item; we were unable to reach him for an update.

Research

"A Novel Method of Recycling Returned Concrete Using Extended Life Admixtures—A Japanese Experience," Seiji Nakamura, Lawrence Roberts, *Proceedings of the European Ready Mixed Concrete Organization (ERMCO) Congress*, 1998.
http://knelsoncr.xplorex.com/sites/knelsoncr/files/report-01.pdf
This paper describes methods for using hydration stabilizing admixtures for the reuse of RPC. According to the abstract, "dosage planning and control procedures are outlined," and "data are provided to confirm the retention of the cement's strength-producing ability."

"Admixtures for Recycling of Waste Concrete," Marco Paolini, Rabinder Khurana, *Cement and Concrete Composites*, Vol. 20, No. 2-3, April 1998: 221-229.
http://www.sciencedirect.com/science/article/pii/S0958946597000668
From the abstract: This paper deals with an overview of the chemistry and mechanisms of action of [stabilizer and activator] admixtures, their main practical uses, the effects of the use of extended set-control admixtures on the properties and durability of concrete in comparison with reference concrete, and with an overview of some other applications where this system has been successfully used.

Reusing Non-Admixtured Returned Concrete, Colin Lobo, Richard D. Gaynor, Aberdeen Group Publication No. J980621, 1998.
http://www.nrmca.org/research/34%20ret%20conc.pdf
This document summarizes research on reusing non-admixtured RPC to find out whether blending old and freshly batched concrete had harmful effects on setting time or compressive strength. "Principal variables were the amount of old concrete to be blended (5 percent, 25 percent and 50 percent by weight) and the age of the old (original mix) concrete being blended (45 minutes, 90 minutes, three hours and six hours)." The study found that "reuse of returned concrete in cool weather, under conditions where delivery and discharge are possible without excessive delay, doesn't significantly affect compressive strength. However, almost all the blended concretes in the study set faster. Thus, the blended concrete should be used in applications where setting characteristics are less critical."

Evaluation of Applications of DELVO Technology, Steven A. Ragan, Frank T. Gay, U.S. Army Corps of Engineers, Final Report CPAR-SL-95-2, December 1995.
http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA304411
The introduction (page 3 of the report) states that "the objectives of this study were (a) to verify the performance test results reported by Master Builders for concrete containing the DELVO Stabilizer and Activator and (b) to develop new applications for DELVO technology in order to reduce concrete mixture costs, increase concrete construction productivity, and reduce the adverse environmental impact associated with the disposal of waste fresh concrete." The conclusions and recommendations (page 108 of the report) address standard DELVO applications, use of DELVO in lean mass concrete and use of DELVO in mass roller-compacted concrete.

"A Study on the Reuse of Plastic Concrete Using Extended Set-Retarding Admixtures," Colin Lobo, William F. Guthrie, Raghu Kacker, *Journal of Research of the National Institute of Standards and Technology*, Vol. 100, No. 5, September-October 1995: 575-589.
http://www.nrmca.org/research/37%20nist.pdf
From the abstract: In a statistically designed experiment, the properties of blended concrete containing stabilized plastic concrete were evaluated. The variables in the study included (1) concrete age when stabilized, (2) stabilizer dosage, (3) holding period of the treated (stabilized) concrete prior to blending with fresh ingredients, and (4) amount of treated concrete in the blended batch. The setting time, strength, and drying shrinkage of the blended concretes were evaluated. For the conditions tested, batching 5 percent treated concrete with fresh material did not have a significant effect on the setting time, strength, or drying shrinkage of the resulting blended concrete. Batching 50 percent treated concrete with fresh materials had a significant effect on the setting characteristics of the blended concrete, which in turn affected the water demand to maintain slump.

"Use of Recycled Wash Water and Returned Plastic Concrete in the Production of Fresh Concrete," Jeff Borger, Ramon L. Carrasquillo, David W. Fowler, *Advanced Cement Based Materials* Vol. 1, Issue 6, November 1994: 267-274.
http://www.sciencedirect.com/science/article/pii/1065735594900353
From the abstract: This research project investigated the potential for recycling these waste concrete materials for the production of fresh concrete and mortar. A relatively new stabilizing admixture was also investigated as an aid in the recycling process. The resulting mortar was tested for compressive strength, sulfate resistance, workability, and setting time.

"Reuse of Returned Concrete by Hydration Control: Characterization of a New Concept," F. D. Kinney, *Superplasticizers and Other Chemical Admixtures in Concrete*, Vol. 119, 1989: 19-40.
http://www.concrete.org/PUBS/JOURNALS/AbstractDetails.asp?ID=2389
From the abstract: [This research] discusses a chemical approach … that allows use of concrete up to 72 hours after batching. This two-part chemical system is comprised of a stabilizer that strongly retards the hydration of all clinker minerals and a hydration initiator or activator added to stabilized concrete prior to its placement. … Data from field-batched mixes demonstrate that the plastic and hardened properties of concrete made using this chemical system are no different than those of conventionally batched concrete.

DELVO System, Master Builders Technologies, Technical Report No. 128, 1988.
Appendix H
This is the technical documentation on cement stabilizing admixture DELVO, referenced in the Army Corps of Engineers citation on page 20 of this Preliminary Investigation.

A summary of findings for **Part 1. Returned Plastic Concrete** appears in the **Executive Summary** for this Preliminary Investigation on page 2.

Part 2. Crushed Concrete – Survey

The first section of the survey described in Part 1 of this Preliminary Investigation addressed RPC. The same survey continued with a second section to address how state DOTs use crushed concrete as aggregate.

Overview of Findings

Highlights of the survey findings are summarized here. Following these highlights are the survey questions in full as well as all responses.

- Among 30 responding agencies in the United States and Canada, 26 agencies (87 percent) allow the use of crushed concrete for transportation applications. For most, there is no distinction drawn between regulations for crushed new concrete compared with crushed old concrete.
- Agencies were surveyed about which applications allow crushed concrete to be used as aggregate:
  - Twenty-four agencies said that they allow crushed concrete for “fill, embankments or noise barriers,” and four said it is commonly used. Twenty-four agencies allow it for “pavement base or subbase layers,” and 10 said it is commonly used.
  - Ten agencies allow crushed concrete for “nonstructural pavement (sidewalks, curbs and gutters, median barriers),” but only one said it is commonly used. Likewise, 10 said it is allowed for “concrete road surface course,” but only two said it is commonly used.
  - Less commonly allowed applications are asphalt road courses (three agencies), bridge substructures (three agencies) and bridge superstructures (two agencies).
- Percent weight limitations on crushed concrete vary by agencies. Those agencies that nominally allow 100 percent typically have restrictions: limitations to coarse aggregate, requirements that sources must be known and usage on only certain applications.
- Only four agencies indicated use of crushed concrete for lean base, with maximum values ranging from 25 percent to no upper limit.
- Most agencies noted the same specifications for crushed concrete as with other aggregate types. Some exceptions are noted.
- About half of the respondents (11 out of 22) cited problems in using crushed concrete as aggregate. Top among these: high pH levels (related to ASR) and groundwater leaching, high absorption of crushed asphalt concrete, and debris and contamination.
- Less than half of the respondents (nine out of 23) have considered expanding the use of crushed concrete as aggregate. Several agencies cited availability as a barrier to expanded use of crushed concrete as aggregate.
- Several agencies provided standard specifications or special provisions addressing crushed concrete as aggregate.

Survey Text, Questions and Detailed Responses

PART B. REUSE OF CRUSHED CONCRETE AS AGGREGATE
These questions center around how your agency crushes hardened concrete and reuses it as new aggregate.

12. Does your agency allow the use of crushed concrete as aggregate for transportation applications?

> Among 30 agencies responding, 26 answered “Yes” and four answered “No.” Two agencies that responded to the first section of the survey did not respond to this section.

- Yes: Alabama, Arkansas, California, Colorado, Delaware, District of Columbia, Florida, Georgia, Illinois, Indiana, Iowa, Louisiana, Maryland, Michigan, Nevada, New Hampshire, New Mexico, New York State, Ohio, Oklahoma, Pennsylvania, South Carolina, Texas, Virginia, Wyoming, British Columbia.
- No: Alaska, Hawaii, Kentucky, Utah.
- No response: Idaho, New Jersey.

If you answered “yes,” please answer these follow-up questions. Otherwise, please skip to the bottom of the page and click “continue” to conclude this survey.

13. Please describe how your agency’s practices or specifications differ for the use of crushed new concrete as aggregate compared with crushed used concrete produced by demolishing old pavements and structures.

Most of the respondents reported no differentiation in requirements between the use of new and used crushed concrete. Both Iowa and New York State noted source requirements for pavements to be recycled. Some states used this question as an opportunity to discuss further the circumstances and applications under which crushed concrete may be used as aggregate. These are addressed in more detail in Question 14.

Detailed responses follow.

Alabama	The specifications are the same for both new and old concrete. Any recycled concrete proposed for use as aggregate must meet the same specifications of approved coarse aggregate sources.
Arkansas	Considered the same.
California	No difference is made between crushed new concrete and crushed used concrete. We can only use crushed concrete as aggregate in minor concrete as long as they comply with the specifications for aggregate.
Colorado	The aggregate must meet the full aggregate requirements and all mix design criteria.
Delaware	We only use crushed concrete as a base.
Florida	No difference.
Georgia	Only allow crushed used concrete.
Indiana	No difference.
Iowa	Use any pavement under our jurisdiction, regardless of aggregate. Other pavements, must know aggregate source.
Louisiana	No difference. We don’t distinguish the two: No one crushes “new” concrete to make aggregate.
Maryland	Maryland SHA does not currently use crushed new concrete as aggregate. However, MD SHA does utilize crushed used concrete produced by demolishing old pavements and structures as a base material [to replace aggregate base material and fill embankment].
Michigan	Crushed concrete aggregate [CCA] is acceptable as an equal alternative to natural materials for most unbound applications. CCA is permitted for use as a coarse aggregate in concrete only for low volume pavement applications and other non-critical uses.
Nevada	If we were to use it as base aggregate material, it would have to pass all tests as if it were base aggregates.
New Hampshire	We do not differentiate.

New York State	Recycled concrete aggregate must come from a DOT project so that we are comfortable we are not getting any contaminates, reactive products, etc.
Ohio	We have a supplement for use of cycled concrete aggregate both as fill and as aggregate in new concrete. While we allow use in new concrete we have not seen the industry use of it as bid costs don't support it.
Oklahoma	Not addressed in our specifications.
Pennsylvania	No differences.
South Carolina	No difference.
Texas	There is no difference in specifications and/or practices for the use of crushed new concrete as aggregates compared with crushed used concrete.
Wyoming	Recycled concrete not allowed in concrete mixes; only use in blended bases at varying percentages.
British Columbia	Concrete structure would be demolished and hauled away or broken up and used in a fill for embankment structure.

14. For which applications is use of crushed concrete as aggregate permitted or not permitted by your agency? For which is it commonly used? (Check all that apply.)

Twenty-eight respondents answered one or more parts of this question. The most common applications by far were "fill, embankments or noise barriers" (24 respondents) and "pavement base or subbase layers" (24). Ten respondents also noted that crushed concrete was commonly used for pavement base or subbase. A summary table follows. Detailed responses by agency are included as a table in Appendix I.

	Permitted	Not Permitted	Commonly Used
Fill, embankments or noise barriers	24		4
Pavement base or subbase layers	24	1	10
Nonstructural pavement (sidewalks, curbs and gutters, median barriers)	10	13	1
Concrete road surface courses	10	13	2
Lean concrete base	6	16	
Asphalt road surface courses	3	19	
Bridge substructures	3	19	
Bridge superstructures	2	19	

Follow-up question: For applications where crushed concrete is used as aggregate, on approximately what percentage of projects?

Responses ranged widely, as shown in the detailed responses below. These are sorted in descending order by percentage of projects.

Texas	It varies by region. Houston area virtually 100% of paving projects.
Wyoming	100% on pavement reconstruction projects; use up to 60% in a blended base.
Iowa	60%-80% use as recycled aggregate granular base.
Louisiana	More than half, by guesstimate; virtually whenever available (second respondent).

New Mexico	Maximum of 50% by weight.
Delaware	25%
Illinois	20%
Michigan	20%
District of Columbia	15%
New York State	Less than 10% of projects use recycled concrete aggregates—mostly for earthwork items.
South Carolina	5%
Florida	Less than 5%.
Georgia	Less than 5%.
Pennsylvania	Less than 5%.
Maryland	2%
Nevada	2%
Alabama	None to date. We have not had a project recently that used crushed concrete.
Ohio	0%
Arkansas	Unknown.
British Columbia	We use very little recycled rigid pavement as our pavements are 99% asphalt cement.
California	Unknown.
Colorado	We do not track that information.
Indiana	We have just completed a study on adding recycled concrete aggregate to concrete. We currently allow recycled concrete aggregate from an existing INDOT contract to be used for subgrade replacement.
New Hampshire	We are not aware that it has been used.
Oklahoma	Unsure for percentage of projects. When old concrete pavements are removed, they are often crushed and reused as the aggregate base layer.

15. What are your agency's limitations of crushed concrete, by percent weight of total aggregate, into a new concrete mix?

Twenty-five agencies responded to this question. Among the nine agencies that allowed crushed concrete, all allowed up to 100 percent, at least under some conditions.

- South Carolina allows 100 percent of coarse aggregate to be crushed concrete from approved sources.
- Texas allows 100 percent coarse aggregate and 20 percent fine aggregate.
- New York State treats crushed concrete as a lightweight coarse aggregate and addressed absorption and gradation issues.
- Nevada and Ohio noted that it must meet aggregate specifications.
- Indiana has used 30 percent to 50 percent crushed concrete in new concrete mix but has not yet determined an upper limit.
- California allows up to 100 percent in minor concrete, fill materials, lean concrete base, aggregate base and subbase.

Eleven agencies said crushed concrete was not allowed for this application. Florida re-emphasized that it is not permitted in structural concrete. Three agencies (including one that allows this practice—Nevada) said it is not used or little used, and two more responded "not addressed" or "not applicable."

Detailed responses follow.

Arkansas	Not allowed.
California	Up to 100% in minor concrete, fill materials, lean concrete base, aggregate base and subbase.
Colorado	None currently; tracking FHWA/CP Tech Center study on this topic.
Delaware	0
District of Columbia	No limitation on percentage.
Florida	None for non-structural. Re-emphasize—not permitted in structural concrete.
Georgia	Not allowed.
Illinois	No limit.
Indiana	We allow up to 100% in embankments and subgrade replacements. Our study using recycled concrete aggregate in concrete used sections with 30% and 50% recycled concrete aggregate. We have not determined the limiting value.
Iowa	N/A.
Louisiana	Not permitted.
Maryland	Maryland SHA does not currently use recycled crushed concrete in new concrete mixes.
Michigan	0
Nevada	Not used. 100% if passed concrete aggregate specs.
New Hampshire	It is not allowed.
New Mexico	Not allowed for use in Concrete mixtures.
New York State	We will allow use of recycled concrete aggregates in concrete without limitations on percentage. We treat RCA like a light weight coarse aggregate because of absorption. This requires pile management, soaking and draining of piles prior to use. Gradation of the crushed material is a lesser issue but still a concern. Management of materials for these issues are cumbersome so we see almost no use as aggregate in concrete—primary use is for embankment and fill applications.
Ohio	Not limited except by mix design strength, shrinkage, durability and workability criteria.
Oklahoma	Not addressed in our specifications.
Pennsylvania	Not permitted.
South Carolina	In PCC pavement up to 100% of coarse aggregate is allowed if source is approved.
Texas	No limit of CA 20% of FA.
Virginia	None.
Wyoming	Not allowed.
British Columbia	Same as before: Very little used.

16. What are the percent weight limitations of crushed concrete specifically for lean concrete base, if permitted by your agency? What other special provisions does your agency have related to crushed concrete as aggregate for lean concrete base?

Among 20 agencies responding, only four indicated use of crushed concrete for lean base, with maximum values ranging from 25 percent to no upper limit.

- Illinois and New York indicated that they do not have limits on crushed concrete for lean aggregate base.
- New Mexico's limit is 50 percent by weight. In California, up to 25 percent has been allowed per special provisions, but generally it is not permitted by standard specifications.

- In addition to California as noted above, two other states, (Delaware and Colorado) responded that crushed concrete was not allowed as aggregate in lean concrete base.
- British Columbia said that "very little" is used; Oklahoma responded that this is not addressed in the state's specifications.
- The remaining 12 agencies indicated that lean concrete base was not allowed or used in their states.

Detailed responses follow.

California	0% per standard specifications; however, occasionally allowed up to 25% per special provisions.
Colorado	Same [referring to Question 15 response: "None currently"].
Delaware	0
Florida	Application not used in Florida.
Georgia	Not allowed.
Illinois	No limit.
Indiana	Do not use lean concrete base.
Iowa	N/A.
Louisiana	Not permitted.
Maryland	MD SHA does not use recycled concrete for this application.
Michigan	Not permitted.
Nevada	Nevada does not use lean concrete.
New Hampshire	It is not allowed.
New Mexico	Maximum of 50% by weight.
New York State	No limitations on percentages in a mixture—same response as Question 15 above.
Ohio	We don't have lean concrete base in Ohio.
Oklahoma	Not addressed in our specifications.
Pennsylvania	Not permitted.
South Carolina	N/A.
British Columbia	Same as before: Very little used.

17. What are your agency's testing requirements or quality control procedures for using crushed concrete as aggregate?

Most agencies noted the same specifications for crushed concrete as with other aggregate types. Specifically cited testing requirements include: gradation/sieve analysis (nine agencies), impurities or deleterious materials (six), L.A. abrasion testing (four), cleanness (three), soundness (three), durability (two), California bearing ratio (two), sand equivalent (one), specific gravity (one), toxicity characteristic leaching procedure (one), acidity/pH (one), harmful coatings (one), plastic limit (one).

A few states noted exceptions when using crushed concrete as aggregate:

- Arkansas does not require the L.A. abrasion test for crushed concrete as aggregate.
- Texas does not require the magnesium sulfate soundness test.
- In Michigan, crushed concrete must originate from a Michigan DOT pavement and is freeze-thaw tested.
- Ohio noted that quality of the aggregate for the source concrete is known.

Detailed responses follow.

Alabama	Same as required for any other approved aggregate type. These include limestone, sandstone, granite, quartzite and gravel.
Arkansas	Same requirements as those for crushed quarry stone, except no requirement for LA abrasion testing.
California	Crushed concrete can be used in above applications if they comply with the specification for aggregate. Loss in LA rattler, Cleanness Value, Soundness, Organic impurities, Sand equivalent, and Gradation.
Colorado	No change.
Delaware	Crushed Concrete must meet the same spec as our GABC (ground aggregate base course) spec.
District of Columbia	CBR and Soundness requirements for use as pavement base and subbase layers.
Florida	Gradation, LA Abrasion, Specific Gravity, Passing #200 sieve, Deleterious materials.
Georgia	Same as for regular unbound base, except where concrete is from general demolition waste. See link to specs below.
Illinois	Same as for virgin aggregates.
Indiana	Only gradation.
Louisiana	L A Abrasion max loss 40% (AASHTO T 96, "Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine"), Magnesium sulfate soundness 5 cycles max loss 15% (AASHTO T104, "Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate"), gradation, and deleterious material checks.
Maryland	Maryland SHA performs toxicity characteristic leaching procedure (TCLP) and also tests for pH, compaction and moisture. During construction placement we test run-off for pH.
Michigan	Same as natural. If used as a coarse aggregate in concrete, it must originate from an MDOT pavement or structure and must be freeze-thaw tested prior to use.
Nevada	SECTION 704 BASE AGGREGATES SCOPE 704.01.01 Materials Covered. This specification covers the quality and size of mineral materials used in base courses. REQUIREMENTS 704.02.01 General. Produce mineral aggregate from approved deposits. The use of aggregates from any source may be prohibited when: (a) The character of the material is such, in the opinion of the Engineer, as to make improbable the furnishing of aggregates conforming to the requirements of these specifications. (b) That character of the material is such, in the opinion of the Engineer, that undue additional costs may be accrued by the State. The mineral aggregate shall be clean, hard, durable, free from frozen lumps, deleterious matter, and harmful adherent coatings. 704.02.02 Deficiencies. If the product of a deposit is deficient in material passing the 4.75 mm (No. 4) sieve, filler from other approved deposits may be added at the crushing and screening plants. 704.02.03 Plastic Limits. When specified, aggregates shall conform to the applicable requirements of the following table (available from Nevada DOT).
New Hampshire	Crushed concrete must meet gradation requirements of the material being substituted and all other requirements of AASHTO M 319 ("Standard Specification for Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course").
New Mexico	Must pass cleanness and aggregate durability tests.

New York State	RCA is tested for the same criteria and test methods as any other coarse aggregate. See section 703 of our standard specifications [https://www.dot.ny.gov/main/business-center/engineering/specifications/english-spec-repository/section700.pdf, page 770].
Ohio	Original concrete would come from already known aggregate sources for aggregate quality. For use in pavement, the testing and acceptance would be based on the concrete's quality that the recycled aggregate is incorporated. There are requirements for a quality control plan and compliance and verification of that plan.
Oklahoma	Same as other aggregates.
Pennsylvania	Same quality requirements for aggregate.
South Carolina	We test for gradation and visual inspection for foreign materials such as glass, brick, wood and joint material.
Texas	Same as virgin rock except no [Magnesium Sulfate Soundness] requirement.
British Columbia	Same as before: Very little used. Just needs to meet an aggregate spec.

18. Has your agency encountered any problems in using crushed concrete as aggregate for transportation applications (beyond use as bulk fill)?

Among 23 agencies responding, 12 answered "Yes" and 11 answered "No."

- Yes: California, District of Columbia, Florida, Georgia, Illinois, Maryland, Michigan, New York State, Ohio, Oklahoma, Pennsylvania, Texas.
- No: Alabama, Arkansas, Colorado, Delaware, Indiana, Louisiana, Nevada, New Hampshire, New Mexico, South Carolina, Wyoming.

Follow-up question: If you answered "Yes," please explain.

Thirteen agencies provided follow-up comments, including two who answered "No" to the previous question. Among the issues mentioned by those who responded were high pH levels (related to the ASR) and groundwater leaching (five respondents), high absorption of crushed asphalt concrete (three respondents), debris and contamination (two respondents), mechanical properties, such as high creep and effects on flexural strength (one respondent), and chemical reactions with the RCA (one respondent).

