SD2023-07

Refinement of Reinforced Concrete Box Culvert Installation Guidelines

Study SD2023-07

Final Report

Prepared by

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16. Abstract

This study developed a refined, data-driven framework to support the selection of reinforced concrete box culverts (RCBCs) in South Dakota, where designers often face uncertainty when choosing between cast-in-place (CIP) and precast systems under complex site conditions. The project combined stakeholder interviews, nationwide surveys, inspection records, cost information, and predictive modeling to evaluate current practices, long-term performance, and constructability constraints. Results show that while precast RCBCs are widely favored for standard installations due to faster construction and reduced traffic impacts, CIP remains the main option for high skews, challenging hydraulics, poor soils, large rises, and specialized geometries. South Dakota performance data show that precast culverts generally maintain high condition ratings in the short- to mid-term, though most are not yet old enough to fully assess long-term durability. In contrast, older CIP culverts have demonstrated reliable long-term performance where properly maintained. Based on these findings, the study proposes selection criteria and revisions to the SDDOT Bridge Design Manual, including updated skew and rise limits for precast units, allowance for hybrid precast–CIP configurations, and preference for multiple single-cell units in multi-barrel designs. The resulting framework enhances consistency, efficiency, and long-term performance in RCBC design and construction across South Dakota.

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AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ANOVA	Analysis of Variance
ASR	Alkali-Silica Reaction
ASTM	American Society for Testing and Materials
BrM	Bridge Management
CalTrans	California Department of Transportation
CIP	Cast-in-Place
CM/GC	Construction Manager/General Contractor
DOT	Department of Transportation
FHWA	Federal Highway Administration
ft^3	cubic foot
HEC	Hydrologic Engineering Center
HL	Highway Load
IDOT	Illinois Department of Transportation
IIJA	Infrastructure Investment and Jobs Act
JMP	Statistical Software (used for data analysis)
KDOT	Kansas Department of Transportation
LTBP	Long-Term Bridge Performance
LRFD	Load and Resistance Factor Design
MoDOT	Missouri Department of Transportation
MSE	Mechanically Stabilized Earth
NBI	National Bridge Inventory
NCDOT	North Carolina Department of Transportation
NDDOT	North Dakota Department of Transportation
NPCA	National Precast Concrete Association
PCI	Precast/Prestressed Concrete Institute
PE	Professional Engineering
PennDOT	Pennsylvania Department of Transportation
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control

RCBC	Reinforced Concrete Box Culvert
RCP	Reinforced Concrete Pipe
RFB	Request for Bid
RFP	Request for Proposal
RIDOT	Rhode Island Department of Transportation
SCC	Self-Consolidating Concrete
SCDOT	South Carolina Department of Transportation
SDDOT	South Dakota Department of Transportation
SDLTAP	South Dakota Local Technical Assistance Program
SPSS	Statistical Package for the Social Sciences (software)
TS&L	Type, Size, and Location
TxDOT	Texas Department of Transportation
UHPC	Ultra High Performance Concrete
USDOT	United States Department of Transportation
VDOT	Virginia Department of Transportation
WisDOT	Wisconsin Department of Transportation
WSDOT	Washington State Department of Transportation

1.0 EXECUTIVE SUMMARY

This study developed a refined framework for selecting reinforced concrete box culverts (RCBCs) in South Dakota. RCBCs provide cost-effective alternatives to bridges, but site conditions, skew angles, rise, and other design constraints often make selecting the optimal type, precast or cast-in-place (CIP), challenging. Using stakeholder interviews, national surveys, and performance data analysis, the project proposed new criteria to improve decision-making, constructability, and long-term performance.

1.1 Problem Description

RCBCs are widely used for their lower cost and simpler construction compared to bridges. However, current SDDOT guidelines offer limited guidance for complex conditions, such as skew angles over 10 degrees or flared wing walls. This uncertainty can delay design decisions and reduce efficiency. The project's goal was to create a systematic, data-driven framework for selecting the most appropriate RCBC type and to update the SDDOT Bridge Design Manual accordingly.

1.2 Research Objectives

The study aimed to: (i) investigate RCBC options that expand SDDOT's current RCBC site condition guidelines; (ii) establish criteria for selecting the optimum RCBC construction type in South Dakota; and (iii) develop recommendations for the SDDOT Bridge Design Manual that will assist the SDDOT and Local Governments in selecting the optimum RCBC construction type.

1.3 Tasks Descriptions

The project followed a structured approach to evaluate and optimize RCBC selection in South Dakota. It began with a technical panel meeting to review the project scope, objectives, timelines, and deliverables (Task 1). The research team then conducted virtual interviews with SDDOT personnel, contractors, county highway superintendents, consulting engineers, precast suppliers, and representatives from neighboring state DOTs to gather insights on RCBC performance, life-cycle costs, constructability, installation challenges, and quality control issues associated with both precast and cast-in-place (CIP) culverts (Task 2). Additional interviews were later conducted with selected stakeholders from other states to better understand RCBC selection practices and decision-making processes.

Based on the interview findings, two national surveys were developed and distributed through Qualtrics (Tasks 3 and 4). One survey targeted state highway agencies to collect information regarding RCBC performance, costs, installation practices, and selection criteria, while the second focused on precast suppliers and their ability to manufacture and install RCBCs under varying site conditions, including skewed geometries and flared wingwalls. Following the completion of the interviews and survey development, the research team prepared and presented a technical memorandum summarizing the preliminary findings and survey instruments to the technical panel (Task 5). After approval, the surveys were administered nationally and the responses were analyzed to identify trends, regional practices, and recurring challenges related to RCBC applications (Task 6).

The project then focused on analyzing RCBC performance and costs in South Dakota using data from the FHWA Long-Term Bridge Performance (LTBP) database, the AASHTO Bridge Management (BrM) database, SDDOT records, and statewide cost reports (Task 7). The study evaluated 213 precast and 885 CIP RCBCs by analyzing factors such as culvert dimensions, fill height, skew angle, traffic volume, environmental conditions, service life, and construction costs. Statistical analyses and predictive models were also developed to evaluate long-term performance and identify variables influencing culvert condition.

Using the information obtained in Tasks 2 through 7, the research team developed criteria to support RCBC construction type selection in South Dakota (Task 8). The criteria considered factors such as skew angle, hydraulic conditions, transportation and installation limitations, traffic disruption, construction schedules, bedding preparation, and joint protection practices. The results were summarized in a second technical memorandum and presented to the technical panel for feedback (Task 9). Finally, recommendations for the SDDOT Bridge Design Manual were prepared based on the developed criteria (Task 10), and the project concluded with a final report and executive presentation summarizing the methodology, findings, conclusions, and recommendations (Tasks 11–12).

1.4 Findings and Conclusions

Nationwide survey findings showed that most states increasingly use precast for standard installations because of accelerated construction and reduced traffic impacts, while CIP remains important for specialized applications. States employ a range of design and construction practices related to skew limits, span capacities, fill heights, and wingwall configurations, and many use hybrid precast–CIP systems to address complex geometries. Suppliers emphasized the influence of fabrication limits, transport logistics, bedding quality, and joint integrity on long-term performance.

Performance data from across South Dakota demonstrated that geography and climate play a significant role in RCBC condition. Older CIP culverts show more deterioration due to freeze–thaw cycles, heavy precipitation, and fill-related stress, with condition strongly tied to age, length, and open area. By contrast, precast culverts, generally younger and factory-produced, maintain consistently high ratings statewide and offer cost advantages during installation, although most are not yet old enough to fully assess long-term durability. Predictive modeling confirmed that service life, size, and fill height are the primary drivers of condition, while skew, traffic, and construction type have less influence. Overall, the findings indicate that precast RCBCs provide strong short- to mid-term performance and constructability advantages, while CIP RCBCs continue to provide reliable long-term performance under complex or highly customized conditions.

Based on these findings, the study developed recommendations to improve RCBC selection and update the SDDOT Bridge Design Manual. The recommendations include revising allowable skew limits for precast culverts, enhancing joint protection practices, allowing precast-only installations under specific project constraints, incorporating hybrid precast-CIP solutions for complex conditions, prioritizing single-cell units for multi-barrel precast culverts, and increasing collaboration with precast manufacturers. Together, these recommendations provide a more practical and consistent framework for selecting RCBC construction types across South Dakota.

1.4.1 Modify Skew Limits for Precast RCBCs

Update the SDDOT Bridge Manual to provide a precast culvert option for culverts up to 30 degrees skew, consider precast options for skews between 30 and 45 degrees subject to special approval, and restrict precast options for culverts exceeding 45 degrees in skew.

1.4.2 Joint Integration Recommendations

Enhance joint protection practices by installing mastic rope material around the entire perimeter of the box section joint for all standard installations and require a mastic joint wrap at least 9 in. wide on the top and sides of the box culvert joints for culverts exposed to higher water pressures or potential joint movement, such as those located under rivers or streams, skewed culverts, or areas with high groundwater. All sealants and gaskets should comply with ASTM C990, ASTM C877, and ASTM C920.

1.4.3 Allow Precast-Only Installations for Specific Project Constraints

Use precast culverts: (i) when closest ready-mix concrete plant is more than approximately four hours away; (ii) when minimizing traffic disruption or meeting tight construction schedules is critical; and (iii) when the rise is 4 feet or less.

1.4.4 Incorporate More Often Hybrid (Precast-CIP) Options

Encourage more frequent utilization of hybrid construction approaches using precast barrels with CIP ends when site-specific factors, such as skewed geometry, flared wingwalls, or restricted access, make full precast construction impractical.

1.4.5 Prioritize Single-Cell Units for Multi-Barrel Precast Culverts

Specify single-cell precast units when feasible to simplify transportation, handling, and installation; double-units may be used where project conditions or contractor preference make them advantageous.

1.4.6 Incorporate Recommended Revisions into the SDDOT Bridge Manual

Incorporate the proposed revisions presented into the SDDOT Bridge Manual to provide clearer and more comprehensive guidance for the selection and design of CIP and precast RCBC installations.

1.4.7 Partner with Precast Manufacturers

Encourage SDDOT to work directly with precast manufacturers to optimize unit design, joint detailing, and handling. Early collaboration can reduce installation errors, improve constructability, and streamline project schedules. Neighboring states, including Iowa and Minnesota, involve precasters during project planning to refine specifications and installation methods.

2.0 PROBLEM DESCRIPTION

Reinforced Concrete Box Culverts (RCBCs) are the preferred structure when practical. This is primarily due to RCBCs being typically less expensive than a bridge, less complicated to design, and easier to construct and maintain. RCBCs are either cast-in-place (CIP) or precast and both have circumstances in which their construction type is optimum. However, there are many circumstances when choosing the best RCBC option is not clear. Factors such as site conditions, long-term performance, costs, and speed of construction can impact the final selection.

While the South Dakota Department of Transportation (SDDOT) offers both cast-in-place and precast RCBC options, uncertainties remain, particularly with design elements such as skew angles bigger than 10 degrees, flared wing walls, apron slopes, inlets, and water control structures. The existing guidelines offer alternatives, but they lack a streamlined methodology for selecting the most appropriate RCBC construction type. This often results in prolonged decision-making and design phases, causing inefficiencies.

The overarching goal of this project is to develop a refined framework for selecting the most suitable RCBC construction type, tailored to the unique conditions of South Dakota. By systematically addressing the challenges posed by site conditions, performance expectations, costs, and construction timelines, the study aims to streamline decision-making and reduce design time. Incorporating these findings into the SDDOT Bridge Design Manual (South Dakota Department of Transportation (SDDOT), 2021) will ensure that the RCBC selection process is more data-driven, cost-effective, and aligned with the optimal utilization of project funds, providing clear guidance based on situational factors.

3.0 RESEARCH OBJECTIVES

The research project objectives are outlined below, with the tasks associated with each objective illustrated in Figure 3.1.

3.1 Objective 1: Expanding RCBC Options Beyond SDDOT Guidelines

The goal is to **investigate RCBC options that expand SDDOT's current RCBC site condition guidelines**.

To achieve this, the research team conducted comprehensive interviews with key stakeholders in South Dakota, including contractors, SDDOT personnel, consulting engineers, county highway superintendents and precast suppliers, to understand existing practices for selecting RCBC types. Additionally, the team interviewed personnel from the Iowa DOT, Minnesota DOT, Kansas DOT, Wisconsin DOT and South Carolina DOT to understand their processes for updating RCBC guidelines, focusing on the strategies and methodologies they employed during their revisions.

Based on the interview insights, the team explored new options to enhance the RCBC selection process. This effort extended beyond South Dakota through targeted surveys distributed to all state DOTs and precast concrete producers nationwide, feedback from across the United States. This broad outreach expanded the scope of the study, integrated diverse practitioner perspectives, and helped identify innovative solutions for optimizing RCBC applications.

3.2 Objective 2: Developing Criteria for Optimal RCBC Construction in South Dakota

The goal is to **establish criteria for selecting the optimum RCBC construction type in South Dakota.**

To achieve this, the research team distributed and analyzed the results of the surveys developed in previous tasks. The aim was to establish precise criteria for systematically selecting the optimal RCBC construction type, custom-tailored to the unique conditions and requirements of South Dakota. These criteria considered factors such as site conditions, long-term performance, and life-cycle costs. The goal was to develop a streamlined decision-making framework that simplified the selection process and ensured the most suitable RCBC type was chosen for each project, enhancing both efficiency and cost-effectiveness.

3.3 Objective 3: Refining SDDOT Bridge Design Manual to Optimize RCBC Selection

The goal is to **develop recommendations for the SDDOT Bridge Design Manual that will assist the SDDOT and Local Governments in selecting the optimum RCBC construction type.**

To achieve this, the research team employed the criteria previously developed to propose recommendations for updating and optimizing the selection method in the SDDOT Bridge Design Manual. This refinement aimed to streamline the decision-making process, reduce design time, and leverage innovative precast solutions. The goal was to help make well-informed decisions that maximized the effective use of project funds.

Objective 1: Investigate RCBC options that expand SDDOT's current RCBC site condition guidelines.

- Task 1: Project Scope and Work Plan Review Meeting
- Task 2: Virtual Interviews with Stakeholders
- Task 3: Draft Survey Instrument for State Highway Agencies
- Task 4: Draft Survey Instrument for RCBC Precast Suppliers Nationwide
- Task 5: Submission and Presentation of Task 2-4 Results

Objective 2: Establish criteria for selecting the optimum RCBC construction type in South Dakota.

- Task 6: Survey Administration and Summary
- Task 7: Analysis of RCBC Performance and Costs
- Task 8: Criteria Development for RCBC Construction Type Selection
- Task 9: Submission and Presentation of Task 6-8 Results

Objective 3: Develop recommendations for the SDDOT Bridge Design Manual that will assist the SDDOT and Local Governments in selecting the optimum RCBC construction type.

- Task 10: Recommendations for SDDOT Bridge Design Manual
- Task 11: Final Research Report
- Task 12: Executive Presentation to SDDOT Research Review Board

Figure 3.1: Project's objectives with tasks covered.

4.0 TASK DESCRIPTIONS

The tasks of the research project are described below:

4.1 Task 1: Project Scope and Work Plan Review Meeting

Action: Meet with the project's technical panel to review the project scope and work plan.

The research team conducted an initial meeting with the project's technical panel to thoroughly review and refine the project scope and work plan. This meeting ensured that objectives were clearly defined and aligned with the research goals. Additionally, this discussion allowed the team to address preliminary questions, clarify roles and responsibilities, and establish timelines and deliverables.

4.2 Task 2: Virtual Interviews with Stakeholders

Action: Conduct virtual interviews with a representative sample of structural construction contractors, SDDOT personnel, South Dakota County Highway Superintendents, regional precast suppliers, and South Dakota consulting engineers who have advanced knowledge in RCBC design and construction. Interviews will focus on the assessment of cast-in-place and precast RCBC long-term performance, life cycle costs, installation site conditions, and quality control in South Dakota. The list of interviewees and questions shall be approved by the technical panel prior to conducting the interviews.

The team conducted in-depth virtual interviews with a variety of key stakeholders, including structural construction contractors, SDDOT personnel, and RCBC precast suppliers. The list of interviewees, provided by SDDOT, included 10 SDDOT personnel, 4 consulting engineers, 5 precast suppliers, 7 highway superintendents from various South Dakota counties, and 5 contractors. Additionally, representatives from the Iowa Department of Transportation (DOT) and the Minnesota DOT were invited to share insights from their current RCBC standards.

Moreover, after Task 6, the team conducted additional interviews with 4 structural construction contractors, 3 highway superintendents from other South Dakota counties, and 5 representatives from three state DOTs who responded to the Task 6 survey, to gather further insights into their decision-making processes when choosing between cast-in-place (CIP) and precast culverts.

Tables 4.1 to 4.7 list the interviewed personnel, including the extra interviews conducted.

Table 4.1: SDDOT personnel interviewed.

Number	Title	Region
1	Bridge Inspector	Mitchell
2	Project Engineer III	Mitchell
3	Project Engineer III	Aberdeen
4	Bridge Inspector	Aberdeen
5	Engineer Manager II	Rapid City
6	Engineer IV Materials Engineer	Rapid City
7	Bridge Inspector	Rapid City
8	Engineer Manager II	Pierre
9	Project Engineer III	Pierre
10	Bridge Inspector	Pierre

Table 4.2: Consulting engineers interviewed.

Number	Title	Company	Location
1	Senior Project Manager	HRGreen	St. Louis, MO
2	Project Manager/ Structural Group Leader	Benesch	Denton, NE
3	Bridge Engineer/Project Manager	AECOM	Denver, CO
4	Vice President, West Region Transit and Rail Structures Lead	AECOM	Omaha, NE

Table 4.3: Precast suppliers interviewed.

Number	Title	Company	Location
1	Director of Engineering	Rinker Materials	Rapid City & Mitchell SD
2	Project Engineer	Rinker Materials	Rapid City & Mitchell SD
3	Commercial Director	Oldcastle Infrastructure	Sioux Falls, SD
4	Retired	Hancock Concrete Products	North Sioux City, SD
5	President	Cemcast Pipe & Precast	Harford SD

Table 4.4: Highway Superintendents interviewed. Note: 8-10 were interviewed after Task 6.

Number	Title	County	Location
1	Highway Superintendent	Turner	Parker SD
2	Highway Superintendent	Grant	Milbank, SD
3	Highway Superintendent	Lincoln	Canton, SD
4	Highway Superintendent	Pennington	Rapid City, SD
5	Highway Superintendent	Minnehaha	Sioux Falls, SD
6	Highway Superintendent	Union	Elk Point, SD
7	Highway Superintendent	Beadle	Huron, SD
8	Highway Superintendent	Meade	Sturgis, SD
9	Highway Superintendent	Brookings	Brookings, SD
10	Highway Superintendent	Lawrence	Deadwood, SD

Table 4.5: Contractors interviewed. Note: 6-9 were interviewed after Task 6.

Number	Title	Company	Location
1	President	A-G-E Corporation	Fort Pierre, SD
2	Vice President Of Construction	A-G-E Corporation	Fort Pierre, SD
3	Vice President	A-G-E Corporation	Fort Pierre, SD
4	Vice President Construction Division	Webster Scale	Webster, SD
5	Project Manager	SFC Civil Constructors	Sioux Falls, SD
6	Heavy Highway Division Manager	Heavy Constructors	Sturgis, SD
7	Managing Member	Midwest Construction	Marshall, MN
8	Vice President of Internal Operations	BX Civil & Construction	Dell Rapids, SD
9	President	Corr Construction Services, Inc.	Hermosa, SD

Table 4.6: Iowa and Minnesota DOT personnel interviewed.

Number	Title	DOT	Location
1	Bridge Project Development Engineer	Iowa	Ames, IA
2	Standards and Research Engineer	Minnesota	St. Paul, MN

Table 4.7: State DOT personnel interviewed after Task 6.

Number	Title	DOT	Location
1	State Bridge Design Engineer	Kansas	Topeka, KS
2	Chief Structures Design Engineer	Wisconsin	Madison, WI
3	Senior Structural Engineer – Transportation	Wisconsin	Madison, WI
4	Structural Design Support Engineer	South Carolina	Columbia, SC
5	Structural Design Policy Engineer	South Carolina	Columbia, SC

Interview questions, shown in Appendix A, were tailored to each group by aligning them with their specific job roles. For example, precast suppliers were asked specific questions about production challenges, potential production of RCBC with complex designs (e.g., skews higher than 10 degrees or flared wingwalls) and strategies for enhancing durability, given their direct involvement in the manufacturing process. In contrast, SDDOT personnel were asked about their experiences with comparative assessments of precast versus cast-in-place RCBCs, and long-term maintenance concerns, reflecting their focus on project implementation and infrastructure longevity.

