BUREAU OF RECLAMATION

Concrete Materials Research Roadmap

For the Advancement and Sustainment of Reclamation Infrastructure

Science and Technology Program
Research and Development Office

TSC CSL Report No. 8530-2023-07

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14. ABSTRACT The Concrete and Structural Laboratory of the Bureau of Reclamation's Technical Service Center performed a survey of government, academic, and private concrete industry professionals to develop a database of potential concrete research topics related to water, irrigation, and hydropower. This report provides this database, along with an explanation of the survey methodology and results.			
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Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Cover Photo – Photograph of concrete cylinders in the Concrete and Structural Laboratory fog room (Photo credit, Reclamation).

Acronyms and Abbreviations

%	percent
CSL	Concrete and Structural Laboratory
R&D	Research and De elopement
S&T	Science and Technology
TSC	Technical Service Center

Roadmap for Concrete Materials Research for the Advancement and Sustainment of Reclamation Infrastructure

TSC CSL Report No. 8530-2023-07

Concrete and Structural Laboratory
Technical Service Center

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Executive Summary

Reclamation's mission is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. As part of this mission, Reclamation operates numerous dams and hydroelectric powerplants which employ large amounts of concrete within their construction. As concrete ages, it is susceptible to a plethora of deterioration mechanisms which must be mitigated. In addition, modifications to concrete dams and hydroelectric facilities rely heavily on the design, specification, and construction of new concrete structures. As such, concrete is central to Reclamation's mission.

Reclamation's Science and Technology (S&T) program—under the Research and Development (R&D) Office—has sponsored a study aimed at identifying a set of potential research topics that are most pertinent to Reclamation's mission. Reclamation's Technical Service Center (TSC) operates a Concrete and Structural Laboratory (CSL), which engages in a longstanding practice of performing applied research. This research is completed in order to expand Reclamation's expertise, develop more effective design and repair methods, and contribute to the knowledgebase of the concrete industry.

In this study, the CSL polled concrete industry professionals from Reclamation, other government agencies, academia, and private industry involved in design, construction, and operations to identify problem areas for concrete dams and hydroelectric facilities. The survey responses were reviewed by the CSL to identify a subset of 31 problems which could feasibly be addressed by further research. For each of these problems, a gap analysis was performed, in which a potential solution to the problem is identified; then, the "gap" between the problem and the solution is identified. The gap constitutes the research need.

Each of the research needs were reviewed by a Steering Committee which consisted of engineering professionals in the CSL and TSC. These professionals were asked to rate each research need on its importance to Reclamation; this allowed the research needs to be ranked from most to least important. Once the research needs were ranked, the CSL reviewed the top 11 research needs and identified five which are most likely to represent a large return on investment relative to the cost of the research. The 11 research needs are presented below, with the high return on investment needs bolded; this list constitutes Reclamation's "Concrete Research Roadmap."

- Identify or develop a better method of quantifying residual expansion due to ASR.
- Research cost effective alternatives to limit ASR deterioration.
- Evaluate the freeze/thaw resistance of various concrete repair materials, potentially including both ready-mixed and prepackaged repair materials.
- Determine best practices concerning vertical surface repairs over freeze/thaw deteriorated and eroded substrates.

- **Evaluate the efficacy of lightweight/cellular concrete at reducing substrate flow velocities.**
- **Develop guidelines for acceptable temperatures for mass concrete in relation to developed strength.**
- **Perform thermal studies of concrete using current mix designs, including blended cements.**
- **Conduct research into using natural pozzolans. Assess the effect of single source variability of harvested fly ash on concrete properties. Identify qualification tests and other requirements for new supplementary cementitious materials.**
- Research automated monitoring and structural condition assessment programs.
- **Research and develop new technology for spillway chute monitoring, including UAS photogrammetry and LiDAR.**
- Test new surveying systems (including total stations) in a controlled environment to assess accuracy compared to conventional surveying methods.

The CSL and R&D Office plan to utilize this list of research topics in order to develop and prioritize research projects in the coming fiscal years. In this way, available research funding can be directed to where it will have the most impact on Reclamation's mission.

Introduction

The Technical Service Center (TSC) Concrete and Structural Laboratory (CSL) performs research, materials testing, concrete design materials selection, onsite assessments, and concrete repair primarily related to dams, waterways, and hydroelectric power generation. The CSL's work is performed to advance Reclamation's mission to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

As part of a longstanding and well-respected practice, the CSL routinely performs applied research in order to expand Reclamation's expertise, develop more effective design and repair methods, and contribute to the knowledgebase of the concrete industry as a whole. Much of this research is funded by Reclamation's Science and Technology (S&T) program under the Research and Development (R&D) Office. Leadership within the CSL views research as a primary function of the group, and it is important that research efforts be directed to where they can most profoundly impact Reclamation's mission.

In order to direct research resources appropriately, the R&D Office has sponsored a detailed study of potential research areas, performed by the CSL. This study is intended to identify research areas that can further Reclamation's knowledge of concrete materials as related to water and power delivery. The ultimate goal of this study is to develop a "Concrete Research Roadmap" that will provide a strategy to advance concrete materials engineering practice for existing and new infrastructure. As part of this study, the CSL consulted Reclamation TSC and Regional personnel, other government agencies, universities, and industry experts to develop a selection of potential research areas relevant to Reclamation's needs. The purpose of this report is to describe this study, report the results, and identify the most salient potential research areas.

Methodology

The CSL developed a poll consisting of a variety of concrete related problems and potential solutions and solicited feedback from participants, "Concrete Engineering Professionals," with a wide range of concrete knowledge and expertise. This feedback was then analyzed and ranked by a panel of internal concrete experts, "Steering Committee." The first part of this effort, the poll, is referred to as the "General Survey," and the second part, the analysis, is referred to as the "Survey Response Study." A flowchart showing the overall methodology is provided in figure 1. This process is explained in more detail in the following sections.

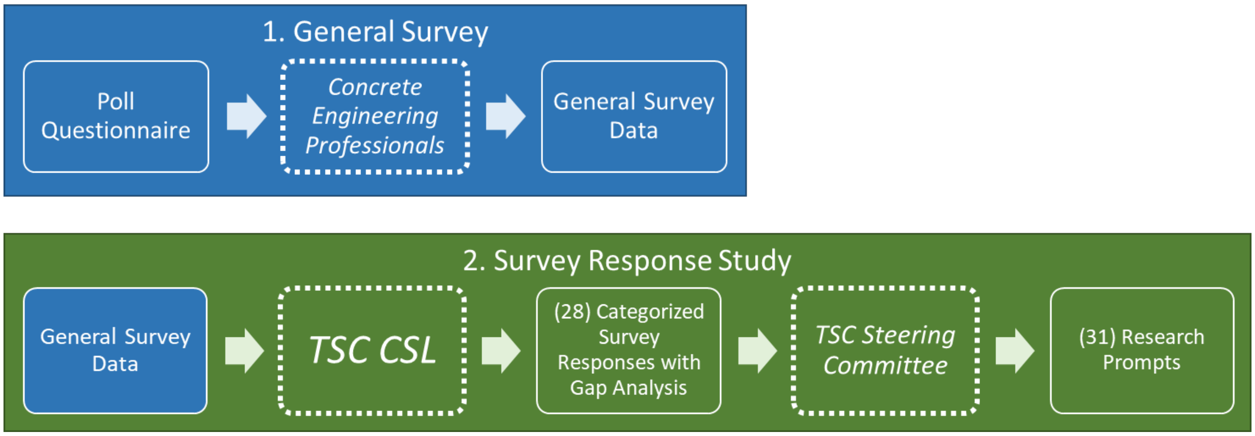


Figure 1.—Survey methodology flowchart.

General Survey Methodology

The CSL developed a poll questionnaire, which was sent via email on March 17, 2022, to 73 individuals mostly within Reclamation, plus a few selected experts in other government agencies, universities, and industry experts who are routinely involved in concrete construction, repair, and/or assessment. A copy of the questionnaire can be seen in appendix A.

