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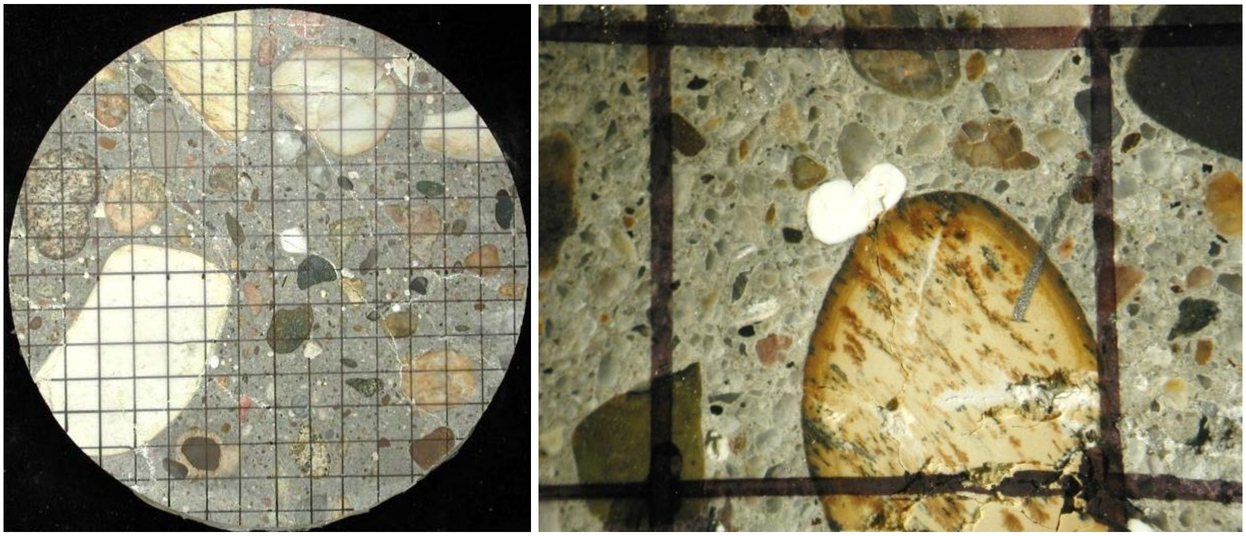
Managing Water in the West

Report DSO-2014-03

Seminoe Dam - Assessment of Concrete by Quantitative Methods – The Petrographic Damage Rating Index

Dam Safety Technology Development Program



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Douglas R. Hurcomb, P.G.

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14. ABSTRACT

The Damage Rating Index (DRI) method was conducted on mass concrete cores to determine the value of the method for overall evaluation of damage to Reclamation's concrete structures. This study compares the current Seminoe Dam compressive strength trends with DRI results and contemplates how the results could be used to evaluate concrete from structures suffering from ASR in Reclamation's aging concrete infrastructure. The DRI can be performed on a limited number of samples and provides a semi-quantitative value related to alkali-silica reaction (ASR) aggravated concrete damage. The DRI value can be used to evaluate the extent of damage caused by ASR and appears to correlate well with the traditional petrographic concrete quality approach. The approach may be a useful way to estimate the extent of damage in a concrete structure.

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Alkali-silica reaction, alkali-aggregate reaction, mass concrete, damage rating index (DRI), Seminoe Dam, petrography, compressive strength, freezing and thawing, petrographic quality

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Dam Safety Technology Development Program

Prepared by:

Doug Hurcomb, Geologist, Materials Engineering and Research Laboratory

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BUREAU OF RECLAMATION
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DSO-2014-03

Seminoe Dam
Assessment of Concrete by Quantitative Methods – The Petrographic Damage Rating Index

Doug Hurcomb
Prepared: Doug Hurcomb, PG.
Geologist, Materials Engineering and Research Laboratory Group, 86-68180

Audrey Rager
Checked: Audrey Rager
Geologist, Materials Engineering and Research Laboratory Group, 86-68180

Westin T. 6/26/14
Technical Approval: Westin Joy, P.E.
Civil Engineer, Materials Engineering and Research Laboratory Group, 86-68180

REVISIONS					
Date	Description	Prepared	Checked	Technical approval	Peer review

ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
ASR	Alkali-Silica Reaction
DRI	Damage Rating Index
MERL	Materials Engineering and Research Laboratory
TSC	Technical Service Center

Symbols

cm	centimeters
mm	millimeters

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Conclusions and Summary

The DRI can be performed on a limited number of samples and provides a semi-quantitative value related to qualitative rating of ASR aggravated concrete damage. The value can be used to evaluate the extent of damage caused by ASR. The approach may be a useful way to estimate the extent or amount of damage in a concrete structure with only a few well-chosen samples. A legitimate sample must be representative of the structure being evaluated, exhibit evidence of ASR, and have about 200 square cm of surface area. The literature suggests concrete exhibiting symptoms of ASR with a DRI value of 50 or greater has experienced deleterious ASR (Thomas, 2012). The evidence is visual and easily photographed for documentation. It should be noted that DRI results are not a failure criteria and DRI values may vary from petrographer to petrographer.

The DRI data above and below 35 feet in the Seminoe Dam cores from DH-13-2 appear to show changes in compressive strength (figure 1). The subjective relative degree of reaction and DRI values change from moderate to lower values at about 35 feet. The most notable physical change is the width of the cracks in paste that are easily visible without the aid of magnification on the polished surface above about 35 feet in depth to not visible or only barely perceptible below 35 feet in depth (Table 2).

The DRI data above and below 60 feet in the Seminoe Dam cores from DH-13-3 appear to show property changes recorded in the compressive strength data. The subjective relative degree of reaction and DRI values change from moderate to lower values at about 60 feet. Similarly, the most notable changes are the width of the cracks in paste that are easily visible without the aid of magnification above 60 feet and not visible to only barely perceptible below 60 feet (Table 3).

The DRI method relies on the presence of certain petrographic features unique to ASR. The resulting DRI values indicate the degree of severity of damage.

The criteria in the Petrographic Laboratory’s Analytical Techniques and Capabilities Reference are used to evaluate concrete for a conventional petrographic examination. Experience shows that moderate and especially extensively damaged concrete can affect the durability and service life of a structure. An experienced petrographer is usually required to judge if the examined concrete is satisfactory, fair, or poor petrographic quality using a conventional petrographic examination following the guidance provided by

ASTM C 856. The DRI approach may provide a focused, efficient, and cost effective petrographic assessment on a few well-chosen samples from a structure with an identified ASR problem. The DRI should be performed by an experienced concrete petrographer or under the direct supervision of a qualified petrographer. More work should be considered to fully evaluate the DRI method for mass concrete structures.

Introduction

Seminoe Dam is a 295 foot high concrete structure on the North Platte River in South Central Wyoming. The dam suffers from alkali-aggregate reaction. The dam was constructed in 1939 before the discovery that low alkali cement, air entraining admixtures, and other beneficial modifications to concrete could ameliorate deleterious chemical and physical deterioration. For a detailed historical account of the concrete see Appendix C.