The goal was to gather information on long-term performance, life cycle costs, and installation conditions for both precast and cast-in-place RCBCs. All questions were approved by the technical panel prior to conducting the interviews. The interviews, conducted online and lasting 30 to 45 minutes each, allowed stakeholders to share their opinions and experiences with both precast and CIP RCBC applications. This task was critical for understanding the practical challenges and insights of stakeholders, enabling the team to align research objectives more closely with real-world applications.

4.3 Task 3: Draft Survey Instrument for State Highway Agencies

Action: Develop a draft survey instrument to be distributed to selected State Highway Agencies. The survey instrument should disclose the experiences and perceptions of other State Highway Agencies regarding the long-term performance, life cycle costs, and installation site conditions of cast-in-place and precast RCBC. The survey instrument should also reveal the criteria used in the RCBC construction type selection process.

The research team designed a survey to gather further insights from Department of Transportation (DOT) representatives across various states outside of South Dakota. The questions for the survey were derived based on the insights gained from the Task 2 interviews with stakeholders, which identified key areas of interest, including the need for proper bedding techniques, potential hybrid construction approaches, and strategies to mitigate joint-related issues. This survey aims to collect additional data on agencies' experiences with RCBC installations, focusing specifically on performance, cost-efficiency, and site conditions. After drafting the questions, the research team submitted the survey to the technical panel for review. Upon approval, the survey was distributed via Qualtrics, using contact lists provided by SDDOT (sourced from previous projects) and the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures, targeting Chief Bridge Engineers from across the United States.

4.4 Task 4: Draft Survey Instrument for RCBC Precast Suppliers

Action: Develop a draft survey instrument to be distributed to a representative sample of RCBC precast suppliers nationwide. The survey instrument should identify acceptable and innovative RCBC options such as flared wing walls, skew angles, sloped tapered aprons, side tapered inlets, and parapets applicable for various site conditions.

Another survey was conducted after conducting the interviews (Task 2) to obtain more information regarding the feasibility of precast suppliers to build and install RCBC. This survey focused on site-specific conditions such as skew angles, flared wing walls, and other structural design challenges. This task also aims to identify new technologies and methods that can improve RCBC selection processes for unique site conditions, facilitating a comparison between traditional and modern solutions. Once the questions were developed, the research team submitted the survey to the technical panel for review. After drafting the questions, the research team submitted the survey to the technical panel for review. Upon approval, the survey was distributed through Qualtrics to precast companies from across the United States, with the research team reaching out to at least three companies in each state.

4.5 Task 5: Submission and Presentation of Task 2 through 4 Results

Action: Submit and present to the technical panel a technical memorandum summarizing the results of Tasks 2 through 4.

Following the completion of Tasks 2, 3, and 4, the research team compiled a technical memorandum that summarizes the insights gathered from stakeholder interviews and the survey development. This memorandum was presented to the technical panel, offering a comprehensive overview of findings to date and allowing for feedback on both the interview findings and potential adjustments to both surveys before administering them. This step ensures the technical panel remains informed on project progress and that early findings align with the study's objectives.

4.6 Task 6: Survey Administration and Summary

Action: Upon approval by the technical panel of the survey instruments, administer and summarize the survey results.

Upon approval by the technical panel, both surveys (developed in Tasks 3 and 4) were administered through Qualtrics. The State Highway Agencies’ survey utilized contact lists provided by SDDOT (sourced from previous projects) and the AASHTO Committee on Bridges and Structures, specifically reaching Chief Bridge Engineers from states across the United States. Excluding South Dakota, Iowa, and Minnesota (already represented in the interview phase), 47 states were eligible to participate. In each eligible state, the survey was sent to at least three DOT personnel. Responses were received from 18 states, many of which are geographically or regionally connected to South Dakota, as shown in Figure 4.1.

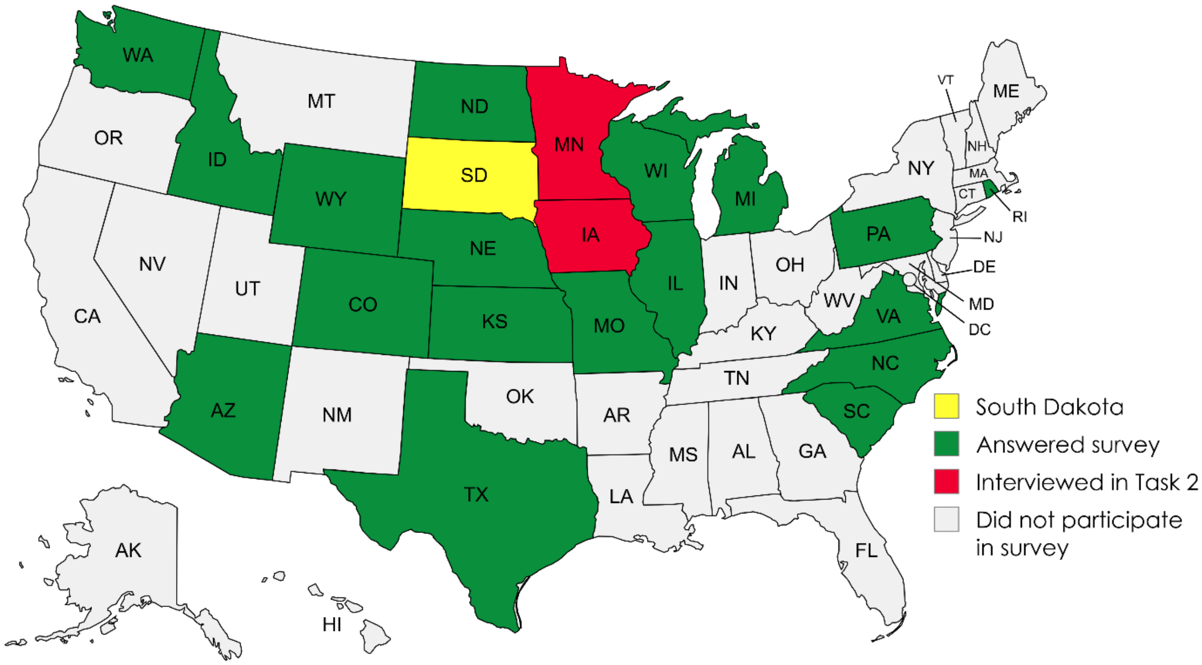

Figure 4.1: States whose DOTs responded to the survey or participated in the interview phase.

Table 4.8 summarizes the respondents by state and includes the job titles of those who completed the survey.

Table 4.8: State DOT survey respondents.

Number	Job Title	State DOT
1	Senior Civil Engineer (Bridges)	Pennsylvania
2	State Bridge Design Engineer	Washington
3	Engineer of Bridge Design	Illinois
4	Assistant State Bridge Engineer	Missouri
5 (2 responses)	State Bridge Engineer / Bridge Design Group Leader	Idaho
6	Senior Design and Construction Engineer	Colorado
7	Bridge Division Deputy Director	Texas
8 (2 responses)	State Bridge Design Engineer / Assistant Bureau Chief	Kansas
9 (2 responses)	Structures Policy Engineer / Chief Structures Design Engineer	Wisconsin
10	State Bridge Engineer	Wyoming
11	Asst. State Structures Engineer	North Carolina
12	Assistant State Structure and Bridge Engineer	Virginia
13	Structural Design Support Engineer	South Carolina
14	Bridge Preservation Manager	Arizona
15	Engineer	Nebraska
16	Managing Engineer and Bridge Engineering	Rhode Island
17	Bridge Design Team Lead	North Dakota
18	Deputy Chief Bridge Engineer	Michigan

Similarly, the survey targeting precast suppliers was sent to companies nationwide. The research team aimed to contact at least three precast companies in each state. Despite multiple reminders and follow-up emails, the response rate was low, with only six companies participating. Table 4.9 lists these companies along with the respondents' job titles and locations.

Table 4.9: Precast supplier survey respondents.

Number	Job Title	Location	Company
1	President	Boston, MA	Shea Concrete Products
2	Vice President of Products Group	McPherson, KS	McPherson Concrete Companies
3	Box Culvert Project Engineer	Chicago, IL	S&M Precast Inc
4	Sales Engineer	Chestertown, MD	Gillespie Precast
5	Managing Member	Rapid City, SD	Engineered Concrete Products, LLC
6	V.P. Specialty Precast Sales	Wall Township, NJ	Garden State Precast/Wall, NJ

Once the surveys are completed, the research team conducted a detailed analysis of the responses. Quantitative data were summarized to identify national trends. For example, determining how many states permit the use of precast RCBCs or impose specific restrictions on allowable fill heights. Simultaneously, qualitative feedback was analyzed by grouping similar comments to uncover recurring ideas, such as concerns about joint integrity or the logistical challenges of installing precast segments in remote locations.

To ensure the accuracy and completeness of the findings, the team also reviewed any technical manuals, or specifications referenced by the respondents. This review helped validate the survey data and provided additional context.

Moreover, after the initial survey responses were received, additional interviews were conducted with more contractors and highway superintendents from other South Dakota counties, as well as DOT representatives from Kansas, South Carolina, and Wisconsin.

4.7 Task 7: Analysis of RCBC Performance and Costs

Action: Analyze and compare the long-term performance, life-cycle costs, and installation site conditions of precast and cast-in-place RCBC on South Dakota state and local roads. RCBC inspection reports, construction costs, maintenance costs, and plans should be used in the evaluation.

After the surveys were completed, the research team conducted a comprehensive analysis of Reinforced Concrete Box Culverts (RCBCs) in South Dakota. The research team utilized data from the Long-Term Bridge Performance (LTBP) database (Federal Highway Administration (FHWA), 2025) and the Bridge Management (BrM) database (American Association of State Highway and Transportation Officials (AASTHO) & South Dakota Department of Transportation (SDDOT), 2025). The South Dakota DOT provided data on 213 precast and 885 CIP RCBCs constructed within the state.

The combined dataset integrates comprehensive information from multiple sources. Construction year, location, skew angle, average daily traffic (ADT), and number of culverts were obtained from the LTBP database (Federal Highway Administration (FHWA), 2025). Details on culvert type (precast or CIP), length, fill height, and size were extracted from the BrM database (American Association of State Highway and Transportation Officials (AASTHO) & South Dakota Department of Transportation

(SDDOT), 2025). Finally, construction costs were estimated based on culvert volume in cubic feet (ft^3) using data from the SDOT Cost Reports from 2021-2025 (Table 4.10).

Table 4.10: Estimation of construction costs per culvert volume (ft^3)

Number of barrels	CIP	Precast
1	$37.41	$35.73
2	$35.07	$25.13
3	$36 .67	$20.89

Culverts were mapped across diverse regions and counties. To contextualize site conditions, regional environmental data , including average monthly rainfall, annual temperature fluctuations, and humidity (Weather Spark, 2025), were collected for major cities in each area.

Culvert condition was assessed using inspection-based ratings classified as Good, Fair, or Poor obtained from LTBP database (Federal Highway Administration (FHWA), 2025). These ratings served as reference for long-term performance and were analyzed in relation to different parameters. For instance, the study examined whether regions with higher rainfall, such as Sioux Falls (Mitchell region) and Aberdeen, experienced accelerated deterioration, particularly for CIP culverts, which may be more vulnerable to installation-related weather exposure.

The research also explored the impact of variables such as culvert dimensions, fill height, skew angle, traffic volume, and service life on structural performance. Statistical analyses were performed to identify factors influencing culvert condition over time. Data visualization techniques, including box plots, scatter plots, and distribution charts, were used to illustrate patterns, regional variability, and outliers. In addition to performance, construction costs were included in the comparative analysis across culvert size categories. This helped assess the cost-effectiveness of each construction method when focusing on durability.

Finally, to support decision-making for long-term performance, the team developed a predictive model to estimate future culvert condition ratings. A multiple regression approach was used, incorporating variables such as culvert type, service life, fill height, open area, length, unit cost, traffic volume, and skew angle. Model performance was validated by comparing predicted ratings against actual inspection outcomes, with residuals analyzed separately for precast and CIP structures to detect potential systematic biases.

4.8 Task 8: Criteria Development for RCBC Construction Type Selection

Action: Based on the information obtained in Tasks 2 through 7, develop criteria for the selection of a cast-in-place or precast RCBC construction type in South Dakota.

Based on performance data from existing culverts, stakeholder interviews, and survey feedback, the research team developed a set of criteria to guide the selection of RCBC construction type based on project-specific conditions. The criteria consider factors such as skew angle, hydraulic and soil conditions, availability of ready-mix concrete, transportation and installation limitations, traffic disruption, construction schedule constraints and formwork limitations. Additional considerations include bedding preparation, joint protection practices, hybrid construction approaches (precast barrel with CIP ends), and the use of multiple single-cell precast units.

4.9 Task 9: Submission and Presentation of Task 6 through 8 Results

Action: Submit and present to the technical panel a technical memorandum summarizing the results of Tasks 6 through 8.

Following the completion of Tasks 6 through 8, the research team compiled and presented to the technical panel a technical memorandum summarizing the results. This document summarized the synthesized findings, detailed analyses, and criteria development. It also provided data-driven criteria to optimize decision-making processes for the selection and implementation of RCBCs on South Dakota roads, considering multiple influencing factors.

4.10 Task 10: Recommendations for SDDOT Bridge Design Manual

Action: Prepare recommendations for the SDDOT Bridge Design Manual, utilizing the criteria developed in Task 8, to assist the SDDOT and local governments in selecting the optimum RCBC construction type.

Using the criteria developed in Task 8, the research team prepared practical and informed recommendations for the SDDOT Bridge Design Manual. These recommendations were developed to assist SDDOT in selecting the optimum RCBC construction type, restructuring decision-making processes, and ensuring efficient allocation of project resources.

4.11 Task 11: Final Research Report

Action: In conformance with the Guidelines for Performing Research for the SDDOT, prepare a final report summarizing the research methodology, findings, conclusions, and recommendations.

The research team prepared a comprehensive final report summarizing the research methodology, findings, conclusions, and recommendations. This report served as a detailed reference document, providing transparency on the research process and main findings.

4.12 Task 12: Executive Presentation to SDDOT Research Review Board

Action: Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

The research team concluded the project by delivering an executive presentation to the SDDOT Research Review Board. This presentation highlighted key aspects of the research, emphasizing methodology, significant findings, conclusions, and actionable recommendations, ensuring effective communication of the project's impact and outcomes.

5.0 FINDINGS AND CONCLUSIONS

This section presents a summary of the findings based on three key components: (i) stakeholder engagement through interviews and surveys; (ii) the analysis of RCBCs database at South Dakota; and (iii) the development of criteria and recommendations for decision-making at optimizing long-term performance of culverts. These findings will help the research team to the main research objectives, providing insights into RCBC selection challenges, performance considerations, and recommendations for improving the SDDOT Bridge Design Manual (South Dakota Department of Transportation (SDDOT), 2021).

5.1 Stakeholder Engagement

5.1.1 Preliminary Interviews

This section presents the key insights for each stakeholder group and synthesizes the principal findings from the preliminary interview phase.

5.1.1.1 SDDOT Personnel

SDDOT personnel highlighted regional differences regarding the use of CIP and precast RCBCs. When recommending RCBC types during Type, Size, and Location (TS&L) site inspections, responses varied across regions. One region consistently preferred CIP, citing concerns with precast durability, the greater number of joints, and uncertainty about long-term joint sealing and fabric placement during backfilling. Another region routinely recommended precast, especially in remote areas where delivering quality concrete for CIP is challenging and shortages of skilled labor can compromise CIP construction quality. A third region noted that TS&L inspections typically do not include formal recommendations, while the fourth based its recommendations on project-specific considerations such as skew, channel alignment, and the impacts of road closures.

Regarding advantages and disadvantages, CIP RCBCs were preferred for their demonstrated durability, long-term performance, fewer joints, and design flexibility. The main drawbacks included longer construction times, dependency on skilled labor, and weather-related issues during construction. Precast RCBCs, while newer in SDDOT practice, are faster, simpler, and provide consistent quality through plant fabrication. Precast is particularly advantageous in remote locations and where labor availability or construction timeline constraints exist.

Experience with complex precast designs, such as skewed boxes or flared/tapered inlets, was limited. Most regions were unaware of precast RCBCs with skew angles over 10 degrees. However, a few projects demonstrated successful implementations, such as multiple 14’×14’ precast boxes with skewed configurations (in the Pierre region) and CIP-flared wing walls (in the Rapid City region), which are performing well.

CIP construction challenges included honeycombing, insufficient cover, form blowout, cracking in large sections, unskilled workmanship, and maintaining a dry construction site during flooding or extended timelines. Precast challenges included poor joint fit, cracking, chipped ends during delivery, and improperly prepared bedding. Mitigation strategies for precast included match casting or pre-fitting joints and reducing section sizes.

SDDOT monitors long-term RCBC performance primarily through inspections following National Bridge Inventory (NBI) standards, with inspection intervals ranging from 2 to 5 years depending on structure condition. CIP culverts are generally considered longer-lasting due to fewer joints and well-understood construction practices. Precast culverts are still relatively new, with design detailing and construction practices evolving.

Over time, CIP issues primarily occur during construction, with occasional cracking, efflorescence, settlement, and scour. Precast culverts often experience joint leakage and, in some cases, joint failure. Scour occurs in both CIP and precast RCBCs, typically at aprons, inlets, outlets, or behind wing walls, and is mitigated with riprap or other similar protection. Both culvert types require similar maintenance, including addressing cracking, spalling, and debris accumulation; however, joints are a more significant concern for precast boxes.

SDDOT personnel emphasized the incorporation of feedback from ongoing projects into design improvements. Examples include adjusting minimum section heights, including inlet/outlet aprons, and improving precast detailing. Availability of precast units is generally not problematic for standard sizes, but larger or customized sections can face production or lead-time delays.

5.1.1.2 Iowa and Minnesota DOT

Iowa DOT and MnDOT both make extensive use of precast RCBCs, though their approaches and observations are different. Iowa DOT employs alternate bidding, allowing contractors to choose between CIP and precast based on project conditions and costs. As a result, the use of CIP and precast is relatively balanced. In contrast, MnDOT predominantly uses precast box culverts, with most installations constructed using precast units due to schedule efficiency, controlled quality, and reduced cost. CIP is rarely used. When watertightness is required, MnDOT specifies the use of external joint wraps rather than switching to CIP construction.

In both states, CIP RCBCs show consistent long-term performance, with aging issues that are generally predictable. Precast RCBCs also perform well structurally but exhibit greater variability, most of it linked to installation quality. The most common installation-related issues are joint leakage, inconsistent joint gaps, edge spalling, and occasional damage during transport or handling. Outlet scour was identified by both agencies as a recurring concern for both CIP and precast installations.

Construction practices play a significant role in performance outcomes. For precast systems, both states highlighted contractor-to-contractor differences in joint assembly, bedding preparation, dewatering, and geotextile placement. For CIP culverts, the primary issues involve formwork quality, concrete consolidation, and curing, though these tend to be less frequent once work is initiated.

Design and dimensional requirements introduce further differences. Iowa DOT's Bridge Design Manual Chapters 4 and 7 provide general guidelines and restrictions for both types of culverts (Iowa Department of Transportation, 2024b), being more restrictive for precast RCBC. CIP box culverts are generally excluded from consideration only when construction speed is a critical factor. Iowa DOT has made their design details for precast culverts (Iowa Department of Transportation, 2024d), culverts in general (Iowa Department of Transportation, 2024c), and pedestrian tunnels (Iowa Department of Transportation, 2024e) publicly available on their website. Additionally, their approach includes structural analysis using ET Culvert software (Iowa Department of Transportation, 2024a) and meets

ASTM standards for concrete and reinforcement materials. Table 5.1 provides a summary of the design requirements for precast RCBCs in Iowa.

Table 5.1: Design requirements for precast RCBCs in Iowa

Category	Precast RCBC
Fill Heights	• Fill heights 2-25 feet for spans ≤12 feet. • Fill heights 2-16 feet for spans of 14–16 feet. • Custom designs can accommodate greater spans or fill heights with special approval.
Length	75 to 250 feet
Wall Thickness	Minimum 8 inches
Skew Angles	0 to 45 degrees
Concrete	Minimum of 5 ksi
Joint Design and Sealing	Joints must include butyl rope gaskets and tie rods for proper alignment and sealing
Hydrologic Design	Designed for free surface flow; Includes flow rates, water velocity, debris impact
Allowing Dual Cells?	Iowa DOT does not permit the use of monolithic dual-cell precast boxes on the state system. Instead, side-by-side single-cell boxes are approved for use. However, Iowa cities and counties may allow monolithic dual-cell precast boxes on local systems. These structures are typically custom-designed, as no standard specifications currently exist.
Settlement Criteria	Anticipated culvert settlement shall less than 12 inches for a single line of single cell boxes and less than 6 inches for side-by-side single cell boxes. We have made some limited exceptions in the past
Bedding Limitations	Precast culverts are not allowed to be placed directly on bedrock
Inspection Policies	All culverts large enough to qualify as a bridge undergo biennial inspections to monitor their condition and address maintenance needs.