One "No" respondent also noted that "ensuring only PCC is used for the raw material is difficult to monitor and virtually impossible to detect once crushed and blended."

Detailed responses follow among those who answered "Yes" to Question 18:

District of Columbia	Not allowed in undercut areas where groundwater and soft materials are encountered. Also not allowed in underdrains around filter fabrics.
Florida	Minor—some contamination which involves revisiting the source to offer suggestions on extra cleaning or pre-screening (selecting) material.
Georgia	Determination of maximum dry density and optimum moisture requires special attention apparently due to high absorption of the material.
Illinois	High absorption of AC in HMA High water demand in PCC Concern of road salt contamination in PCC Concern of high alkalis from existing and new cement when making PCC (ASR).

Maryland	pH issues. If pH is measured at 12.5 Standard Units or above, it is considered hazardous materials by the Maryland Department of the Environment.
Michigan	Leachate.
New York State	Concerns with source and material characteristics, based on ASR problems and mixture handling from higher absorptions (long ago) lead to the requirements described above.
Ohio	Ohio does not allow the use of RCA as a replacement for aggregate base. There are environmental runoff issues and we have had issues with the RCA re cementing and causing a change in support of the above concrete pavement. That leads to cracking and deterioration of the concrete pavement.
Oklahoma	Problems with contamination from construction debris and soil when crushed concrete came from a source that collected general construction demolition waste.
Pennsylvania	A recent investigation of settled concrete pavement indicated a possible reaction between recycled concrete aggregate used as subbase material when slag aggregate was used as an open-graded subbase drainage layer on top of the recycled concrete layer.
Texas	We have learned positive and negative lessons. In light of higher creep values, recycled concrete aggregates are no longer allowed in structural concrete. In addition, the project showed recycled fine aggregate has an adverse effect on flexural strength. We also learned that the material is highly absorbent, making moisture control of recycled aggregate critical. We recommended being selective in what is crushed, maintaining uniformity of material types in stockpiles and aggressively monitoring moisture for success in using recycled aggregate in concrete paving applications.

Detailed responses follow among those who answered "No" to Question 18:

Delaware	We don't use crushed concrete in new concrete because of ASR.
Louisiana	However, ensuring only PCC is used for the raw material is difficult to monitor and virtually impossible to detect once crushed and blended.

19. Has your agency considered expanding the use of crushed concrete as aggregate (higher allowed percentages or for more applications)?

Among 23 agencies responding, nine answered "Yes" and 14 answered "No."

- Yes: California, Florida, Georgia, Indiana, Louisiana, Maryland, Michigan, Ohio, Pennsylvania.
- No: Alabama, Arkansas, Colorado, Delaware, District of Columbia, Illinois, Iowa, Nevada, New Hampshire, New Mexico, New York State, Oklahoma, South Carolina, Texas.

Follow-up question: If you answered "Yes," please describe the outcome of such efforts.

Expanded applications of crushed concrete include use in French drains, foamed asphalt, open graded unbound base and gabions. Several agencies cited availability as a barrier to expanded use of crushed concrete as aggregate.

Detailed responses follow:

California	2006 Standard Specifications originally only allowed up to 50% use of crushed concrete for subbase or base. The new 2010 Standard Specifications lift the limit and increases the allowable amount of crushed concrete to 100% in the above applications.
Florida	Currently researching use for French drains (ex-filtration trenches in other states). Expansion limited by availability of sources.
Georgia	Has been considered, but no current research is underway.
Indiana	Considering more applications for use of recycled concrete aggregate in concrete.
Louisiana	We would like to use more of it, but there is a limited supply. We have just wrapped up our revisions to our Standard Specifications book (published every five years or so), and the final draft does not have any new uses or allowances for RPCC. I was on that committee and there was virtually no discussion on expanding where it could be used.
Maryland	We are currently expanding use in foamed asphalt. We also may be looking to used crushed aggregate in noise barriers and new concrete. Currently we are researching these efforts.
Michigan	Recently permitted its use for open graded unbound base. It is permitted for use by special provision in permeable stabilized aggregate base under concrete pavements.
Ohio	See above [response to Question 18].
Pennsylvania	Use in gabions.

20. Please provide links to any state DOT standards or mix designs for use of crushed concrete as aggregate. (If these are not available online, please email files to brian.hirt@ctcandassociates.com.)

Sixteen agencies provided specifications. Links are provided below:

Alabama	Standard Specifications for Highway Construction, http://www.dot.state.al.us/conweb/doc/Specifications/2012%20DRAFT%20Standard%20Specs.pdf, Section 501 (page 246) and Section 450 (page 215).
Arkansas	Allowed by Contract Special Provision. Provided via email: Appendix J.

California	• 2010 Standard Specs: http://www.dot.ca.gov/hq/esc/oe/specifications/std_specs/2010_StdSpecs/2010_StdSpecs.pdf:
	  o Section 19 - Earthwork (page 259).
	  o Section 28 - Lean Concrete Base (page 375).
	  o Section 90 - Concrete (page 967).
	• CalRecycle info on Caltrans Specifications for Aggregate Base and Subbase, http://www.calrecycle.ca.gov/condemo/Specs/CaltransAgg.htm.

District of Columbia	Standard Specifications for Highways and Structures, http://www.dc.gov/DC/DDOT/Projects+and+Planning/Standards+and+Guidelines/DDOT+Standard+Specifications+for+Highways+and+Structures+-+2009.
Florida	• Coarse Aggregate: ftp://ftp.dot.state.fl.us/LTS/CO/Specifications/SpecBook/2010Book/901.pdf. • Base (as Graded Aggregate Base): ftp://ftp.dot.state.fl.us/LTS/CO/Specifications/WorkBook/Jan2012/SP2040000.pdf. • Mix designs: proprietary and not available.
Georgia	Special Provisions, Section 815—Graded Aggregate, http://www.dot.ga.gov/doingbusiness/TheSource/special_provisions/shelf/sp815.pdf.

Illinois	Recycling Portland Cement Concrete into Aggregate, http://www.dot.state.il.us/materials/pdf/7-08.1recyclingportlandcementconcrete.pdf.
Indiana	Standard Specifications, http://www.in.gov/dot/div/contracts/standards/book/index.html.
Louisiana	Specifications and Forms for Construction Proposals, http://www.dotd.la.gov/highways/specifications/.
Maryland	Provided via email [Appendix K].
Michigan	2012 Standard Specifications for Construction, http://mdotwas1.mdot.state.mi.us/public/specbook/2012/.
New York State	Same mix design procedures used for RCA as for mixtures using virgin aggregates—just need to manage RCA differently. 99.9% of use is for earthwork items under Section 203 (page 156 of Standard Specifications, https://www.dot.ny.gov/main/business-center/engineering/specifications/english-spec-repository/espec-english-cd.pdf) and Section 304 (page 209). Use in PCC happens only about once every 10 years because producers feel QC and QA is too cumbersome when sufficient supply of virgin materials exists.
Ohio	Supplement 1117: Concrete Using Recycled Coarse Aggregate for Concrete Pavement and Incidental Items, http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/S%201117Concrete%20using%20Recycled%20Coarse%20Aggregate%20for%20Concrete%20Pavement%20and%20Incidental%20Items%20.pdf.
Pennsylvania	Guidance Document for Reclaimed Portland Cement Concrete, ftp://ftp.dot.state.pa.us/public/Bureaus/design/SEMP/RPCC/RPCC%20Guidance-final.pdf.
South Carolina	Standard Specifications for Highway Construction, http://www.scdot.org/doing/doingPDFs/2007_full_specbook.pdf. See section 305 (page 159) for Graded Aggregate Base Course. Special provision for recycled concrete used as coarse aggregate in PCC pavement provided via email [Appendix L].
Texas	Recycled Concrete Aggregate, http://www.txdot.gov/business/contractors_consultants/recycling/concrete_aggregate.htm.

Part 2. Crushed Concrete – Interviews

The survey results shows that the use of crushed concrete as aggregate is common among many states, and barriers related to processing and availability are partly why the use of crushed concrete is not more widespread. We focused our expert interviews to learn more about what is coming next regarding crushed concrete as aggregate: How are standards changing? What are the new national priorities? What technologies are coming?

Recycled Materials Resource Center
David Gress, Assistant Director, RMRC, and Professor of Civil Engineering, University of New Hampshire

During our discussions with David Gress (see **Interviews and Issues** in Part 1 of this Preliminary Investigation, page 14), we also addressed the topic of crushed concrete used as aggregate.

Gress provided a great deal of technical information about the use of crushed concrete in a recent publication: Chapter 8, "End of Life Recycling Concepts and Strategies" in the CP Tech Center publication *Sustainable Concrete Pavements: A Manual of Practice*. (See the full citation in **Resources** on page 35.) In this chapter, Gress presents the comparative performance of pavements built from recycled and virgin aggregate; those built from RCA were found to perform as well or better than their controls.

He also discussed latest trends in crushed concrete reuse among DOTs, describing how many are not taking full advantage of the latest technology, but instead are using it as a low value aggregate such as pavement base material. He described a move at FHWA toward promoting use of multiple-lift concrete pavements—a practice once common in the United States and still common in Europe, as discussed in more detail in FHWA's August 2007 issue of *Focus* magazine, "Take a Look at Two-Lift Concrete Paving" (http://www.fhwa.dot.gov/publications/focus/07aug/02.cfm).

FHWA is soliciting proposals (request for applications no. DTFH61-12-RA-00014) for a five-year program titled "Technology Transfer of Concrete Pavement Technologies" to promote the two-lift procedure as high priority. Gress said that for a two-lift concrete pavement, recycled concrete can be effectively used as aggregate in constructing the thicker bottom lift, which is then covered by a thin top lift made of high-quality aggregate. Using a concrete with lower elastic modulus in the bottom lift increases the fatigue life of the pavement, thus reducing life-cycle costs. Virgin aggregate can be imported as needed for the thin (one- to two-inch) top layer designed for noise reduction or improved skid resistance—both very important public and user issues. Gress said this technique has the "tremendous advantages" of sustainable design and lower costs.

Gress also mentioned guidance by the NRMCA about the process of bringing unused fresh concrete back to the plant, letting it harden and then crushing and using it as an aggregate substitute in new concrete. This issue is addressed in the 2007 NRMCA report, Crushed Returned Concrete as Aggregates for New Concrete (cited in **Resources** on page 36).

National Ready Mixed Concrete Association
Colin Lobo, Senior Vice President, Engineering

During our discussions with Colin Lobo (see **Interviews and Issues** in Part 1 of this Preliminary Investigation, page 14), we also addressed the topic of crushed concrete used as aggregate.

Lobo described how crushed concrete used as aggregate is a recognized process in many states. FHWA has documented projects where crushed concrete—typically the coarse fraction—is used as aggregate in concrete for new pavement. In addition, crushed concrete is commonly used as pavement base.

Lobo suggested that we discuss new FHWA initiatives on the expanded use of crushed concrete with Tom Cackler, director of the CP Tech Center at Iowa State University. He said that AASHTO is also looking at revising its crushed concrete standard (AASHTO MP16, Standard Specification for Reclaimed Concrete Aggregate for Use as Coarse Aggregate in Hydraulic Cement Concrete, cited in **Resources** on page 35) to see how to make its use more achievable in practice. This is discussed further in our interview with Scott Seiter, which follows.

Oklahoma DOT
Scott Seiter, Assistant Division Engineer

We spoke with Scott Seiter, chair of Technical Section 1c (Aggregates) of the AASHTO Highways SOM, and he discussed recent work by that group to address crushed concrete. Seiter said that SOM is balloting revisions to AASHTO MP16. He explained that the main issue with the current version of this document is that it came out several years ago and included language related to RCA that now appears overly cautious. SOM is aiming to bring the language up to date with other AASHTO specifications and current practice and research. The goal is to make the guide specifications more usable for states that are to employ RCA. Substantial work on revised language has been done by the RCA Expert Task Group, which was established through efforts of FHWA and the CP Tech Center.

Seiter said that preliminary balloting on revisions to AASHTO MP16 is in process this summer. Ideally it will be formally balloted to all states this winter and adopted in 2013.

American Concrete Institute
Mohamed Mahgoub, Chair, ACI Committee 555: Concrete with Recycled Materials, and Assistant Professor, Department of Engineering Technology, New Jersey Institute of Technology

We spoke with Mohamed Mahgoub, incoming chair of American Concrete Institute Committee 555 (Concrete with Recycled Materials). As noted on the committee's web page (http://www.concrete.org/COMMITTEES/committeehome.asp?committee_code=0000555-00), the mission of this committee is to "develop and report information on recycled concrete and other recyclable materials in concrete."

Mahgoub said that the committee has been developing new guidelines for RCA, and he expects these to be published soon. He said Caltrans should contact him to learn more about the committee's upcoming open meeting October 22, 2012, in Toronto. Mahgoub also said that next year's Innovation in Conservation conference, to be held October 20-24, 2013, in Phoenix, will feature two technical sessions with paper presentations on the state of the art for recycled concrete.

Related Resources:

Older ACI publications related to this committee's activity are available for purchase through the committee's web page:

SP-219: Recycling Concrete and Other Materials for Sustainable Development, 2004.
This publication presents 11 papers that promote and encourage the use of recycled concrete and other materials in concrete construction, taken from presentations at the 2003 ACI Spring Convention in Vancouver. "Specific subject areas include the global perspective, challenges and

opportunities of concrete recycling, the barriers to recycling concrete in highway construction, and current practices in the European Union, Japan, and [the United States].”

According to Mahgoub, some of the materials in this publication will be updated and incorporated into ACI’s forthcoming guidelines on RCA.

555R-01: Removal and Reuse of Hardened Concrete, 2001.
This report “presents information on removal and reuse of hardened concrete. Guidance for assessment of concrete structures for complete or partial demolition is provided. … Considerations for evaluating and processing waste concrete for production of aggregates suitable for reuses in concrete construction are presented.”

Part 2. Crushed Concrete – Resources

Several resources are provided for more information about the use of crushed concrete as an aggregate. They are grouped into four areas:

- **Specifications and National Guidance** include documentation to assist with the use of crushed concrete as aggregate for U.S. pavement applications.
- **Research and Case Studies** further explore the use of crushed concrete as aggregate, examining issues and addressing common concerns.
- **International Guidance and Research** touches on the use of crushed concrete globally, presenting a few points from Europe and Oceania describing the state of the practice overseas.
- **Web Sites** includes details about several of the organizations noted throughout this investigation.

Specifications and National Guidance

Sustainable Concrete Pavements: A Manual of Practice, Tom Van Dam, Peter Taylor, Gary Fick, David Gress, Martha VanGeem, Emily Lorenz, National Concrete Pavement Technology Center, January 2012.
http://publications.iowa.gov/12058/1/971efe90-1ec8-4486-a915-a59ba0679169.pdf
From the abstract: "Developed as a more detailed follow-up to a 2009 briefing document, *Building Sustainable Pavement with Concrete*, this guide provides a clear, concise, and cohesive discussion of pavement sustainability concepts and of recommended practices for maximizing the sustainability of concrete pavements."

> **Chapter 8, End of Life Recycling Concepts and Strategies**, David Gress, page 67.
> As noted in **Interviews** on page 32 of this investigation, this chapter provides a comprehensive review of RCA, including physical, chemical and mechanical properties of RCA aggregate; the properties of plastic and hardened RCA concrete; and the use of RCA as a base material.

AASHTO MP16, Standard Specification for Reclaimed Concrete Aggregate for Use as Coarse Aggregate in Hydraulic Cement Concrete, 2012.
https://bookstore.transportation.org/item_details.aspx?ID=1652
From the abstract: This specification covers coarse aggregate derived from reclaimed concrete for use in hydraulic cement concrete.

Properties of Concrete Containing RCA, fact sheet, American Concrete Pavement Association, 2010.
http://www.pavement.com/Downloads/TS/EB043P/TS043.5P.pdf
This fact sheet describes the differences in properties between RCA and virgin aggregate and the resulting concrete mix derived from either of these. It addresses the properties both of fresh RCA concrete and hardened RCA concrete. A table presents the expected impacts on 14 properties of hardened concrete by using either coarse RCA or coarse and fine RCA, as compared with virgin aggregate.

Recycling Concrete Pavements, American Concrete Pavement Association, Publication No. EB043P, 2009.
https://netforum.avectra.com/eweb/shopping/shopping.aspx?site=acpa_org&prd_key=d8f0e4a2-465a-4386-a7c9-875b29eea221
This is a comprehensive guide on recycling concrete for use in new concrete pavement structures. Chapters cover production, properties, characteristics and uses of RCA as well as properties, performance and recommendations for concrete pavement structures containing RCA. A number of appendices address guidelines for removing and crushing existing concrete, using RCA in unstabilized (granular) subbases and using RCA in concrete pavement mixtures.

Research and Case Studies

"Concrete Recycling: RCA's Better Picture—ASR-Affected Concrete Can Still be Used for Recycling," Matthew P. Adams, Jason H. Ideker, *Better Roads*, January 2012.
http://www.roadsbridges.com/concrete-recycling-rca%E2%80%99s-better-picture
This article describes research to address questions about RCA durability related to deterioration from ASR. The findings show promise for the feasibility of using ASR-affected RCA.

A Technology Deployment Plan for the Use of Recycled Concrete Aggregates in Concrete Paving Mixtures, S. Garber, R. Rasmussen, T. Cackler, P. Taylor, D. Harrington, G. Fick, M. Snyder, T. Van Dam, and C. Lobo, National Concrete Pavement Technology Center, June 2011.
http://www.intrans.iastate.edu/reports/RCA%20Draft%20Report_final-ssc.pdf
This report addresses the barriers that limit the use of RCA in new concrete paving mixtures, grouping these into three primary categories: compliance, quality and production. It proposes the creation of a technical working group and four programs to address these barriers: outreach and communication, training, technical support and demonstration projects. The report also includes the results of a survey of state DOTs to benchmark current use of RCA in new concrete paving mixtures.

Crushed Returned Concrete as Aggregates for New Concrete, Karthik Obla, Haejin Kim, Colin Lobo, National Ready Mixed Concrete Association, September 2007.
http://www.nrmca.org/research_engineering/documents/cca_study,final_report,9-07.pdf
This research describes an experimental program on aggregate produced from returned concrete that is allowed to harden and then is crushed. Distinctions are drawn between such crushed concrete aggregate (CCA) and RCA sourced from demolishing old concrete structures. The experimental component of the study describes the properties of CCA in detail and compares concrete made with CCA and with virgin aggregates.

Transportation Applications of Recycled Concrete Aggregate—FHWA State of the Practice National Review, FHWA, September 2004.
http://www.rmrc.unh.edu/Research/tools/RCAREPORT.pdf
This report explores performance, resource conservation and economic factors associated with using RCA by examining five states as case studies (California, Michigan, Minnesota, Texas and Virginia). Construction issues discussed in detail include water demand, workability, air entrainment, compaction/drainage and base stiffness leading to reflective cracking. This report was summarized in detail by Caltrans in advance of the request for this Preliminary Investigation.

Recycling Portland Cement Concrete Pavements, *NCHRP Synthesis Report 154*, 1989.
http://www.trb.org/Publications/Blurbs/154476.aspx
From the abstract: Information is provided on the processes and procedures used by a number of states in using PCC pavement as aggregate in reconstructed concrete pavement. … This report … describes the processes used on various projects in several states, giving details of construction procedures, as well as test results on various properties of the recycled aggregates and the resultant concrete.

International Guidance and Research

"Guide to Pavement Technology Part 4E: Recycled Materials," *Austroads*, 2009.
https://www.onlinepublications.austroads.com.au/items/AGPT04E-09
From the abstract: Part 4E of the Guide to Pavement Technology presents the latest information on recycled materials as they pertain to products manufactured from recycling various wastes accepted through registered recycling and reprocessing facilities. In particular, this guide deals with the specification, manufacture and application of incorporating recycled materials into products commonly used in pavement construction. … An environmental process which may be followed to evaluate the suitability of a new source of waste with the potential to be recycled into pavement material products is introduced in this guide.

"Using Recycled Concrete Aggregates in New Zealand Ready-Mix Concrete Production," Wentao Zhang, Jason M. Ingham, *Journal of Materials in Civil Engineering*, Vol. 22, No. 5, 2010: 445-450.
http://trid.trb.org/view/2010/C/918592
From the abstract: Although current New Zealand practices include some use of crushed concrete in road construction, use of RCA in low specification concrete is currently infrequent and the use of recycled concrete as an aggregate source in structural concrete applications is rare. To make such recycling feasible, the properties of RCA must be related to the properties of new concrete that utilizes the recycled aggregates. In response to this need, a study was undertaken to investigate the feasibility of using RCA as a viable alternative to natural aggregate (NA) in the production of concrete manufactured in a conventional New Zealand ready mix concrete plant. Aggregate properties and hardened and fresh concrete properties of RCA concrete were studied and compared with the associated properties derived from NA concrete. Results indicated that RCA is a viable alternative to NA in the production of concrete.

"Quality of Reused Crushed Concrete: Strength, Contamination and Crushing Technique," Christer Molin, Kjell Larsson, Håkan Arvidsson, *Proceedings of the International RILEM Conference on the Use of Recycled Materials in Buildings and Structures*, Barcelona, Spain, November 2004.
http://congress.cimne.upc.es/rilem04/admin/Files/FilePaper/p199.pdf
This Swedish research highlighted relevant factors influencing the quality of reused crushed concrete. Researchers compared common understanding and trends with their experiences with typical Swedish materials.

Recycling and Use of Recycled Aggregates, ECOserve, 2003.
http://www.eco-serve.net/publish/cat_index_78.shtml
European Construction in Service of Society, or ECOserve, is a network launched by the European Commission in 2003. Its main objective is "to identify the needs of the European Construction Industry in its endeavor towards sustainability of the industries' products and production processes." The outlook for concrete recycling in Europe is summarized on this page.

Web Sites

ConcreteRecycling.org, Construction Materials Recycling Association, 2012.
http://www.concreterecycling.org/
From the web site: Created by the Construction Materials Recycling Association, this site provides all of the available information about concrete recycling. Information contained here will assist recyclers in increasing their markets and will answer questions regulators and purchasing agents for end markets, such as state DOT officials, might have about the recycled concrete aggregate product.

American Concrete Institute, 2012.
http://www.concrete.org
ACI is a nonprofit technical and educational society that addresses matters and solves problems related to all aspects of concrete. It conducts such activities through "conventions and meetings; the *ACI Structural Journal*, the *ACI Materials Journal*, *Concrete International*, and technical publications; chapter activities; and technical committee work." Its mission is to "provide knowledge and information for the best use of concrete."