Seminoe Dam is experiencing ongoing alkali-silica reaction that has affected the durability and integrity of concrete in the dam (Dolen et al., 2003). Alkali-aggregate reaction was first noted in a 1950's petrographic examination of the concrete. In a 1970's petrographic examination, cores indicated extensive damage to the upper 5 feet with minimal to moderate damage to about 20 feet. In a 1980's petrographic examination, cores indicated extensive damage to the upper 8 feet of concrete and minimal to moderate damage below 8 feet. In the 1990's areas of extensive damage were observed to 18 feet.

There are problems with the upper 10 to 20 feet of concrete in the dam structure due to alkali-aggregate reaction and likely freeze-thaw action. Currently, structural, seismic, stress, photographic, and foundation investigations are underway to understand the response of the dam to the progressive and changing condition of the concrete.

In 2013, a coring program provided fresh cores drilled from five vertically oriented drill holes on the crest. Selected intact core fragments were tested for physical properties and strength conditions and as well as petrographic analysis to determine the current condition of the concrete. In 2013, evidence of alkali-silica reaction (ASR) was observed in cores up to 75 feet depth.

Seminoe Dam concrete core was previously examined and documented in Bureau of Reclamation memoranda internally published in 1980, 1998, 1999, 2004, 2009, and 2013. Please refer to petrographic referral 80-46 dated July 24, 1980 and in ESRL 8340-98-45 and 8340-99-10 (petrographic referral 98-20 and 99-05) dated Oct. 26, 1998 and Mar. 30, 1999, respectively. Reclamation's Material Engineering and Research Laboratory reported strength conditions in 1998-99 Concrete Coring-Laboratory Testing Program, Seminoe Dam, Kendrick Project, Wyoming, by C. Mohorovic et al., dated August 1999. The 2003, 2009, and current testing results are reported in MERL-2005-03 dated February 23, 2005, MERL-2010-07 dated May 3, 2010, and MERL-2014-26 dated April 23, 2014, respectively.

The purpose of this work is to review the Damage Rating Index (DRI) method to determine the value of the method for overall evaluation of damage to Reclamation's concrete structures. This study compares the current Seminoe Dam compressive strength trends with DRI results and contemplates how the results could be used to evaluate concrete from structures suffering from ASR in Reclamation's aging concrete infrastructure.

Background

Summary of Previous Petrographic Examinations

The concrete from cores recovered from the FY13 Seminoe Dam Concrete Core Testing Program, were previously examined following ASTM C 856, Standard Practice for Petrographic Examination of Hardened Concrete. The examination determined the concrete was poor to satisfactory quality. Extensively damaged, poor quality concrete was observed from zero to about 5 feet and minimally to moderately damaged, fair quality concrete, was observed to about 75 feet. The observed damage is due to the significant effects of progressive ASR. ASR exhibits alkali-silica gel soaked and cracked paste and aggregates, alkali-silica gel filled cracks and voids, and weakened or failed paste-coarse aggregate bond.

A major portion of the coarse aggregate fraction is slightly fractured, water-worn, generally rounded, and deleteriously alkali-reactive quartzite gravel and cobbles, which exhibits a generally smooth to slightly rough surface texture. The finer aggregate fractions contain deleteriously-reactive glassy volcanics, chert, and shale in amounts previously determined to be about 4.5 percent. Examined disbonded quartzite aggregate show evidence of alkali-silica gel lining aggregate surfaces and lining rock-sockets. Cracks were observed penetrating both paste and aggregates in both the fine and coarse fractions and are usually filled or associated with alkali-silica gel deposits.

Freshly exposed saw cut and cored surfaces typically develop a white efflorescent coating due to the carbonation of the alkali-silica gel product. If the freshly exposed core surfaces are kept in a sufficiently moist condition, gel deposits form in situ within a few hours, days, or weeks of exposure to moisture. Failure surfaces of certain test specimens exhibit some evidence of ASR up to 80 feet depth after exposure. The condition of the paste, aggregate, and paste-aggregate bond in each tested core specimen appears to determine its strength.

The Damage Rating Index Method (DRI)

Several authors have proposed rating systems (Grattan-Bellew, 1995; Clemena et al., 2000; Rivard et al., 2000 and 2002) for systematic examination of concrete structures. Occurrences of certain petrographic features observed during a low-magnification examination of a polished concrete surface are weighted by feature. The results are summed and the rating normalized for the area observed. The weighting assigned to a particular feature is somewhat subjective based on consideration of its indication of damage related to ASR. The process provides a means of achieving an objective quantitative rating of ASR-related damage from a petrographic examination.

There are a few recent examples of the use of the DRI method in the literature which were briefly reviewed during this study. The Federal Highway Administration's ASR Development and Deployment Program have been active in this regard (Fournier, et al., 2009 and 2012 and Thomas, et al., 2012). The DRI approach provides a quantitative assessment of the condition of concrete in existing structures including bridge abutments, retaining walls, barriers, and pavements. The examples include laboratory studies that compare DRI to expansion data from fresh mixes with different aggregate sources and concrete cores from existing mass concrete structures.

The concrete core fragments examined in this study were from two drill holes. The core samples and compressive strength results from DH-13-2 and -3 were available for study and easy to access. Five vertically oriented drill holes were drilled evenly distributed on the arch dam centerline from the left side of the structure to the right side. Briefly DH-13-2 and -3 were located left of center and at center, respectively. The exact drill hole locations are documented by Joy, 2014.

Figure 1, a plot of the 2013 compressive strength data compared to depth, showed compressive strength trends with great amounts of scatter. The dam's principal engineer described the distribution of compressive strength values with depth as "parabolic". Cores from 0 to 5 feet were generally not available for strength testing or DRI analysis due to their poor condition after recovery. At certain depth intervals compressive strength trends were observed, which allowed selection of samples above and below about 35 feet depth for cores from DH13-2 and above and below about 60 feet depth for cores from DH13-3. Sketched trend lines illustrate changes in the concrete's compressive strength with increasing depth. The compressive strength data are provided in Appendix D.