MnDOT guidelines (Minnesota Department of Transportation, 2024) are based on AASHTO standards. They are currently updating them to 2024 AASHTO standards. Table 5.2 shows an overview of the different design requirements for precast and CIP RCBCs in Minnesota.

Table 5.2: Design requirements for precast RCBCs in Minnesota

Category	Precast RCBC
Span	6 to 16 feet
Rise	4 to 14 feet
Length Sections	6 feet (larger boxes 4 feet)
Wall Thickness	Minimum 8 inches
Fill Heights	2-25 feet
Skew Angles	0 to 45 degrees
Concrete	5-6 ksi
Joint Design and Sealing	Geotextiles are wrapped around the exterior of tongue-and-groove joints to prevent soil intrusion, while mastic is applied within the joint itself. Sometimes using a membrane to cover joints before backfilling and ensuring consistent compaction of surrounding soils

Category	Precast RCBC
Hydrologic Design	Designed empty and full of water
Allowing Dual Cells?	Side-by-side single-cell boxes are approved for use
Settlement Criteria	Check that settlements are not excessive based on AASHTO
Compaction	Compact the first 1.5’ (loose) of fill above the box with light compaction equipment such as plate compactors or walk behind rollers
Inspection Policies	Inspections are conducted based on the National Bridge Inspection Standards, with intervals varying depending on the structure's condition. Structures in good condition may be inspected every five years, while those in lesser condition are inspected more frequently.

Table 5.1 and Table 5.2 highlight several key differences between Iowa and Minnesota. Iowa imposes more restrictive limits on fill heights, allowable settlement, and the use of multi-cell precast boxes. MnDOT permits a wider range of precast spans, though projects remain constrained by transport limits and joint detailing requirements. Both states allow large skew angles. While CIP construction may offer greater flexibility for complex or nonstandard geometries, standard precast details are available for skew angles up to 45 degrees, and these are commonly used in Minnesota. Cost considerations also influence decision-making. Iowa’s alternate bidding system typically results in whichever option (CIP or precast) results in the lower overall project cost. MnDOT generally defaults to precast, using CIP only when joint leakage, geometric constraints, or transportation limits make precast less practical. Inspection practices are similar in both states. Routine inspections are used to evaluate long-term performance, and findings are incorporated into periodic design updates. Iowa is currently placing particular emphasis on monitoring precast installations to address remaining gaps in long-term performance data.

5.1.1.3 Engineer Consultants

Engineer consultants revealed that the selection between CIP and precast RCBCs is driven primarily by project-specific considerations. Engineers consistently emphasized that there is not always a preference for one type over the other; instead, the decision depends on construction speed, site conditions, skew angle, logistics, and owner expectations. Precast RCBCs are commonly used when rapid installation is essential, such as in projects where traffic disruption must be minimized or in Construction Manager/General Contractor (CM/GC) delivery methods. Precast culverts are typically preferred when skews are below 10 degrees, in dry-weather construction windows or sites located more than approximately 45 minutes from a ready-mix plant. However, projects requiring more than two barrels or box sizes larger than about 7x7 feet often lean toward CIP RCBCs. Although aesthetics sometimes influence decisions, client preference and previous project experience tend to play a more significant role.

Engineers identified clear advantages and disadvantages for each construction type. Precast culverts offer consistent quality due to controlled manufacturing and allow for much faster installation, but they are constrained by the need to fit within standard dimensions, generally from 4×4 feet up to about 12×12 feet, and by transportation limitations. Differential settlement was noted as a recurring issue in precast installations; in some railroad applications, the joints between precast elements are sometimes tied with 1–1.5-inch bars to keep the segments aligned and prevent differential movement between them. In contrast, CIP culverts, although slower to build and more dependent on labor skill, allow for fully customizable geometries, making them preferable for curved or skewed culverts and for sites requiring more structural adaptability.

Skew angles were one of the most consistent differentiating factors. Precast RCBCs are rarely recommended beyond a 10-degree skew, with 20 degrees used only in special, time-sensitive situations. Custom features, such as flared wingwalls, are possible but they quickly increase cost and complexity. They mentioned that some states, like Kansas, have used hybrid configurations (e.g., precast middle sections with CIP ends) to accommodate higher skews.

Site conditions are also a significant determinant. Poor foundation soils, high anticipated settlements, and challenging hydraulic conditions tend to favor CIP construction because of its ability to tolerate movement and adapt to non-standard geometries. Cost considerations generated mixed responses. Precast is often more cost-effective for small projects due to reduced labor needs and faster installation, while CIP tends to be less expensive for larger boxes or projects with significant skews. Transportation distance and the proximity of precast or ready-mix plants were frequently cited as cost drivers. In some cases, engineers reported that CIP had been consistently cheaper in their past experience. Some interviewees also discussed using multiple single-cell precast boxes instead of a multi-cell option, filling the gaps with controlled low-strength flowable fill; this can reduce costs and improve constructability, but the approach is discouraged in poor soil conditions due to differential settlement concerns.

Regarding performance, engineers identified foundation preparation as the single most important factor for long-term behavior in both precast and CIP systems. For precast culverts, the most common long-term problems included joint openings, typically caused by differential settlement, and spalling resulting from joint rotation. These issues can be mitigated with proper bedding, careful joint detailing, and improved connection designs; expansive soils were not reported as a significant concern in South Dakota. CIP structures generally show fewer long-term issues aside from construction-related problems, with occasional cracking caused by inadequate compaction or variations in subgrade water content.

Engineers also commented on challenges and improvements needed during installation. Precast units may present alignment difficulties and require careful consideration of equipment size, with excavators or cranes selected based on whether the segments exceed roughly 7x7 feet. Bedding selection and contractor training were highlighted as essential for avoiding settlement and joint problems. CIP installations face construction challenges such as formwork failures (occasionally in the top slab), insufficient reinforcement cover, unskilled labor, cold-weather concrete placement, and over-vibration in tall culverts. These issues can be addressed through stricter inspections, better quality control, and contractor prequalification.

Finally, when asked about decision-making frameworks and potential improvements to the SDDOT Bridge Design Manual, interviewees reported that most decisions are made case-by-case rather than through formalized tools. They recommended that the manual includes more explicit guidance on when to consider CIP, precast, or hybrid options, particularly with respect to soil settlement, skew angle limitations, construction speed, and site constraints. Several also suggest incorporating input from precasters and providing criteria related to traffic, anticipated settlement, and the possible use of bell joints to reduce differential movement.

5.1.1.4 Precast Suppliers

Precast suppliers consistently highlighted that the primary challenges associated with transporting large precast components relate to size, weight, and logistics. Most RCBC units can be hauled as long as one dimension remains under 16 feet, with typical weight limits near 65,000 lb., although loads around 48,000 lb. per box are preferred for cost-effective trucking. Oversized units often require special permits. Installation challenges largely depend on having appropriate or well-maintained equipment, as well as improper handling during placement, such as failing to lift and align cells correctly or pushing material into joints.

Regarding geometric constraints, all suppliers reported the ability to manufacture single-cell RCBCs with skews up to 45 degrees. This capability also applies when using multiple independent single-cell barrels placed in parallel. However, double- or triple-cell (multi-cell) box culverts cannot typically achieve such skews of this magnitude. Most suppliers pre-fit sections in the plant and recommended that SDDOT require this practice for all RCBC fabrication. Flared wing walls are generally avoided due to added cost and limited hydraulic benefit, though some states (e.g., North Dakota, Montana) commonly use mechanical connections or closure pours to construct them successfully.

The most consistent message across all interviews was the critical importance of proper bedding. Suppliers noted that RCBCs perform only as well as the bedding beneath them. A uniformly hard, level sub-base topped with a 1.5–2 inches soft, uncompacted sand layer (meeting ASTM 1675-19) was considered essential. This sand layer should be screeded using a board and must remain untouched prior to placement.

Quality assurance procedures in precast plants were described as difficult to replicate in the field. Certified inspections, detailed checks of steel placement, fit-up testing, and high material standards contribute to consistent plant quality. Pre-fitting sections, strength testing, and regular audits by industry associations provide additional reliability. Suppliers emphasized that joint integrity has improved significantly with bolting, fabric wrapping, mastic application, and in some cases full-length waterproof membranes.

Several interview questions focused on how precast RCBCs could be designed and delivered more efficiently. Across suppliers, there was strong support for adopting standardized base sheets or plates for SDDOT. Standardization would dramatically reduce design time, accelerate approvals, allow steel orders to be placed immediately upon project award, and permit producers to maintain inventory. States such as Iowa and Minnesota already benefit from this approach. Standardization would also streamline bid processes by reducing uncertainty, leveling the playing field between precast and cast-in-place options, and removing the need for a structural engineer to design each unique RCBC.

Suppliers also emphasized that cast-in-place structures currently have certain competitive advantages in SDDOT projects. Because cast-in-place plans are fully developed by the state, precasters must design and obtain approval for their own structures, a process that can take up to 12 weeks when accounting for design development, state approval, and steel procurement. Additionally, precast prices are publicly shared during bidding, enabling cast-in-place contractors to strategically underbid. Improvements to the supply chain, including standardized designs and earlier material procurement, would greatly reduce lead times and enhance precast competitiveness.

Finally, suppliers noted increasing demand for precast RCBCs driven by their construction speed and suitability for remote locations. While demand in South Dakota remains steady, other states such as Iowa have seen significant growth.

5.1.1.5 Highway Superintendents

Highway superintendents provided insights into the factors that influence the selection, installation, and maintenance of RCBCs in county-level projects. The decision between CIP and precast RCBCs is largely driven by site conditions, structure geometry, and long-term performance expectations. About half of the superintendents favored CIP, while the other half preferred precast.

When comparing advantages and disadvantages, precast RCBCs are valued for their rapid and simple installation, suitability for most weather conditions, and adaptability for future relocation or expansion. Precast units are often initially less expensive than CIP, but they require large cranes and more joints, hardware, and careful attention to site conditions. Their long-term performance remains less documented, which may limit confidence in some situations. Conversely, CIP RCBCs are highly durable, flexible in geometry, and well understood from decades of performance. The drawbacks of CIP include longer construction times, weather limitations, labor intensity, and the need for skilled crews, particularly in remote locations.

Site-specific conditions, including skew angles, hydraulic demands, and soil conditions, strongly influence the choice of RCBC type. Larger installations, high-flow channels, and projects with more than two barrels generally favor CIP due to its adaptability and ability to accommodate complex hydraulics. Precast RCBCs are preferred for smaller, simpler installations, low hydraulic demands, and less disruptive sites, such as gravel roads. Regarding inventory, most counties reported that CIP RCBCs outnumber precast units with ratios as high as 10:1. None of the counties had culverts with a skew exceeding 10 degrees, and hybrid designs combining precast and CIP elements were not reported.

When balancing cost against long-term performance, superintendents often select CIP for durability despite higher initial costs, whereas precast is chosen when time savings and budget constraints are critical. Improvements in precast construction, such as tied joints wrapped with fabric and sealed with mastic, have increased their acceptance. Both CIP and precast RCBCs can last decades when installed properly. While CIP is generally considered more durable due to its long track record, some precast installations have demonstrated longevity up to 90 years.

Common maintenance concerns differ by RCBC type. Precast boxes historically experienced joint separation, and soil or salt infiltration through joints, particularly in older installations without tied and sealed joints. Solutions include internal joint repairs, top-access sealing, use of galvanized or stainless steel, dual-layer joint sealants, and riprap to prevent scour. CIP RCBCs generally encounter fewer long-term issues, with most concerns occurring during construction. Debris accumulation at inlets, outlets, and around center columns remains a concern for larger culverts in both types.

Scour and undermining occur in both precast and CIP RCBCs, with location being more critical than construction type. Preventive measures include fabric liners, riprap, and cut-off walls beneath the culvert to minimize scour. Overall, CIP structures require less maintenance due to fewer joints, though debris management is the most common task for both types.

Availability of precast RCBCs was not reported as a major issue, provided proper planning and strong supplier relationships are maintained. However, some interviewees noted occasional delays extending up to eight months in specific cases.

5.1.1.6 Contractors

Unlike owners or engineers, contractors are typically not given a choice between CIP and precast; however, when they are, factors such as site location, project risk, budget, timeline, material availability, and weather heavily influence the decision. In eastern South Dakota, where precipitation is higher (Figures 5.26 and 5.27), precast RCBCs offer a clear advantage by reducing the need for dewatering and mitigating weather-related delays. In remote western areas, sourcing high-quality concrete for CIP projects is more challenging, further favoring precast construction. Cost considerations also generally favor precast, which is often cheaper than CIP, while CIP remains the choice for projects requiring greater flexibility, complex site conditions, or longer spans.

Contractors highlighted the main advantages and disadvantages of both types of RCBCs. CIP culverts provide design flexibility, uniformity, and fewer joints, which can reduce long-term issues like joint deterioration or movement. Their main drawbacks include extended construction timelines, weather dependence, and high labor requirements, up to 25 workers compared to 4–5 for precast installations. Precast RCBCs are faster, easier, less expensive, and less dependent on weather conditions. Additionally, quality control at the plant ensures more consistent construction compared to field-placed concrete. However, precast installation requires precise bedding preparation, and large multi-cell structures demand cranes and site conditions capable of handling their size. Single-cell precast units, in contrast, are easier to transport and install and can be arranged in multiple lines to distribute weight and mitigate differential settlement.

Regarding durability, most contractors observed no significant difference between the long-term performance of CIP and precast RCBCs. One contractor considered CIP more durable due to uniform construction and ease of repair. Precast installations have encountered challenges with bedding stability, particularly when using base course material in wet conditions. Contractors have found that using 1–3 feet of crushed quarry material, such as limestone or quartzite, provides a stable, drained bedding surface that mitigates flotation or misalignment. Proper bedding, along with ensuring adequate crane capacity and site preparation, were identified as critical to successful precast installation.

Contractors reported limited experience with precast RCBCs featuring skew angles greater than 10 degrees or flared wing walls. However, a few notable projects demonstrated successful implementation. For example, the Jackson County / PCN 05V5 project on SD Highway 248 used three lines of 12×12 feet single-cell precast barrels with flared precast wing walls connected via closure pours, eliminating the need for large cranes. A similar large precast structure near the Bison Golf Course featured flared wing walls attached with welded plates, and an early precast RCBC on SD

Highway 45 (built in 1980) remains functional, illustrating the durability of well-executed precast installations.

Recent technological advancements have improved precast RCBC installations, including the use of smaller, high-capacity cranes, job-site cameras, GPS planning, drones for inspections, self-consolidating concrete, and improved joint sealing techniques. These innovations have enhanced installation speed, precision, and long-term performance. Quality control during precast installation includes verifying component specifications, tie bolt placements, bedding preparation, joint tolerances, and proper backfilling. Federal projects often involve stricter standards and on-site inspectors to ensure compliance. Contractors emphasized that planning and coordination with suppliers are crucial to avoid delays, particularly for customized precast sections.

5.1.2 Survey and Interview Results

This section presents the findings from both nationwide RCBC surveys, but it also includes information gathered through interviews with Iowa DOT, MnDOT, and precast suppliers. Combining both sources allows for a more complete understanding of current practices and challenges.

5.1.2.1 State DOT Survey and Interviews

States like Idaho, Michigan, Minnesota, North Dakota, and Wyoming have largely adopted precast RCBCs as their default choice (Figure 5.1). However, CIP RCBCs remain important in complex site conditions, non-uniform foundations, multiple bends, large spans, or MSE wall configurations, where flexibility is crucial. Selection often depends on engineering judgment, project specifics, and in some cases, formal approval processes. Only about half of the states have formal standards or manuals guiding the choice between precast and CIP, while others rely on experience and site-specific decision-making.

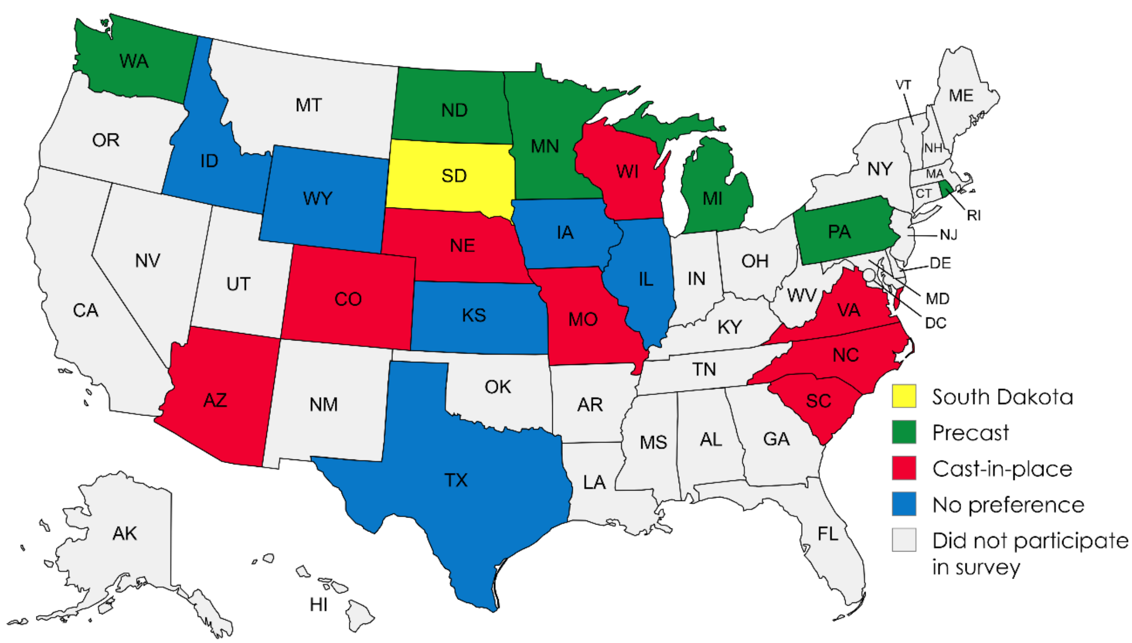

Figure 5.1: Map showing the preferred culver type per state.

Overall, DOTs report that current practices function adequately, though there are some problems that could be solved (Figure 5.2). Precast units sometimes face capacity issues during peak demand, challenges with high skew angles, and construction quality concerns such as improperly set inverts or joint failures. Several states are working to expand precast use, formalize guidelines, or update software tools for culvert design. When both options are offered in bidding, precast is generally awarded due to faster construction and lower traffic disruption (Figure 5.3 and Figure 5.4), though some states maintain a more balanced selection or leave the choice to contractors (Figure 5.5).