Respondents were asked to respond to multiple-answer multiple choice questions that were grouped into the following five topic areas:

- Mix and Materials
- Properties and Testing
- Construction
- Condition Assessment
- Durability and Repair

Under each topic, respondents selected common subtopics (for example, "Crack Mapping," "Cavitation Damage," and "Mass Concrete") that present problems or that they experience issues with. In total, respondents could select from 72 subtopics within the five topic areas.

The general survey also included an option for respondents to further describe their main problems related to each topic in a long form written format; respondents were also asked to provide their current solution(s) to the given problem. In addition, respondents could indicate whether problems related to a topic were "long-term/reoccurring" or "new/emerging."

Survey Response Study Methodology

Results from the general survey were studied by the CSL in order to glean potential research topics from the dataset. Long form written survey responses were categorized by a team of CSL personnel into a list of 102 unique problems sorted between the 72 subtopics and five main topic areas. Long form responses were edited for completeness, but every effort was made to represent the intent of the original survey response as accurately as possible. Of the 102 problems, the CSL team selected a subset of 28 problems that were deemed most appropriate for further research. Problems that were excluded from the subset already had an appropriate solution available, could not be solved with research, or did not represent an adequate return on investment if research were to be conducted.

For each of the 28 problems identified as most applicable, CSL staff performed a gap analysis. In a gap analysis, a solution is identified for a problem. Then, the "gap" is the work—or, in this case, the research—that would have to be completed in order for the solution to be reached. This helped identify a particular research need to address each problem. In some instances, a potential solution was provided in the survey response; in other instances, CSL staff responded with a solution based on the CSL's understanding and expertise.

A spreadsheet of the 28 problems—along with the gap analysis results—was provided to a Steering Committee. This panel included ten Reclamation program managers, engineers, and engineering technicians, in addition to six CSL engineers. The breakdown of panel members by role is provided in table 1. For each of the 28 research needs, the panel members were asked to provide a rating between 1 and 5 based on the degree to which they viewed the research need as important, with 5 rating the highest. During this process, the CSL also received and ranked additional "write-in" research needs from respondents, and one of the 28 research needs was removed from the list because it was nearly identical to another entry. This brought the total number of research needs to 31. The CSL then summed the panel member numeric ratings for each research need to develop a score that could be used as a basis for ranking the 31 research needs from most to least important. For research needs that had identical scores, the response frequency for the research need's subtopic (the percentage of respondents to each question that identified the subtopic as a problem area) was used as a tiebreaker.

Table 1.—Survey streering committee panel member summary

Division	Title	Number of Panel Members
Field Engineering	Supervisor Engineering Technician	1
Four Corners Construction Office	Supervisor Engineering Technician	1
Dam Safety Office	Program Manager	2
Technical Services	Supervisory Civil Engineer	1
Waterways and Concrete Dams 1	Civil Engineer	1
Waterways and Concrete Dams 3	Civil Engineer	1
Engineering and Laboratory Services Division	Division Chief	1
Asset Management Division, Dam Safety, and Infrastructure	Program Manager	2
Concrete and Structural Laboratory	Supervisory Civil Engineer	1
Concrete and Structural Laboratory	Civil Engineer	5

Results

General Survey Results

Forty-five individuals responded to the general survey, although response rate varied from question to question. Appendix B provides data and bar charts summarizing the responses. Questions are broken out into their respective topics.

For each question, the number of respondents received is indicated, along with the number of respondents that marked each subtopic as a problem area (the "Count" column), as shown in figure 2. The "Frequency" column is calculated as the ratio between the "Count" and the number of respondents to the question. Thus, "Frequency" is the proportion of respondents who indicated that the given subtopic is a problem area. A bar charts provide a visual representation of the results shown in the "Count" column, as shown in figure 3.

Number of Respondents: 36

Topic	Count	Frequency
Strength	13	36%
Slump and Workability	13	36%
Air Entrainment	11	31%
Shrinkage	11	31%
Temperature Control	17	47%
Creep	3	8%
Water and Air Permeability	4	11%
Water Absorption	1	3%
Other	5	14%

Figure 2.—Example summary data (question 5, Properties and Testing).

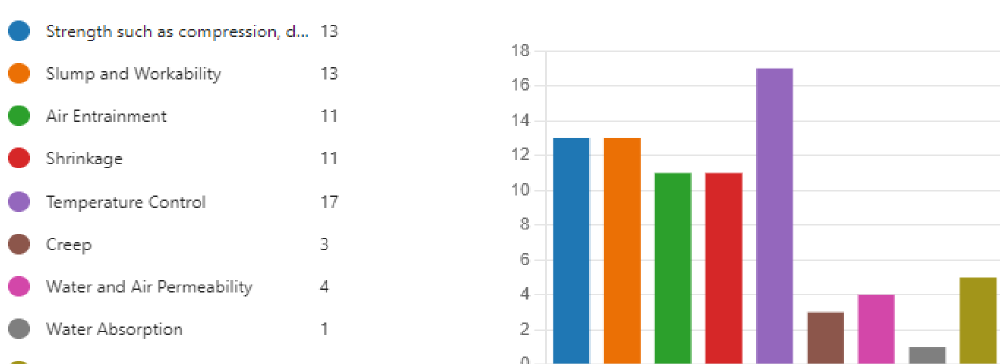


Figure 3.—Example survey plot (question 5, Properties and Testing).

Under each topic, appendix B also provides data indicating whether respondents perceived problems within the topic as primarily long-term/reoccurring or new/emerging.

The full open response question results for each topic are not provided in appendix B. The results from the open response questions are discussed further in the *Survey Response Study Results* section of this report.

Survey Response Study Results

As noted previously, the CSL used open response results from the general survey to produce a set of the most salient problems experienced by survey respondents. These problems were then provided to a Steering Committee of 16 individuals to provide ratings in a survey response study; said ratings were used to rank the problems from most to least important. The resulting research areas, in order from highest to lowest rank, can be seen in appendix C.

Discussion

The results of the General Survey and Survey Response Study will be used to shape Reclamation's research efforts in the coming fiscal years. The following sections discuss the results of each part of the survey in more detail.

General Survey Discussion

Prior to sending out the survey, key team members personally reached out to recipients to explain the survey intent and desire for good information to inform future research prioritization. We believe this encouraged a greater number of meaningful responses. Response rate to the poll questionnaire was generally acceptable. Approximately 62 precent (%) of individuals who received the questionnaire responded to some or all poll questions. In addition, responses were received from individuals with a variety of job positions. Approximately 44% of respondents self-identified as engineers (including supervisory engineers); the remaining 56% of respondents indicated various non-engineering technical or managerial job titles.

The general survey provides an overview of the subtopics (under each of the various topic areas) that present the most problems for Reclamation facilities according to the survey respondents. Subtopics that present significant problems may represent good potential research areas. As research opportunities arise, this information can be used to determine how Reclamation should prioritize its limited resources so that funds are directed toward subtopics that will have the most significant impact on the organization's mission.

The data suggests that most problems faced by Reclamation are long-term or reoccurring problems. This is evidenced by the fact that upwards of 70% of respondents indicated that the problems they face related to that topic are "long-term/reoccurring."

Survey Response Study Discussion

The survey response study provides a ranked set of well-defined research needs that Reclamation can used to develop research plans and for evaluation of proposals. Appendix C provides a full set of the 31 research needs.

Realistically, the CSL and R&D Office do not have sufficient funding or personnel to address all 31 research needs in a timely manner. As such, the CSL suggests that the following top eleven research needs (table 2) should be the primary objectives for the coming fiscal years as they are indicative of areas with the biggest need and most frequent issues facing Reclamation. In addition, the CSL has identified five research needs in particular which are the most likely to represent a high return on investment relative to the cost of the research, seen in bold in table 2. The entries in this table constitute the CSL's proposed "Concrete Research Roadmap."