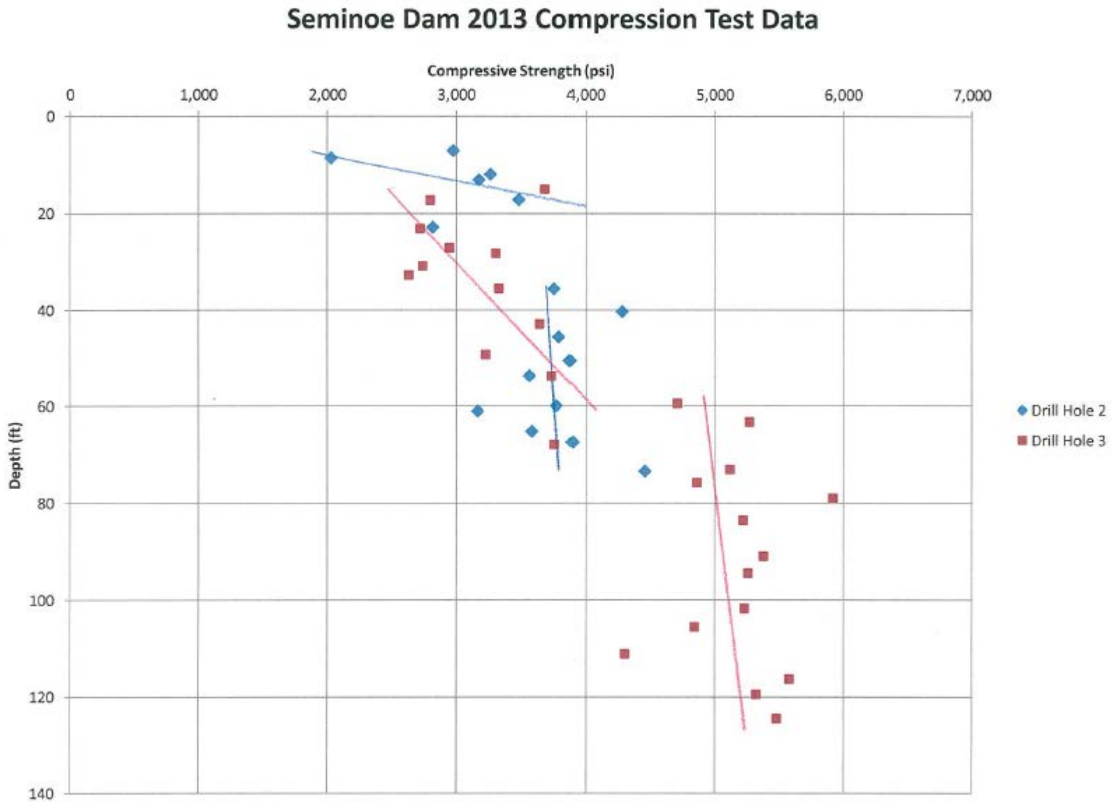

Figure 1. Plot of compressive strength data for the 2013 Seminoe Dam Concrete Core Testing Program with trend lines sketched for groups of data points. This data and plot provided by W. Joy and trend lines drawn by author.

Methods

Sample Preparation Procedures

Samples were selected from available saw cut areas and end pieces of test specimens from the Seminoe Dam 2013 Concrete Core Test program. Saw cut specimens were collected for DRI analysis from the test results. A gypsum-cement leveling pad was applied to each specimen if an irregular bond failure surface was present (figure 2). Each saw cut surface was polished for examination and a grid was applied.

Seminoe Dam cores present a unique problem during sample preparation. The aggregates are large, up to 6 inch diameter quartzite aggregates, and difficult to cut. It is difficult to prepare a concrete section without the occurrence of a paste-aggregate bond failure. Many cores were not amenable to strength testing or DRI, especially at shallower depths. This study took advantage of available core fragments with pre-existing saw cuts that were amenable to DRI examination.

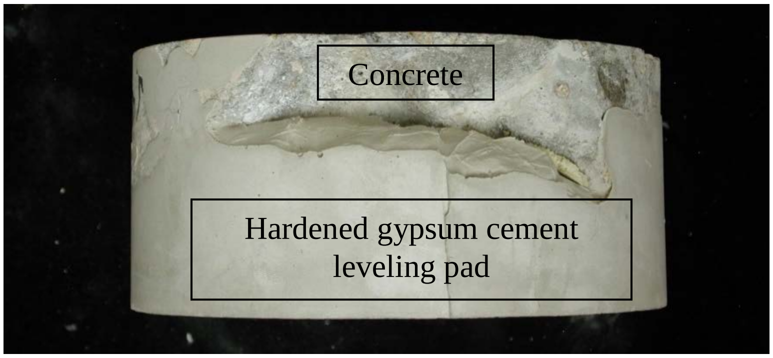

Figure 2. A typical concrete core specimen with a molded gypsum cement leveling pad on the bottom. The leveling pad keeps the top working surface level during examination. The original break surface was highly irregular.

The available surfaces provided by previous saw cuts were fairly uneven and contained significant saw cut grooves and irregularities. Initially, the grooves and irregularities were ground out of the specimens using a lap wheel with diamond polishing pads, which was difficult and time consuming.

Significant problems arose due to the inability to polish the whole surface with a lap wheel. Enormous amounts of effort were required to get the entire surface area of the core specimen smooth and free of saw marks.

The polishing problem was solved with the discovery of a small diameter diamond polishing pad system designed to polish domestic concrete countertop installations. Figures 3 and 4 show the three inch metal bond diamond polishing pad system and specimen arrangement for polishing. In the countertop situation, the concrete is placed, leveled, hardened, and polished to a fine surface.

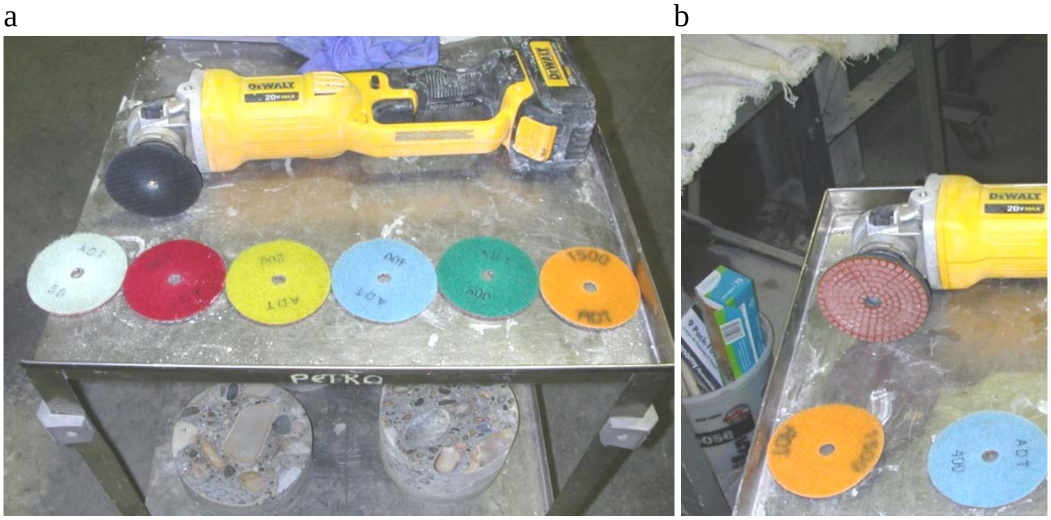

Figure 3. The polishing system used to prepare the polished surface for examination. The color coded, three inch diamond polishing pads range from a grit of 50 to 3000. The polishing pads adhere to a hard rubber disc with Velcro attachment system. The bottom tray of the cart holds specimens for preparation. Image (b) shows the resin grinding pad attached to the back holder.

Figure 4. A six-inch diameter concrete specimen sits on a stand during the polishing process. The hose provides limited water to keep the working surface wet and lubricated for polishing.