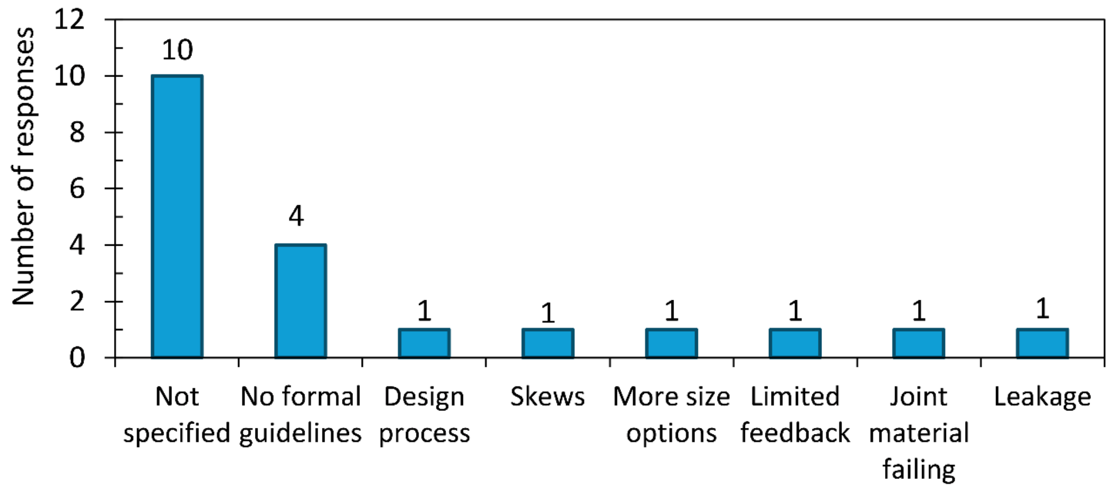

Figure 5.2: Limitations and problems

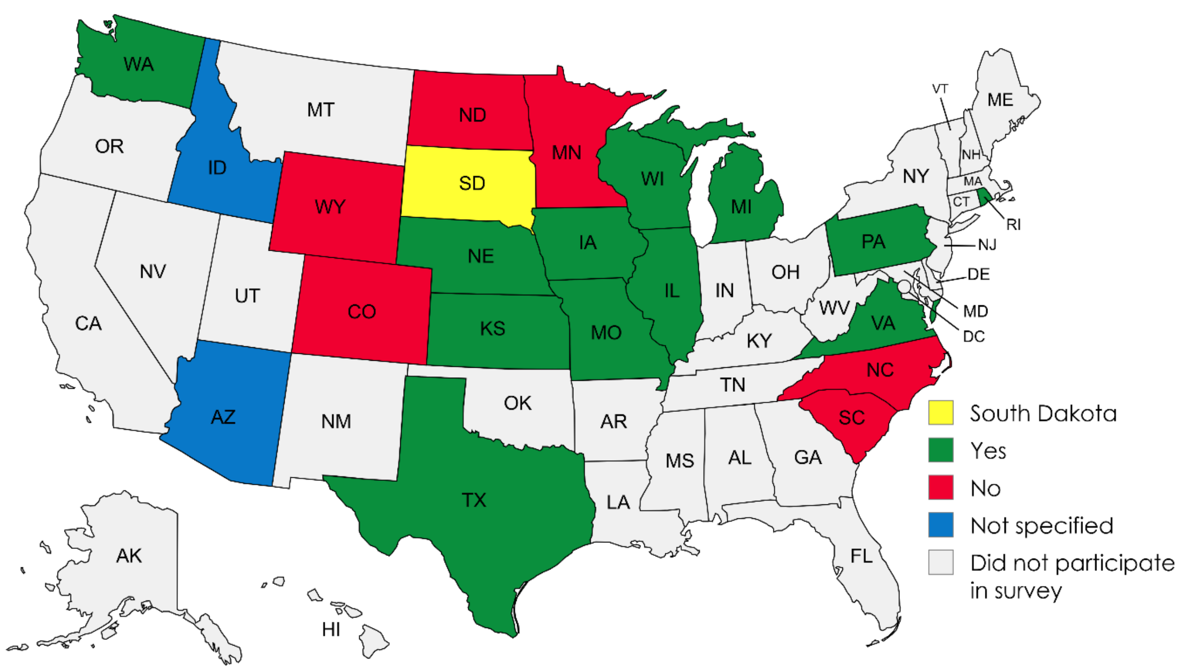

Figure 5.3: Map indicating which state DOTs offer both precast and CIP RCBC options during bidding and design.

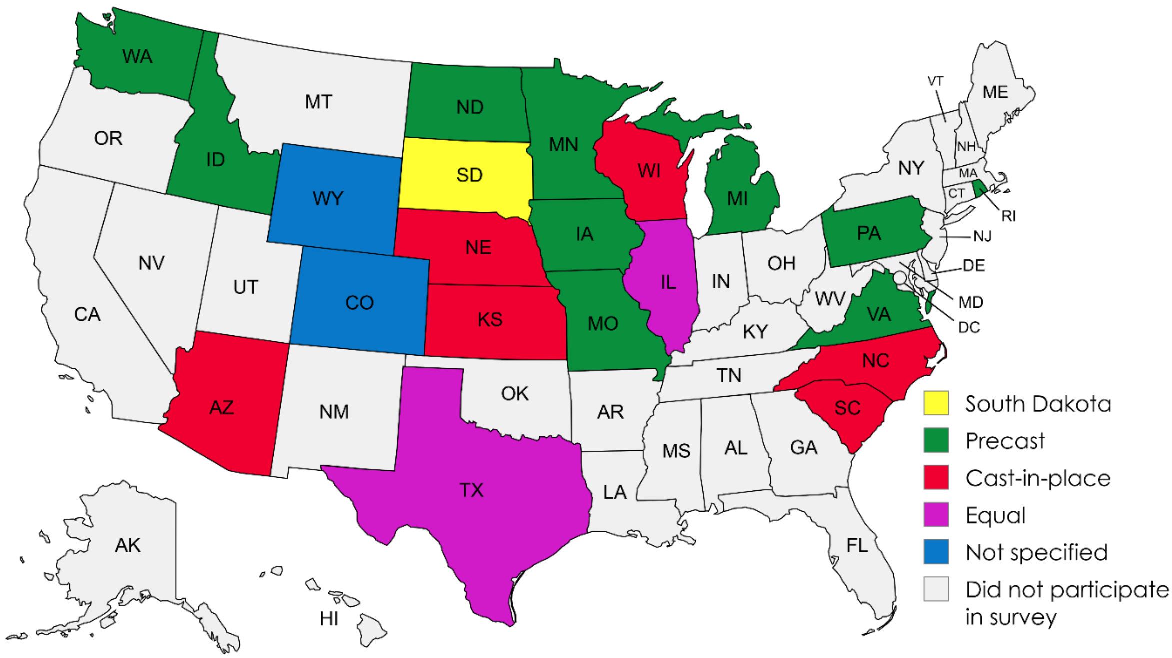

Figure 5.4: Map showing what type of culvert typically awarded in each state DOT.

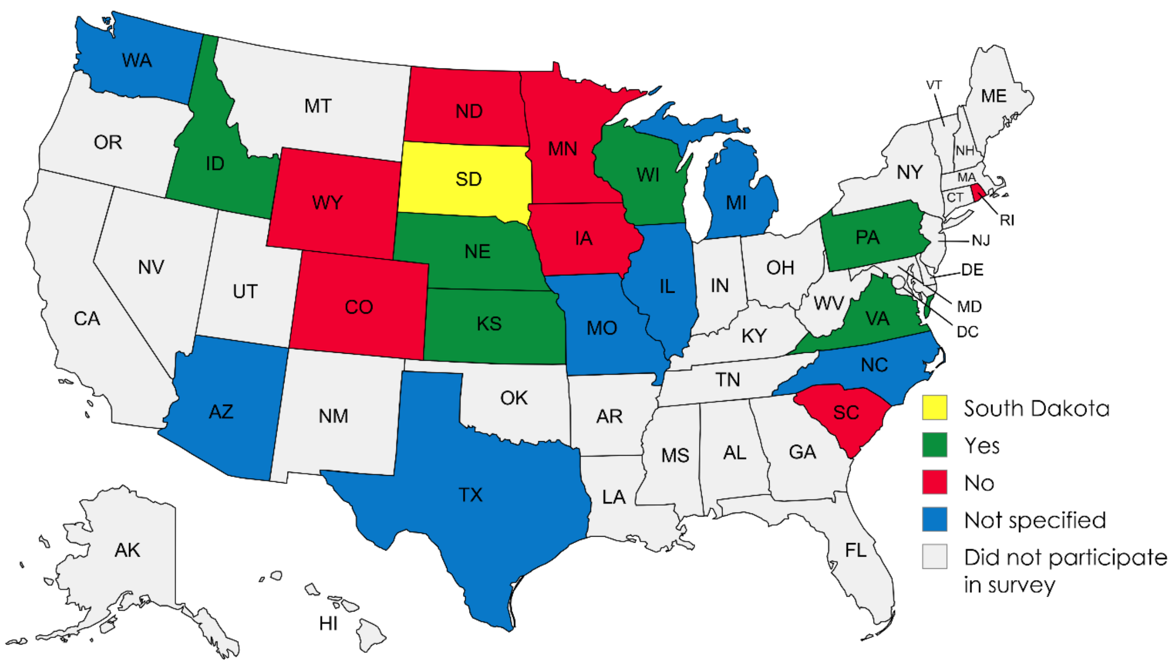

Figure 5.5: Map indicating which state DOTs allow contractor's preference.

Regarding design resources, many states employ standard plates, design tables, or in-house software for both precast and CIP RCBCs (Figure 5.6), often based on ASTM standards, engineering judgment, or previous experience. Some states, however, leave design largely to contractors or fabricators.

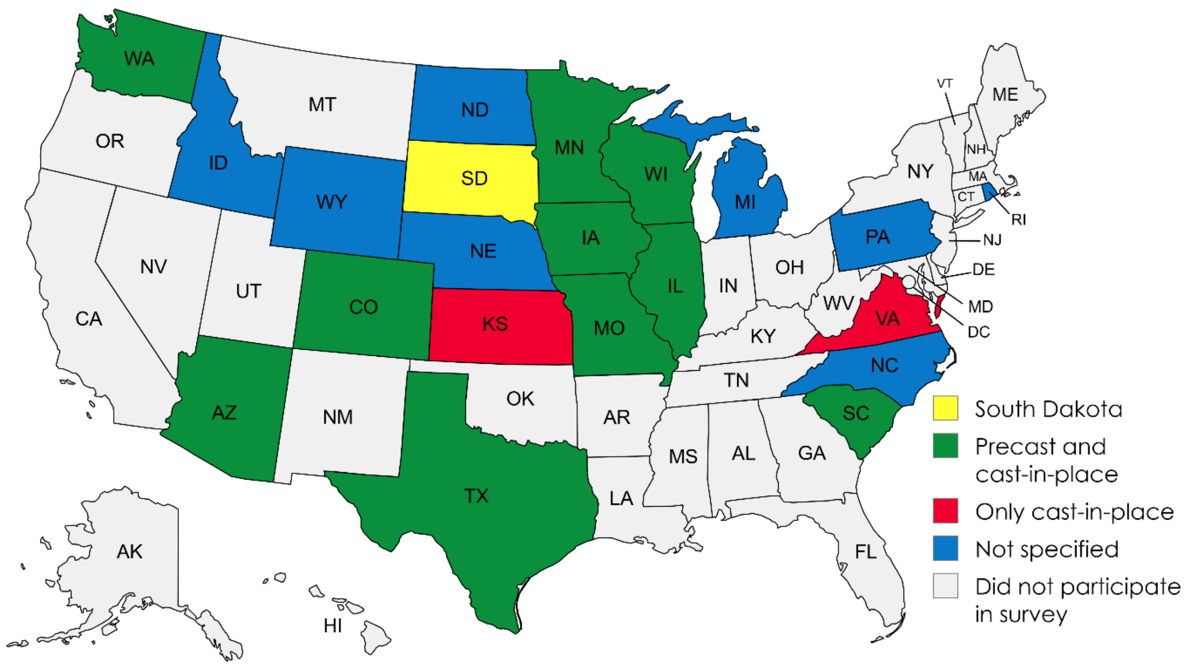

Figure 5.6: Map showing the use of standard culvert plans and practices adopted by each state DOT.

Limitations on precast RCBC use vary by state and include skew, wingwalls, span/rise, depth of fill, and hydraulic conditions. Moderate to high skew angles are often permissible (Figure 5.7), though additional costs or fabrication challenges may happen. Precast flared wingwalls are less common but used successfully in certain states (Figure 5.8). Span/rise and fill height limitations generally reflect fabricator capabilities or ASTM guidance (Figure 5.9, Figure 5.10 and Figure 5.11). Hydraulic considerations, such as high-flow or scour-prone areas, sometimes favor CIP structures, though many states allow designers to choose. Other factors, such as settlement, debris accumulation, or segment size, could also influence design decisions.

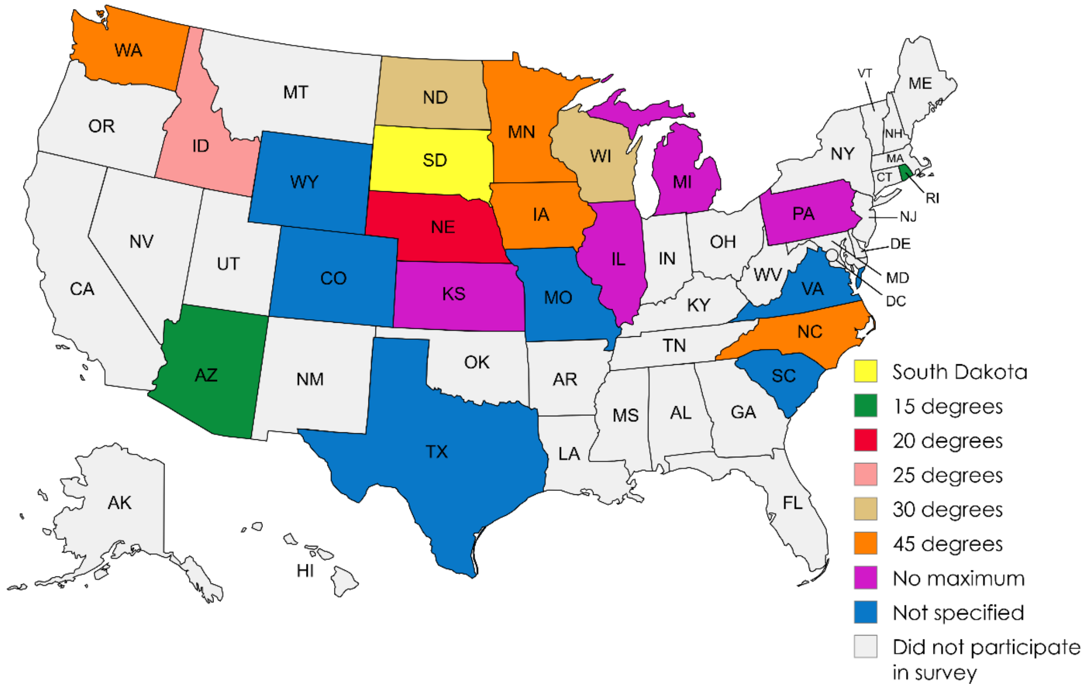

Figure 5.7: Map indicating the maximum skew angle in each state.

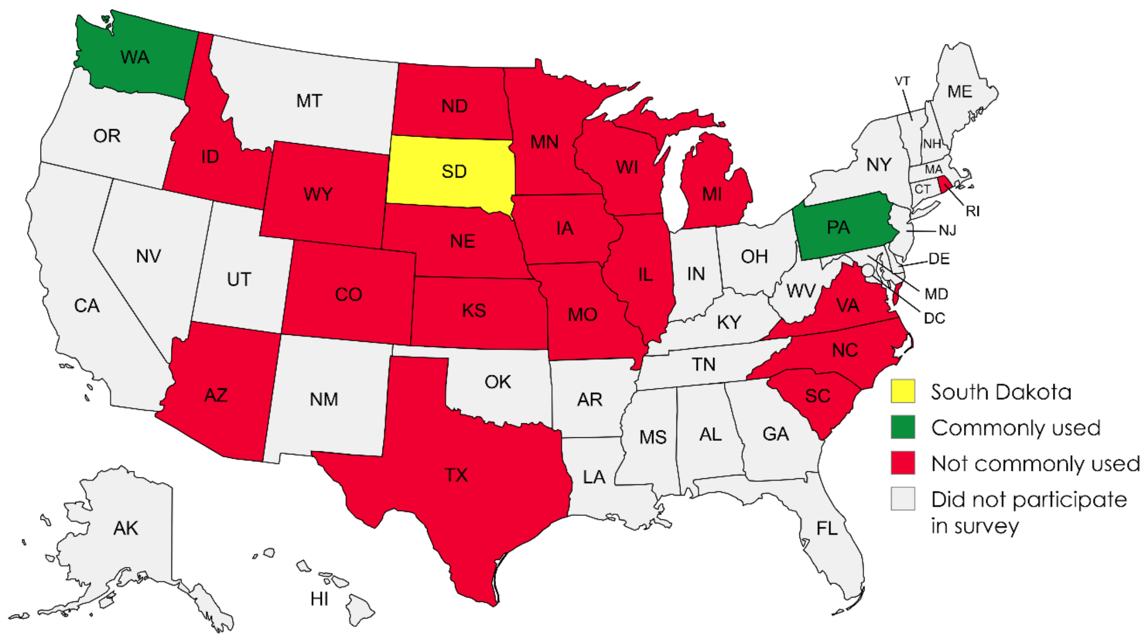

Figure 5.8: Map showing which state DOTs commonly use precast flared wingwalls.

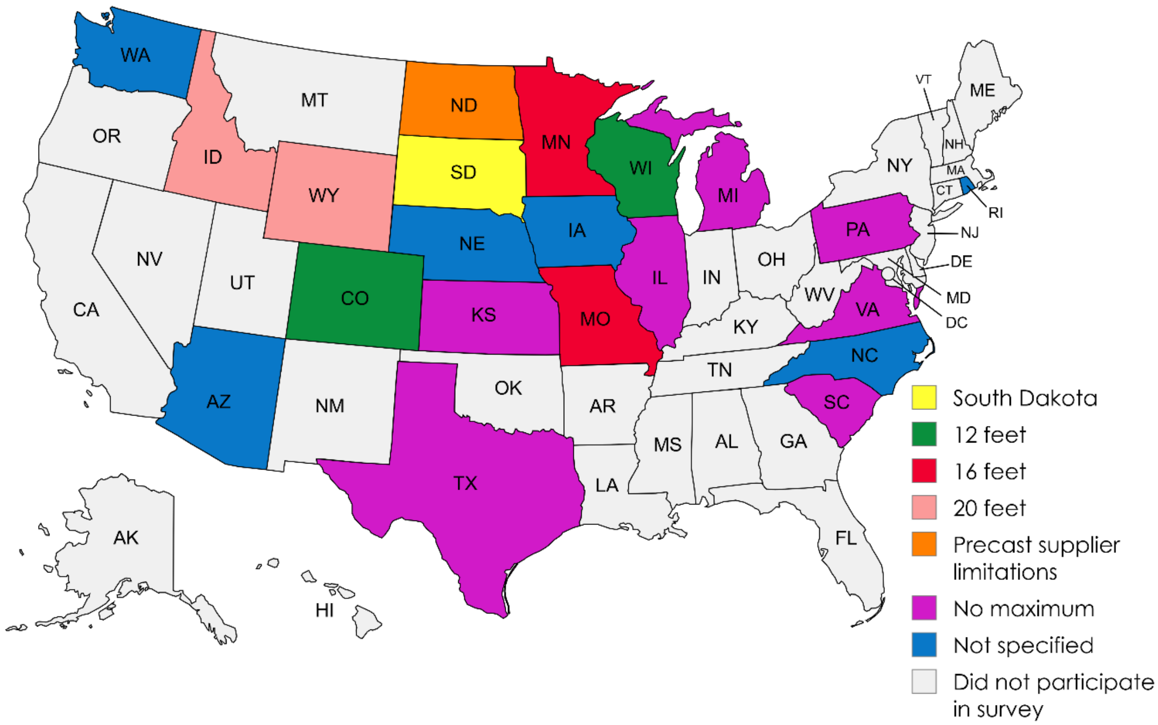

Figure 5.9: Map indicating span/rise limitations for each state DOT.

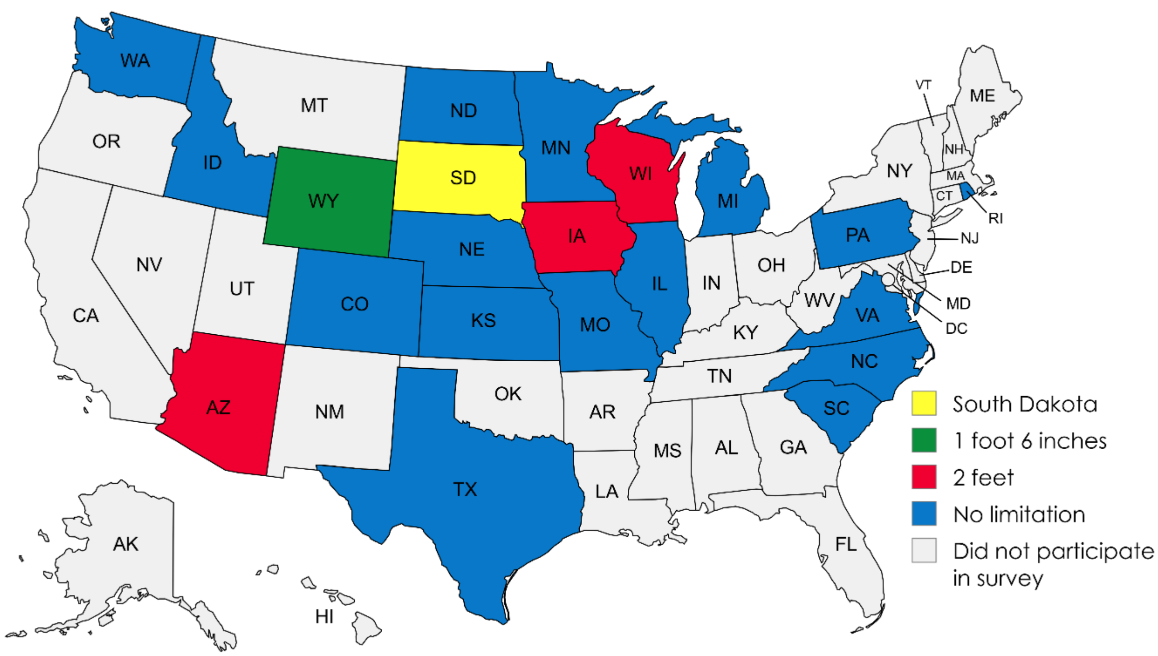

Figure 5.10: Map showing the minimum fill height limit for each state DOT.