American Concrete Pavement Association, 2012.
http://www.pavement.com/
From the web site: American Concrete Pavement Association is the premier national trade organization for concrete paving contractors, cement and material producers, equipment manufacturers and any company with an interest in concrete airports, highways, roads, streets and industrial pavements.

National Ready Mixed Concrete Association, 2011.
http://www.nrmca.org/
From the web site: The National Ready Mixed Concrete Association is the leading industry advocate [of the ready-mixed concrete industry]. Our mission is to provide exceptional value for our members by responsibly representing and serving the entire ready mixed concrete industry through leadership, promotion, education and partnering to ensure ready mixed concrete is the building material of choice.

National Concrete Pavement Technology Center, 2010.
http://www.cptechcenter.org/
From the web site: The National Concrete Pavement Technology Center (National CP Tech Center) at Iowa State University is a national hub for concrete pavement research and technology transfer. The Center was founded in 2000 and currently has four industry sponsors: the American Concrete Pavement Association (ACPA), the Concrete Steel Reinforcing Institute (CRSI), the Iowa Department of Transportation, the Iowa Concrete Paving Association (ICPA), and the Portland Cement Association (PCA). The Center has been instrumental in developing and helping to advance the nation's strategic plan for concrete pavement research, The CP Road Map.

Recycled Materials Resource Center, 2010.
http://www.rmrc.unh.edu/
The Recycled Materials Resource Center is a partnership between the University of New Hampshire and the University of Wisconsin.

From the web site: The Center has four basic missions:

- To systematically test, evaluate, develop appropriate guidelines for and demonstrate environmentally acceptable increased use of recycled materials in transportation infrastructure construction and maintenance.
- To make information available to state transportation departments, the Federal Highway Administration, the construction industry, and other interested parties.
- To encourage the increased use of recycled materials by using sound science to analyze potential long-term considerations that affect the physical and environmental performance.
- To work cooperatively with Federal and State officials to reduce the institutional barriers that limit widespread use recycled materials and to ensure that such increased use is consistent with the sustained environmental and physical integrity. The center has a special interest in the long-term physical and environmental consequences of recycled material use.

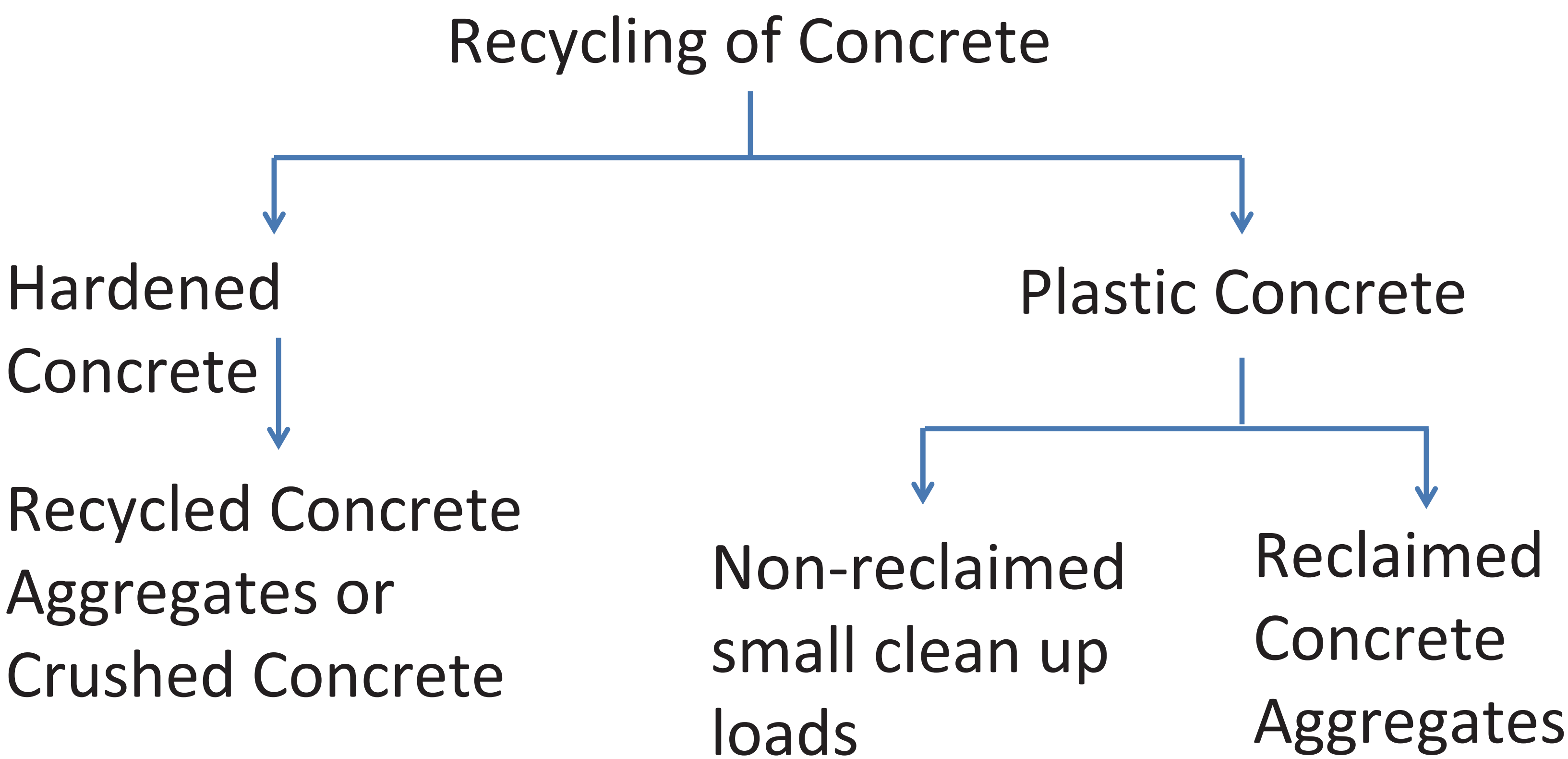
International Center for Aggregates Research, University of Texas at Austin, 2012.
http://www.icar.utexas.edu/index.cfm
From the web site: The Center's mission encompasses research, education, and information exchange:

- To conduct scientific and technical research related to aggregates.
- To develop undergraduate and graduate engineering courses and continuing education and training program on aggregate topics.
- To establish a central information clearinghouse on aggregates technology.
- To provide technology transfer to translate research results to practice.
- To cooperate and do cooperative aggregate research with other universities when appropriate.
- To establish appropriate business school or marketing input to improve the application of programs and results in the construction industry.

AASHTO Highways Subcommittee on Materials, undated.
http://materials.transportation.org/default.aspx
This web site includes rosters, announcements and links for all AASHTO SOM technical sections, including 1c (Aggregates).

A summary of findings for **Part 2. Crushed Concrete** appears in the **Executive Summary** for this Preliminary Investigation on page 3.

Recycling of Concrete



Recycled Concrete Aggregates

Definition: Crushing of existing concrete to generate aggregates

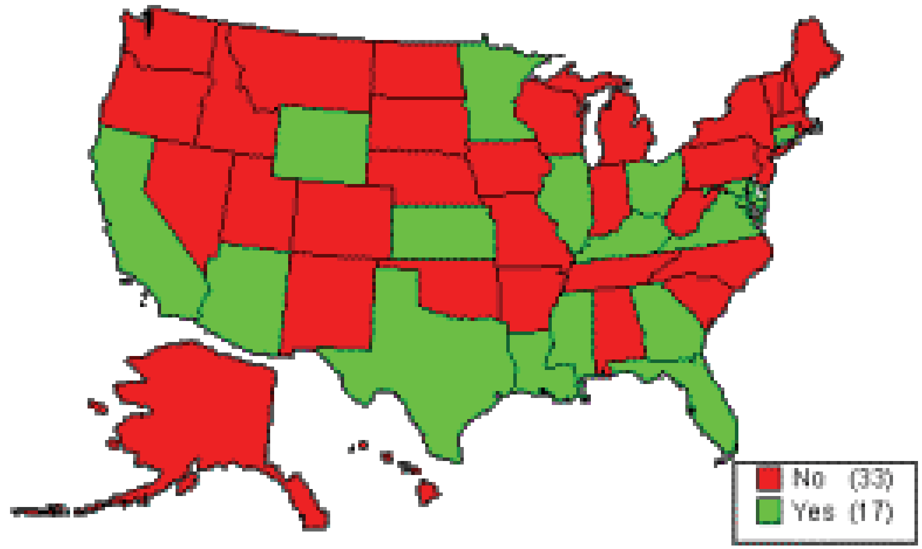


Figure 5 Miscellaneous aggregate

California is one of the 17 states that uses recycled concrete aggregates for variety of applications*

*http://www.fhwa.dot.gov/Pavement/recycling/rca.cfm

Where Caltrans Uses it?

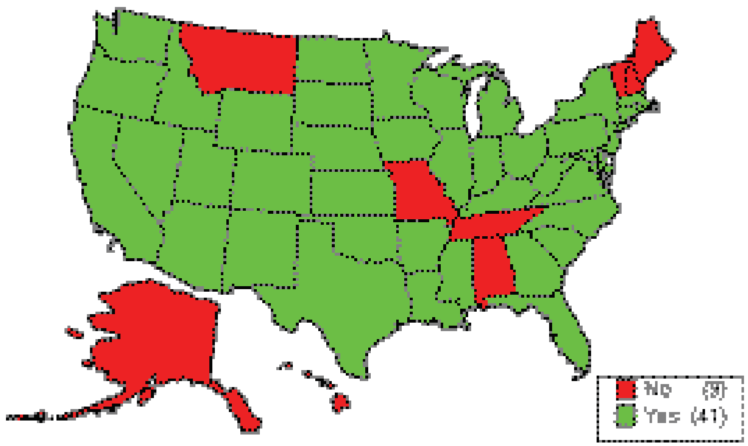


Figure 1 Recycling concrete as aggregate

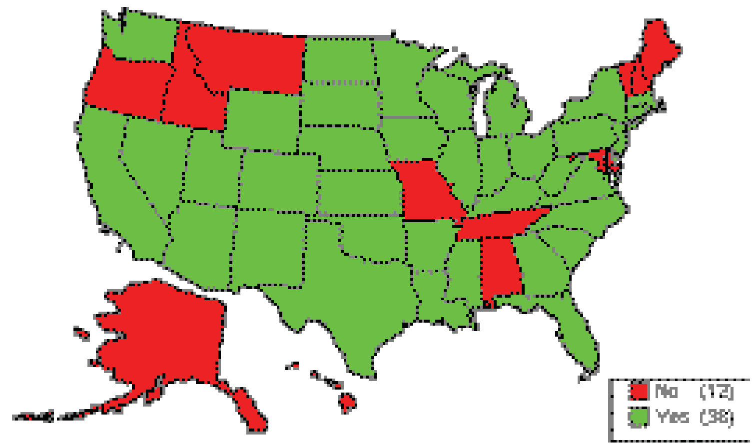


Figure 2 Base Aggregate

Caltrans has always allowed RCA for base and sub-base courses

Latest Caltrans Specifications addressing RCA:

Section 19: Earthwork (new addition)

Section 25: Aggregate Sub-base

Section 26: Aggregate Bases

Section 90: Concrete (new addition)

Section 19- Earthwork

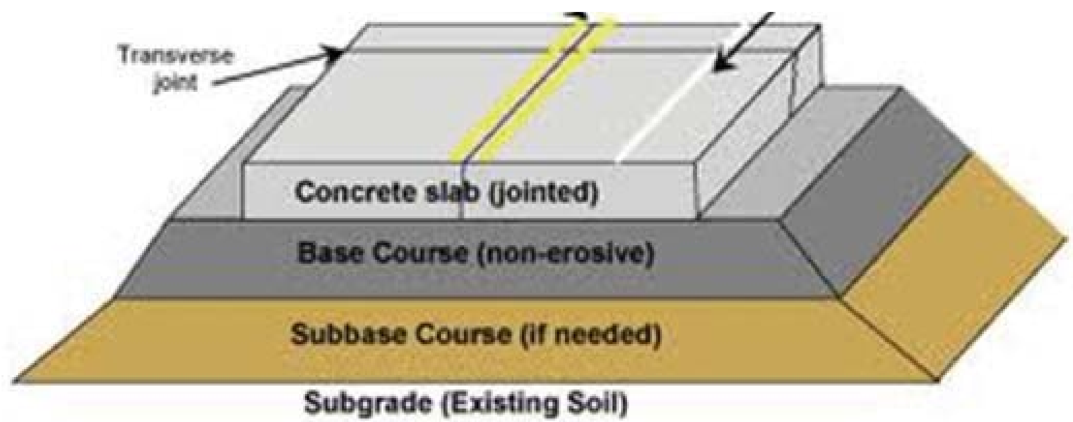
2006 Specification did not explicitly allow for backfill or backing

2010 Specifications allow up to 100% recycled concrete for shoulder backing and other backfill

Section 25: Aggregate Sub-base

Aggregate sub-base: A layer of rocks supporting and distributing heavy pavement loads to the ground

2006 Standard Spec only allowed up to 50% by volume of recycled concrete



2010 Specification allows up to 100% of recycled aggregates in aggregate in all classes of sub-base

Section 26: Aggregate Bases

Aggregate Bases: The layer supporting pavement and transferring loads to sub-base

2006 Standard Spec only allowed up to 50% by volume of recycled concrete

2010 Specification, allows up to 100% of recycled aggregates in aggregate bases for most classes

Recycled concrete being used on base course

Recycled Concrete Aggregates in PCC

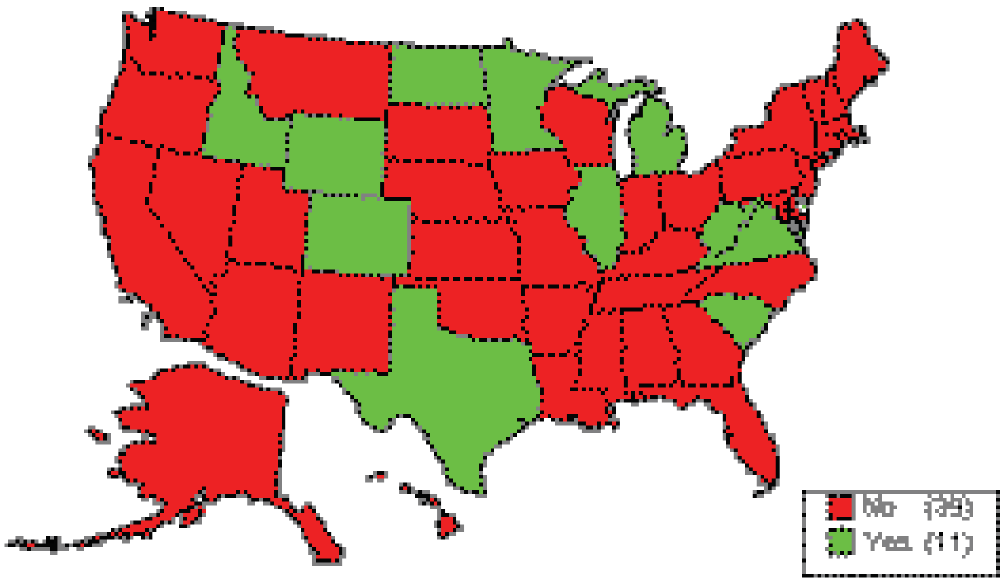


Figure 3 PCC aggregate

Even though 2008 FHWA study* doesn't reflect it,

*http://www.fhwa.dot.gov/Pavement/recycling/rca.cfm

Recycled Concrete Aggregates in PCC

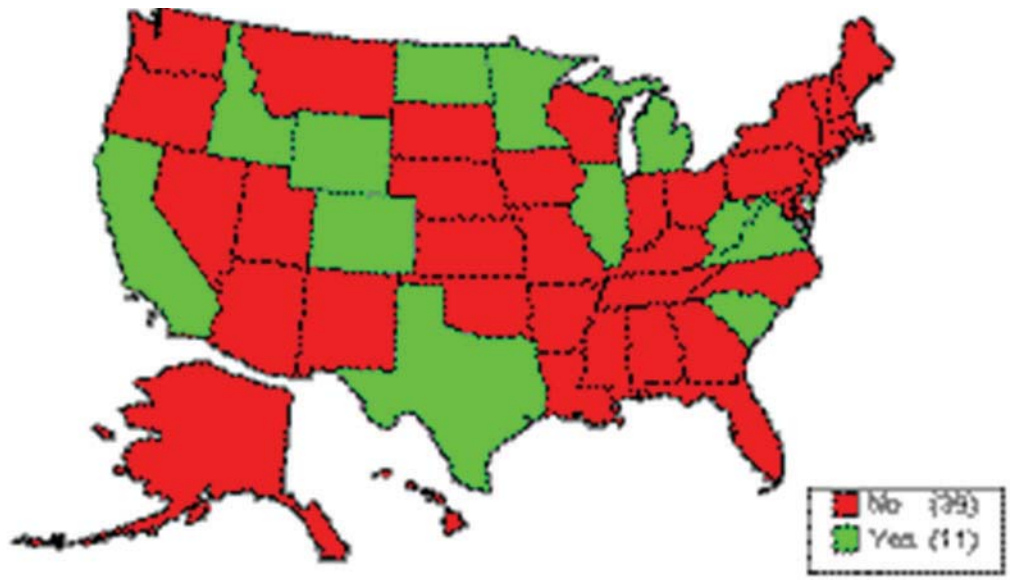


Figure 3 PCC aggregate

Even though 2008 FHWA study* doesn't reflect it,

Caltrans is now one of the 12 states that allow RCA in Portland Cement Concrete

2009 Amendments & 2010 plain language allows recycled concrete aggregates (Crushed concrete) in minor concrete

*http://www.fhwa.dot.gov/Pavement/recycling/rca.cfm

Section 90: Concrete

- **Minor concrete is a significant portion of Caltrans Portland Cement Concrete (PCC)**

- **Present in most projects to typically include following bid items**
  - Minor structures
  - Curb, sidewalks
  - Barrier rails
  - Gutters
  - Conduits, pipes
  - Ditch linings, backfills
  - Miscellaneous construction etc.

Section 90: Concrete

2010 Specifications allow up to 100% use of crushed concrete

"You may use crushed concrete or reclaimed aggregate"

"Minor Concrete" is referred in 10+ other sections of the standard specifications, allowing its use in variety of members and applications

Plastic Concrete: Clean up loads

Caltrans Pours:

Typically large pours with specialized structural concrete

Very insignificant quantities of clean up load
-Well calculated pre-approved quantities
-Clean up only called at the end with specific needs

Excess concrete may not be used without pre-approval for other structures, however always can be reclaimed

Plastic Concrete: Reclaimed

Reclaimed Concrete Aggregates: Recovered from plastic concrete by washing away the cementitious material

Can be used for any concrete, section 90 allows it for **Structural** as well as **Minor concrete** **up to 100%**

Wash water (from washing trucks and reclamation) can also be used **as mix water** for concrete mixes

Summary

- Recycled Concrete Aggregate is allowed for backfill, sub-base, base material and minor concrete
- Latest revisions in the specification promote more use of recycle concrete aggregates
- Caltrans is among the few states which allow recycled concrete aggregates for PCC
- Reclaimed aggregates and wash water can be used for all concrete

Updates on latest RPC activity

- Updated scoping document submitted on Dec 13, 2011
- Project team to refine scoping document, detailed workplan and schedule in next few months and submit for TG approval
- Industry looking to promote more use of crushed concrete, however need to determine primary concerns to be able to make necessary changes
- Industry also looking to use returned concrete, however need to address key questions regarding business practices, quality management and limitations of use based on past experience and research

Appendix B
CalCIMA Survey: Questions

TIME SENSITIVE—PLEASE RETURN ASAP
REUSE OF RETURNED PLASTIC CONCRETE
AUGUST 14, 2012

The California Construction and Industrial Materials Association (CalCIMA) and the California Department of Transportation (Caltrans) have formed a working group to learn the scope of Returned Plastic Concrete (RPC) reuse among concrete producers. This survey addresses RPC and will provide background information for Caltrans as they consider allowing the use of returned concrete in some applications. These questions center on recycling plastic concrete mix in its entirety, rather than practices involving washing the aggregate components out of fresh concrete to reclaim them.

1. (Optional, although a contact name is preferred in case there are questions about any response) Please provide your name, title and company. Your name and title will not be published in any report.

Name ________________________________ Title __________________________________

Company _____________________________ State ________________________________

Phone _______________________________ Email ________________________________

2. Does the DOT in your state or province allow the reuse of returned plastic concrete (RPC) for transportation applications?

Yes
No

If you answered "Yes," please indicate the permitted applications in question number 3. Otherwise, please skip to question number 4.

3. For which applications is reuse of RPC mixed with new concrete permitted or not permitted by your agency? For which is it commonly used? (Check all that apply)

Application	Permitted	Not permitted	Commonly used
Sidewalks, curbs or slopes			
Footings for lighting, signs or fences			
Median barriers			
Pipe or pull box filler			
Lean concrete base			
Controlled low strength material			

Culvert backfill

Low volume roads

High volume roads/highways

Bridge substructures

Bridge superstructures

For applications where RPC is used, on approximately what percentage of projects include RPC? (Free response)

____

4. Aside from transportation applications, what are other applications where your company would use RPC (for example, foundations, sidewalks, etc.)?

____

5. Are there limitations or guidelines by weight or volume on the use of RPC in fresh concrete? If so, what are the limits?

____

6. If you use admixtures to prevent hydration of RPC intended for reuse, please provide details: What type of admixtures? When are they used? Are they required by the standards or specifications in your state or province? (Free response)

____

____

7. Please note any batching or quality control requirements for the mixing process. (Check all that apply)

Existing RPC may be weighed in-truck and batched with a new concrete mix

Existing RPC may be weighed in-truck and batched with a new concrete mix

The commercial code (usually the Bureau of Weights and Measures) in my state/province has specific requirements for the reuse of RPC. If so, please provide details

Other—please explain

(Free response)

____

8. Has your company encountered any problems in reusing RPC for transportation applications?

Yes
No

If you answered "Yes," please explain. (Free response)

____

9. Has your company considered expanding the reuse of RPC (higher allowed percentages or for more applications)?

Yes
No

If you answered "Yes," please describe the outcome of such efforts. (Free response)

____

____

10. Please provide links to any state or provincial DOT standards or specifications related to the reuse of RPC. (Free response)

11. Aside from DOT standards or specifications, is there any other guidance for reuse of RPC is there in your state? For an example, follow this link to the California Greenbook: Standard Specifications for Public Works Construction)? (Free response)

____

____

Please return the completed survey to Charley Rea by fax, a scan of your responses or electronically [complete the form in Word and email it]. Time is of the essence.