The polishing pads easily removed saw marks from the core cut surface and smoothed and polished the concrete. The resulting surface is not absolutely flat but the surface has an excellent mirror-like finish which is outstanding for viewing surface details with a low magnification binocular microscope at 16x.

A recent report and publications (Thomas, Fournier et al., 2012) discussing the DRI Method indicated about 200 squares should be examined per sample. The samples available for this study are horizontal cuts on vertical six inch diameter concrete cores. Therefore the surface area of the cores provide only about 190 squares or partial squares for examination per sample due to the 6-inch cross-section of each core specimen.

The DRI examination and tabulation of features and defects for each individual specimen was accomplished generally in less than an hour. The results are easily calculated with a simple spreadsheet. Any notable petrographic features should be systematically recorded and documented.

Prior to applying the grid pattern, the sample was oriented to a level position using a spirit level. The grid pattern was applied in a north-south and east-west arrangement. This allowed the oriented sample surface to remain reasonably in focus during the examination. The examination began at the top (north) of the specimen and proceeded to the bottom (south). A pencil mark was applied to each grid during the examination to avoid double counting or skipping squares.

A grid was applied using a fine felt pen, centimeter scale ruler, and a protractor. Initially, center was found and a straight guide-line was applied through center. The compass was used to draw a guide-line through center normal to the previous line. Additional lines were added parallel to the two guide-lines with a spacing of 10 mm (figure 5) until a grid covered the entire polished surface.

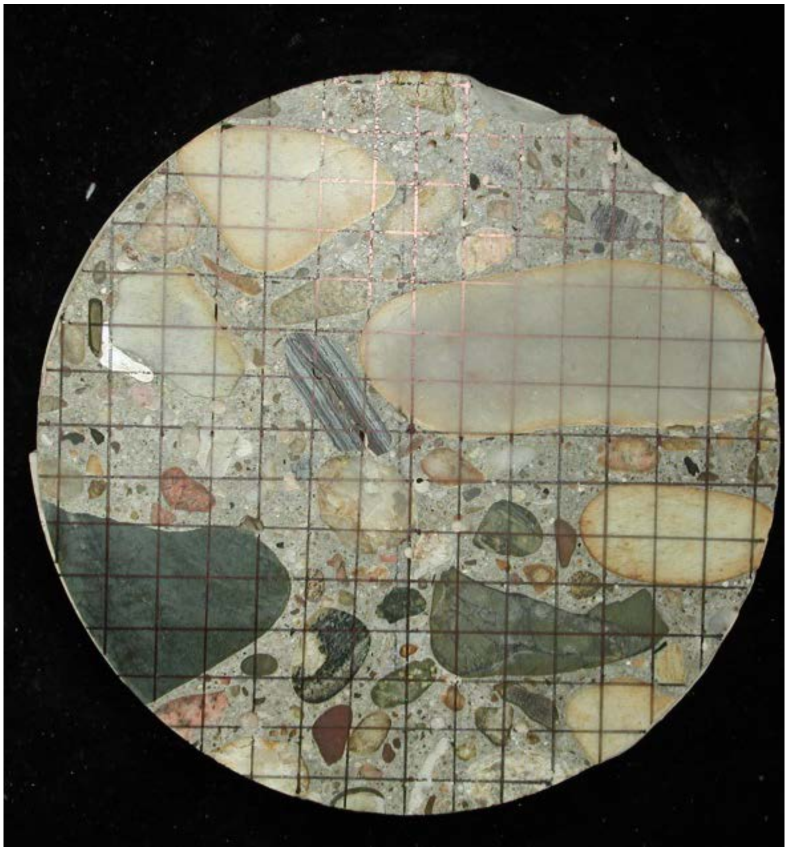

Figure 5. The final surface of the polished core specimen with the application of a 10 mm x 10 mm grid system. The relationship pi r^2, where r is 7.6 cm, indicates only about 182 square cm of surface area. Each whole and partial square was systematically examined.

As each square was encountered it was marked and any petrographic features or defects were recorded on a tally sheet. After the entire specimen was examined the tally sheet data was manually entered into a spreadsheet.

The method of calculation of DRI is provided in the procedure in Appendix A. There is no consensus for a rating system for DRI values at this time. The literature suggests a DRI value of 50 or greater indicates the concrete has experienced ASR (Thomas, 2012).

Polished surfaces were prepared on cores from DH13-2 at depths of 9.1, 11.5, 16.6, 22.45, 36.15, 45.15, 60.55, and 74.0 feet. Changes in the compressive strength trends were observed at about 35 feet (figure 1). Polished surfaces were also prepared on cores from DH13-3 at depths of 16.8, 28.75, 36.15, 53.3, 59.95, 72.6, 90.0, and 125.0 feet. Changes in compressive strength trends were observed at about 60 feet.

Defect types examined

The specimens were examined with a stereo microscope at 16x which provides a magnified view of each individual grid square.

The defect features observed in each square of the grid were:

- Alkali-silica gel filled cracks
- Alkali-silica gel filled cracks penetrating aggregates
- Alkali-silica gel filled cracks penetrating paste and aggregates
- Alkali-silica gel filled cracks surrounding aggregates
- Alkali-silica gel filled air voids (entrapped air)
- Alkali-silica gel and ettringite filled air voids

Figures 6 to 11 show examples of some of these features and defects.

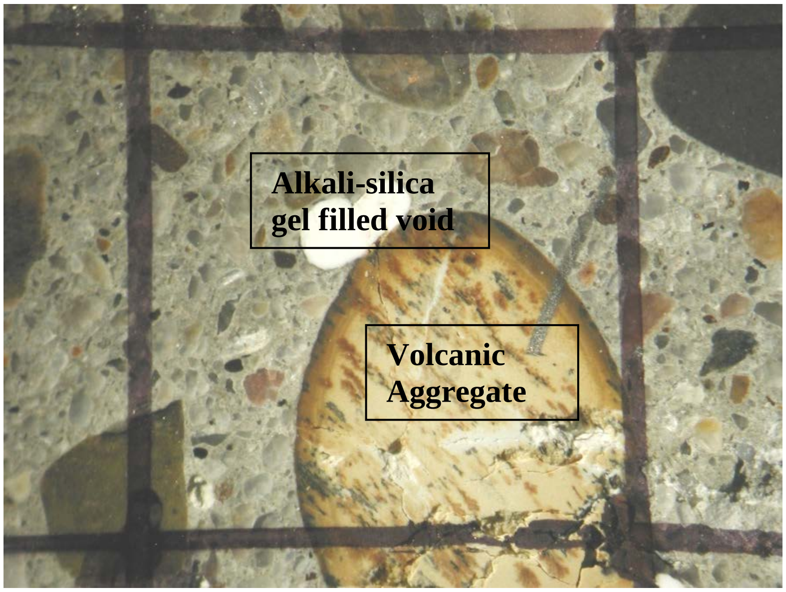

Figure 6. A reactive volcanic aggregate exhibiting a reaction rim with internal cracks filled with alkali-silica and a white gel filled entrapped air void. The examined grid square received a count each for coarse aggregate with crack and alkali-silica gel, cracked paste filled with gel, reaction rim, and an air void lined or filled with gel. The grid square is about 10 by 10 millimeters in size.