Table 2.—Concrete research roadmap

Topic	Subtopic	Research need (gap)
Condition Assessment	Crack Mapping	Research automated monitoring and structural condition assessment programs.
	Movement Monitoring	**Research and develop new technology for spillway chute monitoring, including UAS photogrammetry and LiDAR.**
		Test new surveying systems (including total stations) in a controlled environment to assess accuracy compared to conventional surveying methods.
Durability and Repair	Alkali Silica Reaction (ASR)	Identify or develop a better method of quantifying residual expansion due to ASR.
		Research cost effective alternatives to limit ASR deterioration.
	Freeze/Thaw Deterioration	Evaluate the freeze/thaw resistance of various concrete repair materials, potentially including both ready-mixed and prepackaged repair materials.
	Repair Material Bond to Existing Concrete	Determine best practices concerning vertical surface repairs over freeze/thaw deteriorated and eroded substrates.
Mix and Materials	Lightweight Concrete	**Evaluate the efficacy of lightweight/cellular concrete at reducing substrate flow velocities.**
	Mass Concrete	**Develop guidelines for acceptable temperatures for mass concrete in relation to developed strength.**
		Perform thermal studies of concrete using current mix designs, including blended cements.
	Supplementary Cementitious Materials (SCM)	**Conduct research into using natural pozzolans. Assess the effect of single source variability of harvested fly ash on concrete properties. Identify qualification tests and other requirements for new supplementary cementitious materials.**

Conclusion

This Concrete Research Roadmap can be used as a tool for considering current research needs and priorities through the lens of the survey participants. Although great effort was made to get input across Reclamation, some areas of need may not have been identified in this study. Future research merit should be evaluated based on this roadmap and all other available information at the time of funding,.

Appendix A

Survey Questions

Concrete Research Roadmap Survey

Reclamation's Science and Technology Program would like your input on important concrete topics to provide strategic development of concrete research as it relates to Reclamation's mission of efficient water and power delivery.

A Concrete Research Roadmap will be developed based on the results of this survey. The goal of this roadmap is to advance concrete materials engineering practice for existing and new concrete infrastructure. In general, concrete research topic areas include concrete materials, material properties, deterioration mechanisms, novel repair applications, and life cycle analysis. This effort is being lead by the Technical Service Center's Concrete and Structural Laboratory.

All of the questions in this survey are optional to allow you the flexibility to focus on providing answers in areas that are relevant to you, however please comment on as many as you can. The survey should take about 15 minutes. We value your input and appreciate the time you have taken to give us your thoughts.

Section 1 ...

1. About You

Please provide information about yourself.

1. What is your role in Reclamation?

- ◯ Materials Technician
- ◯ Inspector
- ◯ Engineer
- ◯ Lab Chief
- ◯ Supervisory Engineer
- ◯ Facility Manager
- ◯ Program Manager
- ◯ Other

2. Concrete Mixes and Materials

This section includes questions related to Concrete Mixes and Materials.

2. Which of the following Concrete Mix and Materials topics do you experience issues or have problems with? Consider topics that require large resources - time or money.

- [ ] Fiber Reinforced Concrete
- [ ] High Performance and Ultra-high Performance Concrete
- [ ] Lightweight Concrete
- [ ] Mass Concrete
- [ ] Polymer Concrete
- [ ] Precast Concrete
- [ ] Prestressed and Post-Tensioned Concrete
- [ ] Printed Concrete
- [ ] Recycled Concrete
- [ ] Roller Compacted Concrete
- [ ] Self-Consolidating Concrete
- [ ] Shotcrete
- [ ] Shrinkage-Compensating Concrete
- [ ] Soil Cement
- [ ] Sustainable Concrete Materials
- [ ] Admixtures

- [ ] Aggregates including sourcing, lightweight, and artificial
- [ ] Blended Cements such as IL (limestone), IS (slag), IP (pozzolan)
- [ ] Controlled Low-Strength Materials (CLSM)
- [ ] Reinforcement including fiber, non-metallic, and coated
- [ ] Supplementary Cementitious Materials (SCMs) such as slag, fly ash, silica fume, and natural pozzolan
- [ ] Carbon Sequestration/Decarbonization
- [ ] Other

3. What is your MAIN Concrete Mix and Material problem or issue from the list above *and* what are you currently doing to address it?

Enter your answer

4. Regarding your MAIN Concrete Mix and Material problem/issue, is this something you have been dealing with for a long time or is it a new problem?

- ○ Long-term/Reoccurring Issue
- ○ New/Emerging Issue

3. Concrete Properties and Testing

This section includes questions related to Concrete Properties and Testing.

5. Which of the following Concrete Properties and Testing topics do you experience issues or have problems with? Consider topics that require large resources - time or money.

- [ ] Strength such as compression, direct tension, flexure, or shear
- [ ] Slump and Workability
- [ ] Air Entrainment
- [ ] Shrinkage
- [ ] Temperature Control
- [ ] Creep
- [ ] Water and Air Permeability
- [ ] Water Absorption
- [ ] Other

6. Based on your answers to the previous question, what is your MAIN Concrete Properties and Testing problem or issue and *and* what are you currently doing to address it?

Enter your answer

7. Regarding your MAIN Concrete Properties and Testing problem/issue, is this something you have been dealing with for a long time or is it a new problem?

- ◯ Long-term/Reoccurring Issue
- ◯ New/Emerging Issue

4. Concrete Construction

The section includes questions related to Concrete Construction.

8. Which of the following Concrete Construction topics do you experience issues or have problems with? Consider topics that require large amounts of resources - time and money.

- [ ] Excessive Mix Water
- [ ] Inadequate Consolidation such as honeycombing and rock pockets
- [ ] Improper Finishing causing popouts and other issues
- [ ] Hot Weather Placement
- [ ] Cold Weather Placement
- [ ] Concrete Curing
- [ ] Concrete Anchors and Anchoring
- [ ] Aesthetics and Matching Colors
- [ ] Building Code related to water control structures
- [ ] Formwork
- [ ] Equipment Cementitious Grout Pads
- [ ] Slab Size
- [ ] Joints and Joint Placement
- [ ] Concrete Placement Operations
- [ ] Quality Assurance

- [ ] Concrete Specifications
- [ ] Sustainable Concrete
- [ ] Other

9. Based on your answers to the previous question, what is your MAIN Concrete Construction problem or issue *and* what are you doing to address it?

Enter your answer

10. Regarding your MAIN Concrete Construction problem/issue, is this something you have been dealing with for a long time or is it a new problem?

○ Long-term/Reoccurring Issue

○ New/Emerging Issue

5. Concrete Condition Assessment

This section includes questions related to Concrete Condition Assessment.

11. Which of the following Concrete Condition Assessment topics do you experience issues or have problems with? Consider topics that require large amounts of resources - time and money.

- [ ] Crack Mapping
- [ ] Surveying
- [ ] Instrumentation
- [ ] Movement Monitoring
- [ ] Visual Inspection
- [ ] Delamination Mapping such as chain drag, hammer sounding, or infrared (IR) thermography
- [ ] Nondestructive Testing such as ultrasonic pulse velocity, ultrasonic echo, impact echo, Spectral Analsis of Surface Waves (SASW), impulse response, nuclear radiometry, covermeters, infrared thermography, and ground penetrating radar (GPR)
- [ ] Photogrammetry
- [ ] Aerial/Underwater/Robotic Investigations for Inaccessible Features
- [ ] Life-cycle Analysis
- [ ] Other

12. Based on your answers to the previous question, what is your MAIN Concrete Condition Assessment problem or issue *and* what are you doing to address it?

Enter your answer

13. Regarding your MAIN Concrete Condition Assessment problem/issue, is this something you have been dealing with for a long time or is it a new problem?

- ◯ Long-term/Reoccurring Issue
- ◯ New/Emerging Issue

6. Concrete Durability and Repair

This section includes questions related to Concrete Durability and Repair.

14. In which concrete features do you observe the most durability related issues or tend to repair the most?

- [ ] Dams
- [ ] Spillways
- [ ] Powerplants
- [ ] Stilling Basin
- [ ] Outlet Works
- [ ] Draft Tubes
- [ ] Canals
- [ ] Bridges
- [ ] Tunnels
- [ ] Concrete Pipe
- [ ] Other

15. Which of the following Concrete Durability and Repair topics do you experience issues or have problems with? Consider topics that require large amounts of resources - time and money.