Fax: (916) 554-1042 Email: crea@calcima.org

If you have questions, you can reach Charley Rea at Phone: (916) 554-1000 Ex. 103

If you prefer to send an anonymous response, you can mail it to: CalCIMA, 1029 J Street, Suite 420, Sacramento, CA 95814

Thank you for your assistance!

Appendix C
CalCIMA Survey: Responses

SURVEY RE
REUSE OF RETURNED PLASTIC CONCRETE
UPDATE AUGUST 28, 2012

Total Responses – 7

1. Below are the states in which the respondents operate:

   #1 – Florida
   #2 – Virginia, North Carolina, South Carolina, Georgia, Texas, and Arkansas
   #3 – Massachusetts, New Hampshire
   #4 – Texas
   #5 – Virginia
   #6 – North Dakota
   #7 – Kentucky

2. Does the DOT in your state or province allow the reuse of returned plastic concrete (RPC) for transportation applications?

   #1 – No
   #2 – No
   #3 – No
   #4 – No
   #5 – No
   #6 – No
   #7 – No

3. Although all respondents answer "no" to question #2, respondent #6 said that it is permitted for "footings for lighting, signs, or fences" and "lean concrete base." That respondent also said approximately 5% of projects include RPC.

4. Aside from transportation applications, what are other applications where your company would use RPC (for example, foundations, sidewalks, etc.)?

   #1- Residential and light commercial applications
   #2 - In 2011, we re-used approximately 14,000 CY of RPC without any problems.
   #3 – None
   #4 – Foundations, residential site work
   #5 – Reuse of returned concrete is limited to footings and walls.
   #6 – footings & walls
   #7 – footings & foundations. Also cast bin blocks for resale.

5. Are there limitations or guidelines by weight or volume on the use of RPC in fresh concrete? If so, what are the limits?

#1 – Yes. When our RPC program was started we had no limitations. In recent changes to the program, we now are limited to 50%.
#2 – Yes. Ratio of 1:1 RPC to fresh concrete.
#3 – Never Use RPC.
#4 – Yes. Age of concrete and concrete temperatures.
#5 – No.
#6 – No.
#7 – Yes. Internal guidelines for concrete temperature and slump.

6. If you use admixtures to prevent hydration of RPC intended for reuse, please provide details: What type of admixtures? When are they used? Are they required by the standards or specifications in your state or province? (Free response)

#1 – WR Grace Recover used in accordance with dosage rate excel program. The program takes into account RPC age from batch time, cement type and content, temperature, etc. Not required by specification.

#2 – BASF's Delvo stabilizer and Delvomatic software

#3 – N/A

#4 – Delvo to stabilize and additional water reducer, same as what was originally in the concrete to bring sump back up instead of water. We only ship RPC to orders of the same or less specified strength and to orders that will not relieve a hard troweled burnished finish.

#5 – We use stabilizing admixtures such as Sika 440. When considering returned concrete for reuse the age of the concrete is determined and the temperature is measured. If both are deemed acceptable, then a dosage rate is determined and the concrete is stabilized for later use.

#6 – Delvo Hydration Stabilizer supplied by BASF. No standards or specifications exist.

#7 – Do not use.

7. Please note any batching or quality control requirements for the mixing process. (Check all that apply)

(Respondent #2 checked both of the first two boxes)

XXX Existing RPC may be weighed in-truck and batched with a new concrete mix

X Existing RPC may be weighed in-truck and batched with a new concrete mix

The commercial code (usually the Bureau of Weights and Measures) in my state/province has specific requirements for the reuse of RPC. If so, please provide details

XXX Other—please explain

#1 – The RPC volume is determined by the truck operator and new concrete is added as required.

#2 – eye-balling, scales, and calibrated hopper.

#7 – Internal guidelines for concrete temperature and slump.

8. Has your company encountered any problems in reusing RPC for transportation applications?

#1 – N/A
#2 – No – Have been in use since 1988 with 99.99% success.
#3 – N/A
#4 – Yes – Not allowed. We do not ship RPC to DOT projects.
#5 – No
#6 – No
#7 – We do not use for transportation applications.

9. Has your company considered expanding the reuse of RPC (higher allowed percentages or for more applications)?

#1 – No
#2 – Yes. LEED projects, etc.
#3 – No.
#4 – No. Right now we feel we are using the maximum amount without taking risks that would result in claims.
#5 – No.
#6 – No.
#7 – No.

10. Please provide links to any state or provincial DOT standards or specifications related to the reuse of RPC. (Free response)

No responses.

11. Aside from DOT standards or specifications, is there any other guidance for reuse of RPC is there in your state? For an example, follow this link to the California Greenbook: Standard Specifications for Public Works Construction)? (Free response)

#1 – not aware of any
#2 – BASF Guidance
#3 – No
#4 – no answer
#5 – No
#6 – no answer
#7 – Not aware of any guidance.

CALIFORNIA PUBLIC RESOURCES CODE SECTION 16000-16004

16000. The Legislature finds and declares all of the following:

(a) Facilitating the recycling of natural resources is in the best interest of the state.

(b) This division is intended to encourage the use of recycled concrete as provided in this division.

16001. For the purposes of this division, "recycled concrete" means reclaimed concrete material used in concrete mixtures in accordance with the "Greenbook Standard Specifications for Public Works" 2003 edition, or the most current revision of those requirements. "Recycled concrete" includes mix designs or aggregate gradations that are in accordance with specifications of the American Concrete Institute (ACI), the American Society of Testing and Materials (ASTM), the International Building Code (IBC), the International Residential Code (IRC), the Uniform Building Code (UBC), or Caltrans Standard Specifications. However, reclaimed concrete material that is in compliance with ASTM-94 specifications is exempt from this division.

16002. (a) Recycled concrete materials may be used if a user has been fully informed that the concrete may contain recycled concrete materials.

(b) For the purposes of this section, "fully informed" means informed of the potential use of recycled materials in a concrete product prior to or at the time of ordering, either orally or in writing, and informed by the delivery receipt as to the recycled ingredients at delivery acceptance.

16003. No recycled concrete shall be offered, provided, or sold to the Department of Transportation or the Department of General Services for any use, including, but not limited to, any project under its affiliation, contract authority, or oversight responsibility unless specifically requested and approved by the department.

16004. Nothing in this division shall supersede the requirements of the Uniform Building Code or other provisions of law.

Appendix E

2009 Greenbook: Standard Specifications for Public Works Construction (excerpt)

201-1.2.6 Reclaimed Concrete Material. Reclaimed concrete material may be used in concrete mixtures in accordance with this section when approved by the Engineer. Reclaimed concrete material may be either:

a) Reclaimed plastic portland cement concrete (RPPCC)
or
b) Reclaimed non-plastic portland cement concrete materials

The Contractor is required to maintain suitable equipment to classify reclaimed concrete material and document its use in the proportioning of concrete mixtures. The addition and characteristics of reclaimed concrete material will be monitored to ensure the final portland cement concrete composite conforms to the specifications for its Class and use.

All mixtures incorporating reclaimed concrete material will be represented by mix designs in accordance with section 201-1.1.1. The Contractor shall evaluate all mix designs by laboratory or field trial batches. Each trial batch shall conform to the materials, proportions, and slump as proposed by the mix design. When approved by the Engineer, field trial batches may be placed in the Work at designated locations where concrete of lower quality is specified. Concrete so placed will be considered for the purpose of payment to be the type of concrete specified at that location. A minimum of ten test cylinders shall be molded from the trial batch containing the maximum water content indicated by the mix design. Five of the cylinders shall be tested at 7 days to establish 7-day average compressive strength information. The remaining five cylinders shall be tested at no more than 28 days after molding. For field trial batches the average 28 day compressive strength shall be at least 600 psi (4 MPa) greater than the specified strength. For laboratory trial batches the average 28-day compressive strength shall be at least 1000 psi (7 MPa) greater for specified strengths less than 3000 psi (21 MPa), 1200 psi (8 MPa) greater for specified strengths between 3000 psi and 5000 psi (21 MPa and 36 MPa) and 1400 psi (10 MPa) greater for specified strengths greater than 5000 psi (36 MPa). The minimum strength of any one cylinder shall not be less than the specified strength. Changes in the source of materials or established procedures may require new trial batches. Changes in the quality of materials or failure to comply with the compressive strength requirements of 201-1.1.4 shall require new trial batches unless otherwise approved by the Engineer.

Reclaimed concrete material may not be used in special exposure mixtures and is not normally recommended for use in portland cement concrete where architectural aesthetics are a concern.

a) **Reclaimed Plastic Portland Cement Concrete (RPPCC).** A maximum of 15 percent by volume of reclaimed plastic portland cement concrete conforming to this section may be incorporated into fresh portland cement concrete. Each weighmaster certificate shall show the exact volume of RPPCC in addition to the weighmaster certificate requirements of section 201-1.4.3.

RPPCC may be any un-hardened portland cement concrete provided its design strength is 2000 psi (14 MPa) or greater, its constituent material conforms to section 201-1.2, and it has not attained or has been delayed from attaining initial set either by time or by the incorporation of set-delaying chemical admixtures. When set-delaying chemical admixtures are used, they will be used at the manufacturer’s recommended dosage rates and have a proven history of specifically maintaining and extending both plasticity and set. The contractor will maintain process documentation, mix designs, and supportive concrete test data and shall provide the information to the Engineer upon request.

RPPCC will be proportioned by volume in accordance with section 201-1.3. RPPCC may be added at any point during the proportioning process that results in a consistent, uniform, and homogeneous final product. For design and proportioning purposes, all RPPCC will be considered as a 2000 psi (14 MPa) mixture, consisting of 470 pounds (280 kg) of cementitious material. Additional portland cement will be added to achieve the minimum portland cement content and/or strength as required for a mixture's Class and use. The quantity and/or constituent materials of the RPPCC shall be monitored and proportioned such that the final portland cement concrete gradation conforms to the requirements of section 201-1.3.2.

b) **Reclaimed Non-Plastic Portland Cement Concrete Materials.** Non-Plastic Portland Cement Concrete Materials shall consist of an individual amount of or a combination of materials resulting from the reclaiming of portland cement concrete. Before reclamation, these materials shall conform to section 201-1.2. The materials shall be designated as either reclaimed aggregates (RA) or reclaimed water (RW).

When crushed portland cement concrete is used as aggregate it shall, when combined with the nonreclaimed aggregate at the proposed percentage of use, conform to section 201-1.2.2. A maximum of 30 percent RA by weight of total aggregate may be incorporated into fresh portland cement concrete. RA shall consist of crushed and graded concrete aggregates and/or a reclaimed naturally occurring aggregate. Reclaimed naturally occurring aggregates may contain minor residual amounts of portland cement concrete components as a result of reclamation. When 15 percent or less RA by weight of total aggregate is used, the requirements of 201-1.2.2 may be waived by the Engineer provided the final portland cement concrete gradation conforms to the requirements of section 201-1.3.2.
RW may consist of non-deleterious amounts of hydrated and un-hydrated portland cement, admixtures, minor amounts of fly ash and fine aggregate. The reclamation process for RW shall include a mechanism to ensure uniformity and homogeneity of the RW. A maximum of 35 percent RW by weight of batch water may be incorporated into fresh portland cement concrete.
RA and RW will be proportioned by weight in accordance with section 201-1.3. RA and RW may be added at any point during the proportioning process that results in a consistent, uniform, and homogeneous final product. The quantity and/or constituent materials of the RA shall be monitored and proportioned such that the final portland cement concrete gradation conforms to the requirements of section 201-1.3.2.

Appendix F

CSTIC Project Profile:

Developing a Protocol and Running A Demonstration Test for Increasing the Beneficial Use of Plastic "Returned Concrete"

--DRAFT--

CSTIC Project 2010-1

This is a profile for a project under the Collaborative for Sustainable Transportation and Infrastructure Construction. The CSTIC project profile is designed to provide in tangible form essential details of a project in such as way as to allow others to review, engage, develop creative ideas and refinements, and provide capacities to the project.

Between 2% and 7% of concrete leaving batch plants returns to the plant in the truck unused. Such concrete is "left over" - perhaps a little more than was necessary to complete the construction work at the end of a job segment, shift or day, for instance.

What is CSTIC?

A voluntary, action-based collaborative dedicated to increasing the sustainability of the construction of infrastructure, based on a lifecycle materials management view.

- *Do you want to participate in this CSTIC project?*
- *Do you have something to add or to improve it?*

CSTIC is dependent on the creative input of its membership. If you have useful capacities, input, or wish to participate in this project, please contact Jeff Dhont at (415) 972 3020 or dhont.jeff@epa.gov.

Sustainability Problem and Cost Burden Posed by Returned Concrete

The great majority of returned concrete is wasted currently. Concrete embodies significant environmental impacts including mineral resources, energy, greenhouse gases, and water. Those costs to the environment are re-incurred when returned concrete is disposed and replaced by new concrete. Disposal of returned concrete also results in the unnecessary filling of landfills.

While returned concrete is still undergoing hydration and is workable, it is referred to as "plastic." Currently, only small amounts of plastic concrete can be reused. Once solidified, concrete is referred to as "hardened." Some hardened concrete can be crushed for use later as aggregate for either new concrete or as base material, but historically the former use especially is limited.

The management and disposal of returned concrete can be expensive. It creates a reduced yield on raw materials. In addition, concrete batch companies incur significant costs to handle returned concrete, transport it by truck or rail to landfills, and to pay tipping fees. Management of returned concrete at batch plants requires space, grinding, moving and storage equipment, and large amounts of water. Reuse of hardened concrete as aggregate requires acquisition and operation of an additional silo or bin for a material that may not be ordered routinely.

The Purpose of this Project

There are at least three ways that the environmental and economic costs of returned concrete could be reduced: 1) reduce the amount of concrete subject to return at job sites in the first place; 2) reuse more plastic concrete from one job site at other job sites before it hardens; and 3) reuse more hardened concrete as base aggregate or aggregate in new concrete. All of these would be beneficial. Among these, (1) would be the most preferable as it represents a *reduction* of the material stream subject to waste or reuse. Option (2) would be next in preference because in theory it could be implemented with little cost by modifying the procedures used for reusing plastic concrete. Option (3) requires capital and operational costs for equipment and handling of hardened concrete, but still increases reuse/recycling for any returned concrete that cannot be handled through (2).

This project focuses on Option (2) – reusing plastic concrete at other jobs. Its primary purpose is to explore and develop, if feasible, a protocol under which returned plastic (that is, hydrating and workable) concrete can be re-batched with fresh concrete and used, within appropriate limits, on other construction jobs with sufficient quality controls to robustly ensure the concrete performance needed. The protocol would address the conditions and limitations which could apply to use of concrete with higher plastic returned-concrete content to ensure it performs according to specifications and sufficient buyer assurances.

Options (1) and (3) remain as valid and promising topics for projects which could be undertaken by CSTIC in the future. Option (1) could involve an examination of concrete batching, timing, and transport to minimize the amount of returned concrete. And, while specifications generally limit the use for hardened concrete as aggregate in new concrete because it can present engineering challenges (such as increasing water demand and reducing concrete strength), this could be further evaluated with an eye to expanding and the use of hardened concrete as base material.

Obstacles to Greater Use of Returned Plastic Concrete

Generally, the reuse of returned plastic hydrated concrete is either not allowed by typical specifications, or in some cases, allowed by specification up to a small percentage of 10-15% by weight. Often these specifications are prescriptive, rather than performance-based.

As shown in demonstration tests by concrete companies, it is *possible* to produce a re-batched concrete using significantly higher percentages of returned plastic concrete (e.g. 50%) that performs equally well to one with 0-15% returned plastic concrete.

However, while returned plastic concrete has been used at various places and times, there are significant obstacles to its routine adoption over the broad spectrum of concrete applications and producers in the market. Significantly, the purchaser of re-batched concrete must be able to verify the content and performance characteristics of the concrete he is purchasing. For plastic concrete reuse to be economically viable there must be confidence in the product as produced by a wide range of concrete makers. An intent of the objective protocol is to provide this confidence and define cases where it may be appropriate to use higher return concrete percentages than are typical presently.

Among factors subject to uncertainty that could impact the performance characteristics of concrete rebatched with returned plastic concrete are:

- The mix composition of both the returned and fresh components of the concrete (e.g. cement, fly ash, slag, aggregates, and their proportions);
- The class (ACI, ASTM) of both the new and returned components of the rebatched concrete;
- The design strength of both components;
- The proportion of the rebatched concrete that is returned versus fresh;
- The relative "age" (progression of the hydration reaction) of the returned concrete at the time of rebatching;
- The water content of the returned concrete and how much water may have been added at the job site to which the returned concrete was originally sent;
- Admixture chemicals (retarders, accelerants, slump retention agents) and when they were added to the mix.

Another obstacle to reuse can be regulations designed to ensure the fairness of saleable quantities – for instance, those overseen by the Bureau of Weights and Measures. Some of these require that trucks be weighed empty, rather than allowing them to be tared. This can effectively prohibit the beneficial use of returned concrete. Protocol development will need to seek ways of satisfying the objectives of fair business practices espoused by weights and measures rules, while at the same time addressing sustainability and concrete performance needs.

Project Team

CSTIC collaborators **American Concrete Institute (ACI)**, **Central Concrete, Inc.,** and the **National Ready Mixed Concrete Association (NRMCA)**, with **EPA Region 9** coordination, are currently serving as the project team. Participation by other collaborators is encouraged as appropriate.

Objectives

The objectives of the project are to:

- Reduce or eliminate the embodied environmental and economic impacts associated with the disposal of returned concrete;
- Create and publish a peer-reviewed protocol a protocol under which returned plastic concrete can be re-batched with fresh concrete and used, within appropriate limits, on other construction jobs with sufficient quality controls to robustly assure the concrete performance needed.
- To expedite the adoption of rebatched returned concrete in the marketplace for concrete;
- Identify and explore market and technical barriers to the reuse of plastic concrete; and
- Afford buyers of rebatched concrete with confidence that if the protocol is followed, the quality and performance characteristics of the concrete are assured.

Proposed Approach

The approach anticipated for the project is as follows:

1. Draft a protocol and quality control guidelines for the use of returned plastic concrete in new concrete, based on their own experience. The draft protocol will propose the measurements, verifications, documentation, and limitations that will allow the average batch concrete company to use returned plastic concrete in levels above the typical 0-15%, while preserving adequate assurances of performance.
2. Put the draft guidelines before the broader Collaborative for deliberation, input, discussion, and refinement.
3. Demonstrate the refined protocol and performance of concrete in an actual field application while documenting measurements and analyses. As a matter of preference, the demonstration may take place using a venue provided by a local city or county government, who may engage in the project.
4. If problems are identified that need rectification or refinement to the protocol, then discussions and consultation will take place with specifiers, producers, designers and regulators to make necessary amendments. If the protocol is shown feasible, it will be discussed with specifiers with the objective of raising the allowed percentage of returned concrete subject to appropriate conditions and limitations. It will also be submitted to ACI, ASTM, and/or departments of transportation for consideration for adoption.
5. Document the project products, including guidelines, outstanding issues, follow-up items, and test results.

Draft

Designation: Sustainability Protocol DSD - 1, 2010

Standard Practice for Same Day Recycling of Returned Plastic Ready-Mixed Concrete

1. Scope

1.1 This practice method covers the process, verification and recordkeeping procedures for recycling returned plastic concrete with or without stabilizing admixtures.

1.2 The values stated in either inch-pounds or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 The text of this standard references notes which provide explanatory material. These notes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. Terminology

2.1 *Definitions of Terms Specific to This Standard*

Hydration Stabilizing Admixtures—extended set retarding admixtures that control the hydration of cement in applications of managing returned concrete and water from concrete production.

Same Day Stabilization – the practice of preserving concrete (keeping it plastic), by using a hydration stabilizing admixture, for four (4) hours or less.

2. Summary of Practice

2.1 Returned or plastic concrete leftover from a jobsite is preserved in a ready-mixed concrete truck and is recycled by batching fresh materials depending on its characteristics. A hydration control admixture can be used to keep the material fresh for a designated time period before the plastic concrete is then recycled into concrete production to be incorporated into a new load of concrete batched the same day. The performance of the blended concrete is designed to meet the requirements for the intended application of the new load.

4. Significance and Use

4.1 This practice provides protocols for recycling fresh fresh, returned concrete in new concrete in new concrete batches and establishes the necessary documentation to support this practice. Recycling fresh returned concrete supports sustainable practices for the production and use of ready mixed concrete

4.2 This practice allows for returned plastic concrete from one project, that otherwise might be targeted for disposal, to be put to constructive use by becoming part of a fresh batch of concrete for a second project under certain conditions. The practice will ensure that the concrete delivered to the second project is of known and verifiable quality, characteristics, and performance, and that it will meet the specific needs of the application.

5. Management

5.1 The concrete producer's recycling program must be actively managed by the producer's QC manager. The program shall be periodically audited by a registered engineer. This shall include: training operations personnel, reviewing QA/QC involvement, reviewing the log of performance data, determining the appropriate HSA dosages producers' recycling protocol at least annually.

5.2 The concrete producer shall establish a statement on the delivery ticket or by other means that informs the purchaser that concrete may or does contain recycled concrete.

5.3 The concrete producer should periodically test concrete batches made with recycled returned fresh concrete and maintain documentation of the conditions of recycling and the resulting properties. Concrete producers should maintain past performance data of at least 3 different batches of recycled returned concrete made within the past 12 months.

6. Materials

6.1 *Hydration Stabilizing Admixture* a ready-to-use liquid admixture for making more uniform and predictable high-performance concrete. The hydration-controlling admixture shall meet these requirements:

- ASTM C 494/C494M requirements for Type B retarding and Type D, water-reducing and retarding admixtures
- Control the hydration of portland cement and other cementitious materials
- Neither initiate nor promote corrosion of reinforcing steel in concrete

- Shall not contain intentionally-added chloride or other chloride based ingredients
- Shall be compatible with other admixtures used in the concrete
- Shall have demonstrated at least 5 years of success in a same-day stabilization application

7. Procedure

7.1 When a batch of concrete is mixed initially for a project, the date, plant number, truck number, initial batch time, concrete mixture design identification and proportions shall be recorded in a Returned Concrete Log Sheet (see samples in the appendix).