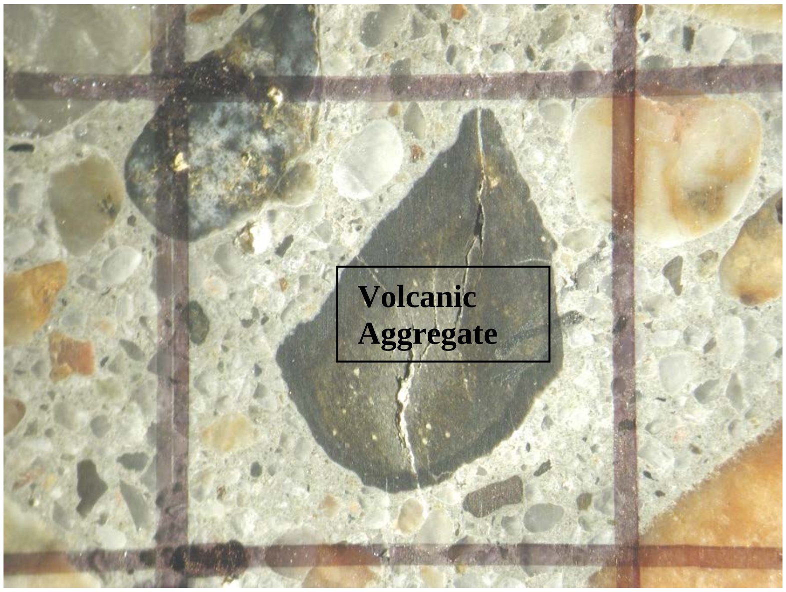

Figure 7. A reactive volcanic aggregate with internal cracks filled with alkali-silica gel with the cracks penetrating paste. The examined squares received a count each for coarse aggregate with crack and gel and cement paste with crack and gel (CA+G and CP+G following the defect types of Rivard, 2002). The grid square is about 10 by 10 millimeters in size.

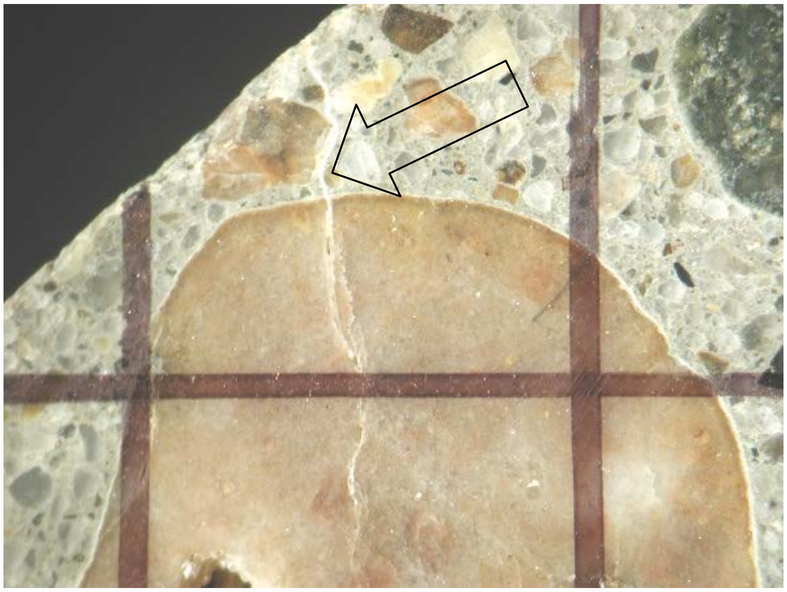

Figure 8. A reactive quartzite aggregates shows internal cracks filled with alkali-silica gel with the cracks penetrating paste (arrow). The examined square received a count each for coarse aggregate with crack and gel and cement paste with crack and gel (CA+G and CP+G following the defect types of Rivard, 2002). The grid square is about 10 by 10 millimeters in size.

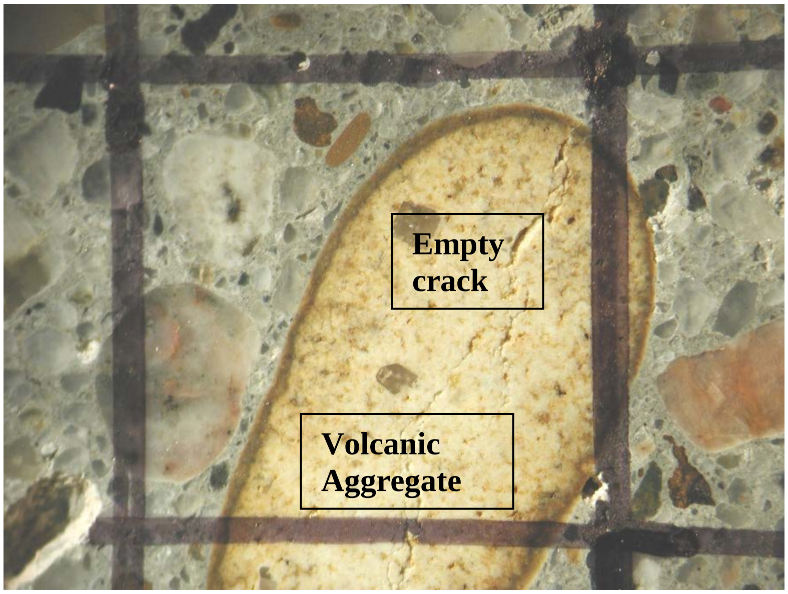

Figure 9. A volcanic aggregate with a continuous internal crack which appears to be empty. The aggregate exhibits a prominent reaction rim. The examined square received a count each for coarse aggregate with crack and reaction rim around aggregate (CA and R following the defect types of Rivard). The grid square is about 10 by 10 millimeters in size.

Figure 10. A reactive aggregate particle exhibits an internal crack filled with alkali-silica gel. The filled crack also penetrates paste. The examined square received a count each for coarse aggregate with crack and gel, cement paste with crack and gel, and reaction rim around aggregate (CA+G, CP+G, and R following the defect types of Rivard, 2002). The grid square is about 10 by 10 millimeters in size.

Figure 11 Fresh alkali-silica gel exuded onto the polished surface following sample preparation (arrow). The gel is transparent and the incident light on the irregular surface causes it to sparkle slightly. The grid square is about 10 by 10 millimeters in size.

Positive alkali-silica gel observations were verified during the grid counting process by picking material out of cracks and voids, preparing a grain mount, and utilizing the analyzing power of the petrographic microscope.