- [ ] Alkali Silica Reaction (ASR)
- [ ] Freeze/Thaw Deterioration
- [ ] Sulfate Attack
- [ ] Abrasion or Erosion Damage
- [ ] Cavitation Damage
- [ ] Corrosion of Reinforcing Steel
- [ ] Acid Exposure
- [ ] Cracking from overloads or movement (not related to the other causes listed)
- [ ] Repair Bond to existing concrete
- [ ] Chemical Grouting for leak repair
- [ ] Epoxy Injection for structural repair
- [ ] Thin Cementitious Repairs (less than 1 inch)
- [ ] Thick Cementitious Repairs (greater than 1 inch)
- [ ] Vertical or Overhead Cementitious Repairs
- [ ] Sealants for Concrete
- [ ] Other

16. Based on your answers to the previous question, what is your MAIN Concrete Durability and Repair problem or issue *and* what are you doing to address it?

Enter your answer

17. Regarding your MAIN Concrete Durability and Repair problem/issue, is this something you have been dealing with for a long time or is it a new problem?

- ◯ Long-term/Reoccurring Issue
- ◯ New/Emerging Issue

7. Conclusion

18. Please provide any comments or suggestions for solutions or research that you think could be performed to better address these concrete related issues.

Enter your answer

19. Are there any other concrete related research areas, not mentioned above, that are important to Reclamation's mission?

Enter your answer

Appendix B

General Survey Results

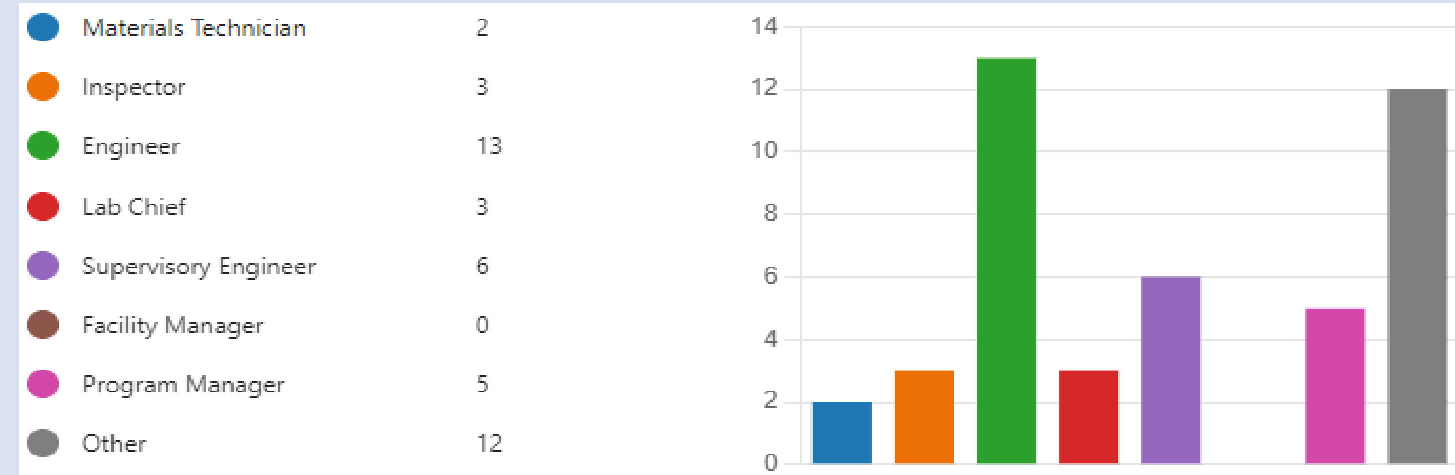
General Survey Results

Question 1 ***Role***

What is your role in Reclamation?

Number of Respondents: 44

Role	Count	Frequency
Materials Technician	2	5%
Inspector	3	7%
Engineer	13	30%
Lab Chief	3	7%
Supervisory Engineer	6	14%
Facility Manager	0	0%
Program Manager	5	11%
Other	12	27%



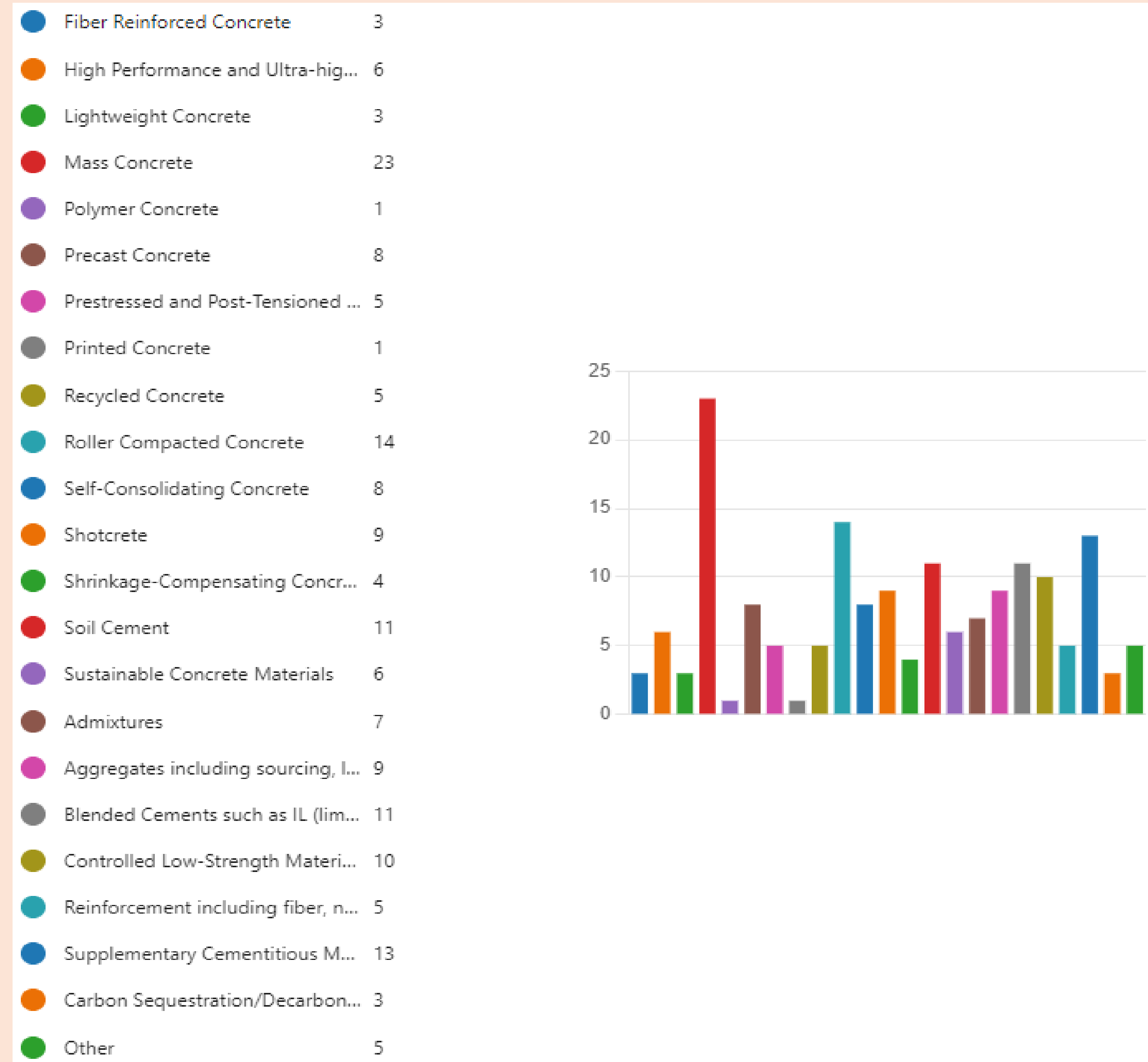
Question 2

Mix and Materials

Which of the following Concrete Mix and Materials topics do you experience issues or have problems with? Consider topics that require large resources - time or money.