7.2 Immediately following discharge of a load of concrete at a jobsite, the Concrete Delivery Professional shall inform the Dispatcher, or other person designated by the concrete producer, if there is leftover plastic concrete being returned to the plant.

7.2. The Dispatcher or other designated person shall review the concrete mixture design identification and proportions from the batch ticket to determine if the returned plastic concrete meets the initial suitability criteria to be suitable for recycling, and whether there are other jobs in queue for which the recycled concrete could be appropriate.

Note 1 - There may be some returned plastic concrete mixtures that cannot be recycled because they contain an accelerating admixture, fiber, liquid color, or lightweight aggregate. If the returned plastic concrete is not suitable for recycling, it will have to be disposed in some other manner (manufacturing concrete products, washout pits, landfill, etc.).

7.3 If the returned plastic concrete passes general threshold criteria for recycling, the Concrete Delivery Professional shall determine the mass of the truck and returned concrete using a truck scale.

7.3.1 The company shall establish criteria for recycling of returned concrete that are communicated to the responsible persons at a concrete plant. The criteria shall include at a minimum:

- Quantity of returned concrete
- Age from time of initial batching to the point of admixture treatment or recycling
- Temperature
- Quantity of water added = to what portion of load – and calculated to the quantity of returned concrete on a lb/cy basis.
- Cementitious materials content of return batch
- Means of documenting batch recordation and batch quantities and for this practice

- Applications as per company policy for which this practice will be followed

The criteria shall include conditions that will permit the recycling of returned concrete without admixture and shall at a minimum shall include:

- Age and temperature of returned concrete
- Maximum volume of returned concrete
- Maximum amount of water in the returned batch in lb/cu. Yd
- Maximum percentage of returned concrete in the re-constituted load

7.4 Calculate the quantity of returned concrete using the following equation.

$$RPC = [(MTWRC - MT)/4{,}000^{*}] - 150^{**}$$

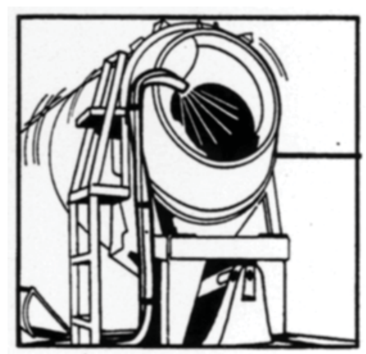
Where:

RPC = returned plastic concrete, volume
MTWRC = mass (weight) of the truck with returned concrete
MT = mass (weight) of the truck when empty

*4,000 = typical weight (mass) of a cubic yard of concrete. If the exact weight is known from the batch ticket, use that value.
**150 = typical weight (mass) of one cubic foot of concrete. Subtracted to allow for variances in tare weight.

Note 2: Other methods of determining the quantity of returned concrete may be acceptable.

7.5 Record the quantity of returned concrete on the same day concrete stabilization log sheet.



7.6 At the appropriate location at the concrete plant, add the minimum amount of cold water to the returned plastic concrete to achieve a slump of 5 to 7 in. (125 – 180 mm). The total amount of water added to the concrete shall be recorded in the Returned Concrete Log Sheet.

7.7 Mix the concrete at mixing speed (12 to 16 RPM) for one minute.

7.8 Following mixing, reverse the truck drum to back the concrete up to the top of the drum. Insert a thermometer into the concrete, or use an infrared thermometer, for at least 30 seconds until the temperature stabilizes. Record the concrete and ambient temperatures in the Returned Concrete Log Sheet.

7.9 Determine the age of the concrete in hours and minutes using the following equation.

$$AC = TR - TB$$

Where:
AC = age of the concrete, hrs:min
TR = time concrete is returned to the plant
TB = time the concrete was batched

7.10 Suitability Criteria: Returned concrete is considered suitable for recycling if the returned concrete in the truck is less than 4 hours old before dosing with HCA, less than 100 ºF and the stabilized concrete can be used in less than 4 hours after stabilizing. These criteria can be exceeded when there is supporting test documentation to support it.

7.11 If the returned plastic concrete is suitable for recycling, add a hydration controlling admixture to the truck at a dosage that allows the concrete to remain preserved for a specified time period. Record the dosage in the Returned Concrete Log Sheet.

Note 3 - a typical same day concrete stabilization time frame (preservation time) is 30 minutes to 4 hours).

Note 4 – Hydration stabilizer dosage charts are established by field testing based upon, concrete mixture identification, proportions, volume of concrete returned to the plant, type and total amount of cementious materials per volume of concrete, concrete temperature concrete age from initial batching, and desired length of time for preservation.

7.12 Mix the returned concrete with the hydration control admixture (at 12 to 16 RPM) for three minutes and park the truck at a safe location at the plant. Before the desired stabilization time expires, the preserved concrete can be used as part of another load of new concrete.

7.13 As required by an order for new concrete, batch new concrete on top of the recycled concrete and mix for three minutes. The minimum amount of new concrete to be batched on top is based on a ratio of 1:1. Reduce the amount of mix water in the new concrete to compensate for the additional water added to the recycled concrete.

7.14 The total volume of recycled and new concrete shall be equivalent to a full truck load of concrete.

7.15 Record the concrete batch time, the volume of new concrete batched on top, and the concrete mixture design identification and proportions, in the Returned Concrete Log Sheet.

7.16 Send the concrete consisting of recycled and new concrete to applications that are of equal or lower strength than the concrete which is being recycled, not to exceed 5,000 psi, unless the results of the testing and QA program support recycling concrete at higher strength levels.

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APPENDIX

See attached sample log sheets

2709 System **Appendix H** #1281

Research & Development

#1281

Technical Report

No. 128

DELVO™ SYSTEM

Master Builders Technologies

(ATTACH THIS SHEET TO PUBLICATION)

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I. DISPOSAL OF RETURNED CONCRETE AND CONCRETE WASH WATER

1.1 The disposal of returned plastic concrete, whether during the day or at the end of a day, has become a major problem for the ready-mix industry. To realize how big the problem is, in 1987, 247 million cubic yards of concrete were produced and approximately 2.5 to 10 million cubic yards of the concrete produced was returned for disposal. Conventional methods for the disposal of returned plastic concrete include:

- being sold as part of the next load
- paving ready-mix plant yard
- producing concrete products (barrier blocks, manhole covers, etc.)
- using expensive reclaimer/recycler units having continuous maintenance costs
- dumping returned concrete which can result in expensive labor costs, excessive wear and tear on front-end loaders, and costly hauling charges

1.2 There are now increasing environmental concerns and restrictions regulating the disposal of returned plastic concrete. The Environmental Protection Agency considers returned plastic concrete when being disposed of to be a hazardous material.

1.3 At the end of each day, when a 10 cubic yard (7.7 cubic meter) ready-mix truck returns to the plant with no leftover concrete, that truck will contain approximately 600 lb (356 kg) of cement, fine aggregate and coarse aggregate adhering to the inside of the truck drum. It is a common practice in the ready-mixed concrete industry to wash this residue out using approximately 150-300 gallons (509-1137 liters) of water to thoroughly clean the inside of the truck drum. Conventional methods for the disposal of concrete wash water include dumping:

- at the jobsite
- at a landfill
- into a reclaimer/recycler unit
- into a concrete wash water pit
- in the ready-mix plant yard

1.4 The removal of hardened concrete from a wash water pit can result in expensive labor costs, excessive wear and tear on front-end loaders, and costly hauling charges.

1.5 The Environmental Protection Agency classifies both returned concrete and truck wash water as a hazardous waste and regulates their disposal. The CFR (Code of Federal Regulations) 40, Part 116 of the Water Quality (Clean Water) Act states, "Any solutions and mixtures containing caustic soda and/or caustic potash are designated hazardous substances." Returned concrete and truck wash water contain both of these substances. In addition, both materials have a pH high enough to be considered hazardous by the EPA under the definition of corrosivity.

1.6 The disposal of hazardous materials falls under various regulations: The Resource Conservation and Recovery Act, (RCRA), which deals with hazardous waste; the National Pollutant Discharge Elimination System (NPDES), part of the Water Quality Act, deals with the discharge of any waste (primarily liquid) into the water system; and the Superfund Amendments and Reauthorization Act (SARA), deals with the community right to know.

1.7 All of the regulations mentioned have an impact on the disposal of returned plastic concrete and/or truck wash water. These regulations require very specific ways to handle hazardous waste. Very accurate and precise record keeping and reporting of each disposal must be kept for three years and submitted to the EPA.

1.8 The availability of landfill sites authorized for the disposal of returned concrete and truck wash water will be drastically reduced in the future as projected in the following chart:

Returned Concrete
Landfill Availability

Year	No. of U.S. Landfills
1981	50,000 (100%)
1987	12,000 (24%)
1994	5,000 (10%)

1.9 In 1981, there were 50,000 landfills available in the United States for the disposal of returned concrete and wash water from truck drums. In 1987, the number of available landfills was reduced to 12,000. It's been estimated that by the year 1994 there will only be 5,000 landfills available for waste material (a reduction of 90% in comparison to 1981).

1.10 The environmental regulations being legislated are becoming increasingly costly to the ready-mixed concrete industry. In an effort to assist producers with these difficult issues, Master Builders has developed a cost-effective alternative to the disposal of returned plastic concrete and concrete wash water. The Delvo System from Master Builders utilizes new technology to keep our environment clean and safe and provides an economical way for ready-mix producers to comply with new environmental regulations.

II. CHEMICAL SYSTEM DESCRIPTION AND USE

2.1 The DELVO System is a two-component, non-chloride chemical system developed to control the dynamics of cement hydration.

2.2 Returned plastic concrete treated with the DELVO System can be kept in a plastic state in the drum of a ready-mix truck, or in a central holding vessel for a few minutes, a few hours, overnight or over a weekend. On the same day, the next day, or after a weekend, the stabilized concrete can be activated (if necessary) and combined with freshly manufactured concrete and sent to the jobsite.

2.3 The DELVO Stabilizer, when dispensed into plastic concrete stops cement hydration by forming a protective barrier around cementitious particles. This barrier prevents portland cement, fly ash and granulated slag from achieving initial set. The DELVO Activator, when dispensed into stabilized concrete, breaks down the protective barrier around cementitious particles, and permits normal cement hydration to proceed.

2.4 Concrete treated with one or both components of the DELVO System, when combined with freshly manufactured concrete – either the same day, the next day or after a weekend – will result in concrete performance equal or superior to reference concrete manufactured conventionally.

2.5 There are numerous DELVO System applications for ready-mix producers including:

- overnight/weekend stabilization of concrete wash water from truck drums
- same day stabilization of returned plastic concrete
- same day stabilization of conventionally manufactured concrete for long hauls
- same day stabilization of returned plastic concrete/conventionally manufactured concrete during truck breakdowns
- overnight/weekend stabilization of concrete wash water for central mixers
- same day/overnight stabilization of leftover concrete from pump lines in the concrete hopper
- overnight/weekend stabilization of returned plastic concrete

NOTE: A detailed explanation of the numerous DELVO System applications can be found in Section IV entitled "DELVO System Applications."

2.6 The recommended dosage range of DELVO Stabilizer for same day, overnight and weekend stabilization of concrete is 5 to 130 fl oz per 100 lb (325 to 8,460 ml per 100 kg) of cementitious material. Activation of such stabilized concrete is achieved by a dosage range of DELVO Activator from 10 to 150 fl oz per 100 lb (650 to 9,760 ml per 100 kg) of cementitious material. **Safety glasses or goggles and rubber gloves must be worn when handling both DELVO Stabilizer and DELVO Activator.**

2.7 The specific dosage for a given concrete mix will depend on the chemical admixtures, concrete materials and mix design used, elapsed time from initial batching, the returned plastic concrete temperature, quantity of concrete being treated, and the stabilization time required.

2.8 For overnight stabilization of concrete wash water, the recommended dosage range of DELVO Stabilizer is 32 to 64 fl. oz. (946 to 1892 ml.) per truck. For weekend stabilization the dosage range of DELVO Stabilizer is 64 to 96 fl. oz. (1892 to 2839 ml.) per truck.

2.9 When using Type III cement the recommended dosage range of DELVO Stabilizer is 48 to 80 fl. oz. (1419 to 2366 ml.) per truck for overnight stabilization, and 80 to 112 fl. oz. (2366 to 3312 ml.) per truck for weekend stabilization.

2.10 The stabilized concrete wash water is re-used as mix water in subsequently manufactured concrete either the next day or after a weekend.

III. CHEMICAL SYSTEM CONTROL OF CEMENT HYDRATION

3.1 Portland cement concrete acquires setting time and strength characteristics by a chemical reaction between cement compounds and water to form a rigid material called calcium silicate hydrate gel (CSH gel). This process is called hydration and produces a rapid release of calcium ions into solution and forms a CSH gel rind around the cement particles. As concrete sets, hydrates formed by cement hydration flocculate (clump up) as shown in Figure 1. It is this process which turns workable concrete into a stiff mass.

3.2 Master Builders has developed the DELVO System, a two-component non-chloride chemical system to control the dynamics of cement hydration. The first component of the DELVO System, DELVO Stabilizer, when dispensed and thoroughly mixed into returned plastic concrete, controls the rate of hydrate formation by tying up (complexing calcium ions on the surface of cement particles. Figure 2 shows that the DELVO Stabilizer performs a dual purpose by stopping cement hydration by forming a protective barrier around cementitious particles, and acts as a dispersant preventing hydrates from flocculating (clumping up) and setting. The protective barrier around cementitious particles prevents portland cement, fly ash, and granulated slag from achieving initial set.

3.3 The stability of the protective barrier around cement particles is so great that returned plastic concrete can be stabilized and kept plastic for a few minutes, a few hours, overnight or over a weekend. The DELVO Stabilizer is different from conventional retarding admixtures because it (DELVO Stabilizer) is a surface active material having a greater affinity for calcium ions on cement hydrate surfaces. The DELVO Stabilizer controls (stops) cement hydration by acting on all phases of cement hydration. Conventional retarding admixtures at normal dosage rates do not act on C_3A, a primary cement mineral which contributes to setting time and early age strength characteristics of concrete. The use of retarding admixtures at high dosage rates may cause severe concrete stiffening, flash set and low strength performance.

3.4 The second component of the DELVO System, DELVO Activator, when dispensed and thoroughly mixed into stabilized concrete either the same day, the following day or after a weekend, breaks down the protective barrier around cementitious particles as shown in Figure 3. As soon as this is completed and the activated concrete is combined with freshly manufactured concrete, normal cement hydration (flocculation), setting time and strength performance takes place (see Figure 4).

Figure 1 – As concrete sets, hydrates formed by cement hydration flocculate (clump up).

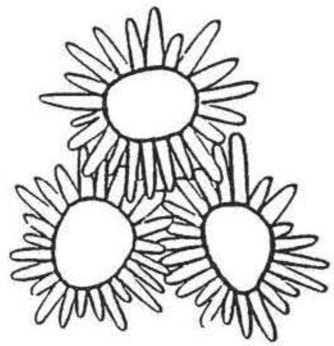


Figure 2 – The DELVO Stabilizer, when dispensed and thoroughly mixed into returned plastic concrete, stops cement hydration by forming a protective barrier around cementitious particles.

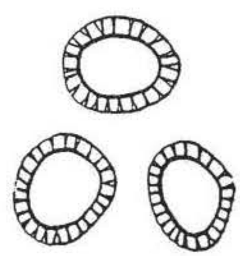


Figure 3 – The DELVO Activator, when dispensed and thoroughly mixed into stabilized concrete, breaks down the protective barrier around cementitious particles.

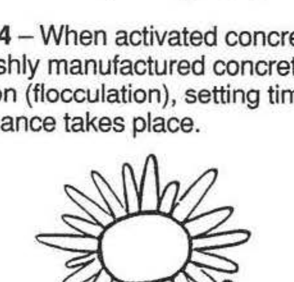
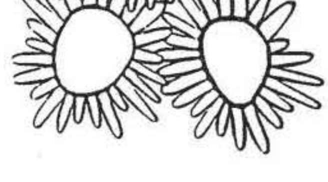


Figure 4 – When activated concrete is combined with freshly manufactured concrete, normal cement hydration (flocculation), setting time and strength performance takes place.



IV. DELVO SYSTEM APPLICATIONS

4.1 The DELVO System was originally developed for two applications, overnight/weekend stabilization of returned plastic concrete. Now, there are numerous DELVO System applications including:

4.2 Overnight/Weekend Stabilization of Concrete Wash Water From Truck Drums
The initial application of the DELVO System for many ready-mix producers is the DELVO Wash Water Application. Instead of disposing of wash water by conventional methods, it can now be stabilized with one component of the DELVO System, DELVO Stabilizer, in the drum of a ready-mix truck on an overnight/weekend basis and be re-used as part of the mix water in concrete batched the next day or after a weekend.

4.3 Same Day Stabilization of Returned Plastic Concrete
This application will allow producers to utilize one component of the DELVO System, DELVO Stabilizer, to stabilize returned plastic concrete either: (1) immediately upon return to the plant. After stabilization, fresh concrete is batched on top and sent to the jobsite. (2) for a short period of time (1 hour, 2 hours, etc.). The reason for this stabilization period is to allow the producer to have a flexible amount of time to find a job for the stabilized concrete. When the stabilization period is completed, fresh concrete is batched on top and sent to the jobsite. In most cases, the second component of the DELVO System, DELVO Activator, is not needed in the same day stabilization application.

4.4 Same Day Stabilization of Conventionally Manufactured Concrete for Long Hauls
With this application, the DELVO Stabilizer is utilized to control the dynamics of cement hydration for partial to full truck loads of concrete for a short period of time (30 minutes, 1 hour, 2 hours, etc.) which will be subjected to long hauls.

4.5 Same Day Stabilization of Returned Plastic Concrete/Conventionally Manufactured Concrete During Truck Breakdowns
In the event of a truck breakdown, as long as the drum can be turned to obtain sufficient mixing action, the DELVO Stabilizer can be used to stabilize the concrete (a partial or full truck load) for any desired length of time. Depending on the length of stabilization time, the concrete should be re-used before the stabilization period is over, or transferred into one or more trucks and combined with fresh concrete and sent to the jobsite.

4.6 Overnight/Weekend Stabilization of Concrete Wash Water for Central Mixers
This application permits producers to reduce concrete build-up on central mixer fins, and utilize the DELVO Stabilizer to stabilize concrete wash water for central mixers on an overnight/weekend basis. The stabilization of wash water normally used to clean central mixers, will reduce/eliminate conventional disposal methods, environmental (EPA) concerns, and can be re-used as part of the mix water in concrete batched the next day or after a weekend.

4.7 Same Day/Overnight Stabilization of Leftover Concrete From Pump Lines in the Concrete Hopper
The cleaning of concrete from pump lines during and/or after the work day can be time consuming and result in expensive labor costs. The DELVO Stabilizer can be used to stabilize leftover concrete from pump lines in the concrete hopper on a same-day/overnight basis. The stabilized concrete is typically pumped into the ready-mix truck for mixing before re-use.

4.8 Overnight/Weekend Stabilization of Returned Plastic Concrete
The original two applications of the DELVO System utilizes both components, DELVO Stabilizer and DELVO Activator. Returned plastic concrete treated with the DELVO Stabilizer can be kept in a plastic state in the drum of a ready-mix truck, or in a central holding vessel overnight (typically 12 to 18 hours), or over a weekend (typically 72+ hours). The next day, or after a weekend, the stabilized concrete is activated with the DELVO Activator and then combined with fresh concrete and sent to the jobsite.

V. DELVO SYSTEM PERFORMANCE DATA

A. FIELD EVALUATION DATA

5.1 The following data are typical of the performance of the DELVO System when in use at a ready-mix plant. This data represents several DELVO System field evaluations conducted throughout the United States and Canada. In addition, Master Builders has conducted a series of laboratory studies to evaluate the engineering properties of concrete treated with the DELVO System. These data will also be presented.

5.2 The test results will cover three applications of the DELVO System currently in use: (1) overnight stabilization of concrete wash water, (2) same-day stabilization of returned plastic concrete and, (3) overnight stabilization of returned plastic concrete.

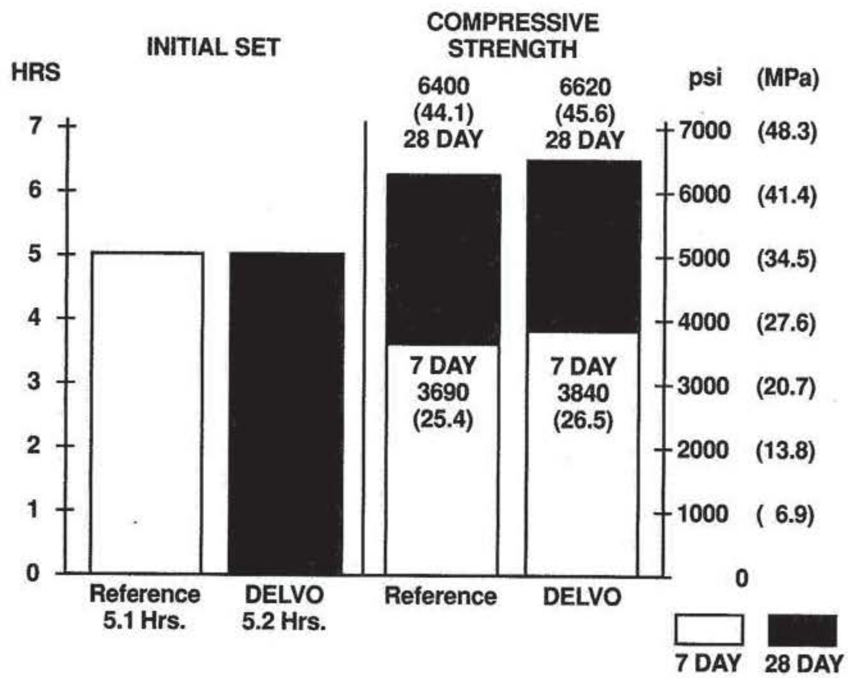
FIELD EVALUATIONS

5.3 Setting Time and Strength Performance for Overnight Stabilization of Concrete Wash Water – Cleveland, Ohio

In this evaluation, the equivalent of 60 gallons (227 litres) of water was added with the addition of 1 qt. (32 fl. oz.) (946 ml) of the DELVO Stabilizer to treat the cement, sand and stone residue on the inside of a mixer. The standard concrete wash water procedure was followed.