Weighting Factor

The factors and defect types of Rivard et al., 2002, were used. Each defect type was assigned an abbreviation and weighting factor which is provided below:

Table 1. DRI features and weighting factors

Features and defects	**Abbreviation**	**Weighting Factor**
Coarse aggregate with crack	CA	0.25
Coarse aggregate with crack and alkali-silica gel	CA+G	2
Dis-bonded coarse aggregate	DCA	3
Reaction rim around aggregate	RR	0.5
Cement paste with crack	CP	2
Cement paste with crack and gel	CP+G	4
Air void lined or filled with gel	AV	0.5

The weighting factor is multiplied times the number of occurrences per sample to determine the uncorrected DRI for each feature type observed in each square of the sample. The uncorrected DRI result is normalized to 100 cm^2 (16 in^2) to obtain the DRI value of the sample. The procedure is detailed in Appendix A.

Results

Table 2. Core DH-13-2. DRI Examination Results

Sample Depth, ft.	**DRI value**	**Notable observations of features influencing DRI**	**Estimated Degree of Reaction ***
9.1	228	-Few visible cracks in paste -Several boundary voids filled with alkali-silica gel -Several cracked quartzite and volcanic aggregates	High
11.5	133	-Few visible cracks in paste -Few boundary voids filled with alkali-silica gel -Several cracked quartzite and volcanic aggregates	Moderate
16.6	198	-Several visible cracks in paste -Few boundary voids filled with alkali-silica gel -Few cracked quartzite and volcanic aggregates	Moderate
22.45	127	-Few visible cracks in paste -Few to several cracked quartzite and volcanic aggregates	Moderate
36.35	108	-Very few visible cracks in paste -Few cracked quartzite and volcanic aggregates	Moderate
45	82	-Very few barely perceptible cracks in paste -Few cracked quartzite and volcanic aggregates	Low
60.55	36	-Very few barely perceptible cracks in paste -Very few cracked quartzite and volcanic aggregates	Low
74.1	71	-No visible cracks in paste -Very few cracked quartzite and volcanic aggregates	Low

* The degree of reaction is not standardized and is only an estimate

Table 3. Core DH-13-3. DRI Examination Results

Sample Depth, ft.	DRI value	Notable features influencing DRI	Estimated Degree of Reaction *
16.8	126	-Few visible cracks in paste -Few to several quartzite, sandstone, and volcanic aggregates	Moderate
28.75	186	-Few to several visible cracks in paste -Few to several cracked quartzite and volcanic aggregates -Very few disbonded aggregates; sockets lined with alkali-silica gel	Moderate
36.15	137	-Few visible cracks in paste -Few cracked quartzite and volcanic aggregates -Few disbonded aggregates; sockets lined with alkali-silica gel - Few boundary voids filled with alkali-silica gel	Moderate
53.3	151	-Few visible cracks in paste -Few disbonded coarse aggregates -Few cracked quartzite and volcanic aggregates	Moderate
59.7	51	-Few barely perceptible visible cracks in paste -Very few cracked quartzite and volcanic aggregates	Low
72.6	91	-Very few, barely perceptible visible cracks in paste -Few cracked quartzite and volcanic aggregates	Low
90	21	-Very few, barely perceptible visible cracks in paste -Few cracked quartzite and volcanic aggregates	Low
125	22	-No visible cracks in paste -Very few cracked quartzite and volcanic aggregates -No evidence of micro-cracks in paste	Nil

* The degree of reaction is not standardized and is only an estimate

Discussion

Sample preparation

The initial time involved in sample preparation was high because the correct path was not clear. Once the steps required and the equipment were identified, sample preparation is trivial as long as a representative concrete section is properly prepared and examined sympathetic to the problem. If the DRI method is adopted for routine examination of deteriorated concrete, the preparation could be performed reasonably quickly and cheaply on just a few samples by a concrete laboratory technician or an assistant to the petrographer. Accompanying this report is a supplemental Proposed Damage Rating Index (DRI) Procedure that details each step (Appendix A).

Examination/Discussion of Results

The criteria in the Petrographic Laboratory's Analytical Techniques and Capabilities Reference and ASTM C856 are used by Reclamation to petrographically evaluate concrete. The reference indicates satisfactory petrographic quality concrete exhibits only minimal damage, fair petrographic quality concrete exhibits minimal to moderate damage, and poor petrographic quality concrete exhibits extensive damage. The FY13 Seminoe Dam DRI values were examined and appear comparable with typical petrographic satisfactory, fair, and poor quality indicators as follows (see Table 4). Satisfactory petrographic quality concrete exhibits only minimal damage which appears to correlate with DRI values below 100 in this study. Fair petrographic quality concrete exhibits minimal to moderate damage which appears to correlate to DRI values between 100 and 200 and the occurrence of visible cracks on polished surfaces. Poor petrographic quality concrete exhibits extensive damage which correlates with either highly damaged core recovered at shallower depths or DRI values greater than 200 showing few to several visible cracks in paste and boundary voids filled with alkali-silica gel. Moderate and extensively damaged concrete can affect the durability and service life of a structure. Figure 12 is an example of poor, extensively damaged concrete from the top few feet of Seminoe Dam which was not available for DRI analysis. Figure 13 is an example of the visual condition of the concrete sampled during the FY13 Seminoe Dam Concrete Core Testing Program which was available for DRI analysis.

Table 4. Petrographic quality evaluation system employed by Reclamation's Petrographic Laboratory as it relates to the DRI rating values in this study.

Petrographic Quality	**DRI rating values**
Satisfactory – minimal damage	< 100
Fair – minimal to moderate damage	100 to 200
Poor – extensive damage	> 200

Figure 12 The condition of concrete core DH-13-2, 0.4 to 5.4 feet. The Seminoe Dam core at shallower depths was not available for DRI. The DRI value at the interval 0 to 5.4 feet, if available, would likely be much higher than that observed at greater depths.

Figure 13 The general condition of concrete core DH-13-2, at depths greater than 5.4 feet for comparison.

The DRI approach supplements petrographic examination results and may be used to better evaluate a concrete structure by a qualified civil engineer as DRI values appear to correlate petrographic features with strength.

Recommendations

Core specimens cut parallel to the core axis will provide a larger surface area for proper examination of concrete containing larger size coarse aggregates.

Excellent candidates for future DRI studies are available:

Ririe Dam Spillway Bridge exhibits cracking and deterioration due to ASR. Ririe Dam is located within the Snake River Plain area and contains “hot” deleteriously reactive concrete aggregates. The aggregate cement combination used in Ririe Dam’s concrete was not properly ameliorated during the concrete mix design investigations and construction and the concrete will likely continue to crack. A 2005 petrographic memorandum (petrographic referral code 05-07 dated September 29, 2005) described the following. “I visited the structure when the reservoir water was drawn down and noted that the spillway bridge abutments and pier were significantly cracked above the reservoir high-waterline and only lightly cracked below the waterline. This remains unexplained but suggests other causes of deterioration, such as freezing and thawing deterioration, could occur above waterline in the winter. No direct evidence of freezing and thawing damage was observed in the examined cores.”

Bartlett, Owyhee, Friant, El Vado, and Parker Dams are other structures where deleterious ASR episodes caused problems. These facilities are excellent candidates for future DRI investigations.

The DRI approach should be applied to other types of concrete structures including spillways to assess damage due to ASR during routine petrographic examination..