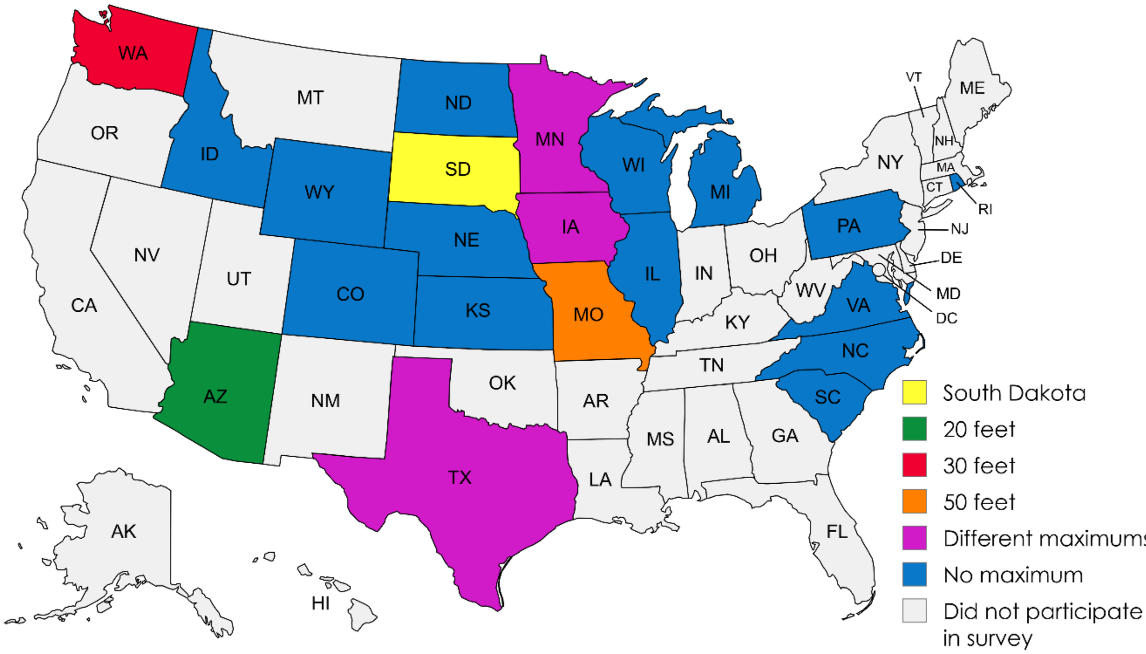

Figure 5.11: Map indicating the maximum fill height limit for each state DOT.

Joint integrity is a critical consideration for precast RCBCs. States employ various sealing methods, including neoprene gaskets, mastic (ASTM C990), ship lap joints, rubber gaskets, and geotextile wraps (Figure 5.12). Common issues include misalignment, construction damage, and early-life settlement, but proper construction and maintenance typically mitigate failures. Bedding specifications are widely recognized as crucial to prevent settlement, with granular layers, aggregate base courses, or compacted layers commonly used, often paired with geotextile fabrics and site inspections (Figure 5.13).

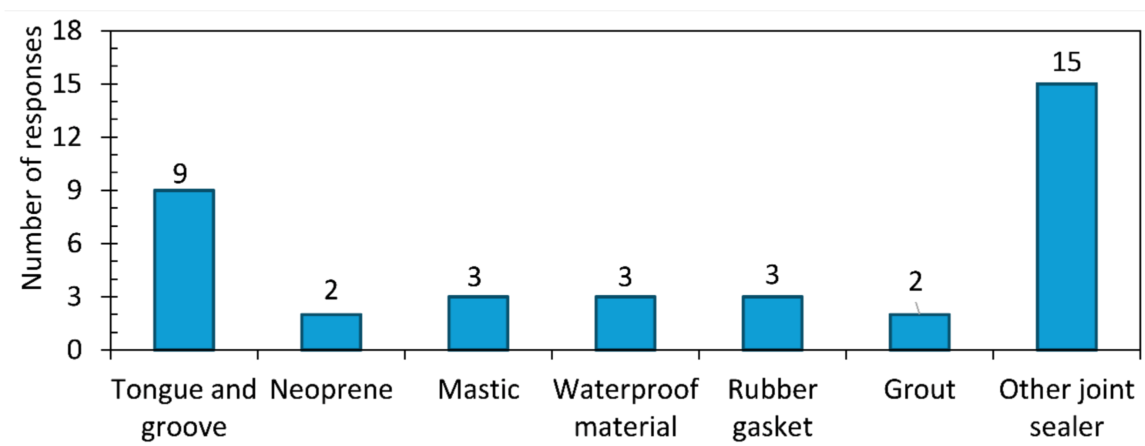

Figure 5.12: Materials or designs used to ensure sealed joints.

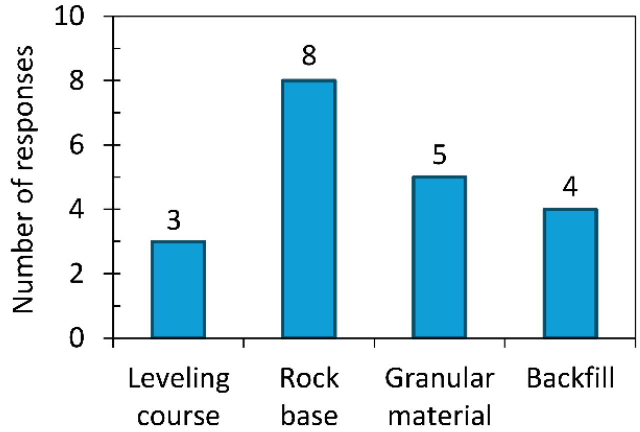

Figure 5.13: Bedding materials used in different state DOTs. Note: Iowa and Minnesota were not included in the figure since this question was not discussed in the interview.

The use of multiple-barrel versus single-barrel precast RCBCs varies. Some states use single large boxes to reduce debris accumulation and maintenance, while others allow multiple single cells for easier handling, shipping, and installation (Figure 5.14). Hybrid approaches, combining precast barrels with CIP wingwalls, are common in several states, providing flexibility for skewed culverts or complex site conditions (Figure 5.15). Challenges include coordination between precast and CIP components and long-term durability concerns.

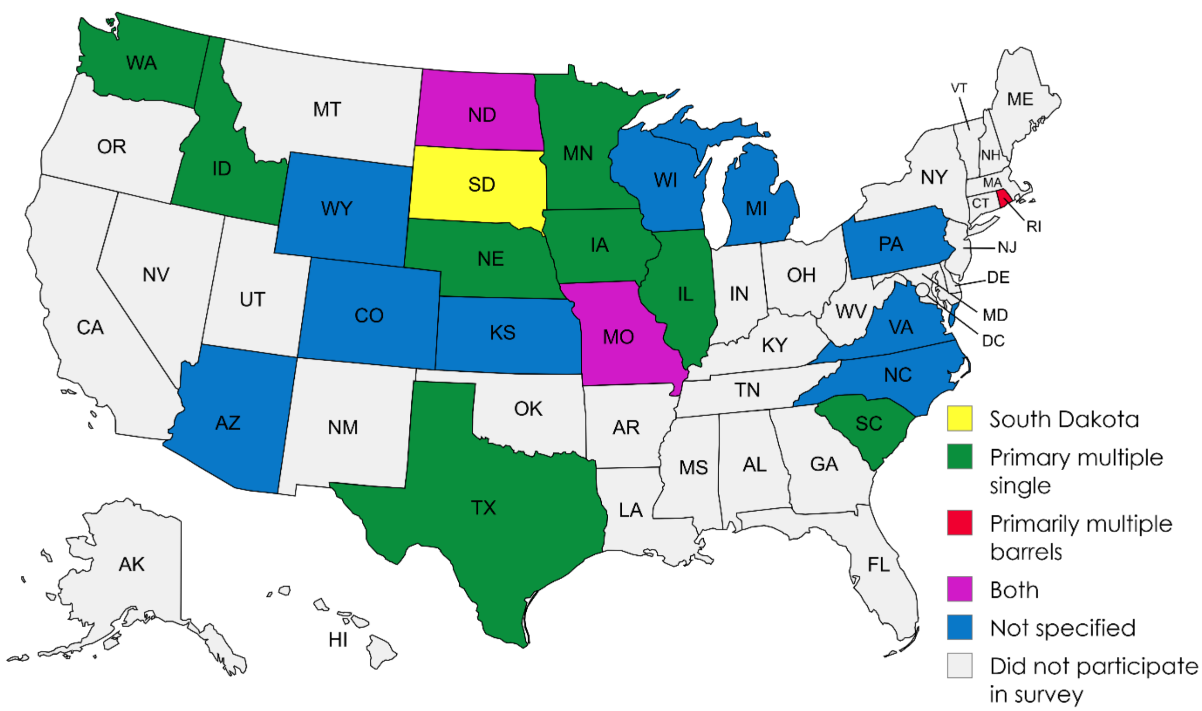

Figure 5.14: Map showing state DOT uses for multi-box culvert configurations.

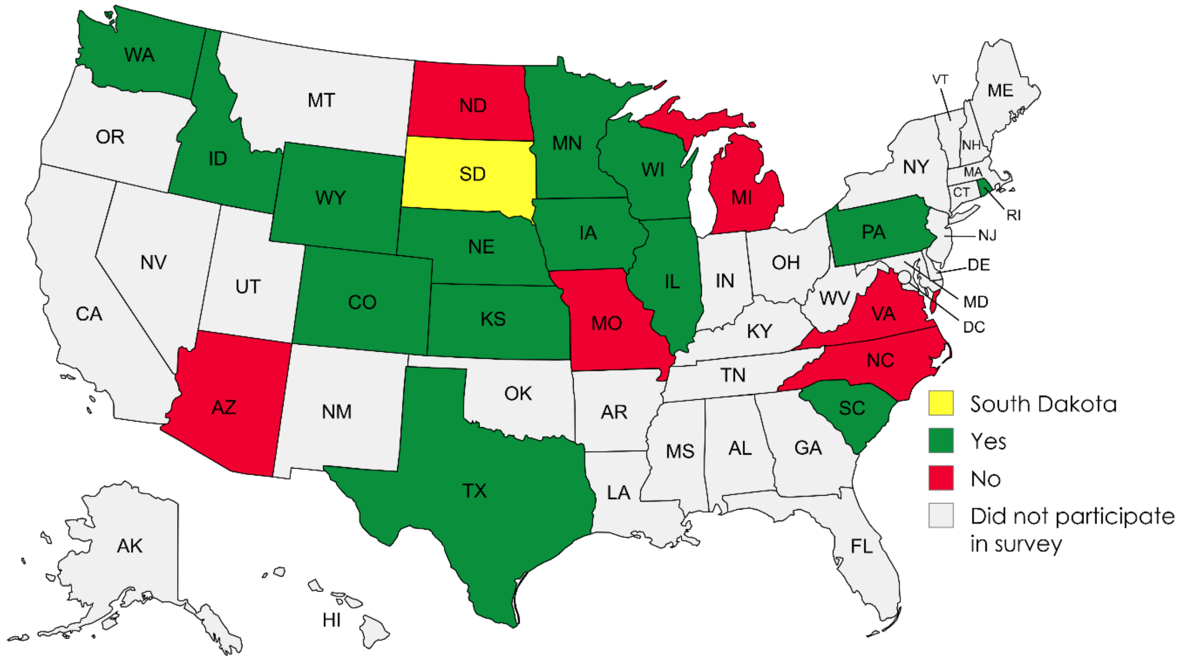

Figure 5.15: Map indicating which state DOTs use hybrid precast–CIP solutions.

Inspection results show that both precast and CIP RCBCs generally perform well, with only minor failures, typically at joints or connections, or due to settlement, occurring over decades (Figure 5.16). Early settlement, joint leakage, and spalling at precast joints are noted, while CIP RCBCs may experience deck or wingwall connection issues.

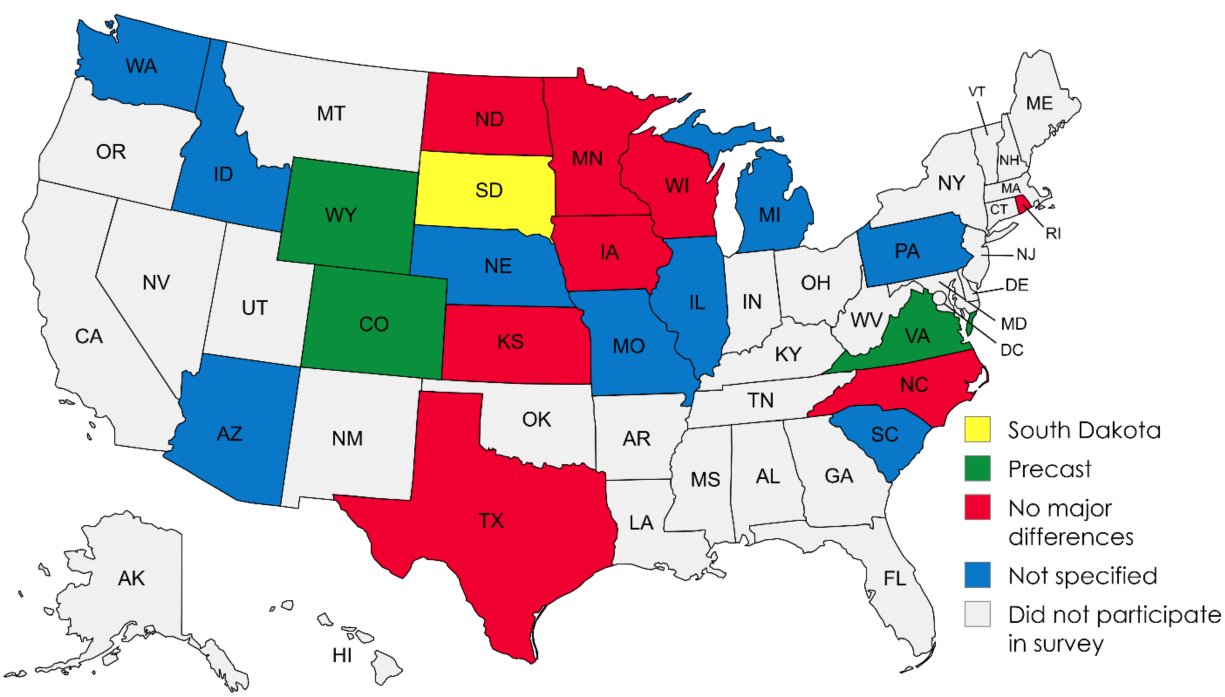

Figure 5.16: Map showing the RCBC type most commonly associated with failures in each state.

If construction speed and traffic are not factors, states' preferences are split (Figure 5.17). Some states, like Texas and North Dakota, leave the choice to contractors, recognizing both options can deliver satisfactory performance.

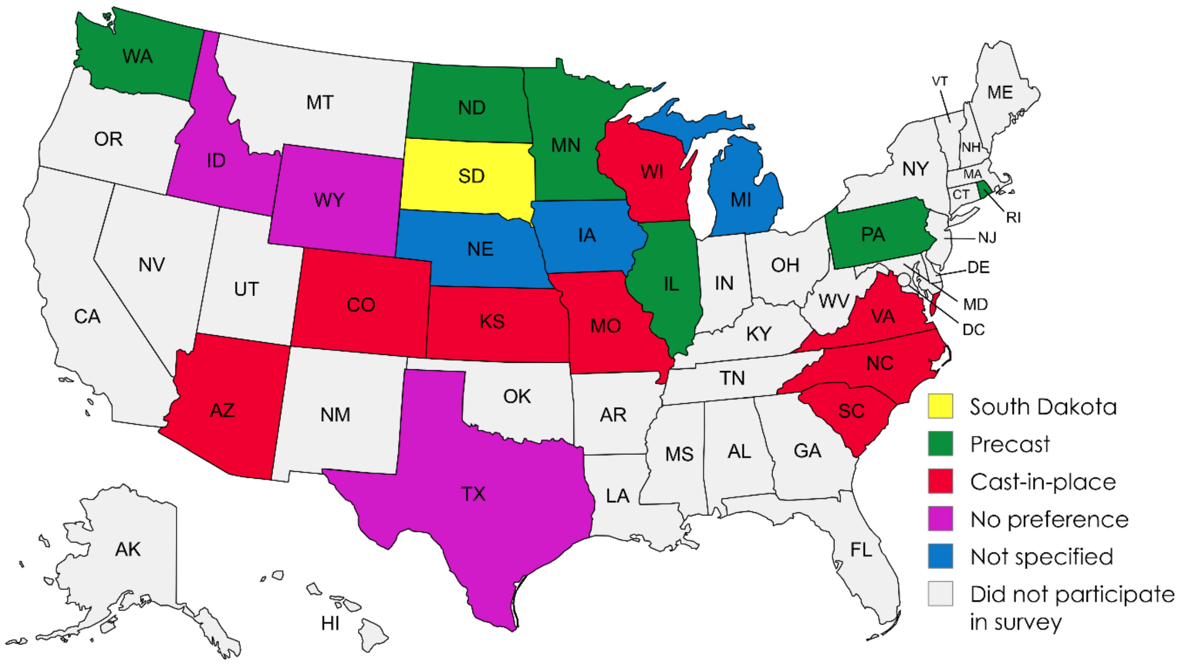

Figure 5.17: Map indicating each state DOT's preferred RCBC type when speed and traffic are not factors.

5.1.2.2 Precast Suppliers Surveys and Interviews

Many precast concrete manufacturers across the United States have experience fabricating RCBCs with end sections skewed at angles greater than 10 degrees. Figure 5.18 illustrates the number of companies that have manufactured culverts with skews exceeding 10 degrees and highlights the main challenges they faced. Moderate skews just above 10 degrees can typically be accommodated with standard forms and minor modifications, leading to only slight cost increases. However, extreme skew angles or large culvert sizes often necessitate custom forming, which adds labor, engineering time, and safety measures, resulting in more significant cost increases as shown in Figure 5.19.

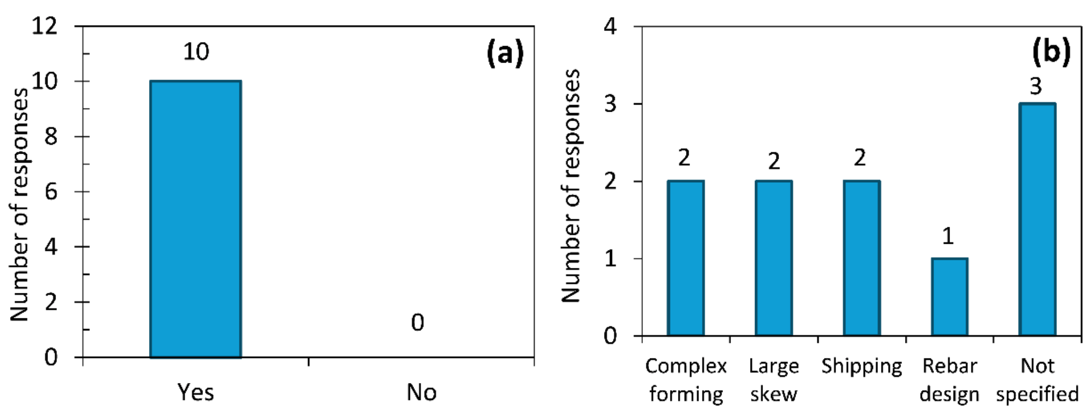

Figure 5.18: (a) Does the company fabricated precast RCBCs with skews over 10 degrees? (b) What are the main challenges faced?