PERFORMANCE DATA
Non-Air-Entrained Concrete

	Reference	DELVO
Type I Cement, lb/yd^3 (kg/m^3)	517 (307)	517 (307)
Slump, in (mm)	4.5 (114)	4.5 (114)
DELVO Stabilizer, oz/truck (ml/truck)	X	32 (946)
Concrete Temperature, °F (°C)	68 (20)	71 (22)
Ambient Temperature, °F (°C)	75 (24)	77 (25)

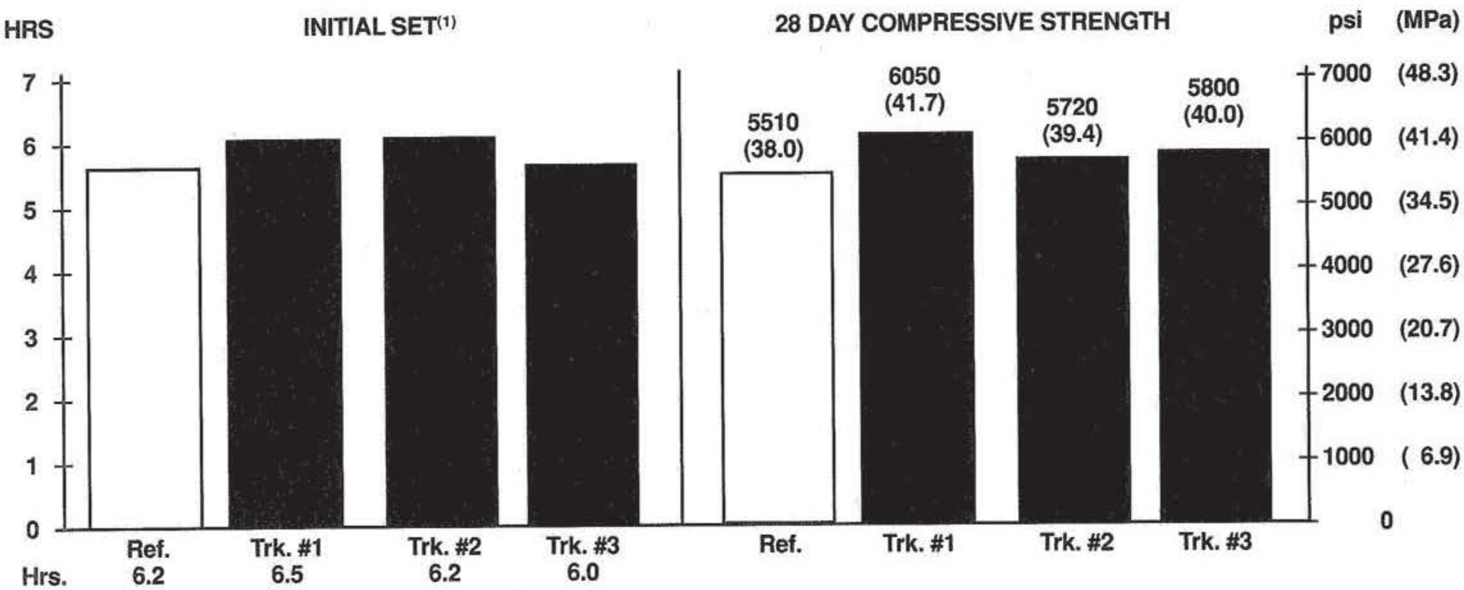


5.4 Setting Time and Strength Performance for Overnight Stabilization of Concrete Wash Water Containing Granulated Slag – Washington, D.C.

For this evaluation, 50 gallons (190 litres) of water was added with the addition of 1 qt. (32 fl. oz.) (946 ml) of the DELVO Stabilizer to each of three ready-mix trucks. The standard concrete wash water procedure was followed.

PERFORMANCE DATA

	Reference	Truck #1	Truck #2	Truck #3
Type I Cement, lb/yd³ (kg/m³)	350 (208)	350 (208)	350 (208)	350 (208)
Granulated Slag, lb/yd³ (kg/m³)	150 (90)	150 (90)	150 (90)	150 (90)
Slump, in (mm)	2.5 (63)	3.0 (76)	3.5 (89)	2.5 (63)
Air Content, %	3.0	3.3	4.1	3.2
DELVO Stabilizer, oz/truck (ml/truck)	— —	32 (946)	32 (946)	32 (946)
Concrete Temperature, °F, (°C)	63 (17)	63 (17)	62 (17)	63 (17)



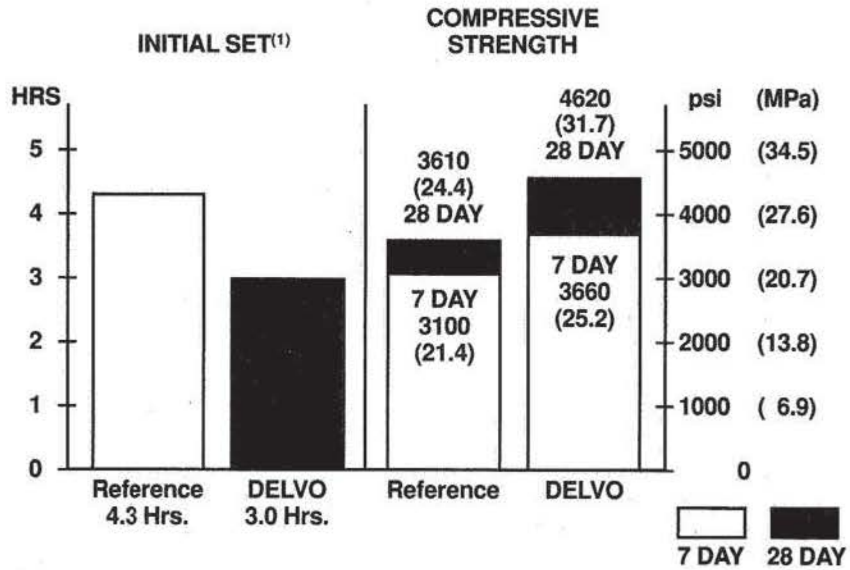
(1) Time of set tests conducted using a pocket penetrometer.

5.5 Setting Time and Strength Performance for Same Day Stabilization of Returned Plastic Concrete – Pittsburgh, PA

The same day stabilization procedure was applied to 3 yd³ (2.28 m³) of returned plastic concrete that was 2 hours in age after batching. Once stabilized, 5 yd³ (3.82 m³) of freshly manufactured concrete was immediately batched on top. This combination when compared to the reference mix was 16 and 26% greater in compressive strength at 7 and 28 days, respectively.

PERFORMANCE DATA

	Reference	DELVO
Type I Cement, lb/yd³ (kg/m³)	611 (362)	611 (362)
Slump, in (mm)	6 (152)	4 (102)
Air Content, %	5.5	5.4
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	10 (651)
Concrete Temperature, °F (°C)	64 (18)	68 (20)
Ambient Temperature, °F (°C)	61 (16)	61 (16)
Concrete Returned, yd³ (m³)	3.0 (2.28)	3.0 (2.28)
Concrete Batched, yd³ (m³)	— —	5.0 (3.82)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs: Mins	— —	2:00
Length of Stabilization, Hrs:Mins	— —	Immediate



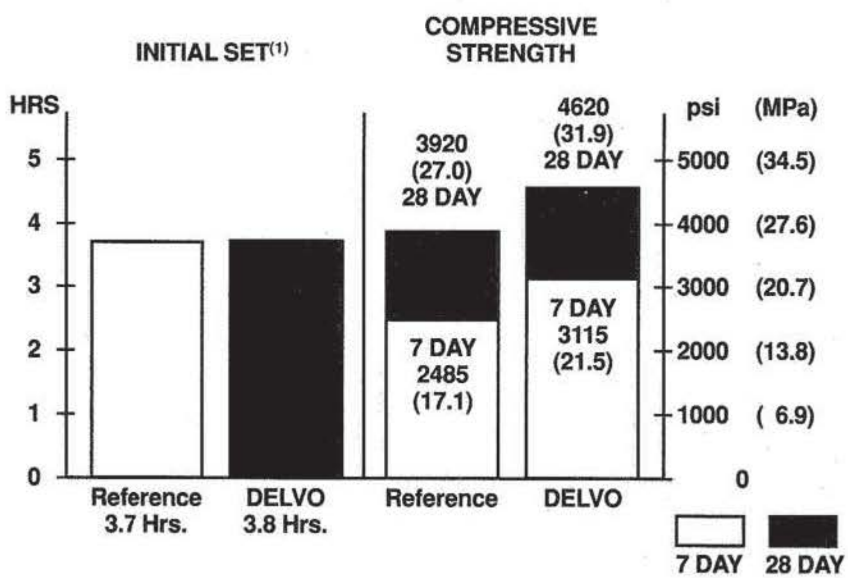
(1) Time of set tests conducted with a pocket penetrometer.

5.6 Setting Time and Strength Performance for Same Day Stabilization of Returned Plastic Concrete – Honolulu, HI

In this evaluation, 1-3/4 yd³ (1.34 m³) of concrete was returned from a job 2 hours and 20 minutes after batching. This returned plastic concrete was dosed with the DELVO Stabilizer following the standard procedures for same day stabilization and 3/4 yd³ (.57 m³) of freshly manufactured concrete was immediately batched on top.

PERFORMANCE DATA
Non-Air-Entrained Concrete

	Reference	DELVO
Type I/II Cement, lb/yd³ (kg/m³)	587 (348)	587 (348)
Slump, in (mm)	6 (152)	5 (127)
Air Content, %	5.5	5.4
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	15 (977)
Concrete Temperature, °F (°C)	89 (32)	85 (29)
Ambient Temperature, °F (°C)	89 (32)	89 (32)
Concrete Returned, yd³ (m³)	1.75 (1.34)	— —
Concrete Batched, yd³ (m³)	— —	.75 (.57)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs: Mins	— —	2:20
Length of Stabilization, Hrs:Mins	— —	Immediate



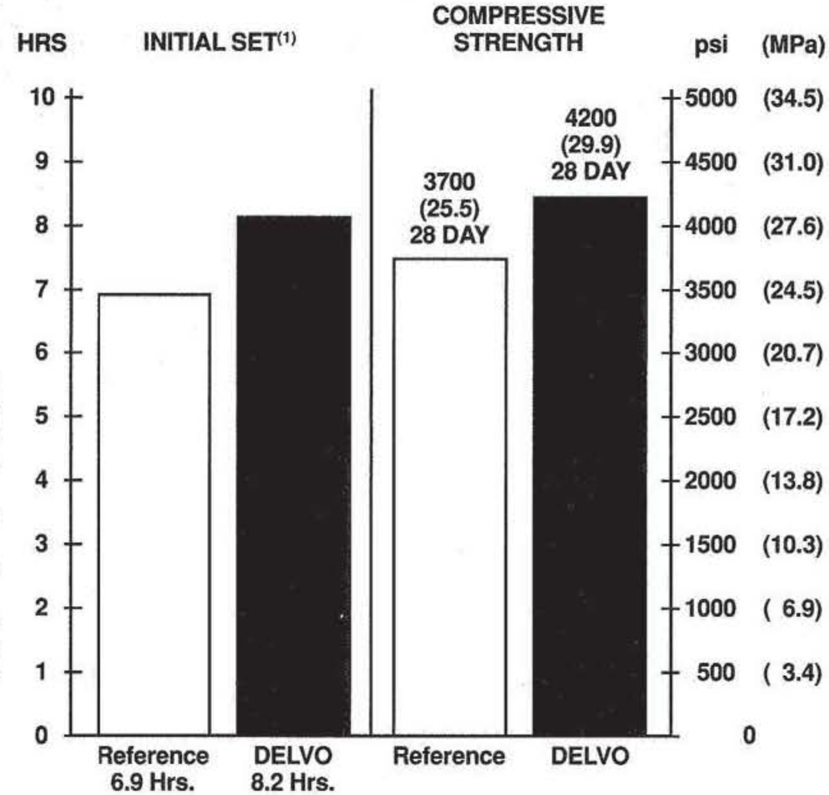
(1) Time of set tests conducted with a pocket penetrometer.

5.7 Setting Time and Strength Performance for Overnight Stabilization of Returned Plastic Concrete Containing Class "F" Fly Ash – Sacramento, CA

Performance of concrete containing a Class "F" fly ash treated with the DELVO System when compared to a reference mix showed increased strength at 28 days.

PERFORMANCE DATA
Non-Air-Entrained Concrete

	Reference	DELVO
Type I/II Cement, lb/yd³ (kg/m³)	400 (237)	401 (238)
Class "F" Fly Ash, lb/yd³ (kg/m³)	45 (27)	44 (26)
Slump, in (mm)	6.5 (165)	5.0 (127)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	35 (2278)
DELVO Activator, oz/cwt (ml/100 kg)	— —	80 (5208)
Pozzolith PolyHeed, oz/cwt (ml/100 kg)	5 (326)	5 (326)
Concrete Temperature, °F (°C)	68 (20)	54 (12)
Ambient Temperature, °F, (°C)	54 (12)	40 (04)
Concrete Returned, yd³ (m³)	2.00 (1.5)	2.00 (1.5)
Concrete Batched, yd³ (m³)	— —	7.5 (5.7)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs:Mins	— —	2:15
Length of Stabilization, Hrs:Mins	— —	15:30



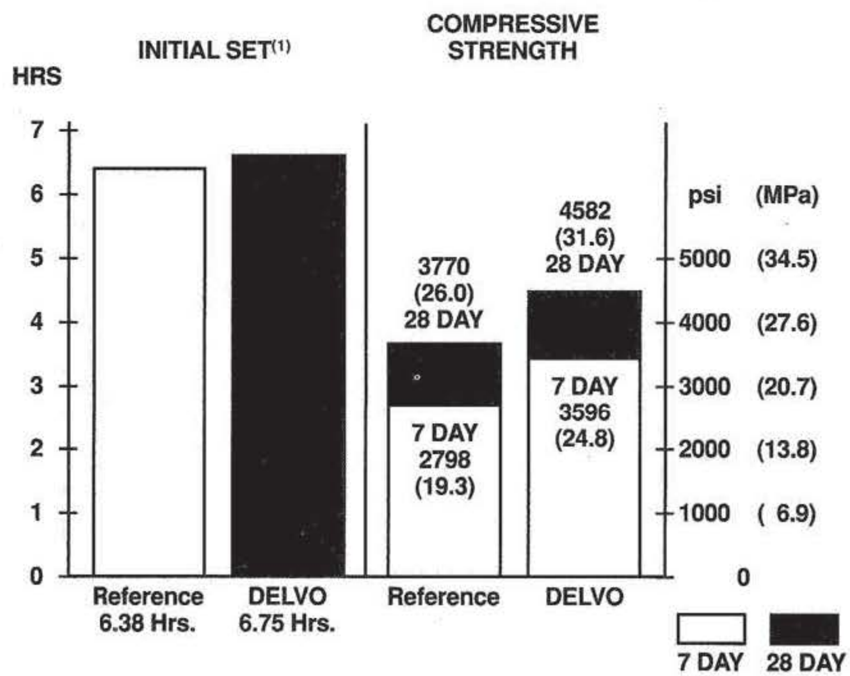
(1) Time of set tests conducted with a pocket penetrometer.

5.8 Setting Time and Strength Performance for Overnight Stabilization of Returned Plastic Concrete – Winnipeg, Canada

Setting time and strength performance of DELVO System treated concrete using Canadian LaFarge Type 10 cement, shows similar setting time when compared to a reference mix as well as increased 7 and 28 day compressive strengths.

PERFORMANCE DATA

	Reference	DELVO
Type 10 Cement, lb/yd³ (kg/m³)	388 (230)	388 (230)
Slump, in (mm)	3.0 (76)	3.25 (82)
Air Content, %	4.5	3.9
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	20 (1302)
DELVO Activator, oz/cwt (ml/100 kg)	— —	90 (5875)
Concrete Temperature, °F (°C)	62 (17)	62 (17)
Ambient Temperature, °F (°C)	— —	— —
Concrete Returned, yd³ (m³)	1.31 (1)	1.31 (1)
Concrete Batched, yd³ (m³)	— —	2.62 (2)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs:Mins	— —	1:10
Length of Stabilization, Hrs:Mins	— —	24:00



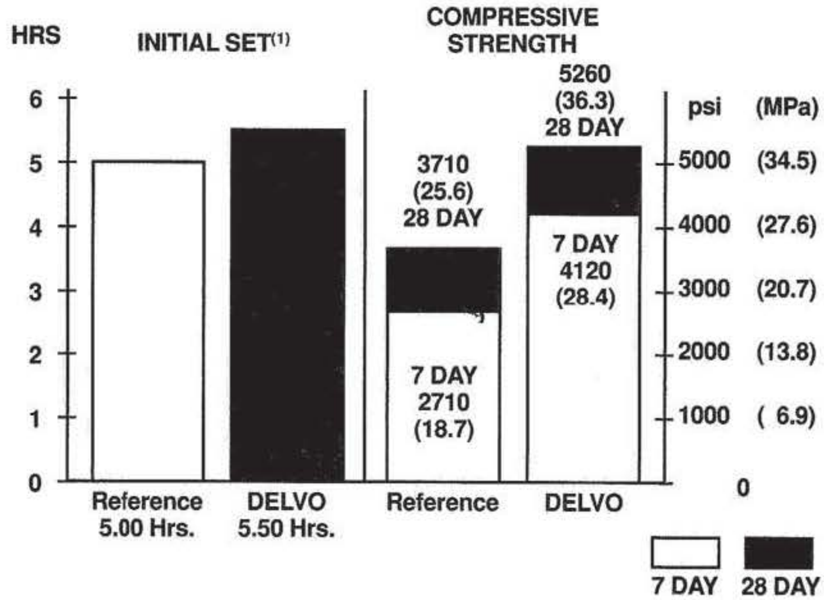
(1) Time of set tests conducted with a pocket penetrometer.

5.9 Setting Time and Strength Performance for Overnight Stabilization of Returned Plastic Concrete – Seattle, Washington

In this evaluation, 1 yd³ (.76 m³) of concrete was returned from the field 2 hours after batching. This returned concrete was dosed with the DELVO Stabilizer following the standard procedure for overnight stabilization. The concrete was stabilized for 14-1/2 hours before the addition of the DELVO Activator and the batching of 2 yd³ (1.52 m³) of freshly manufactured concrete.

PERFORMANCE DATA

	Reference	DELVO
Type I Cement, lb/yd³ (kg/m³)	517 (307)	517 (307)
Slump, in (mm)	6.0 (152)	6.0 (152)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	35 (2278)
DELVO Activator, oz/cwt (ml/100 kg)	— —	40 (2604)
Concrete Temperature, °F (°C)	62 (17)	60 (16)
Ambient Temperature, °F, (°C)	58 (14)	50 (10)
Concrete Returned, yd³ (m³)	1.0 (.76)	1.0 (.76)
Concrete Batched, yd³ (m³)	— —	2.0 (1.52)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs:Mins	— —	2:00
Length of Stabilization, Hrs:Mins	— —	14:30



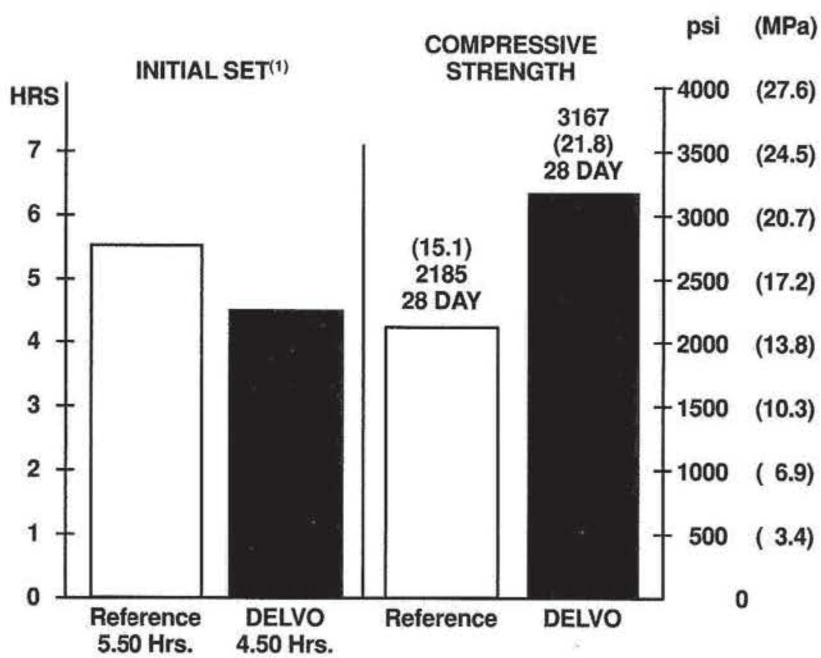
(1) Time of set tests conducted with a pocket penetrometer.

5.10 Setting Time and Strength Performance for Overnight Stabilization of Returned Plastic Concrete – San Luis Obispo, California

A ready-mix truck returned from the field 2 hours after batching with 2-1/4 yd³ (1.71 m³) of concrete. The DELVO overnight stabilization procedure was applied. The concrete was stabilized for 16-3/4 hours before the addition of the DELVO Activator and 5-3/4 yd³ (4.37 m³) of freshly manufactured concrete.