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Appendix A – DRI Procedure

Proposed Damage Rating Index (DRI) Procedure

1. Confirm that ASR actually exists in the concrete structure being investigated. Send a representative sample of deteriorated concrete to an experienced concrete petrographer to confirm the presence of alkali-silica reaction (ASR) in the structure. Alternatively, research the literature for previous petrographic examination report results.

2. Propose a field and laboratory testing plan and consider any other laboratory tests needed in addition to petrographic examination.

3. Develop a Scope of Work, Service Agreement, and Sampling Plan for a concrete structure exhibiting alkali-silica reaction (ASR).

4. Procure representative concrete cores for the investigation from the subject concrete structure exhibiting deterioration.

5. Properly log and label the intact core and protect it during handling and transportation following the procedure in Reclamation’s Engineering Geology Field Manual, second edition, volume 1, p. 306.

6. Sample the concrete such that a longitudinal or horizontal section of each core has a surface area of about 200 cm^2. Example: about 15 by 15 cm (6 by 6 inches) section. A section parallel to the core axis is usually preferable to a section normal to the core axis.

7. Examine and log the as-received core in the laboratory following the procedure in Reclamation’s Engineering Geology Field Manual, second edition, volume 1, p. 306..

8. Cut a section from the core or piece using a diamond rock saw. A reasonably flat surface is desirable.

9. Polish the cut surface of the section to a very fine mirror-like finish using a lap wheel or portable hand polisher and a three inch metal bond diamond polishing pad system. The quality of the surface should be similar to the surface prepared for air void analysis as described in ASTM C 457. Consider purchasing a small diameter diamond polishing pad system designed to polish domestic concrete countertops similar to the system available at http://www.toolocity.com/3-metal-bond-diamond-polishing-pads.aspx.

10. Photograph the polished sections with a scale, location, date, and depth.

11. Draw a regular grid on the polished section which includes about 200 grid squares 1 cm by 1 cm in size.

12. Systematically examine each grid square under the stereomicroscope and tally the petrographic features and defect types in each square.

13. The features and defects, abbreviations, and weighting factors may include the items and values suggested by the literature in the following table. Don't be afraid to experiment and count other features that may be contributing to deterioration of the concrete, e.g., reactive sand v. coarse aggregates.

Features and defects	**Abbreviation**	**Weighting Factor**
Coarse aggregate with crack	CA	0.25
Coarse aggregate with crack and alkali-silica gel	CA+G	2
Dis-bonded coarse aggregate	D	3
Reaction rim around aggregate	R	0.5
Cement paste with crack	CP	2
Cement paste with crack and gel	CP+G	4
Air void lined or filled with gel	AV	0.5

14. After the count, tally the feature and multiply by weighting factors. The petrographic features in each grid are documented and tabulated. The area of the sectioned concrete sample is calculated (pi r^2 in the case of core ends). The feature count results are multiplied by individual factors (uncorrected DRI). The uncorrected DRI result is normalized to 100 cm^2 (16 in^2) to obtain the DRI value of the sample using the relationship uncorrected DRI * 100 divided by area of the grid, in the example below (414*100)/182=228.

Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV	uncorrected	DRI
9.1	7	28	5	7	2	78	44		
x factor	1.75	56	15	3.5	4	312	22	414	
corrected to 100 cm^2 (actual 182 cm^2)									228

15. Suggested Report topics:

- Introduction
- Results of field visual examination
- Material sampled and locations
- Any pertinent mix information
- Description of damage, i.e., Table of Petrographic features with weighting factors for DRI
- Photographs with captions as needed to help the reader visualize damage
- Summary of DRI results
- Conclusions
- Discussion

Appendix B – DRI Data for FY13 Seminoe Dam Cores

Table 2014-1										
DH-2013-2										
Factors	0.25	2	3	0.5	2	4	0.5	sample area	182	Compressi
										Strength, ps
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV	uncorrected	DRI	
9.1	7	28	5	7	2	78	44			
x factor	1.75	56	15	3.5	4	312	22	414	228	2030
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
11.5	11	24	0	6	1	44	19			
x factor	2.75	48	0	3	2	176	9.5	241	133	3270
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
16.6	17	21	0	35	2	71	17			
x factor	4.25	42	0	17.5	4	284	8.5	360	198	3490
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
22.45	13	12	2	2	7	45	6			
x factor	3.25	24	6	1	14	180	3	231	127	2820
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
36.35	7	12	5	21	1	35	5			
x factor	1.75	24	15	10.5	2	140	2.5	196	108	3760
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
45	8	13	1	6	7	24	9			
x factor	2	26	3	3	14	96	4.5	149	82	3800
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
60.55	25	7	1	3	8	6	3			
x factor	6.25	14	3	1.5	16	24	1.5	66	36	3780
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
74.1	16	7	25	3	7	5	2			
x factor	4	14	75	1.5	14	20	1	130	71	4460
corrected to 100 cm^2										
factors after Rivard et al., 2002										

Table 2014-2
DH-2013-3

Factors	0.25	2	3	0.5	2	4	0.5	sample area	182	Compressi
									Strength, ps
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV	uncorrected	DRI	
16.8	18	14	1	2	2	47	3			
x factor	4.5	28	3	1	4	188	1.5	230	126	2800
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
28.75	9	30	4	37	2	60	5			
x factor	2.25	60	12	18.5	4	240	2.5	339.25	186	3310
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
36.15	4	22	17	18	0	35	8			
x factor	1	44	51	9	0	140	4	249	137	3330
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
53.3	25	30	21	9	0	35	2			
x factor	6.25	60	63	4.5	0	140	1	274.75	151	3740
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
59.7	14	12	0	16	0	14	3			
x factor	3.5	24	0	8	0	56	1.5	93	51	4710
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
72.6	19	18	0	17	0	28	9			
x factor	4.75	36	0	8.5	0	112	4.5	165.75	91	5120
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
90	15	2	0	10	1	6	0			
x factor	3.75	4	0	5	2	24	0	38.75	21	5380
corrected to 100 cm^2										
Depth (ft)	CA	CA+G	D	R	CP	GP+G	AV			
125	17	0	0	20	1	6	1			
x factor	4.25	0	0	10	2	24	0.5	40.75	22	5480
corrected to 100 cm^2										

factors after Rivard et al., 2002

Appendix C - Brief History of Seminoe Dam Concrete

This historical summary is an excerpt of unpublished work from G. W. (Bill) DePuy, 2001, retired Reclamation Petrographer and Engineer, deceased January 3, 2002.