Number of Respondents: 41

Topic	Count	Frequency
Fiber Reinforced Concrete	3	7%
High Performance and Ultra-High Performance Concrete	6	15%
Lightweight Concrete	3	7%
Mass Concrete	23	56%
Polymer Concrete	1	2%
Precast Concrete	8	20%
Prestressed and Post-Tensioned Concrete	5	12%
Printed Concrete	1	2%
Recycled Concrete	5	12%
Roller Compacted Concrete	14	34%
Self-Consolidating Concrete	8	20%
Shotcrete	9	22%
Shrinkage-Compensating Concrete	4	10%
Soil Cement	11	27%
Sustainable Concrete Materials	6	15%
Admixtures	7	17%
Aggregates (Sourcing, Lightweight, Artificial)	9	22%
Blended Cements (IL, IS, IP)	11	27%
Controlled Low-Strength Materials (CLSM)	10	24%
Reinforcement (Fiber, Non-Metallic, Coated)	5	12%
Supplementary Cementitious Materials (SCM)	13	32%
Carbon Sequestration/Decarbonization	3	7%
Other	5	12%



Question 3

What is your main concrete mix and material problem/issue from the list above, and what are you currently doing to address it? (RE: Appendix C)

Question 4

Is the problem long-term/reoccurring or new/emerging?	**Responses**	**Frequency**
Long-term/reoccurring	28	70.0%
New/emerging	12	30.0%
Total	40	

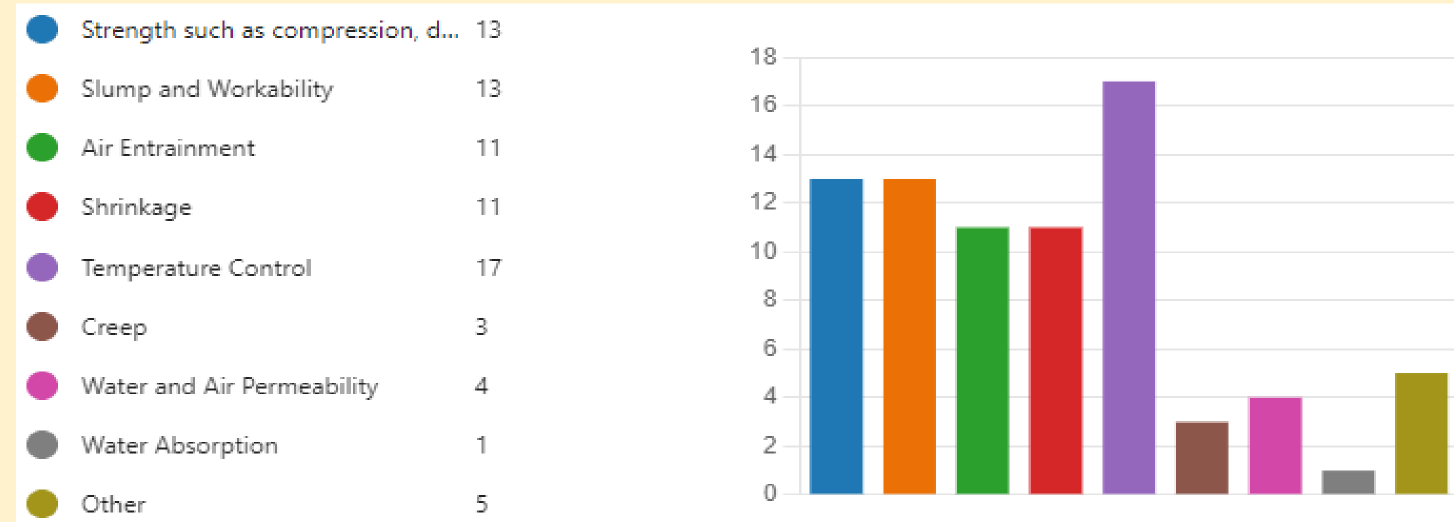
General Survey Results

Question 5 ***Properties and Testing***

Which of the following Concrete Properties and Testing topics do you experience issues or have problems with? Consider topics that require large resources - time or money.

Number of Respondents: 36

Topic	Count	Frequency
Strength	13	36%
Slump and Workability	13	36%
Air Entrainment	11	31%
Shrinkage	11	31%
Temperature Control	17	47%
Creep	3	8%
Water and Air Permeability	4	11%
Water Absorption	1	3%
Other	5	14%



Question 6 *What is your main concrete properties and testing problem/issue from the list above, and what are you currently doing to address it?* (RE: Appendix C)

Question 7 *Is the problem long-term/reoccurring or new/emerging?*

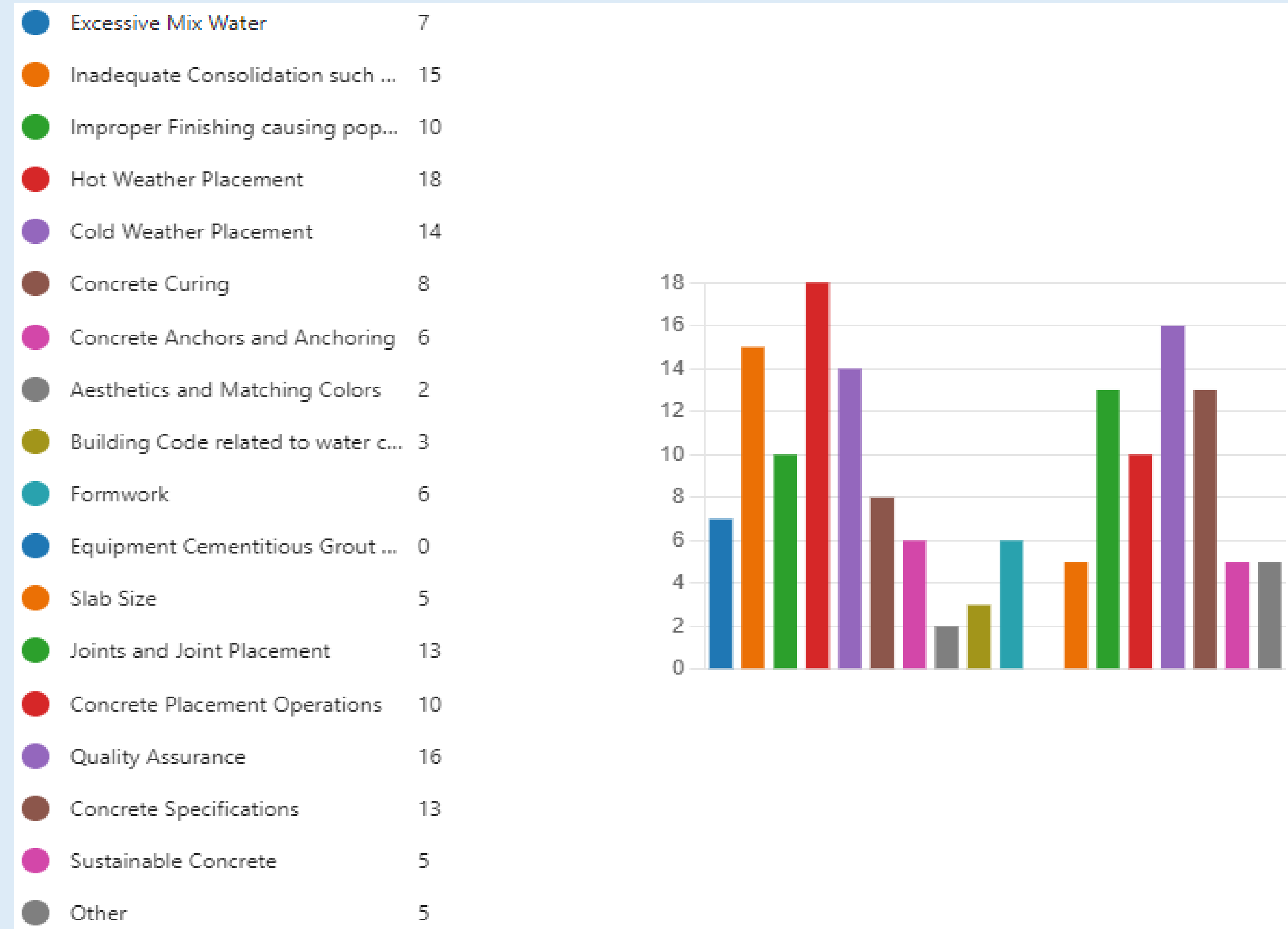
Long-term/reoccurring	31	91.2%
New/emerging	3	8.8%
Total	34	