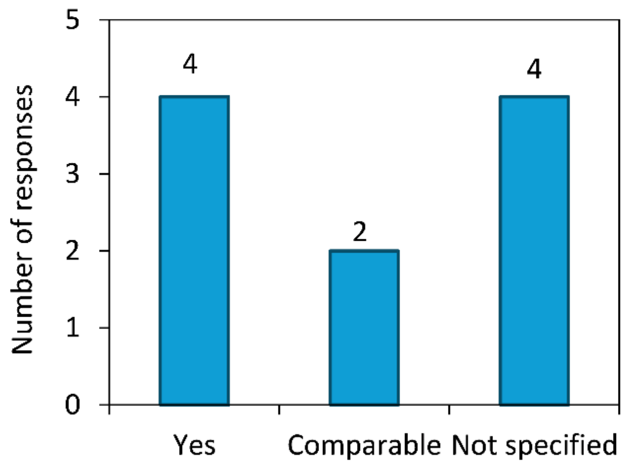

Figure 5.19: Does the culvert with over 10 degrees increase the cost?

Manufacturers such as Shea and S&M identified custom forming and rebar detailing as primary cost drivers. Others, like McPherson, mitigated these challenges by employing self-consolidating concrete (SCC) or breaking the skew into multiple smaller angles to stay within form limitations. Garden State, which has experience with short-span culverts skewed up to 60 degrees, uses design rules based on segment length and shipping constraints, sometimes skewing every section of the culvert to maintain constructability. Rinker Materials has reported manufacturing precast RCBCs with skews up to 45 degrees, noting that maximum feasible skew depends on span length due to the “pie-shaped” sections required for transportation. Similarly, Oldcastle has produced RCBCs with skews up to 45 degrees, while Cemcast employs match casting techniques for extreme skews to ensure precise alignment between sections. All three companies indicated that these products have performed well in service with no significant issues reported.

Additional challenges commonly include formwork setup, rebar congestion, transportation, and fit-up in the field. Some producers avoid precasting skewed ends entirely, preferring to cast them in the field, while others have found innovative ways to restructure production without compromising structural integrity. Despite these challenges, manufacturers generally agree that skewed RCBC ends are feasible and are increasingly common.

Several precast concrete producers also report experience fabricating inlets or outlets with flared wing walls for RCBCs. Figure 5.20 shows the number of companies that have manufactured culverts with precast flared wing walls and whether doing so increased the cost of the culvert. For some manufacturers, such as S&M and Engineered Concrete Products, producing flared wing walls did not involve significant challenges or added costs. Others, like Gillespie, acknowledged additional forming complexity, typically requiring two separate pours (one for the stem with rebar and another for the footing), but still considered this manageable within standard operations.

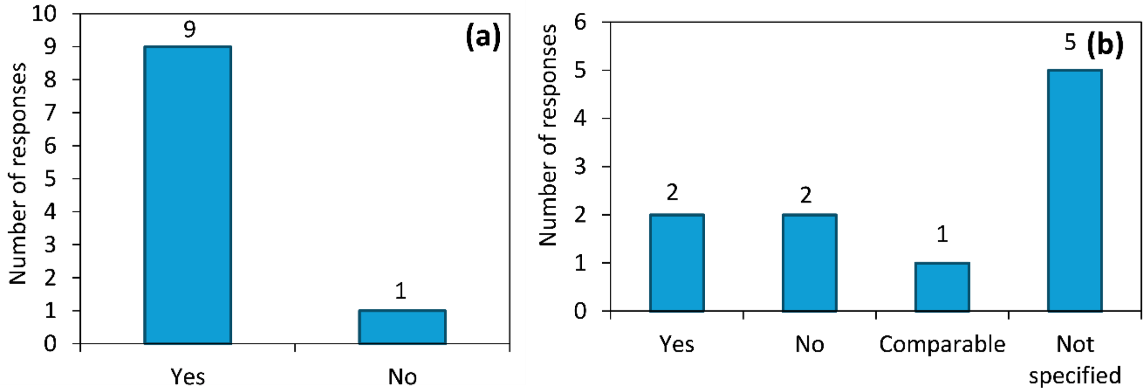

Figure 5.20: (a) Does the company fabricated RCBCs with precast flared wingwalls? (b) Does it increase the cost of the culvert?

Oldcastle Infrastructure has not produced flared wing walls in South Dakota but has completed similar projects in North Dakota, where flared walls were mechanically connected to box sections using welded or bolted plates, sometimes involving closure pours with exposed rebar. Rinker Materials has also manufactured flared wing walls, while Cemcast has not, though they noted that other producers successfully implement welded plate connections. Shea routinely produces precast wing walls (costing between $2,500 and $10,000) but often recommends large retaining wall blocks as a more practical and aesthetic alternative for projects requiring flexibility or site-specific adjustments. Garden State casts flared wings integrally with the last culvert segment for small spans or pours them on separate footings aligned with the culvert.

Several producers also fabricate RCBCs with monolithic parapets at inlets and outlets, as shown in Figure 5.21. Companies such as S&M, Engineered Concrete Products, and Garden State report routine use of monolithic parapets. Garden State typically pours parapets integrally for heights under 30 inches, while taller parapets are designed as L-shaped units bolted on site. Their decision is driven by local labor costs, which make precasting these elements more economical than field construction. Shea provides parapets but notes that modular retaining wall blocks often offer better adaptability, easier installation, and improved aesthetics.

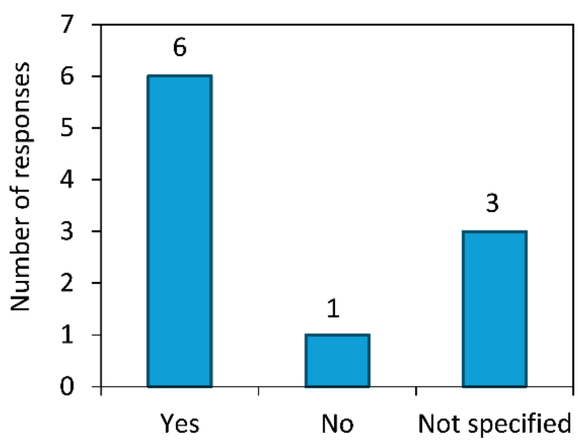

Figure 5.21: Does the company fabricated RCBCs with monolithic inlets and outlets?

In South Dakota, both Rinker Materials and Cemcast have produced RCBCs with customized inlets and outlets, confirming the practicality of these designs in the region. Other producers, such as

McPherson, cite shipping and handling challenges as key barriers, while Gillespie avoids monolithic parapets entirely, either due to lack of experience, preference for field casting, or considering it outside their standard offerings.

Companies generally stay updated on industry design changes through internal drafting and modeling software, industry committees, trade shows, and certification programs. Figure 5.22 shows the number of companies aware of precast RCBC details used by other producers. Most companies reported limited awareness, though Garden State and Gillespie demonstrate strong engagement through ASTM C27 committees, NPCA work, and tracking engineering publications. Other producers rely on in-house expertise, internal standards, and project-specific requirements rather than referencing peer practices.

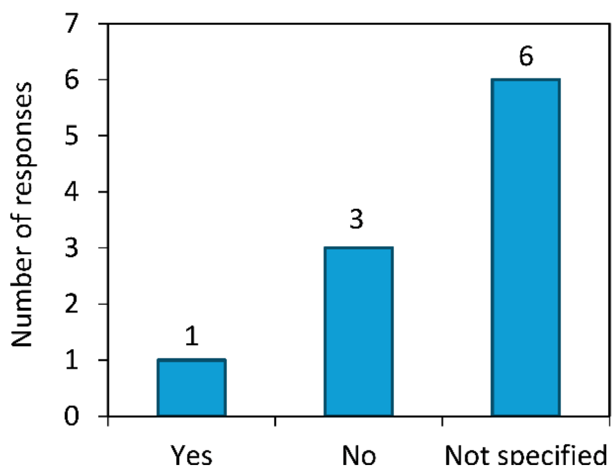

Figure 5.22: Companies that are aware of details of other producers.

Regarding design practices, most companies, including Shea, McPherson, and Engineered Concrete Products, prefer to design each RCBC individually based on project-specific requirements, regulatory conditions, or unique challenges. Standard plates or pre-approved designs are used selectively by companies such as S&M and Oldcastle, which recognize that standardization can reduce lead times, allow pre-stocking of materials, and make precast options more competitive. Custom engineering, however, typically adds 1–2 weeks to production and costs between \$800 and \$2,500 per RCBC; however, these costs are often offset by savings in steel and concrete, and having the flexibility to offer a custom design is generally considered desirable. Standardized designs, on the other hand, can accelerate turnaround and simplify logistics.

Installation practices, joint integrity, and bedding recommendations vary across manufacturers. Figure 5.23, Figure 5.24 and Figure 5.25 summarize common contractor mistakes, best practices for sealing joints, and recommended bedding materials and compaction techniques. Frequent installation issues include unlevel bases, improper bedding, misaligned units, and insufficient training. To ensure proper joint integrity and alignment, manufacturers emphasize level bedding using screedable uncompacted sand, appropriate sealants such as tongue-and-groove joints with preformed mastic (ASTM C-990), mechanical restraints, precise rigging, and ongoing site supervision. Coordination with box producers or contractors can help optimize these details for each project. On-site coaching, proper equipment sizing, and pre-installation preparation further reduce errors and improve long-term performance.

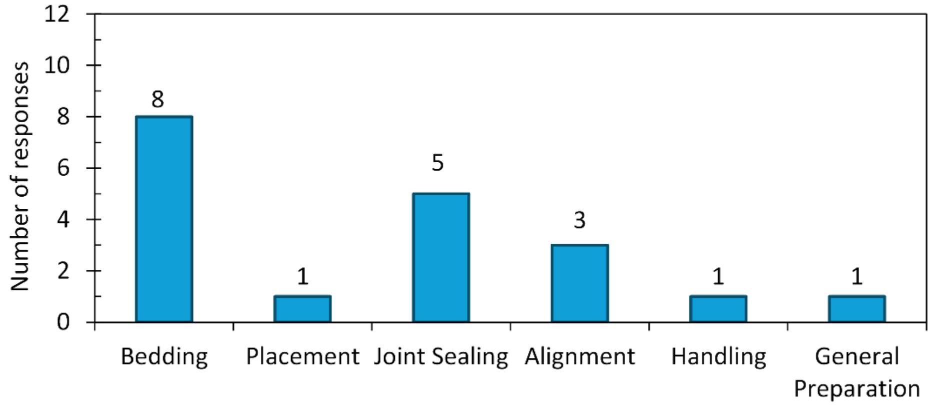

Figure 5.23: General mistakes contractors make when installing precast RCBCs.

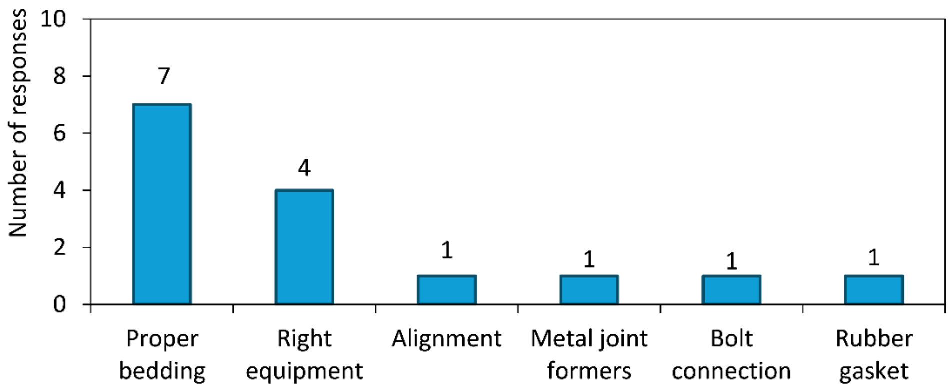

Figure 5.24: Materials or designs used to ensure sealed joints.

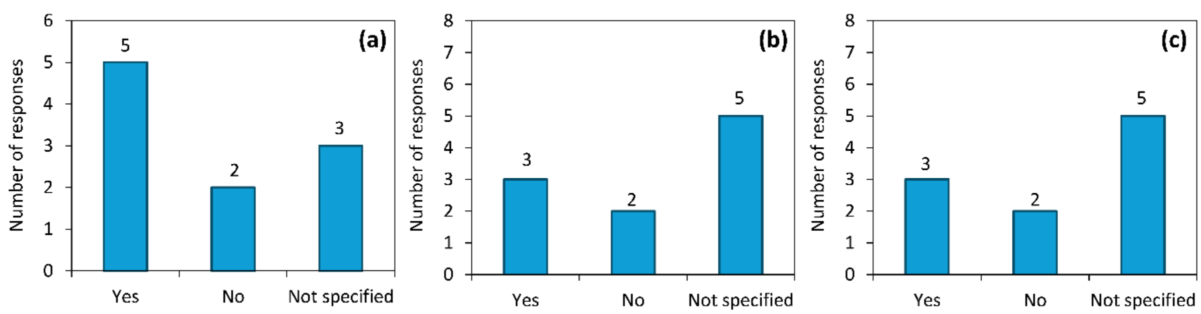

Figure 5.25: (a) Does the company recommend a specific type of bedding? (b) Does the company recommend a specific compaction requirement? (c) Does the company recommend specific joint details?

When considering single-cell versus multi-cell precast RCBCs, manufacturers weigh trade-offs in installation, performance, and cost. Single-cell boxes are easier to produce and transport due to lighter weight and reduced crane requirements, but require joint filling between cells. Double-cell units reduce the number of pieces, which can simplify installation and reduce flowable fill requirements, but may present weight or transport challenges. Match casting is applied when high precision is critical, such as for skewed sections, elbows, or bends, ensuring proper alignment but increasing labor intensity.

Transportation of large precast RCBC components is constrained by width, height, weight, and permitting requirements. Shea and S&M frequently handle oversized loads up to 14 feet wide and

100,000 lbs, while McPherson's dry-casting limits their units to 12 feet wide and 10 feet tall, though wet-cast boxes of up to 20 feet wide have been produced with special handling. Other manufacturers, including Gillespie, Cemcast, and Rinker Materials, report similar challenges, emphasizing the need for pilot cars, escort vehicles, and careful planning for upright placement of large units.

Finally, demand for precast RCBCs has generally increased in response to flooding, bridge failures, and aging infrastructure, prompting manufacturers to expand operations, hire additional staff, and adopt larger spans. Trends in precast RCBC demand over time, showing steady growth and increased adoption of precast solutions for accelerated bridge construction, reduced on-site labor, and improved project efficiency. Manufacturers expect demand to continue rising as agencies prioritize efficiency, reliability, and reduced field construction requirements.

5.2 Long-Term Performance Analysis of South Dakota RCBCs in State and Local Roads

5.2.1 Analysis of South Dakota Regions and Counties

South Dakota has a diverse geography, with the eastern regions, including Aberdeen and Mitchell, being flat and fertile, while western areas such as Rapid City and Pierre have more rugged, erosion-prone terrain (Figure 5.26) (Chris Chubb Cartography, 2025; South Dakota Department of Transportation (SDDOT), 2025). These differences affect soil conditions, water flow, and environmental exposure, all of which influence RCBC performance and durability.

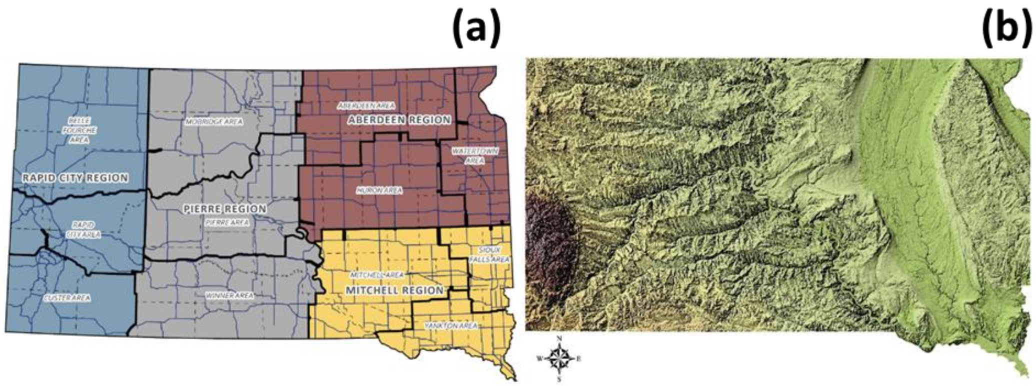

Figure 5.26: (a) South Dakota regions (South Dakota Department of Transportation (SDDOT), 2025); (b) Topographic profile (Chris Chubb Cartography, 2025).

5.2.1.1 Regional Climate Impacts

In terms of average monthly rainfall, Figure 5.27 and Table 5.3 highlight differences across the state ((Weather Spark, 2025). Mitchell and Aberdeen experience the highest precipitation, reaching at 3.7 inches and 3.2 inches in June, whereas Pierre and Rapid City peak at 3.0 inches and 2.7 inches, respectively. These rainfall patterns (National Oceanic & Atmospheric Administration (NOAA), 2025) affect construction practices: on-site CIP culverts are more prone to delays, improper curing, and defects such as honeycombing during heavy rains. Precast culverts, produced in controlled environments, avoid these issues and can be installed quickly, reducing exposure to adverse weather.

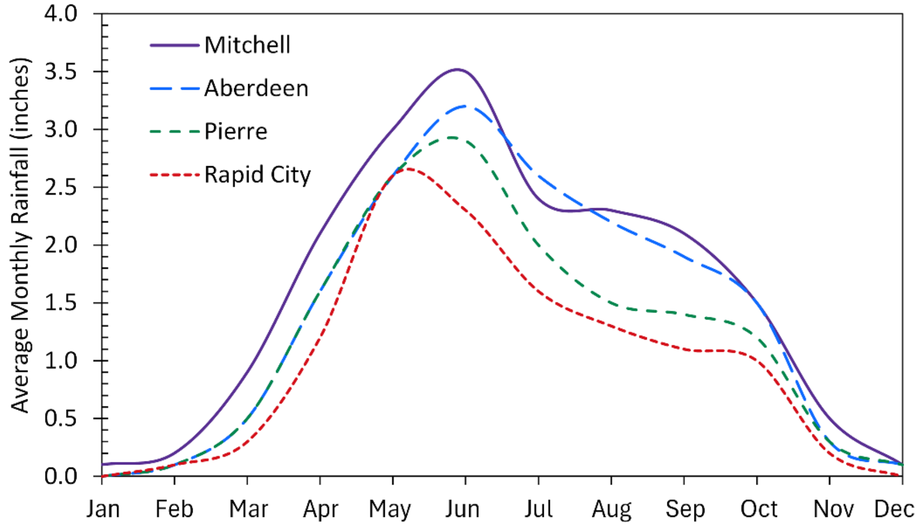

Figure 5.27: Average Monthly Rainfall in South Dakota Regions. Data obtained from (Weather Spark, 2025).

Table 5.3: Numerical Values of Average Monthly Rainfall in South Dakota Regions.

Month	Mitchell (inches)	Rapid City (inches)	Aberdeen (inches)	Pierre (inches)
Jan	0.1	0.0	0.0	0.0
Feb	0.2	0.1	0.1	0.1
Mar	0.9	0.3	0.5	0.5
Apr	2.1	1.2	1.6	1.6
May	3.0	2.6	2.6	2.6
Jun	3.5	2.3	3.2	2.9
Jul	2.4	1.6	2.6	2.0
Aug	2.3	1.3	2.2	1.5
Sep	2.1	1.1	1.9	1.4
Oct	1.5	1.0	1.5	1.2
Nov	0.5	0.2	0.3	0.3
Dec	0.1	0.0	0.1	0.1

Temperature extremes (Figure 5.28) also influence RCBC performance. Aberdeen, Pierre, and Rapid City experience extended periods of freezing conditions from late fall through early spring, leading to repeated freeze–thaw cycles that can accelerate cracking, spalling, and joint deterioration in CIP culverts. High summer temperatures in Pierre and Mitchell may further contribute to thermal expansion and contraction, placing additional stress on older, field-cured concrete. Precast culverts, cured under controlled factory conditions, are generally less susceptible to microcracking and other temperature-related stresses. Data for these figures can be found in Appendix D.