PERFORMANCE DATA
Non-Air Entrained Concrete

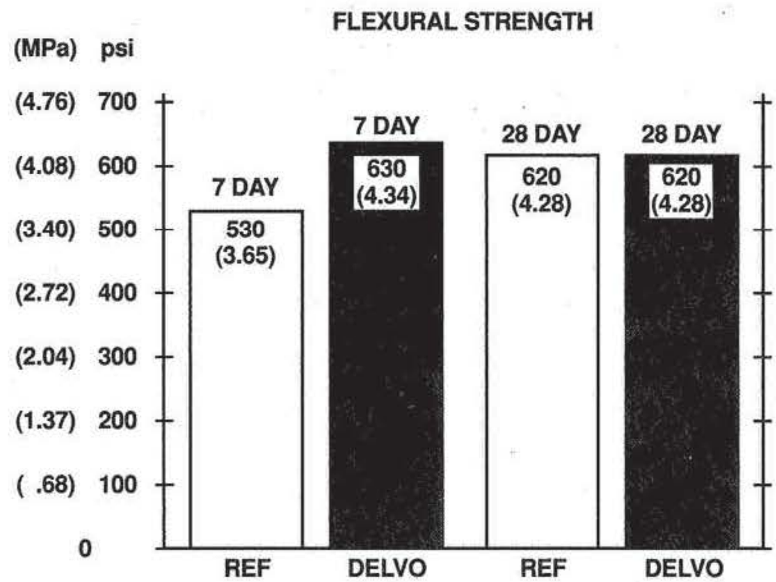
	Reference	DELVO
Type II Cement, lb/yd³ (kg/m³)	470 (279)	470 (279)
Slump, in (mm)	5.5 (140)	3.5 (89)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	30 (1953)
DELVO Activator, oz/cwt (ml/100 kg)	— —	50 (3255)
Concrete Temperature, °F (°C)	63 (17)	64 (18)
Ambient Temperature, °F (°C)	67 (19)	55 (13)
Concrete Returned, yd³ (m³)	2.25 (1.71)	2.25 (1.71)
Concrete Batched, yd³ (m³)	— —	5.75 (4.37)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs:Mins	— —	2:00
Length of Stabilization, Hrs:Mins	— —	16:45



(1) Time of set tests conducted with a pocket penetrometer.

5.11 Flexural Strength of DELVO Treated Concrete vs. Plain Reference Concrete – Seattle, WA

Test specimens were cast from both a reference concrete mix and a concrete mix treated with the DELVO System for overnight stabilization to compare the flexural strength of each. The DELVO treated concrete consisted of 33% DELVO concrete to 67% freshly manufactured concrete. The results show that the flexural strength of DELVO treated concrete at both 7 and 28 days are comparable to those of plain reference concrete.



PERFORMANCE DATA

	Reference	DELVO
Type I Cement, lb/yd³ (kg/m³)	517 (307)	517 (307)
Slump, in (mm)	6.0 (127)	6.00 (152)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	35.0 (2278)
DELVO Activator, oz/cwt (ml/100 kg)	— —	40.0 (5208)
Concrete Temperature, °F (°C)	62 (17)	60 (16)
Ambient Temperature, °F (°C)	58 (14)	50 (10)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs:Mins	— —	2:00
Length of Stabilization, Hrs:Mins	— —	14:30

5.12 Setting Time vs. Dosage Rate

As the dosage rate of DELVO Stabilizer is increased, the length of time ready-mixed concrete will remain in its plastic state before reaching initial set will be extended.

PERFORMANCE DATA
Non-Air-Entrained

	Reference	Mix #1	Mix #2
Type I Cement, lb/yd³ (kg/m³)	517 (307)	517 (307)	517 (307)
Slump, in (mm)	5.0 (127)	5.2 (132)	5.2 (132)
Concrete Temperature, °F (°C)	70 (21)	70 (21)	70 (21)
Ambient Temperature, °F (°C)	70 (21)	70 (21)	70 (21)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	3 (195)	12 (781)
Initial Set, Hrs: Mins	6:30	8:00	25:30
Comparison	— —	+1:30	+19:00

ENGINEERING PROPERTIES OF DELVO TREATED CONCRETE

B. LABORATORY (ENGINEERING) DATA

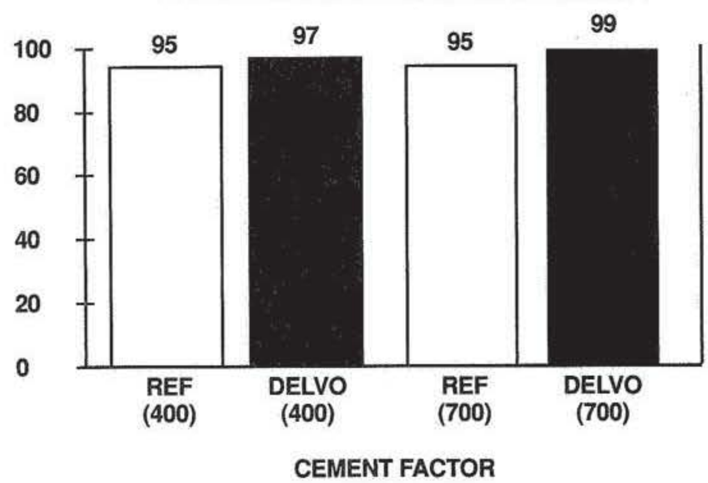
5.13 Freeze/Thaw Durability of DELVO Treated Concrete

DELVO System treated concrete has proved to be as durable as reference air-entrained concrete when subjected to freeze/thaw cycles at both high and low cement factors. In these examples concrete was stabilized overnight and combined with freshly manufactured concrete at a ratio of 25% DELVO treated to 75% freshly manufactured concrete. Concrete beams were tested following ASTM C 666 Resistance of Concrete to Rapid Freezing and Thawing (Procedure A).

PERFORMANCE DATA

	Reference	DELVO	Reference	DELVO
Type I Cement, lb/yd³ (kg/m³)	400 (237)	400 (237)	700 (415)	700 (415)
Slump, in (mm)	5.2 (132)	5.5 (140)	5.0 (127)	5.2 (132)
Air Content, (%)	7.5	6.5	5.8	5.7
Pozzolith 322-N, oz/cwt (ml/100 kg)	5.0 (326)	5.0 (326)	5.0 (326)	5.0 (326)
Micro-Air, oz/cwt (ml/100 kg)	0.8 (52)	0.8 (52)	0.8 (52)	0.8 (52)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	20 (1302)	— —	15 (976)
DELVO Activator, oz/cwt (ml/100 kg)	— —	80 (5208)	— —	80 (5208)
Concrete Temperature, °F (°C)	70 (21)	70 (21)	70 (21)	70 (21)

RELATIVE DURABILITY FACTOR AFTER 300 CYCLES OF FREEZING AND THAWING



5.14 Petrographic Analysis of Freeze/Thaw Beams

DELVO System treated concrete has proved to be as durable as reference air-entrained concrete when subjected to freeze/thaw cycles at both high and low cement factors. In these examples concrete was stabilized overnight and combined with freshly manufactured concrete at a ratio of 25% DELVO treated to 75% freshly manufactured concrete. Concrete beams were tested following ASTM C 666 Resistance of Concrete to Rapid Freezing and Thawing (Procedure A).

400 lb (182 kg) Cement Factor

			Traverse		Parameters of the Air-Void System					
	Beam #	Paste by Vol (%)	Points	Length (in)	Air % by Vol	P/A	n	in.	α in.$^{-1}$	L in.
Reference	1	25.66	2054	101.4	6.91	3.71	10.67	.006	667	.0060
	2	26.09	2058	101.6	8.45	3.09	11.11	.008	500	.0059
	3	21.12	2055	101.5	5.89	3.59	9.61	.006	667	.0055
	4	23.32	2037	100.6	6.82	3.42	10.68	.006	667	.0055
DELVO	1	22.57	2029	100.2	5.96	3.79	8.30	.007	514	.0068
	2	24.87	2039	100.7	5.3	4.69	8.95	.006	667	.0067
	3	25.75	2054	101.4	5.94	4.34	9.70	.006	667	.0065
	4	25.99	2093	103.4	8.22	3.16	11.87	.007	571	.0055

700 lb (318 kg) Cement Factor

			Traverse		Parameters of the Air-Void System					
	Beam #	Paste by Vol (%)	Points	Length (in)	Air % by Vol	P/A	n	in.	α in.$^{-1}$	L in.
Reference	1	29.63	2045	101.0	4.01	7.39	7.66	.005	800	.0069
	2	28.47	2051	101.3	4.00	7.12	7.07	.006	667	.0082
	3	28.34	2064	101.9	4.65	6.09	10.76	.004	1000	.0051
	4	29.69	2065	102.0	5.38	5.52	12.64	.004	1000	.0048
DELVO	1	26.82	2036	100.5	4.17	6.43	7.14	.006	667	.0078
	2	29.60	2051	101.3	4.05	7.31	7.51	.005	800	.0069
	3	20.63	1962	96.9	4.54	6.75	8.19	.006	667	.0080
	4	32.79	2132	105.3	3.75	8.74	8.57	.004	1000	.0060

5.15 CORROSION DATA

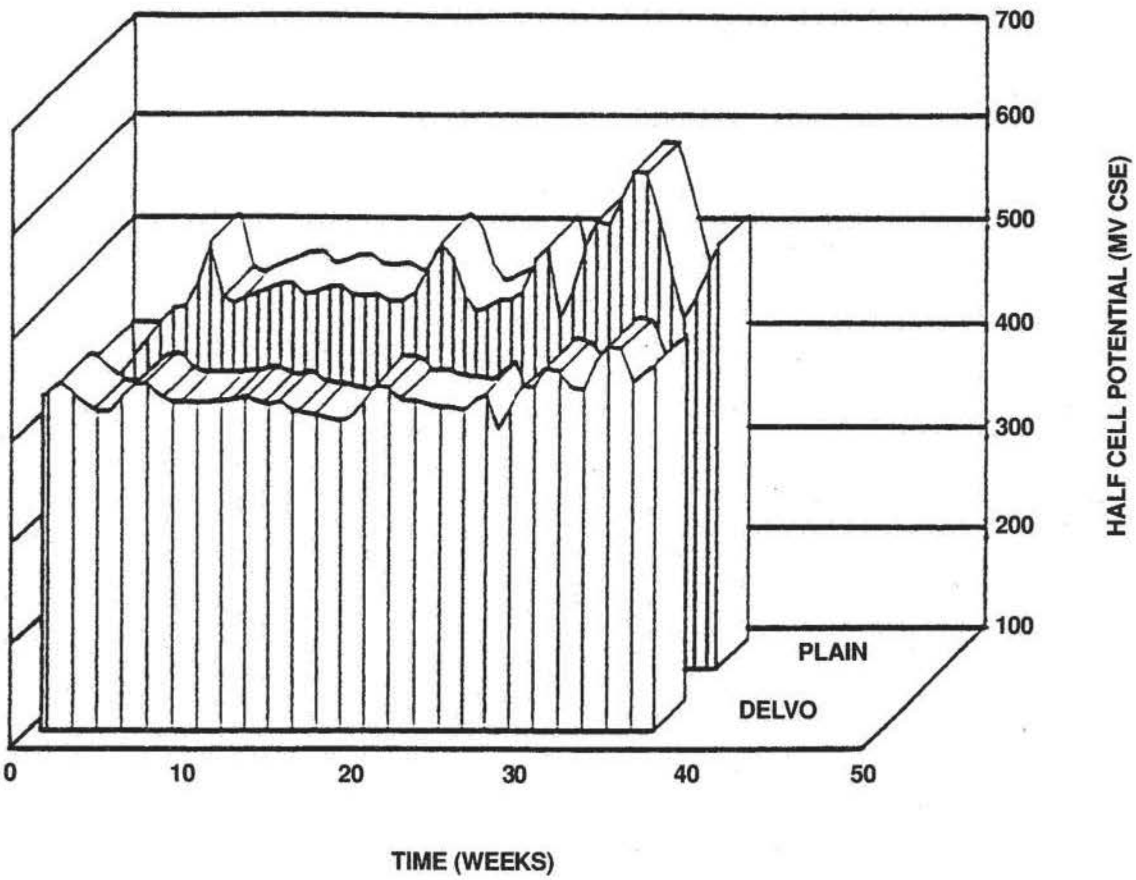
Tests on Reinforced Concrete:

Plain reference concrete was evaluated against DELVO treated concrete (31% DELVO treated concrete to 69% freshly manufactured concrete) following the "Southern Climate Accelerated Test Method" for corrosion. This test method is designed to simulate the amount of corrosion of steel reinforcing bars in concrete as a result of chloride intrusion. The test specimen consists of a 12 in. x 12 in. x 7 in. (30.5 cm x 30.5 cm x 17.8 cm) concrete block containing two layers of #4 reinforcing bar, the hardened concrete block is then ponded with a 15% sodium chloride solution. As the chloride ions begin to migrate down to the first layer of reinforcing bar, the top part of the test specimen becomes conducive to corrision. As corrosion begins to occur, the test specimen becomes polarized with the top rebar being anodic steel and the second or bottom layer of rebar being cathodic steel. The current generated by the corrosion process then travels through the concrete to the bottom reinforcing bar (cathodic steel). An external resistor is connected to both layers of the reinforcing bar to complete the circuit. It is at this point that a multimeter is used to measure the corrosion current. The amount of corrosion of the steel reinforcing bars in a given time is proportional to the area under the corrosion current vs. time curve as illustrated in the corrosion graph. The results show that after 38 weeks, DELVO treated concrete has less corrosion activity than the reference concrete.

PERFORMANCE DATA

	Reference	DELVO
Type I Cement, lb/yd^3 (kg/m^3)	481 (285)	481 (285)
Class "F" Fly Ash, lb/yd^3 (kg/m^3)	36 (21)	36 (21)
Slump, in (mm)	5.0 (127)	4.75 (121)
Air Content, (%)	2.4	2.1
Pozzolith 322-N, oz/cwt (ml/100 kg)	5.0 (326)	5.0 (326)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	95.0 (6184)
DELVO Activator, oz/cwt (ml/100 kg)	— —	150.0 (9765)
Time of DELVO Stabilizer Addition From Initial Batching, Hrs:Min	— —	2:00
Length of Stabilization, Hrs:Min	— —	24:00

5.16 Southern Climate Accelerated Test Method



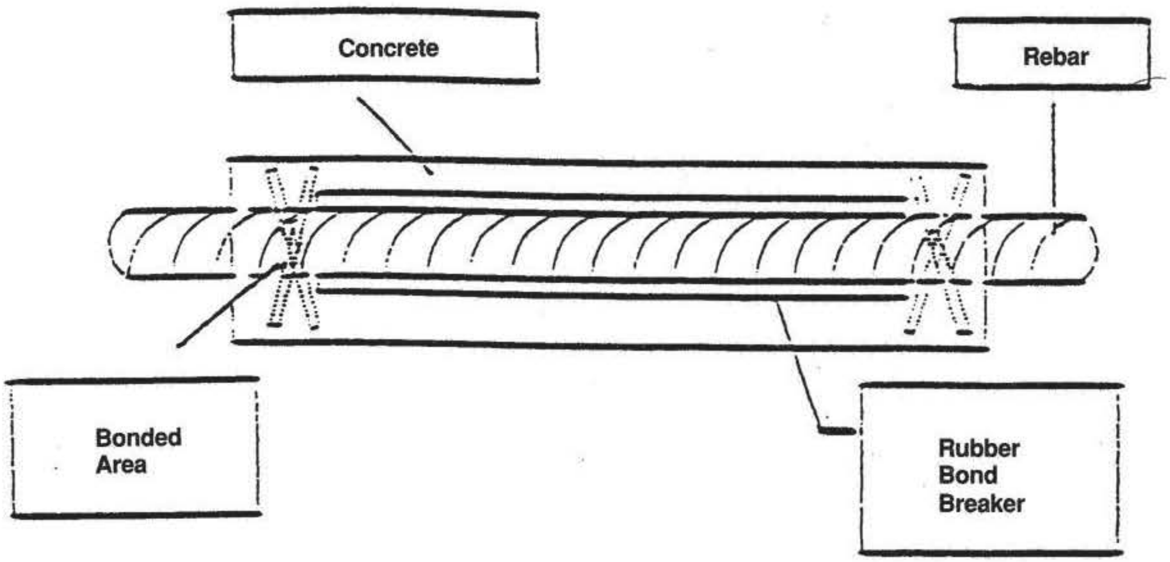
5.17 Susceptibility of DELVO System Treated Concrete To Cracking Vs. Reference Concrete

Laboratory evaluations were conducted to evaluate the tendency or susceptibility of different concrete mixes to cracking. The test set-up used in this evaluation has been used by other researchers including engineers at the California Department of Transportation for the same purpose. A test such as this one is important since shrinkage tests do not always give a good indication of the tendency of concrete cracking because of drying shrinkage. The concrete test specimens used in this evaluation measured 3.5 in x 3.5 in x 40 in (8.9 cm x 8.9 cm x 101.6 cm). A 1-inch (2.54 cm) diameter steel bar ran through the center of the concrete beam. This steel bar had steel pins at the ends of the bar and rubber bond breaker covering the center two-thirds of its length. The idea is that the steel pins would restrain the concrete as it begins to shrink. The rubber bond breaker would allow the concrete in the center of the beam to move towards the ends of the beam during shrinkage thus causing a build-up of internal stresses. When these stresses (due to drying shrinkage) exceed the tensile strength of the concrete, a crack will occur. The diagram on the following page is an illustration of the test beam.

PERFORMANCE DATA

	Reference	DELVO
Type I Cement, lb/yd³ (kg/m³)	700 (415)	700 (415)
Slump, in (mm)	5.0 (127)	5.0 (127)
Air Content, (%)	5.5	5.5
Pozzolith 322-N, oz/cwt (ml/100 kg)	5.0 (326)	5.0 (326)
Micro-Air, oz/cwt (ml/100 kg)	0.8 (52)	0.8 (52)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	20 (1302)
DELVO Activator, oz/cwt (ml/100 kg)	— —	80 (5208)
% DELVO Treated Concrete	— —	25
% Freshly Manufactured Concrete	— —	75
Concrete Temperature, °F (°C)	70 (21)	70 (21)
Length of Stabilization, Hrs:Mins	— —	24:00

5.18 Restrained Shrinkage Concrete Beam



Susceptibility of Concrete to Cracking

	Sample	Age (Days)	Age At Crack (Days)	Crack Width–in. (cm.)
PLAIN	1	191	—	—
	2	191	25	.005 (.013)
	3	191	—	—
	4	191	98	.005 (.013)
	5	163	24	.002 (.005)
	6	163	46	.005 (.013)
DELVO	1	190	—	—
	2	190	—	—
	3	190	—	—
	4	190	—	—
	5	162	—	—
	6	162	25	.005 (.013)

5.19 Other Engineering Properties of DELVO Treated Concrete Vs. Plain Reference Concrete

Engineering properties, other than strength, of hardened concrete were evaluated for both plain reference and DELVO treated concrete. These properties include: modulus of elasticity, maximum straining capacity at peak stress, and toughness. The DELVO System treated concrete contained 33% DELVO concrete to 67% freshly manufactured concrete. The results indicate slight improvements in compressive strength, straining capacity, and toughness for the DELVO concrete when compared to plain reference concrete. The stiffness of the two materials remained the same as indicated by the modulus values.

PERFORMANCE DATA

	Reference	DELVO
Type I Cement, lb/yd^3 (kg/m^3)	517 (307)	517 (307)
Slump, in (mm)	3.75 (95)	5.0 (127)
Air Content, (%)	7.9	6.3
Pozzolith 322-N, oz/cwt (ml/100 kg)	3.0 (195)	3.0 (195)
Micro-Air, oz/cwt (ml/100 kg)	1.75 (114)	1.75 (114)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	35.0 (2278)
DELVO Activator, oz/cwt (ml/100 kg)	— —	80.0 (5208)
Concrete Temperature, °F (°C)	70 (21)	70 (21)
Length of Stabilization, Hrs:Mins	— —	24:00

	Compressive Strength		Max Strain at Peak Stress (x10^{-6})		Modulus of Elasticity (x 10^{6})	Toughness	
	psi	(MPa)	psi	(MPa)		in lb/in	(cm kg/cm)
Reference	5270	(36.3)	2624	(18.1)	2.8	8.4	(3.3)
DELVO	5629	(38.8)	2950	(20.3)	2.7	10.1	(4.6)

Material properties were measured after 28 days of moist curing.

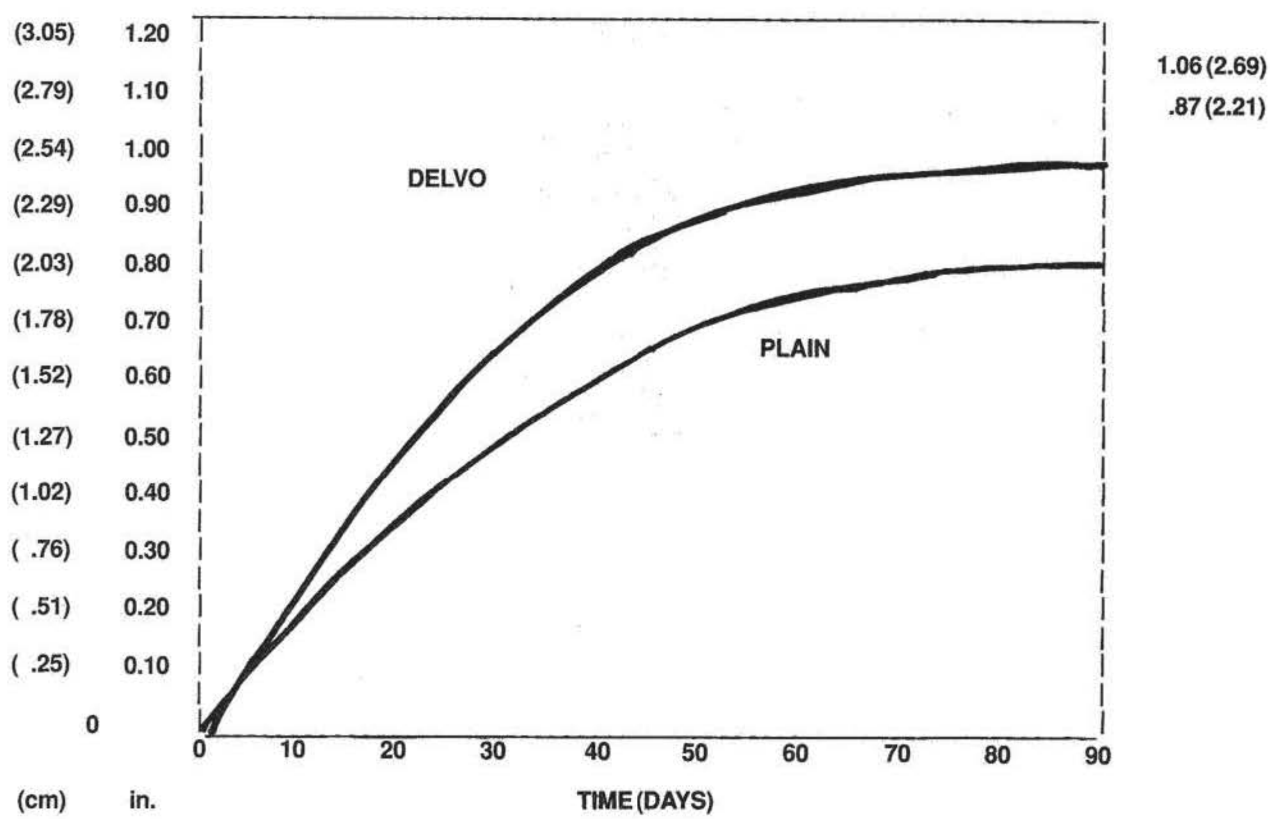
5.20 Creep of DELVO Treated Concrete Vs. Plain Reference Concrete

Creep of the reference and DELVO System treated concrete was measured using ASTM C 512 test method. Both the reference and DELVO treated concrete mixes in this evaluation were proportioned to yield 4000 psi (27.6 MPa) compressive strength at 28 days. After 90 days of loading, the data indicated 22% higher creep for the DELVO treated concrete compared to the reference mix. The increase is well below the accepted variability for measurements of this type.