Construction

Question 8 *Which of the following Concrete Construction topics do you experience issues or have problems with? Consider topics that require large amounts of resources - time and money.*

Number of Respondents: 38

Topic	Count	Frequency
Excessive Mix Water	7	18%
Inadequate Consolidation	15	39%
Improper Finishing	10	26%
Hot Weather Placement	18	47%
Cold Weather Placement	14	37%
Concrete Curing	8	21%
Concrete Anchors and Anchoring	6	16%
Aesthetics and Matching Colors	2	5%
Building Code	3	8%
Formwork	6	16%
Equipment Cementitious Grout Pads	0	0%
Slab Size	5	13%
Joints and Joint Placement	13	34%
Concrete Placement Operations	10	26%
Quality Assurance	16	42%
Concrete Specifications	13	34%
Sustainable Concrete	5	13%
Other	5	13%



Question 9 *What is your main concrete construction problem/issue from the list above, and what are you currently doing to address it?* (RE: Appendix C)

Question 10 *Is the problem long-term/reoccurring or new/emerging?*

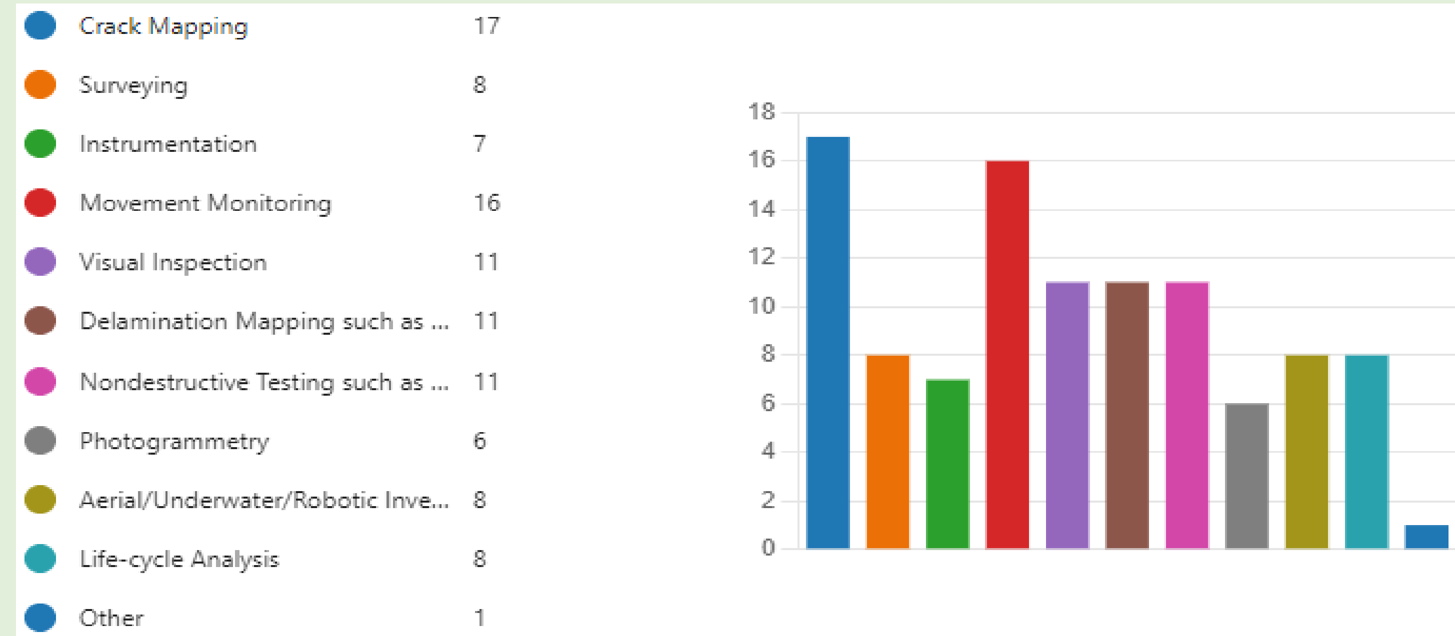
Long-term/reoccurring	29	82.9%
New/emerging	6	17.1%
Total	35	

Condition Assessment

Question 11 *Which of the following Concrete Condition Assessment topics do you experience issues or have problems with? Consider topics that require large amounts of resources - time and money.*

Number of Respondents: 34

Topic	Count	Frequency
Crack Mapping	17	50%
Surveying	8	24%
Instrumentation	7	21%
Movement Monitoring	16	47%
Visual Inspection	11	32%
Delamination Mapping	11	32%
Nondestructive Testing	11	32%
Photogrammetry	6	18%
Aerial/Underwater/Robotic Investigations	8	24%
Life-Cycle Analysis	8	24%
Other	1	3%



Question 12 *What is your main concrete condition assessment problem/issue from the list above, and what are you currently doing to address it?* (RE: Appendix C)

Question 13 *Is the problem long-term/reoccurring or new/emerging?*

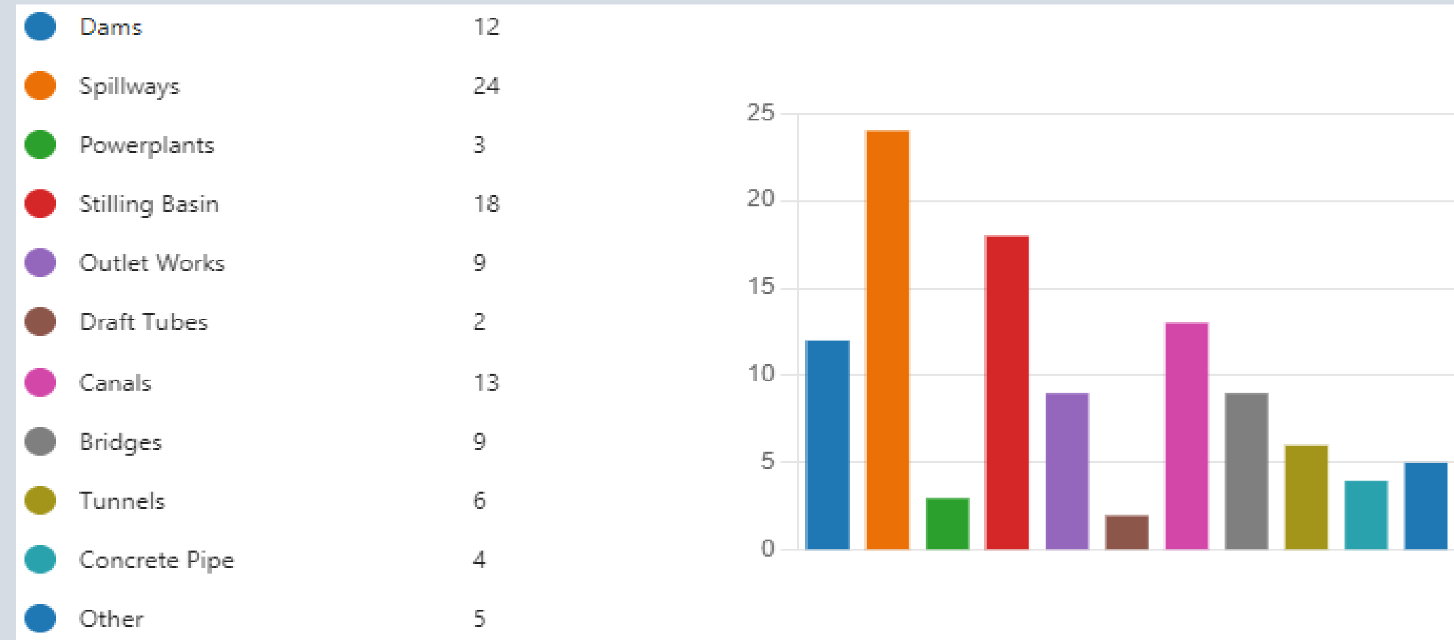
Long-term/reoccurring	24	75.0%
New/emerging	8	25.0%
Total	32	

Durability and Repair

Question 14 *In which concrete features do you see the most durability related issues?*