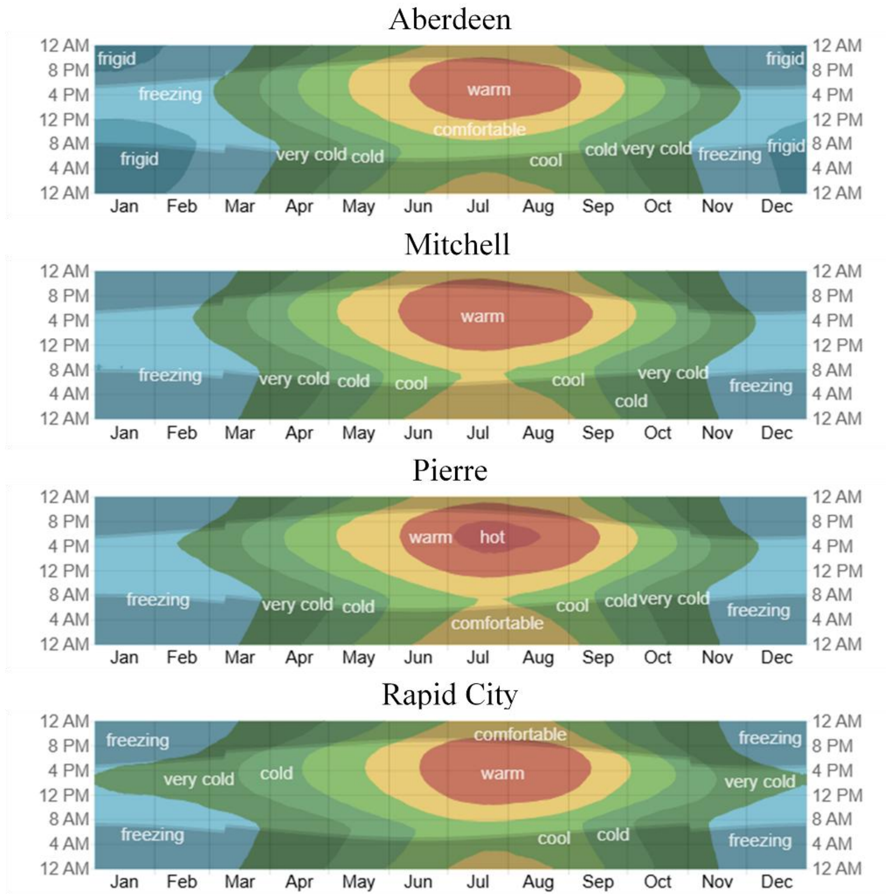

Figure 5.28: Average Hourly Temperature Throughout the Year in South Dakota Regions (Weather Spark, 2025).

Based on regional data, culvert condition ratings vary across counties for both CIP and precast systems. Most CIP culverts (Figure 5.29 and Table 5.4) are rated “Good”; however, performance varies by location. Mitchell has the largest number of CIP culverts (>300), with more than 230 rated “Good.” In Pierre, which has approximately 100 CIP culverts, about 45% are rated “Fair.” Aberdeen also shows a higher percentage of “Fair” CIP culverts compared to Rapid City. These variations likely reflect a combination of factors, including differences in material sources (e.g., local aggregates), soil conditions, construction practices, traffic loading, age distribution, and environmental exposure. However, identifying the specific causes of these variations is beyond the scope of this study.

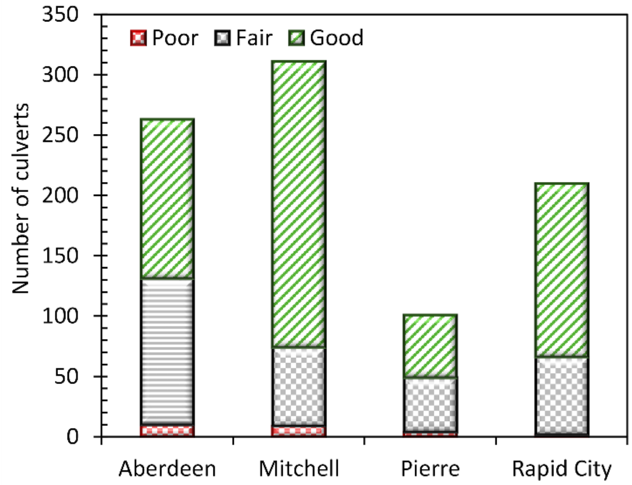

Figure 5.29: CIP RCBCs condition ratings in different South Dakota regions.

Table 5.4: Numerical Values of CIP RCBCs condition ratings in different South Dakota regions.

Regions	Poor Condition	Fair Condition	Good Condition	Total Culverts
Aberdeen	10	121	132	263
Mitchell	9	65	237	311
Pierre	4	45	52	101
Rapid City	2	64	144	210

Precast culverts (Figure 5.30 and Table 5.5) show consistent, strong performance statewide. The proportion rated 'Good' ranges from 75.7% in Aberdeen to 96.3% in Pierre, and none are rated 'Poor.' Only a small percentage are rated 'Fair' (Aberdeen 24.3%, Rapid City 16.5%, Mitchell 4.7%, Pierre 3.7%), likely due to their relatively younger age (<50 years) and limited long-term exposure. While precast culverts currently outperform CIP, continued monitoring is needed to evaluate their long-term durability.

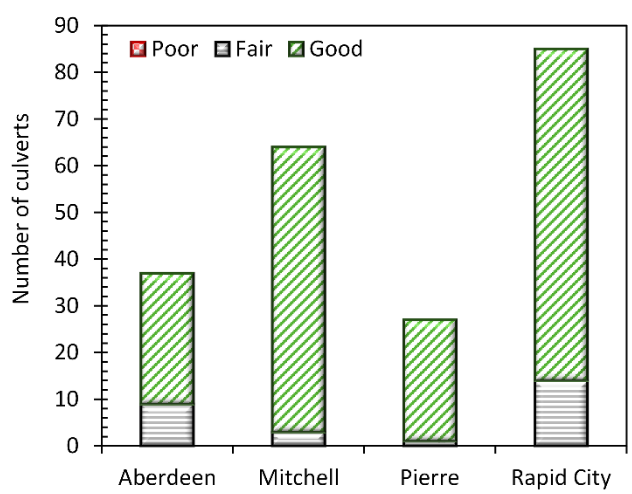

Figure 5.30: Precast RCBCs condition ratings in different South Dakota regions.

Table 5.5: Numerical Values of Precast RCBCs condition ratings in different South Dakota regions.

Regions	Poor Condition	Fair Condition	Good Condition	Total Culverts
Aberdeen	0	9	28	37
Mitchell	0	3	61	64
Pierre	0	1	26	27
Rapid City	0	14	71	85

5.2.1.2 Influence of Design, Age, and Environmental Factors

The performance and condition of RCBCs across South Dakota are affected not only by regional patterns but also by key factors such as service life, length, and fill height. Understanding how these factors influence both CIP and precast culverts is essential for interpreting statewide condition ratings and refining decision-making criteria.

Service Life: Figures 5.31-5.32 and Tables 5.6-5.7 show the relationship between service life and culvert condition. Service life is the most influential factor: CIP culverts rated 'Poor' have a median age of 80–85 years, while those rated 'Good' average about 35 years. Most precast culverts are less than 40 years old, resulting in minimal differences between condition categories. This indicates strong early performance for precast systems but provides limited insight into their long-term durability.

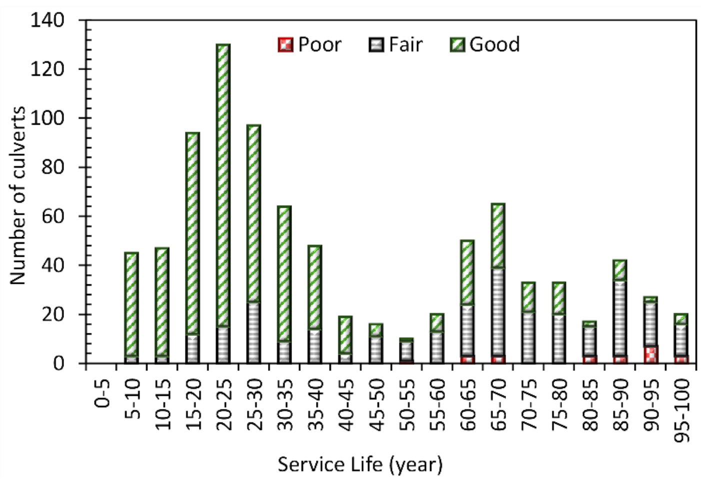

Figure 5.31: CIP RCBCs Condition Ratings vs. Service Life.

Table 5.6: Numerical Values of CIP RCBCs Condition Ratings vs. Service Life.

Service Life (years)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-5	0	0	0	0
5-10	0	3	42	45
10-15	0	3	44	47
15-20	0	12	82	94
20-25	0	15	115	130
25-30	0	25	72	97
30-35	0	9	55	64
35-40	0	14	34	48
40-45	0	4	15	19

Service Life (years)	Poor Condition	Fair Condition	Good Condition	Total Culverts
45-50	0	11	5	16
50-55	1	8	1	10
55-60	0	13	7	20
60-65	3	21	26	50
65-70	3	36	26	65
70-75	0	21	12	33
75-80	0	20	13	33
80-85	3	12	2	17
85-90	3	31	8	42
90-95	7	18	2	27
95-100	3	13	4	20

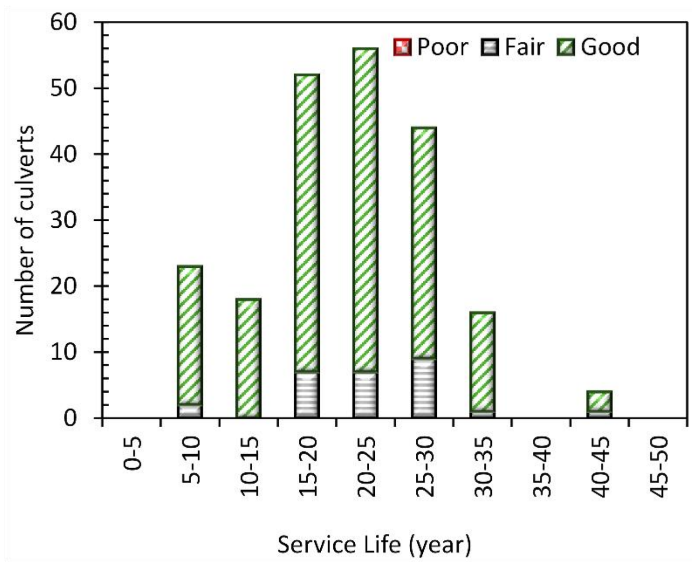

Figure 5.32: Precast RCBCs Condition Ratings vs. Service Life.

Table 5.7: Numerical Values of Precast RCBCs Condition Ratings vs. Service Life.

Service Life (years)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-5	0	0	0	0
5-10	0	2	21	23
10-15	0	0	18	18
15-20	0	7	45	52
20-25	0	7	49	56
25-30	0	9	35	44
30-35	0	1	15	16
35-40	0	0	0	0
40-45	0	1	3	4
45-50	0	0	0	0

Culvert Length: Figures 5.33-5.34 and Tables 5.8-5.9 illustrate the relationship between culvert length and condition. For CIP culverts (Figure 5.33), shorter length (0–25 ft) are more often rated "Fair" or

"Poor," while longer length (25–100 ft) generally receive "Good" ratings. This counterintuitive trend likely indicates differences in age, construction practices, and local hydraulic conditions rather than length alone. In precast culverts (Figure 5.34), longer length show slightly higher "Fair" ratings, likely due to the greater number of joints, which are vulnerable points for water infiltration and settlement.

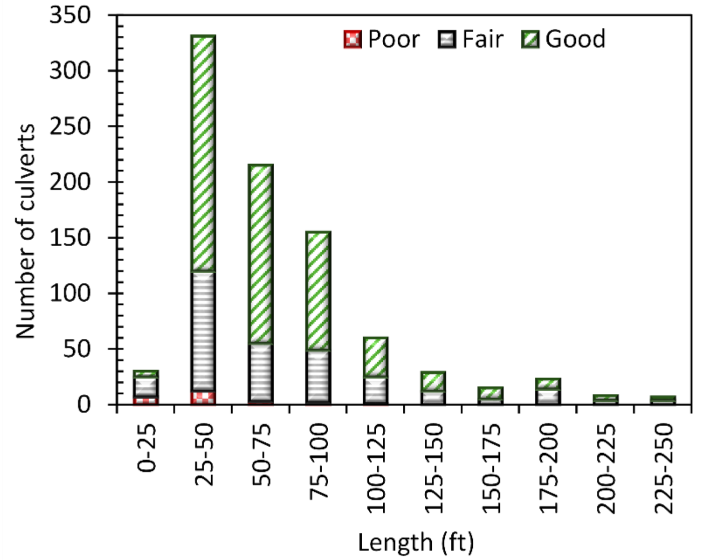

Figure 5.33: CIP RCBCs Condition Ratings vs. Length.

Table 5.8: Numerical Values of CIP RCBCs Condition Ratings vs. Length.

Length (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-25	7	18	5	30
25-50	12	108	211	331
50-75	3	52	160	215
75-100	2	47	106	155
100-125	1	24	35	60
125-150	0	12	17	29
150-175	0	5	10	15
175-200	0	14	9	23
200-225	0	4	4	8
225-250	0	4	3	7

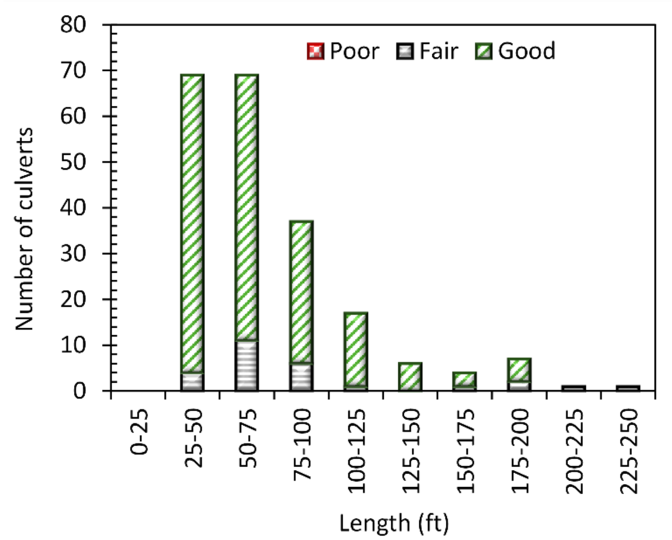

Figure 5.34: Precast RCBCs Condition Ratings vs. Length.

Table 5.9: Numerical Values of Precast RCBCs Condition Ratings vs. Length.

Length (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-25	0	0	0	0
25-50	0	4	65	69
50-75	0	11	58	69
75-100	0	6	31	37
100-125	0	1	16	17
125-150	0	0	6	6
150-175	0	1	3	4
175-200	0	2	5	7
200-225	0	1	0	1
225-250	0	1	0	1

Open Area: Figures 5.35-5.36 and Tables 5.10-5.11 shows that culvert open area has minimal effect on condition. However, very large CIP (Figure 5.35) culverts (>500 ft²) are more frequently rated "Fair," suggesting that extreme size may increase stresses and the risk of cracking. Precast culverts (Figure 5.36) show similar trends, with open area having little impact on overall performance.

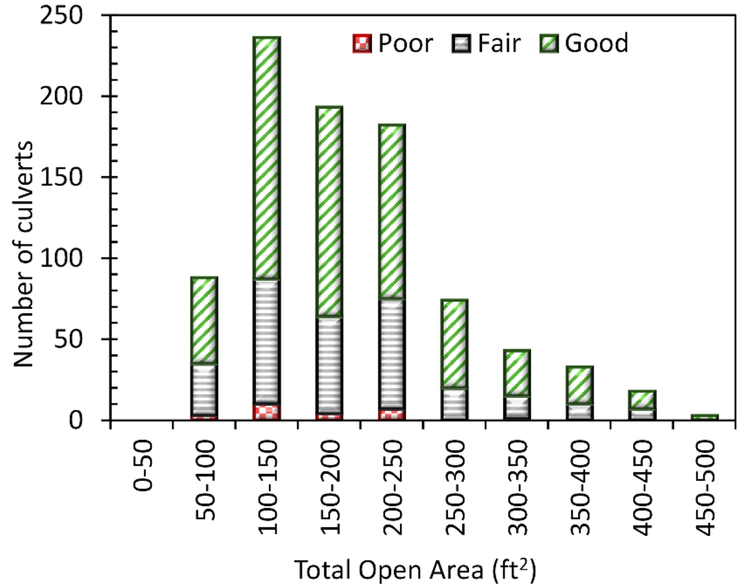

Figure 5.35: CIP RCBCs Condition Ratings vs. Total Open Area.

Table 5.10: Numerical Values of CIP RCBCs Condition Ratings vs. Total Open Area.

Total Open Area (ft^2)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-50	0	0	0	0
50-100	3	32	53	88
100-150	10	77	149	236
150-200	4	60	129	193
200-250	7	68	107	182
250-300	0	20	54	74
300-350	1	14	28	43
350-400	0	10	23	33
400-450	0	7	11	18
450-500	0	0	3	3

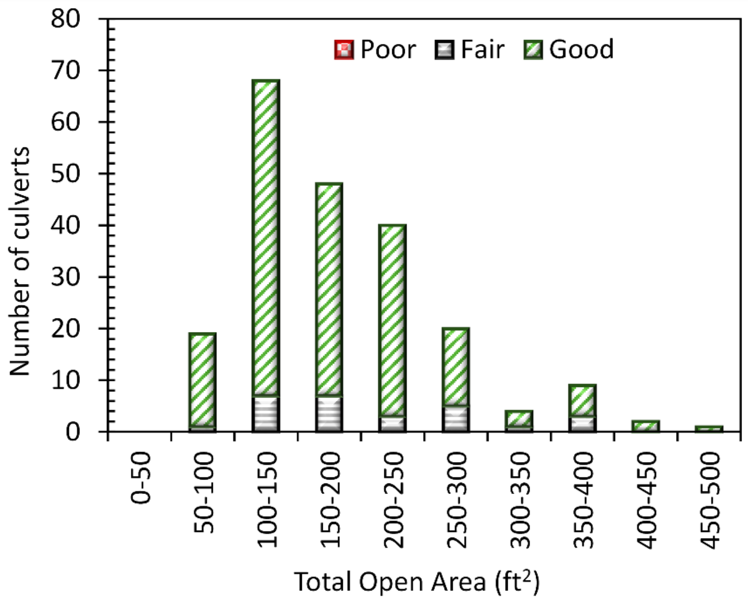

Figure 5.36: Precast RCBCs Condition Ratings vs. Total Open Area.

Table 5.11: Numerical Values of Precast RCBCs Condition Ratings vs. Total Open Area.

Total Open Area (ft^2)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-50	0	0	0	0
50-100	0	1	18	19
100-150	0	7	61	68
150-200	0	7	41	48
200-250	0	3	37	40
250-300	0	5	15	20
300-350	0	1	3	4
350-400	0	3	6	9
400-450	0	0	2	2
450-500	0	0	1	1

Fill Height: Most culverts are installed with low to moderate fill heights (1–3 ft) and perform well (Figures 5.37-5.38 and Tables 5.12-5.13). Very shallow fills (0–1 ft) increase exposure to surface loads and the risk of deterioration, while very deep fills (>6–7 ft) can create compaction and drainage challenges. Precast culverts show similar patterns, with shallow to moderate fills associated with optimal performance.

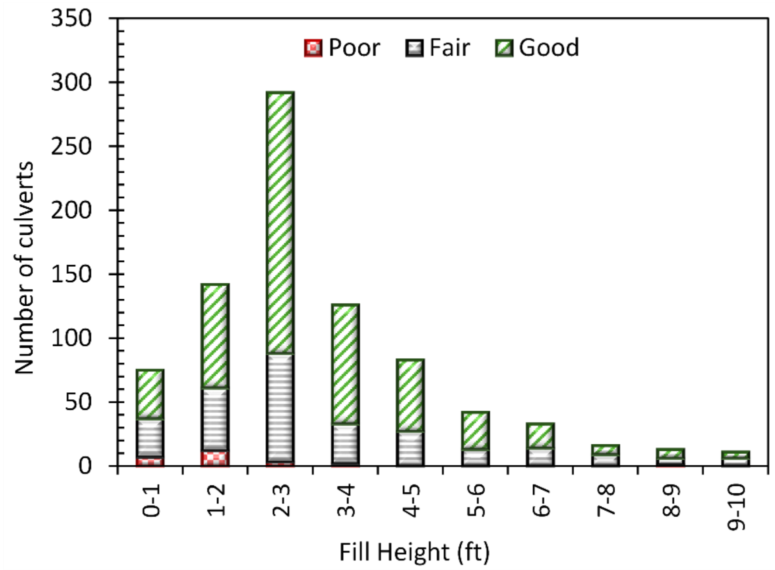

Figure 5.37: CIP RCBCs Condition Ratings vs. Fill Height.

Table 5.12: Numerical Values of CIP RCBCs Condition Ratings vs. Fill Height.