> "Seminoe Dam is a medium-thick concrete arch dam located on the North Platte River approximately 31 miles northeast of Rawlins, WY. The dam is exposed to severe winter conditions, fairly rapid and extreme temperature changes, and frequent freeze-thaw cycles. The dam was completed in 1939. A few years after construction some cracking and deterioration of the concrete was observed chiefly along the upper parapet walls and power house walls."
>
> "In 1951, a petrographic examination of the concrete revealed indications of ASR along with freeze-thaw deterioration (Ramaley 1951). It was not evident whether ASR or freeze-thaw deterioration was the main cause for the deterioration. The examination revealed the presence of about 4.5 % reactive particles, chiefly cherts, andesites, and rhyolites, which were judged to be only marginally deleteriously reactive. Several subsequent petrographic examinations showed more indications of alkali aggregate reaction and that the alkali aggregate reaction was continuing (Bechtold 1975, Hurcomb 1998 and 1999). The later examinations indicated the reaction was a slowly reactive form of ASR involving quartzite containing strained quartz, which is known to be a slowly reactive form of silica."
>
> "The aggregate was excavated by dragline from pits 2.5 to 4 miles upstream from the dam. The contractor was required to wash and screen the aggregate. The aggregate was considered to be of good quality and consisted of stream worn, rounded particles. A nominal 6-inch maximum size aggregate was used in the mix."
>
> "The cement was Type II cement from Monolith Portland Cement Co., Laramie, Wyoming. Analysis of a sample of cement identical to that used in the dam gave an alkali content of 0.81 % K20 and 0.32% Na20 (Ramaley 1951)."
>
> "The concrete contained 1 barrel cement per cubic yard concrete. Mixture proportions were based on the ratio of one part cement to 0.54 parts water to 9.61 parts aggregate by weight (Huber 1942). The 28-day strength of concrete was over 5000 psi, and the 2-year expected strength was

expected to be more than 6500 psi.”

“Petrographic examinations described the gravel particles as ranging from rounded to subangular in shape and composed predominantly of quartzites, metasandstones granites and gneisses. Smaller amounts of cherts, rhyolites, andesite porphyries, schists, diorites, limestones, and claystones were noted. Materials known at that time to be potentially deleteriously reactive with high alkali cement - chert, andesite, and rhyolite - constituted about 4.5% of the gravel, and were considered to be less than necessary to produce harmful reactions (Cook 1950).The sand particles ranged from rounded to angular in shape and were composed of the same rock types present in the gravel and minerals derived from these.”

“Although since the 1950s, ASR was suspected of causing some of the cracking visible at the top of the dam, ASR did not appear to be a major concern. Part of the reason was that petrographic examination indicated a potentially deleterious reaction was unlikely based on the composition of the aggregate particles and tests for reactivity. At this time, most experience with ASR indicated the reaction showed up fairly early in the life of the structure and was fairly easy to identify. These experiences were with more reactive aggregates with structures in warmer climates. Later on, a slower form of ASR was recognized, which occurred with aggregates not formerly identified as being potentially deleteriously reactive. The slower reaction may prove to be as destructive as or more destructive than the more easily recognized fast reaction. These included quartz minerals, particularly fine grained, strained quartz, such as may occur in some quartzites, gneisses and schists. These varieties of quartz are of a much lower reactivity with alkalies, and evidence of a deleterious reaction may not show up for 20 or 30 years after the structure has been built, particularly in cold climates. As with all chemical reactions, the speed of the reaction is among other things dependent on the temperature - the reaction is much faster in warm environments than in cold environments.”

“Drill core samples taken from the dam in 1950 were petrographically examined in 1951 for evidence of ASR (Ramaley 1951). The appearance of the core was generally satisfactory. The concrete appeared sound with no surface fractures, but showed some relatively abundant voids which indicate poor compaction. Mortar bar expansion tests using high alkali cement showed expansion at 6-months of 0.026% for the gravel and 0.022% for the sand. The quick chemical test showed a silica release of 43 millimoles per liter for both the sand and gravel, and a reduction in alkalinity of 48 and 61 millimoles per liter respectively for the gravel and sand. These results do not indicate deleterious reactivity. The examination of the cores revealed small spots of silica gel. The conclusions indicated the reaction was insignificant at the time, but that local distress might become evident at a later time."

"A later petrographic examination of drill core showed a high degree of deterioration in the upper 5 feet, with less noticeable deterioration in the 5 - 20 feet level (Bechtold 1975). Below 20 feet no deterioration was detected. Some indication of alkali reaction was observed, but it appeared the most likely cause for deterioration in the upper 5 feet was the result of freeze-thaw action."

Appendix D – Table of Compressive Strengths with Depth

Table D1. Compressive Strength Results for Concrete Cores DH13-2

Specimen ID	Midpoint Elevation	Midpoint Depth, ft	Compressive Strength, psi
C-13-2-1	6354.2	7.1	2,980
C-13-2-2	**6352.7**	**8.6**	**2,030**
C-13-2-3	**6349.3**	**12.1**	**3,270**
C-13-2-4	6348.2	13.1	3,180
C-13-2-5	**6344.1**	**17.2**	**3,490**
C-13-2-6	**6338.4**	**22.9**	**2,820**
C-13-2-7	**6325.6**	**35.7**	**3,760**
C-13-2-8	6320.9	40.4	4,280
C-13-2-9	**6315.7**	**45.6**	**3,800**
C-13-2-10	6310.7	50.6	3,880
C-13-2-11	6307.5	53.8	3,570
C-13-2-12	**6301.3**	**60.0**	**3,780**
C-13-2-13	6300.3	61.1	3,170
C-13-2-14	6296.1	65.3	3,590
C-13-2-15	6293.9	67.4	3,900
C-13-2-16	**6287.8**	**73.5**	**4,460**

Note: Bold typeface corresponds to assessed DRI specimens.

Table D2. Compressive Strength Results for Concrete Cores DH13-3

Specimen ID	Midpoint Elevation	Midpoint Depth, ft	Compressive Strength, psi
C-13-3-1	6346.3	15.1	3,690
C-13-3-2	**6344.0**	**17.3**	**2,800**
C-13-3-3	6338.2	23.1	2,720
C-13-3-4	6334.2	27.1	2,950
C-13-3-5	**6333.1**	**28.3**	**3,310**
C-13-3-6	6330.4	30.9	2,740
C-13-3-7	6328.5	32.9	2,630
C-13-3-8	**6325.7**	**35.6**	**3,330**
C-13-3-9	6318.3	43.0	3,650
C-13-3-10	6312.0	49.4	3,230
C-13-3-11	**6307.5**	**53.8**	**3,740**
C-13-3-12	**6301.8**	**59.5**	**4,710**
C-13-3-13	6298.1	63.2	5,270
C-13-3-14	6293.4	67.9	3,760
C-13-3-15	**6288.3**	**73.1**	**5,120**
C-13-3-16	6285.5	75.8	4,860
C-13-3-17	6282.3	79.0	5,920
C-13-3-18	6277.7	83.6	5,220
C-13-3-19	**6270.3**	**91.0**	**5,380**
C-13-3-20	6266.8	94.5	5,260
C-13-3-21	6259.6	101.7	5,230
C-13-3-22	6255.8	105.5	4,840
C-13-3-23	6250.2	111.1	4,300
C-13-3-24	6245.0	116.3	5,580
C-13-3-25	6241.8	119.5	5,320
C-13-3-26	**6236.8**	**124.5**	**5,480**

Note: Bold typeface corresponds to assessed DRI specimens.