Number of Respondents: 36

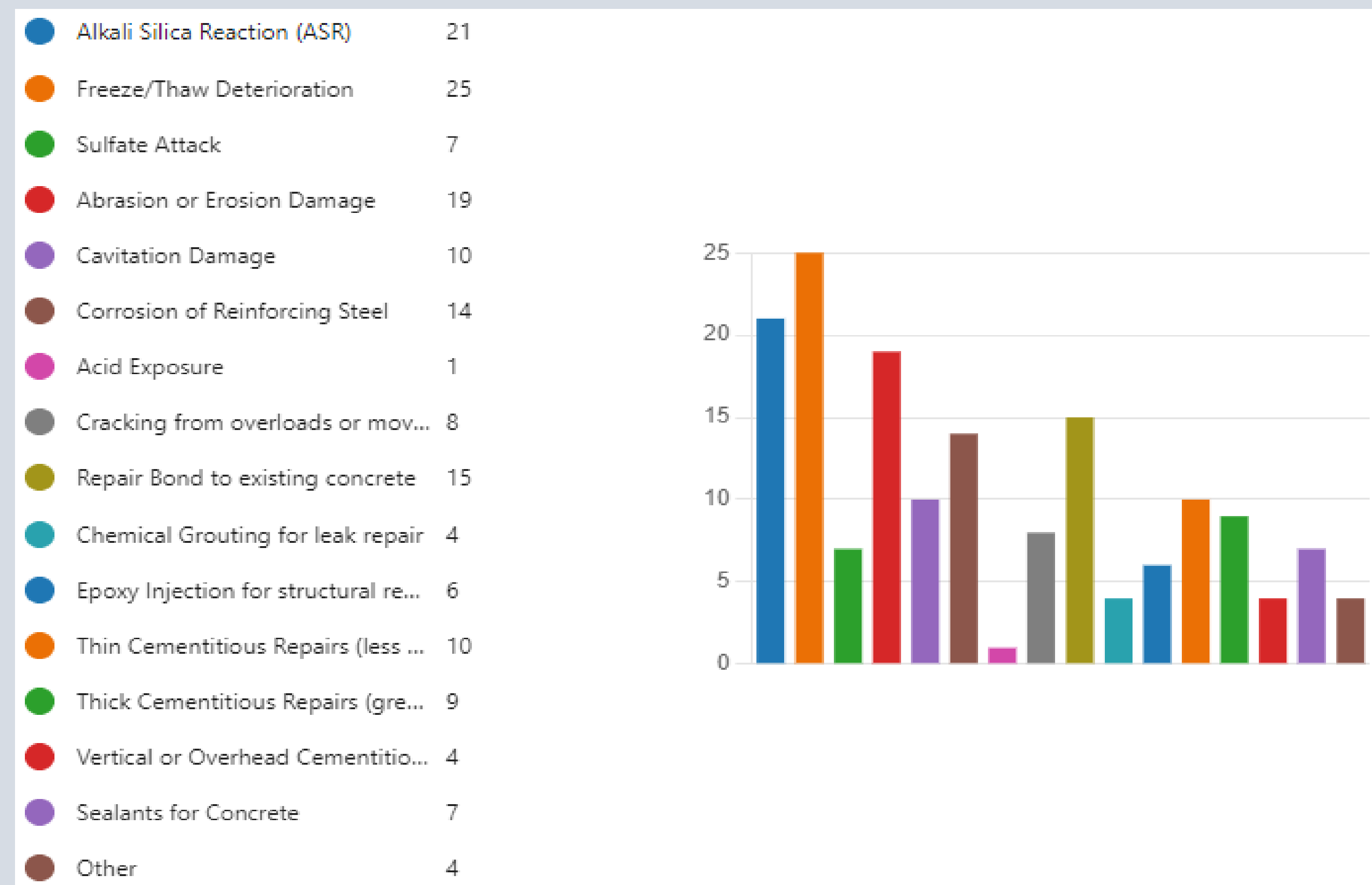
Topic	Count	Frequency
Dams	12	33%
Spillways	24	67%
Powerplants	3	8%
Stilling Basins	18	50%
Outlet Works	9	25%
Draft Tubes	2	6%
Canals	13	36%
Bridges	9	25%
Tunnels	6	17%
Concrete Pipe	4	11%
Other	5	14%



Question 15 *Which of the following Concrete Durability and Repair topics do you experience issues or have problems with? Consider topics that require large amounts of resources - time and money.*

Number of Respondents 36

Topic	Count	Frequency
Alkali Silica Reaction (ASR)	21	58%
Freeze/Thaw Deterioration	25	69%
Sulfate Attack	7	19%
Abrasion/Erosion Damage	19	53%
Cavitation Damage	10	28%
Corrosion of Reinforcing Steel	14	39%
Acid Exposure	1	3%
Cracking (from Overloading or Movement)	8	22%
Repair Material Bond to Existing Concrete	15	42%
Chemical Grouting (Leak Repair)	4	11%
Epoxy Injection (Structural Repair)	6	17%
Thin Cementitious Repairs	10	28%
Thick Cementitious Repairs	9	25%
Vertical or Overhead Cementitious Repairs	4	11%
Sealants	7	19%
Other	4	11%



Question 16 *What is your main concrete durability and repair problem/issue from the list above, and what are you currently doing to address it?* (RE: Appendix C)