PERFORMANCE DATA
Non-Air-Entrained Concrete

	Reference	DELVO
Type I Cement, lb/yd³ (kg/m³)	451 (267)	420 (249)
W/C Ratio	0.65	0.70
Slump, in (mm)	5.5 (140)	6.4 (165)
Unit Weight, lb/ft³ (kg/m³)	150 (2408)	151 (2423)
Compressive Strength, psi (MPa)	3870 (26.7)	3970 (27.4)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	20.0 (1302)
DELVO Activator, oz/cwt (ml/100 kg)	— —	80.0 (5208)
DELVO Treated Concrete, (%)	— —	33.3
Freshly Manufactured Concrete, (%)	— —	66.7
Length of Stabilization, Hrs:Mins	— —	24:00

5.21 Creep of Concrete

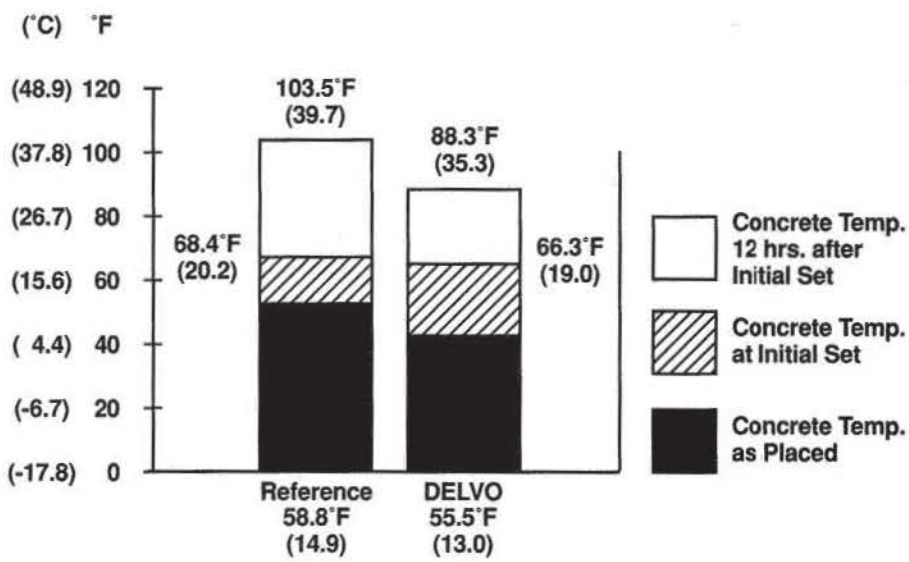


5.22 Heat of Hydration Data

Reference and DELVO System treated concrete samples were isolated in a one cubic foot insulated box. Three temperature probes, interfaced with a computer, monitored the heat that was generated by the hydration process as the concrete began to harden. Both the plain and the DELVO treated concrete started out at approximately the same temperature. At initial set they both had generated approximately the same amount of heat. At 12 hours after initial set, the DELVO System concrete had produced significantly less heat than the plain concrete making it a possible candidate for concreting applications where low heat generation is important.

PERFORMANCE DATA

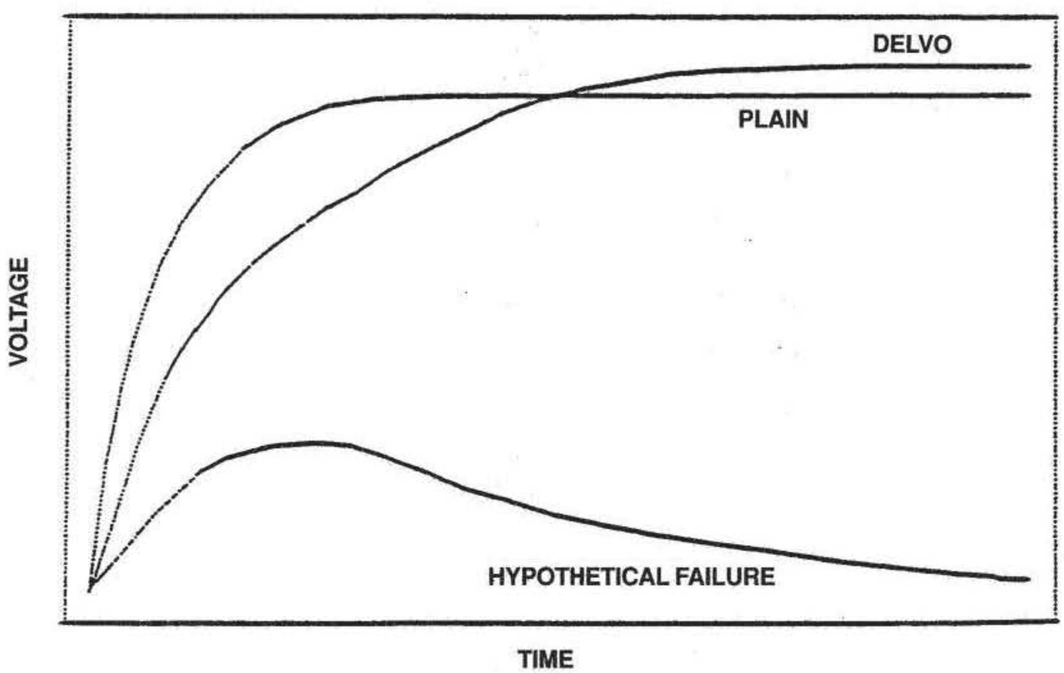
	Reference	DELVO
Type I Cement, lb/yd³ (kg/m³)	517 (307)	517 (307)
Slump, in (mm)	3.75 (95)	5.00 (127)
Air Content, (%)	7.9	6.3
Pozzolith 322-N, oz/cwt (ml/100 kg)	3.0 (195)	3.0 (195)
Micro-Air, oz/cwt (ml/100 kg)	1.75 (114)	1.75 (114)
DELVO Stabilizer, oz/cwt (ml/100 kg)	— —	35.0 (2278)
DELVO Activator, oz/cwt (ml/100 kg)	— —	80.0 (5208)
Ambient Temperature, °F (°C)	68.5 (20)	68.5 (20)
DELVO Concrete (%)	— —	33.3
Freshly Manufactured Concrete (%)	— —	66.7



5.23 Corrosion Data – Mortar

DELVO treated concrete was compared to reference plain concrete for its ability to corrode reinforcement bars embedded in mortar using the Gouda-Monfore Corrosion Test. The data indicates that the DELVO treated concrete exhibited no evidence of reinforcement bar corrosion. The dosages used for the DELVO mix were 95 oz/cwt (6184 ml/100 kg) DELVO Stabilizer and 150 oz/cwt (9765 ml/100 kg) DELVO Activator at a ratio of 31.5% DELVO treated concrete to 68.5% newly manufactured concrete.

GOUDA-MONFORE CORROSION TEST



VI. DELVO SYSTEM BENEFITS

6.1 **Treating Concrete Wash Water**
The DELVO Stabilizer can be used to stabilize concrete wash water in the drum of a ready-mix truck, on an overnight and weekend basis, and provides the following benefits:

- Reduces the amount of water needed to clean ready-mix truck drums.
- Reduces labor costs to wash out trucks.
- Eliminates concrete wash water disposal.
- Eliminates the need for concrete wash water pits and resulting wear and tear on front-end loaders and hauling charges.
- Acts as a cleansing agent, and reduces concrete build up on fins, thereby reducing maintenance costs incurred from chipping out hardened concrete.
- Concrete containing stabilized wash water will experience strength performance equal to or greater than reference concrete without stabilized wash water.
- Reduces/eliminates environmental (EPA) concerns pertaining to the disposal of concrete wash water.

6.2 **Treating Returned Plastic Concrete**
The DELVO Stabilizer can be used to stabilize returned plastic concrete in the drum of a ready-mix truck or central holding vessel, on the same day, overnight and weekend basis, and provides the following benefits:

- Reduces/eliminates the use of expensive reclaimer/recycler units having continuous maintenance costs.
- Reduces/eliminates dumping returned concrete which can result in expensive labor costs, excessive wear and tear on front-end loaders, and costly hauling charges.
- Reduces/eliminates environmental (EPA) concerns pertaining to the disposal of returned plastic concrete.
- Concrete treated with the DELVO System results in performance qualities equal or superior to reference concrete manufactured conventionally.

Appendix I

PART B. REUSE OF CRUSHED CONCRETE AS AGGREGATE. Question 14. For which applications is use of crushed concrete as aggregate permitted or not permitted by your agency? For which is it commonly used? (Check all that apply.)

		Total	AL	AR	CA	CO	DC	DE	FL	GA	IA	IL	IN	LA	MD	MI	NH	NM	NV	NY	OH	OK	PA	SC	TX	WY	BC
Fill, embankments or noise barriers	Permitted	**24**	X*	X	X	X		X	X	X	X	X	X	X	X*	X	X	X	X	X	X	X	X	X	X	X	X
	Not permitted																										
	Commonly used	**4**	X											X					X	X							
Lean concrete base	Permitted	**6**			X*	X						X								X		X			X		
	Not permitted	**16**	X	X				X	X	X			X	X	X	X	X	X	X				X	X		X	X
	Commonly used																										
Nonstructural pavement (sidewalks, curbs and gutters, median barriers)	Permitted	**10**			X	X			X			X				X			X	X	X	X			X		
	Not permitted	**13**	X	X				X		X			X	X	X		X	X					X	X		X	X
	Commonly used	**1**																	X								
Pavement base or subbase layers	Permitted	**24**	X*	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Not permitted	**1**											X														
	Commonly used	**10**	X	X				X		X		X		X								X		X	X	X	
Asphalt road surface courses	Permitted	**3**							X			X													X		
	Not permitted	**19**	X	X	X			X	X	X			X	X	X	X	X	X	X	X	X		X	X		X	X
	Commonly used																										
Concrete road surface courses	Permitted	**10**	X			X						X	X						X	X	X	X		X	X		
	Not permitted	**13**		X	X			X	X	X				X	X	X	X	X					X			X	X
	Commonly used	**2**	X																						X		
Bridge substructures	Permitted	**3**				X						X								X							
	Not permitted	**19**	X	X	X			X	X	X			X	X	X	X	X	X	X		X		X	X	X	X	X
	Commonly used																										
Bridge superstructures	Permitted	**2**				X														X							
	Not permitted	**19**	X	X	X			X	X	X			X	X	X	X	X	X	X		X		X	X	X	X	X
	Commonly used																										

*Notes on responses:

Alabama
- Our specifications only allow crushed concrete to be used in concrete road surface courses. At present we have no approved sources to supply the material.
- However, crushed concrete has been used in fill and embankments on ALDOT projects and were approved for use through a project note when the material was readily available with limitations of maximum size and required minimum cover in the upper two feet of fill.
- Also, if you consider crushed concrete (existing) pavement left in place to be aggregate, then it has been used as a pavement base layer.
- We are not aware of any concrete mix designs approved for use in non structural pavement.

California
Standard specifications do not permit as "Aggregate samples must not be treated with lime, cement, or chemicals before testing for sand equivalent." Permitted as occasionally per project special

Maryland
Maryland SHA does not currently use crushed concrete as aggregate for noise barriers. But, we may consider in the future.

1- 6-94
4-21-03 Rev.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

SPECIAL PROVISION

JOB 020487

REMOVING EXISTING PORTLAND CEMENT CONCRETE PAVEMENT

Section 202 of the Standard Specifications for Highway Construction, Edition of 2003, is hereby amended as follows:

The following requirements are added to **Subsection 202.03**:

The existing concrete pavement shall be removed in a manner that causes minimal disturbance to the underlying base course or to the adjacent shoulders. Any damage resulting from the construction operations shall be repaired by the Contractor at no cost to the Department.

The Contractor shall schedule and perform the work in a manner that will minimize the exposure of the subgrade to the elements. Drainage shall be maintained at all times as necessary by trenching through the existing shoulder or by other approved methods. If the material is to be recycled as specified herein, asphalt patches and joint seal material shall be removed prior to removing the pavement.

Material removed under this item may be used as aggregates for Aggregate Base Course (Section 303). The aggregate produced from salvaged concrete pavement shall be substantially free of steel reinforcement, an excess of thin or elongated particles, clay lumps, vegetation, asphalt pavement, deleterious substances, and adherent coatings that could be considered injurious for the intended use. The material shall be processed to meet all requirements of Section 303 of the Class specified, except that the requirement for loss by the Los Angeles Test is waived.

Excess and/or unusable material, including reinforcing steel, removed under this item shall become the property of the Contractor and shall be disposed of in accordance with the requirements of Section 202.

Subsection 202.04 is deleted and the following substituted therefor:

202.04 Method of Measurement. Removal of existing portland cement concrete pavement will be measured by the square yard. The quantity will be computed from the measured width and length of pavement removed. No deduction will be made for joints less than 6" in width nor for asphalt patches where at least 4" of existing concrete pavement exists beneath the asphalt patch.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

SPECIAL PROVISION

JOB 020487

REMOVING EXISTING PORTLAND CEMENT CONCRETE PAVEMENT

Subsection 202.05 is deleted and the following substituted therefor:

202.05 Basis of Payment. Work completed and accepted and measured as provided above will be paid for at the contract unit price bid per square yard for Removing Existing Portland Cement Concrete Pavement, which price shall be full compensation for removing asphalt patches and joint seal material; removing the pavement; maintaining drainage; processing the removed material for use as aggregate in other portions of the work; disposal of excess and unusable material; and for all labor, equipment, tools, and incidentals necessary to complete the work.

Payment will be made under:

Pay Item	**Pay Unit**
Removal of Existing PortlandCement Concrete Pavement	Square Yard

inCATEGORY 900
MATERIALS

{ TC – "SPI – Section 900.03 – Recycled Materials" }
655 **ADD:** The following after the last paragraph of 900.02 TECHNICIAN QUALIFICATION REQUIREMENTS.

This spec goes in all projects
900.03 RECYCLED MATERIALS.

900.03.01 CERTIFICATION. All recycled or rehandled material furnished or supplied for use may require testing and certification to ensure compliance with all State and local applicable environmental and EPA regulations. The required testing may include, but not be limited to, the EPA Toxicity Characteristic Leaching Procedure (TCLP) or its successor. Provide testing and certification for all recycled materials at no additional cost to the Administration. Evaluation and interpretation of the test data will be made by an OMT Quality Assurance Manager. The above requirements do not preclude the normal materials acceptance process, and the recycled material shall meet all applicable specifications. EPA regulations governing the use of the material, certified test results, and material safety data sheets shall accompany the source of supply letter and sample submitted for approval.

Only highway demolition materials are to be used in constructing RC stockpiles for Administration projects. The use of building materials is prohibited.

Refer to the Contract Documents for recycled materials not covered by this specification.

900.03.02 RECLAIMED/RECYCLED CONCRETE (RC).

Usage. Use RC for the following with written approval:

(a) Graded Aggregate Base (GAB).

(b) Common, Select, or Modified Borrow:

(1) At least 2 ft above saturated soil or groundwater conditions,

(2) At least 100 ft from surface waters (streams, creeks, or rivers),

(3) At least 3 ft from exposed metal surfaces, and,

(4) At least 3 ft from geotextile.

Do not use RC as Capping Borrow nor as aggregate for the following:

(a) Portland cement concrete.

(b) Hot mix asphalt.

(c) Drainage systems.

(d) Mechanically stabilized earth (MSE) systems:

(1) MSE walls.

(2) Reinforced soil slopes (RSS).

(3) Reinforced earth slopes (RES).

(e) In embankment construction as follows:

(1) Within 1 ft of the top surface of any area to be vegetated.

(2) Within 2 ft of saturated soil or groundwater conditions.

(3) Within 100 ft of any surface water course (streams, creeks, or rivers).

(4) Within 3 ft of any metal pipe or shoring.

(f) Under pervious or porous surfaces.

Grading Requirements. The grading requirements for the use of RC are:

(a) Table 901 A when used as GAB or for any other application within the pavement structure.

(b) 204.02 when used in embankment construction.

(c) 916.01 when used as Borrow material.

(d) 901.02.01 when used as riprap.

RC shall not contain more then 5 percent brick and hot mixed asphalt material by mass except when used as Common Borrow.

pH Requirements. RC pH shall be less than 12.4 for all applications. RC usage shall not cause any outfall and infiltration water leaving the site to exceed a pH of 8.5. RC may be blended with natural materials to control the pH. RC used as GAB requires daily testing to monitor the pH, and as directed.

pH Testing.

(a) **Plant:** The producer is required to test pH at the plant per T 289 every 1,000 tons shipped or once a day, whichever yields the greater frequency. Plant pH testing shall be recorded as specified and a history shall be kept at the producer's laboratory. The producer may be required to present TCLP and any other tests conducted by an independent laboratory as directed.

The Administration reserves the right to test the producer's RC at the plant for pH. Material delivery may be terminated if the test results repeatedly meet or exceed a pH of 12.4.

(b) **Construction site:** Monitor, test, and report pH levels of any discharge associated with RC placement as directed. This includes monitoring and testing after all periods of precipitation or dampness.

Quality Control. The producer shall submit a Quality Control Plan and obtain approval prior to production. The plan shall include, but not be limited to, the operational techniques and procedures proposed to produce the RC product. Quality control includes the sampling, testing and data recording performed to validate the quality of the product during production operations.

Quality Assurance. OMT Quality Assurance personnel will perform quality assurance inspection, sampling, and testing at the RC plant and construction site. Additional inspection, testing and compaction control will be performed by the Project Engineer.

900.03.03 RECYCLED ASPHALT PAVEMENT (RAP).

Usage. Use RAP for Common, Select, Capping, or Modified Borrow.

Do not use RAP as aggregate for the following:

(a) Graded Aggregate Base (GAB).

(b) Portland cement concrete.

(c) Drainage systems.

(d) Embankment construction.

(1) Within 1 ft of the top surface of any area to be vegetated.

Refer to MSMT 412 and M 323 for the use of RAP in hot mix asphalt mixes.

Grading Requirements. The grading requirements for the use of RAP are:

(a) 204.02 when used in embankment construction,

(b) 916.01 when used as Borrow material,

(c) 901.02.01 when used as riprap.

Quality Control. Create a captive stockpile for storing the RAP prior to use. Create a new captive stockpile and take new acceptance samples for gradation approval whenever the source of the RAP changes.

Quality Assurance. OMT Quality Assurance personnel will sample and test the RAP stockpiles to ensure that they meet the above gradation requirements. The completed test results will be reviewed by the OMT Soils and Aggregate Division for approval.

Construction of Control Test Strip. The location, equipment, and methods used to construct the control test strip shall be as directed; prior to approval. The equipment and methods used to construct the control test strip shall be the same as those used in subsequent construction. Place and test the control test strip when the RAP is 32°F or higher to establish the maximum density. RAP is temperature sensitive, which may affect the density.

Construct the control test strip that shall be at least 100 ft long, 12 ft wide and a maximum compacted lift thickness of 6 in. Prepare the subgrade for the control test strip in accordance with 204.03.07. Do not construct the control strip, or perform any subsequent construction, on frozen subgrade.

Compact the RAP for the control test strip with one pass of the roller. Measure the density after one pass with a nuclear density gauge (backscatter method) at the frequency for capping material at five random locations distributed across the length and width of the control test strip, as directed. Record the measurements and mark the locations for future reference.

Compact the RAP for the control test strip with a second pass of the roller. Measure and record the density again at the exact locations previously tested and as described above. Prepare a plot of density versus the number of roller passes. Continue this process until the maximum dry density of the control strip is established.

There should be no drop in average density during construction of the control test strip for each lift. A drop in the average density of greater than 2 pcf during construction of the control test strip is an indication that the material is not properly compacting, and a new test strip shall be constructed.

The Project Engineer may require the Contractor to cut into the control test strip for visual inspection. All material, labor, equipment, tools, and incidentals necessary to provide an approved control test strip shall be at no additional cost to the Administration.

Compaction Control. Use the roller pattern and number of passes determined from the construction of the test strip to compact the RAP for production placement. The density of the RAP compacted for production work shall be at least 97 percent of the maximum density obtained from the control test strip. Recheck the density of the production work if it is less than 97 percent of the maximum density obtained from the control test strip. Construct a new control test strip if the second density does not meet the 97 percent requirement. Construct a new control test strip if the measured density of the compacted RAP for production work exceeds 105 percent.

Establish one rolling pattern to achieve maximum density for each use based on the control test strips. Samples or results produced prior to the construction of any new stockpiles will not be considered.

Appendix L

SUPPLEMENTAL SPECIFICATION

Aggregate for Use in Portland Cement Concrete Pavement

Section 3 of Supplementary Technical Specification SC-M-501 is replaced in its entirety with the following:

Fine Aggregate: Use fine aggregate meeting the requirements as specified in Subsection 701.2.9 except that the use of fine aggregate derived from the recycling of Portland Cement Concrete Pavement removed from the project or other recycled PCC is not acceptable. Aggregate derived from limestone is also not acceptable.

Coarse Aggregate: Use coarse aggregate meeting the requirements as specified in Subsection 701.2.10 with the following exceptions. At the option of the Contractor, coarse aggregate derived from the recycling of Portland Cement Concrete Pavement removed from the project may be used. Ensure that the coarse aggregate produced by the recycling of the existing PCC pavement meets the requirements of Subsection 701.2.10, except that the LA Abrasion Loss and sulfate soundness requirements are waived. Do not use PCC for recycling other than that removed from the roadway within the project. Remove all joint sealant and backer material from the existing pavement prior to removal for recycling and ensure that the resulting recycled aggregate is free from sealant, steel reinforcement, wood, and other contaminants. Do not use aggregate derived from limestone or slag.