Question 17 *Is the problem long-term/reoccurring or new/emerging?*

Long-term/reoccurring	31	93.9%
New/emerging	2	6.1%
Total	33	

Appendix C

Survey Response Study Results

Survey Response Study Results

Causal Analysis					Gap Analysis	
Topic	Subtopic	Frq %	Problem	Solution	Gap	Rank
Durability and Repair	Alkali Silica Reaction (ASR)	58%	Deterioration related to ASR is a serious problem in some of our facilities.	Implement more effective ASR mitigation procedures for existing concrete.	Identify or develop a better method of quantifying residual expansion due to ASR.	1
Mix and Materials	Supplementary Cementitious Materials (SCM)	32%	Availability of conventional supplementary cementitious materials is limited in many areas of the country.	Conventional supplementary cementitious materials (fly ash, slag cement, silica fume) must be substituted with alternative materials (ground glass, natural pozzolans).	Conduct research into using natural pozzolans. Assess the effect of single source variability of harvested fly ash on concrete properties. Identify qualification tests and other requirements for new supplementary cementitious materials.	2
Condition Assessment	Crack Mapping	50%	As Reclamation's inventory continues to age, assessing and documenting the condition of the concrete becomes more critical.	Implement rigorous investigation and assessment procedures that can be applied across Reclamation's inventory.	Research automated monitoring and structural condition assessment programs.	3
Durability and Repair	Freeze/Thaw Deterioration	69%	Concrete repair material is often susceptible to freeze/thaw distress.	Specify concrete repairs that provide improved freeze/thaw durability.	Perform laboratory testing to evaluate the freeze/thaw resistance of various concrete repair materials, potentially including both ready-mixed and prepackaged repair materials.	4
Durability and Repair	Alkali Silica Reaction (ASR)	58%	Addressing ASR in mass concrete structures is extremely challenging.	Stress release through slot cutting or restraint through post-tensioning can limit crack width. However, these methods are not effective in all instances.	Research cost effective alternatives to limit ASR deterioration, such as concrete coatings.	5
Mix and Materials	Mass Concrete	56%	Temperature control is challenging for new construction. Thermal cracking resulting from inadequate temperature control can have substantial impacts on a structure.	Develop better temperature control requirements.	Perform research to develop guidelines for acceptable temperatures for mass concrete in relation to developed strength.	6
Mix and Materials	Mass Concrete	56%	Thermal studies for mass concrete mixes are not up to date for current concrete mix parameters.	Internally disseminate new thermal study data based on current mix designs.	Perform thermal studies of concrete using current mix designs, including blended cements.	7
Condition Assessment	Movement Monitoring	47%	Movement (slab jacking) of spillway chutes creates maintenance and serviceability issues, and is difficult to detect and document.	Perform monitoring of spillways to provide early identification of the presence of spillway chute movement.	Research and develop new technology for spillway chute monitoring, including UAS photogrammetry and LiDAR.	8
Mix and Materials	Lightweight Concrete	7%	Conventional concrete can be used as substrate under spillway slabs to fill voids. However, this can result in concentration of higher flow velocities near the bedrock, causing additional erosion.	Lightweight/cellular concrete could potentially be used as a post-installed substrate for void filling, because the porosity may reduce the flow velocity near the bedrock to acceptable levels. However, this approach has not been evaluated.	Develop laboratory testing to evaluate the efficacy of lightweight/cellular concrete at reducing substrate flow velocities.	9
Condition Assessment	Movement Monitoring	47%	New surveys using modern surveying methods (including total stations) have not yielded results that are as accurate as historical surveys.	Prove that new equipment can generate survey results that match the accuracy of conventional surveying methods used in historical surveys.	Test new surveying systems (including total stations) in a controlled environment to assess accuracy compared to conventional surveying methods.	10
Durability and Repair	Repair Material Bond to Existing Concrete	42%	Vertical surface concrete repairs placed over unsound concrete (either due to freeze/thaw distress or erosion) are often not durable.	Provide improved specifications and more rigorous onsite QA/QC practices to improve durability of repairs.	Review research literature concerning vertical surface repairs over freeze/thaw deteriorated and eroded substrates in order to determine best practices.	11
Durability and Repair	Alkali Silica Reaction (ASR)	58%	ASR and freeze/thaw deterioration are primary design concerns that are not fully understood at this time.	Implement materials requirements that result in low ASR expansion and increased durability against freeze/thaw deterioration.	Conduct long-term studies for ASR mitigation alternatives, including fly ash. Research alkali transport processes to develop a more complete understanding of ASR deterioration.	12
Condition Assessment	Visual Inspection	32%	There is a lack of guidance on the way that inspectors should communicate deterioration of in-place concrete structures, resulting in variability between individual inspectors and difficulties in communicating distress severity.	Implement guidance describing concrete distress categorizations, terminology, and communication of severity.	Develop guidance describing concrete distress categorizations, terminology, and communication of severity.	13
Condition Assessment	Crack Mapping	50%	The extent of crack propagation and widening over time at Reclamation structures is not well-documented.	Implement crack mapping procedures and regimens at Reclamation structures.	Develop standardized crack mapping procedures and recommendations outlining when cracks may become problematic.	14
Properties and Testing	Strength	36%	Estimation of concrete tensile capacity for seismic load assessment is often difficult due to limited existing data. The CSL also has long lead times for performing additional concrete tensile testing.	Expedite concrete tensile testing programs for seismic load assessment purposes.	Conduct studies to determine minimum properties needed for seismic analysis.	15
Condition Assessment	Nondestructive Testing	32%	Nondestructive testing is not available and/or not cost effective for area offices.	Provide additional nondestructive testing capabilities and nondestructive testing training support to area offices.	Internally develop nondestructive testing expertise, acquire nondestructive testing equipment, and develop training opportunities for area offices.	16
Mix and Materials	Mass Concrete	56%	Joints are often locations where deterioration of concrete initiates.	Limit number of joints and take care in specifying their locations to minimize the extent of deterioration at joints.	Perform literature and/or laboratory research to fully understand the contributing factors to crack develoment in large slab placements relative to joint spacing and layout.	17
Construction	Quality Assurance	42%	In practice, concrete repair material often does not adequately bond to the concrete substrate. This can be due to contractor means and methods. *(Related to Item #20)*	Better contractor means and methods can result in more durable repairs.	Research newer, modern bonding agents to verify whether the CSL's current stance on the inefficacy of bonding agents remains true. Research chemical surface preparation (acid wash) techniques to evaluate their efficacy.	18
Durability and Repair	Repair Material Bond to Existing Concrete	42%	Repair material often bonds poorly to the original concrete. *(Related to Item #18)*	Specify repair materials and methods which are more likely to result in durable repairs.	Develop a performance monitoring program that includes literature reviews to identify past repair materials, and conduct durability inspections of past repairs.	19

Survey Response Study Results

Causal Analysis					Gap Analysis	
Topic	Subtopic	Frq %	Problem	Solution	Gap	Rank
Construction	Inadequate Consolidation	39%	It is difficult to achieve proper consolidation due to timing related to harsh weather.	Take time and care and use new technologies. In some instances, SCC could be specified.	SCC can be specificed but is often not readily available. Develop a list of ready-mix suppliers that have SCC available, and start asking about SCC during concrete materials investigations.	20
Properties and Testing	Strength	36%	Concrete core test property results show significant variance, which is often problematic as an input in structural analysis of dams.	Correlate concrete core test results to nondestructive geophysical surveys to provide greater confidence in structural analysis and DSO risk estimations.	Develop nondestructive testing expertise within CSL in order to better interface with geophysical testing group.	21
Properties and Testing	Temperature Control	47%	In practice, it is often difficult or impossible to ensure that the temperature of new concrete during curing does not exceed upper limits stated in Reclamation specifications.	Specify reasonable temperature limits for concrete.	Perform research to determine if we can increase our specified upper temperature limit without having deletirious effects on the concrete. Determine the potential effect of this temperature limit increase on concrete strength.	22
Condition Assessment	Visual Inspection	32%	It is difficult to get an accurate and timely assessment from a contracted private industry engineer.	Provide in-house concrete condition assessments by the CSL.	Research and recommend certifications and training required for concrete inspections. Procure equipment to aid in condition assessment. Validate results of new methods against current methods.	23
Condition Assessment	Visual Inspection	32%	Existing concrete often develops ASR distress. *(Related to Item #1)*	Perform periodic assessments and evaluations to determine the extent of ASR deterioration, and its development over time.	Identify or develop a better method of quantifying and documenting extent of ASR damage.	24
Properties and Testing	Strength	36%	With large-sized aggregate mixes, field crews need guidance for relating concrete compression test results from field samples to test results from larger laboratory samples.	Provide guidance to field crews on relating field test results to laboratory test results.	Large aggregate testing is performed at the CSL, but not necessarily in field or commercial labs. Develop a paper for educational purposes, as data on correlation exists.	25
Properties and Testing	Strength	36%	As dams age, the physical properties of the concrete can change significantly. Expected changes over time are difficult to quantify.	Provide guidance for assessing concrete physical properties changes over time.	Reclamation possesses a unique inventory of structures with a long history of physical properties testing data. Develop a searchable database of materials testing results to help quantify the change in concrete properties over time.	26
Properties and Testing	Other	27%	Square bars (rail and axle steel) were used as reinforcement at several Reclamation projects, but information on engineering properties of the steel is not available.	Determine and document properties for reinforcing steel at the relevant Reclamation projects.	Extract and conduct testing of square bars used at Reclamation projects.	27
Durability and Repair	Corrosion of Reinforcing Steel	39%	Cracking causes corrosion of embedded reinforcing steel. It is not clear when cracks need to be addressed to limit the possiblity of corrosion.	Provide guidance on crack treatment practices.	Collaborate with 8540 about when to address cracks before corrosion becomes an issue. Develop a joint paper on the topic.	28
Properties and Testing	Slump and Workability	36%	Slump may no longer be useful as an acceptance criteria for modern concrete, which includes numerous admixtures that greatly impact flow and workability.	Remove slump as an acceptance criteria if industry consensus indicates that it is obsolete.	Conduct a literature review to assess the relevance of using slump as an acceptance criteria in modern concrete.	29
Properties and Testing	Shrinkage	31%	Conventional strain gauges are time consuming and require significant data post-processing. In addition, conventional strain gauges are limited in that they can only measure strain at discrete points.	Implement non-contact strain measurement methods (DIC).	Research and acquire Digital Image Correlation (DIC) technology to provide non-contact strain measurements.	30
Durability and Repair	Abrasion/Erosion Damage	53%	Abrasion resistant materials are needed within Reclamation structures. State-of-the art and best practices are not well understood at this time.	Provide guidance on best practices for resisting abrasion damage.	Research mitigation of abrasion/erosion, depth at which abrasion/erosion section loss becomes detrimental to flow characteristics and structural integrity, and other characteristics (ACI 321 and 201). Develop a paper on the topic.	31