Fill Height (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-1	7	30	38	75
1-2	12	49	81	142
2-3	3	85	204	292
3-4	2	31	93	126
4-5	0	27	56	83
5-6	0	13	29	42
6-7	0	14	19	33
7-8	0	9	7	16
8-9	1	5	7	13
9-10	0	6	5	11

(b)

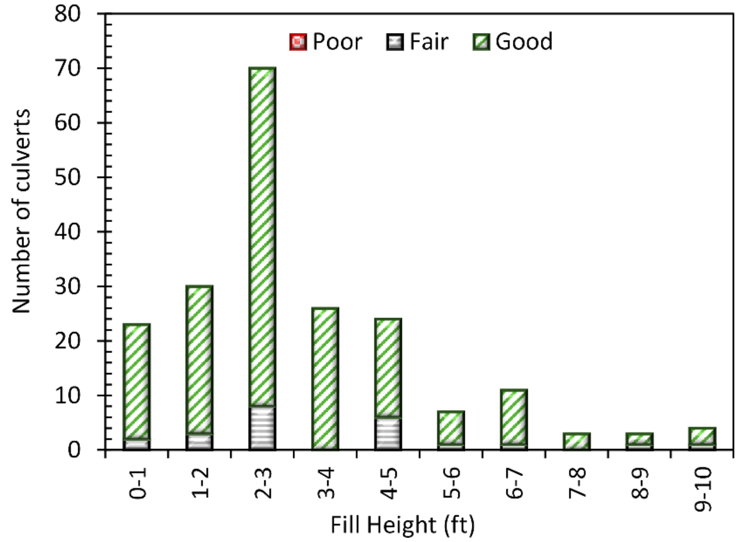

Figure 5.38: Precast RCBCs Condition Ratings vs. Fill Height.

Table 5.13: Numerical Values of Precast RCBCs Condition Ratings vs. Fill Height.

Fill Height (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-1	0	2	21	23
1-2	0	3	27	30
2-3	0	8	62	70
3-4	0	0	26	26
4-5	0	6	18	24
5-6	0	1	6	7
6-7	0	1	10	11
7-8	0	0	3	3
8-9	0	1	2	3
9-10	0	1	3	4

Skew Angle: Figures 5.39-5.40 and Tables 5.14-5.15 present RCBC condition ratings in relation to skew angle for both CIP (a) and precast (b) culverts. Most culverts have low skew angles (0 degrees – 5 degrees). For CIP culverts (Figure 5.39), higher skew angles generally correspond to lower condition ratings. No precast culverts (Figure 5.40) exceed 10 degrees skew, as expected under SDDOT design policies.

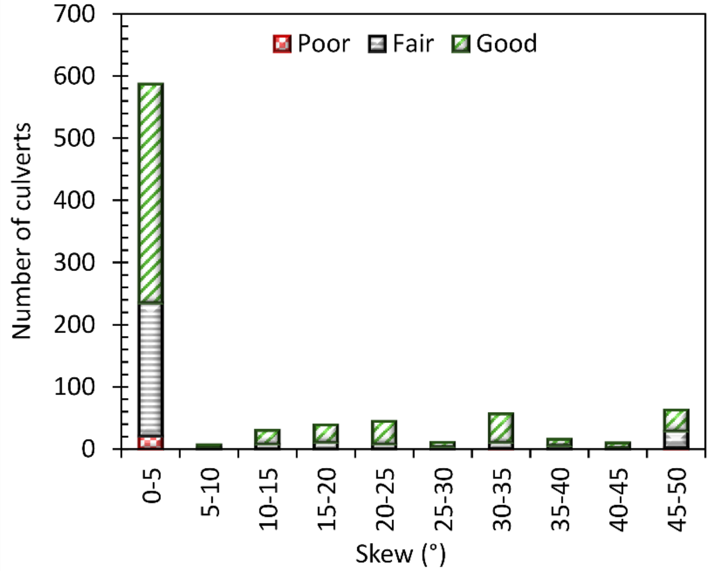

Figure 5.39: CIP RCBCs Condition Ratings vs. Skew Angle.

Table 5.14: Numerical Values of CIP RCBCs Condition Ratings vs. Skew Angle.

Skew Angle (degrees)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-5	21	214	352	587
5-10	0	2	5	7
10-15	0	8	22	30
15-20	0	11	28	39
20-25	0	8	37	45
25-30	0	4	7	11
30-35	1	10	46	57
35-40	0	6	10	16
40-45	0	2	8	10
45-50	2	27	34	63

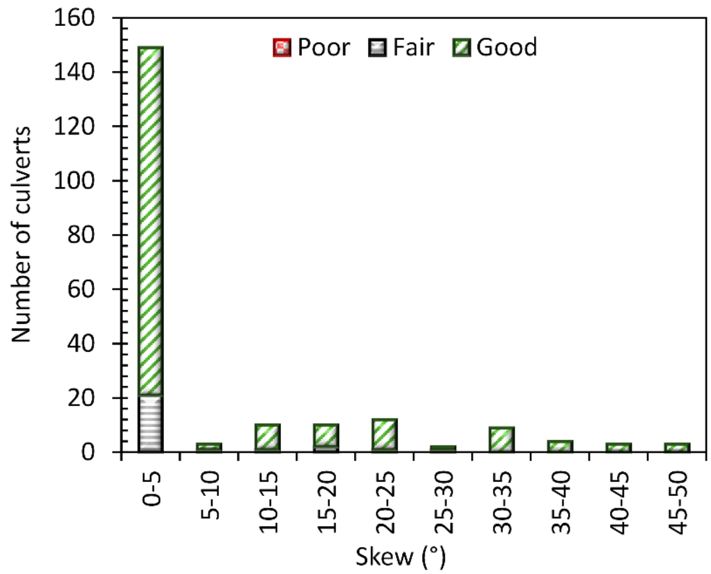

Figure 5.40: Precast RCBCs Condition Ratings vs. Skew Angle.

Table 5.15: Numerical Values of Precast RCBCs Condition Ratings vs. Skew Angle.

Skew Angle (degrees)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-5	0	21	128	149
5-10	0	1	2	3
10-15	0	1	9	10
15-20	0	2	8	10
20-25	0	1	11	12
25-30	0	1	1	2
30-35	0	0	9	9
35-40	0	0	4	4
40-45	0	0	3	3
45-50	0	0	3	3

Traffic Volume (ADT): Figures 5.41-5.42 and Tables 5.16-5.17 show RCBC condition ratings relative to daily traffic (ADT) for both CIP (a) and precast (b) culverts. Most RCBCs are on low-volume roads (<200 vehicles/day). For CIP culverts (Figure 5.41), higher traffic may slightly accelerate deterioration, while precast culverts (Figure 5.42) show little relationship between condition and traffic volume.

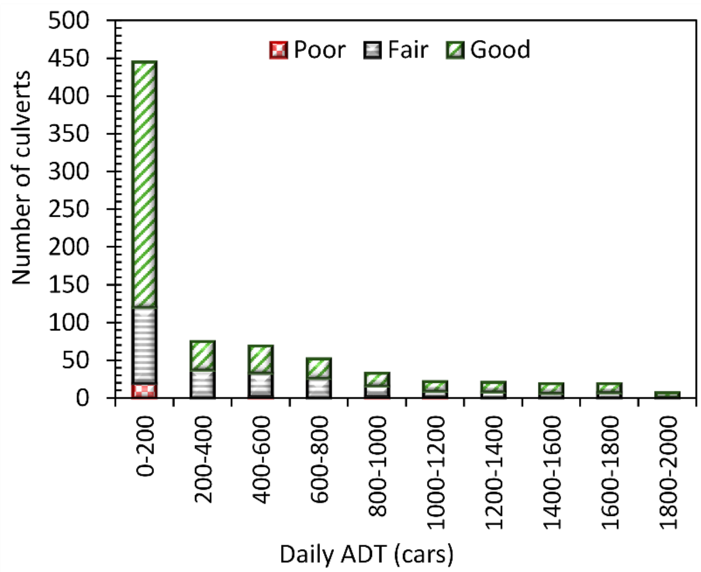

Figure 5.41: CIP RCBCs Condition Ratings vs. Daily ADT.

Table 5.16: Numerical Values of CIP RCBCs Condition Ratings vs. Daily ADT.

Daily ADT (cars)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-200	19	101	325	445
200-400	0	37	38	75
400-600	2	31	36	69
600-800	0	26	26	52
800-1000	2	14	17	33
1000-1200	1	8	13	22
1200-1400	0	8	13	21
1400-1600	0	6	13	19
1600-1800	0	7	12	19
1800-2000	0	1	6	7

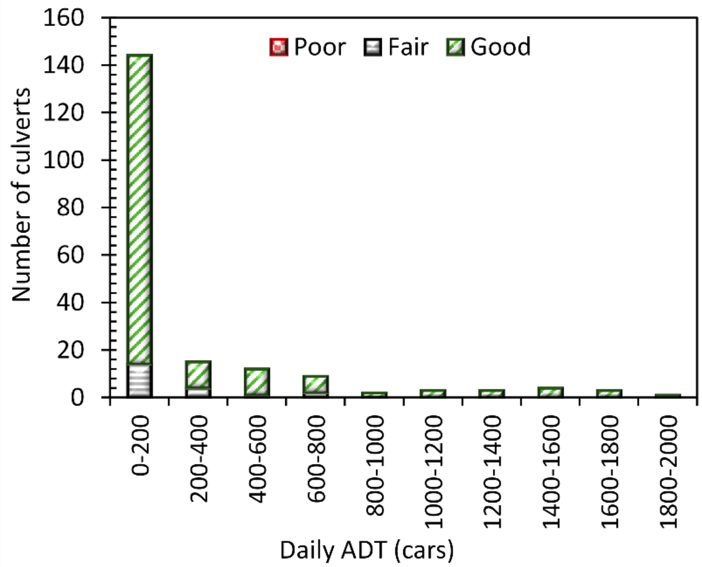

Figure 5.42: Precast RCBCs Condition Ratings vs. Daily ADT.

Table 5.17: Numerical Values of Precast RCBCs Condition Ratings vs. Daily ADT.

Daily ADT (cars)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-200	0	14	130	144
200-400	0	4	11	15
400-600	0	1	11	12
600-800	0	2	7	9
800-1000	0	0	2	2
1000-1200	0	0	3	3
1200-1400	0	0	3	3
1400-1600	0	0	4	4
1600-1800	0	0	3	3
1800-2000	0	0	1	1

Combined Factors: Figure 5.43-5.48 and Tables 5.18-5.23 show how the interaction of multiple factors, such as age, size, and fill height, affects RCBC condition ratings for both CIP and precast culverts. Results exhibit that deterioration risk increases when these factors combine. For CIP culverts, those older than 40 years and longer than 75 ft show 65% “Fair/Poor” ratings, while culverts over 60 years old with 100–400 ft² open area exhibit 40–50% “Fair/Poor” ratings. CIP culverts installed under very shallow (<5 ft) or very high fill conditions experience greater long-term stress. Precast culverts, which are mostly under 40 years old and moderate in length and open area, maintain over 90–95% “Good” ratings.

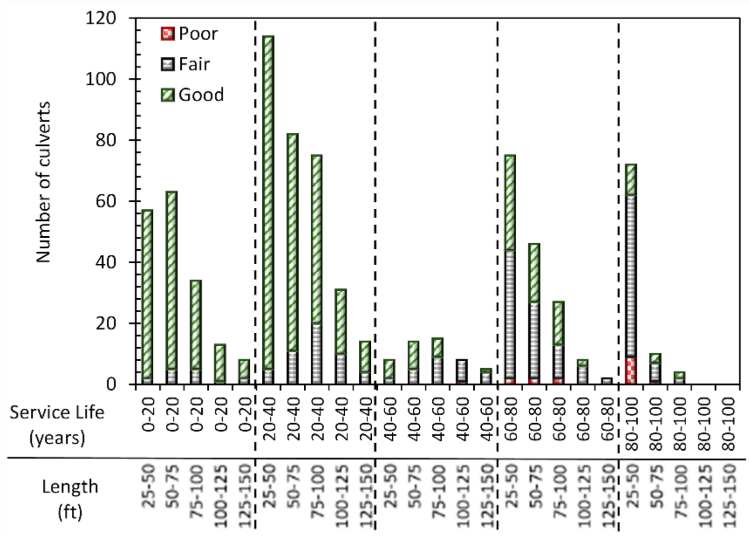

Figure 5.43: CIP RCBCs Condition Ratings vs. Service Life and Length

Table 5.18: Numerical Values of CIP RCBCs Condition Ratings vs. Service Life and Length.

Service Life (years)	Length (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-20	25-50	0	2	55	57
0-20	50-75	0	5	58	63
0-20	75-100	0	5	29	34
0-20	100-125	0	1	12	13
0-20	125-150	0	2	6	8
20-40	25-50	0	5	109	114
20-40	50-75	0	11	71	82
20-40	75-100	0	20	55	75
20-40	100-125	0	10	21	31
20-40	125-150	0	4	10	14
40-60	25-50	0	2	6	8
40-60	50-75	0	5	9	14
40-60	75-100	0	9	6	15
40-60	100-125	1	7	0	8
40-60	125-150	0	4	1	5
60-80	25-50	2	42	31	75
60-80	50-75	2	25	19	46
60-80	75-100	2	11	14	27
60-80	100-125	0	6	2	8
60-80	125-150	0	2	0	2
80-100	25-50	9	53	10	72
80-100	50-75	1	6	3	10
80-100	75-100	0	2	2	4
80-100	100-125	0	0	0	0
80-100	125-150	0	0	0	0

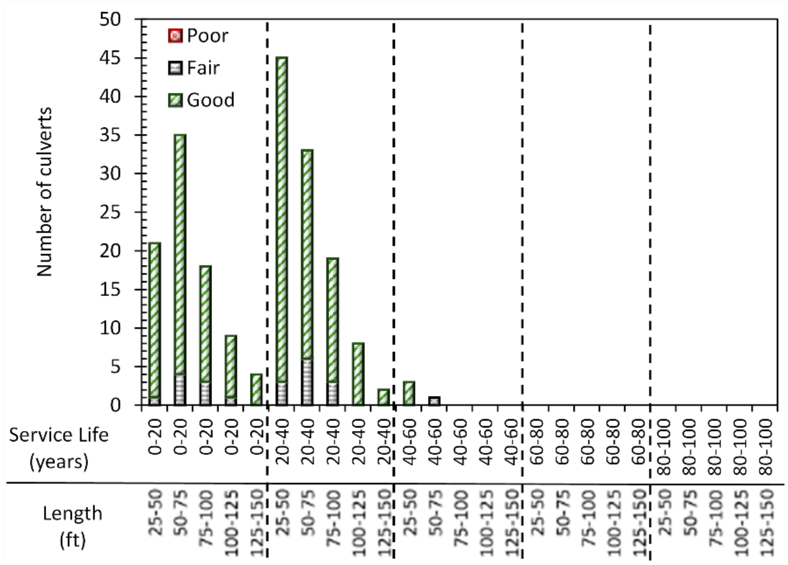

Figure 5.44: Precast RCBCs Condition Ratings vs. Service Life and Length.

Table 5.19: Numerical Values of Precast RCBCs Condition Ratings vs. Service Life and Length.

Service Life (years)	Length (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-20	25-50	0	1	20	21
0-20	50-75	0	4	31	35
0-20	75-100	0	3	15	18
0-20	100-125	0	1	8	9
0-20	125-150	0	0	4	4
20-40	25-50	0	3	42	45
20-40	50-75	0	6	27	33
20-40	75-100	0	3	16	19
20-40	100-125	0	0	8	8
20-40	125-150	0	0	2	2
40-60	25-50	0	0	3	3
40-60	50-75	0	1	0	1
40-60	75-100	0	0	0	0
40-60	100-125	0	0	0	0
40-60	125-150	0	0	0	0

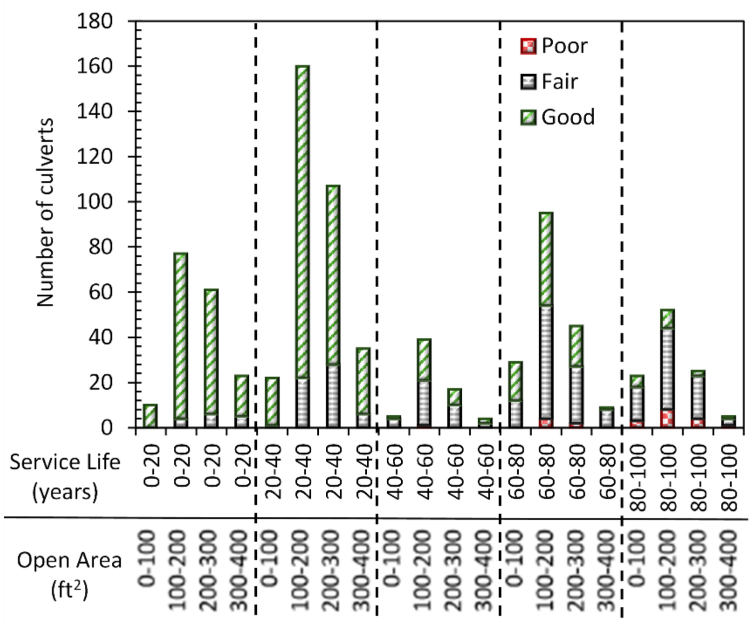

Figure 5.45: CIP RCBCs Condition Ratings vs. Service Life and Open Area.

Table 5.20: Numerical Values of CIP RCBCs Condition Ratings vs. Service Life and Open Area.

Service Life (years)	Total Open Area (ft^2)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-20	0-100	0	0	10	10
0-20	100-200	0	4	73	77
0-20	200-300	0	6	55	61
0-20	300-400	0	5	18	23
20-40	0-100	0	1	21	22
20-40	100-200	0	22	138	160
20-40	200-300	0	28	79	107
20-40	300-400	0	6	29	35
40-60	0-100	0	4	1	5
40-60	100-200	1	20	18	39
40-60	200-300	0	10	7	17
40-60	300-400	0	2	2	4
60-80	0-100	0	12	17	29
60-80	100-200	4	50	41	95
60-80	200-300	2	25	18	45
60-80	300-400	0	8	1	9
80-100	0-100	3	15	5	23
80-100	100-200	8	36	8	52
80-100	200-300	4	19	2	25
80-100	300-400	1	3	1	5

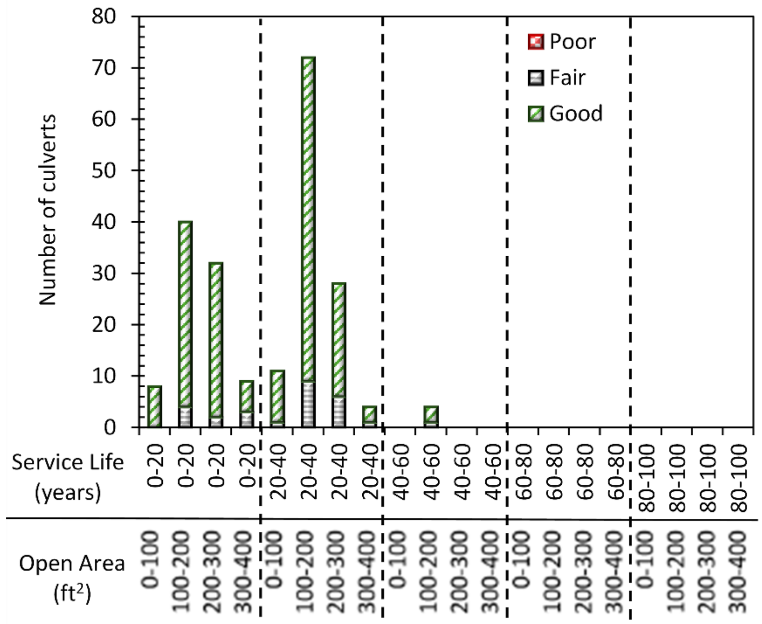

Figure 5.46: Precast RCBCs Condition Ratings vs. Service Life and Open Area.

Table 5.21: Numerical Values of Precast RCBCs Condition Ratings vs. Service Life and Open Area.

Service Life (years)	Total Open Area (ft^2)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-20	0-100	0	0	8	8
0-20	100-200	0	4	36	40
0-20	200-300	0	2	30	32
0-20	300-400	0	3	6	9
20-40	0-100	0	1	10	11
20-40	100-200	0	9	63	72
20-40	200-300	0	6	22	28
20-40	300-400	0	1	3	4
40-60	0-100	0	0	0	0
40-60	100-200	0	1	3	4
40-60	200-300	0	0	0	0
40-60	300-400	0	0	0	0

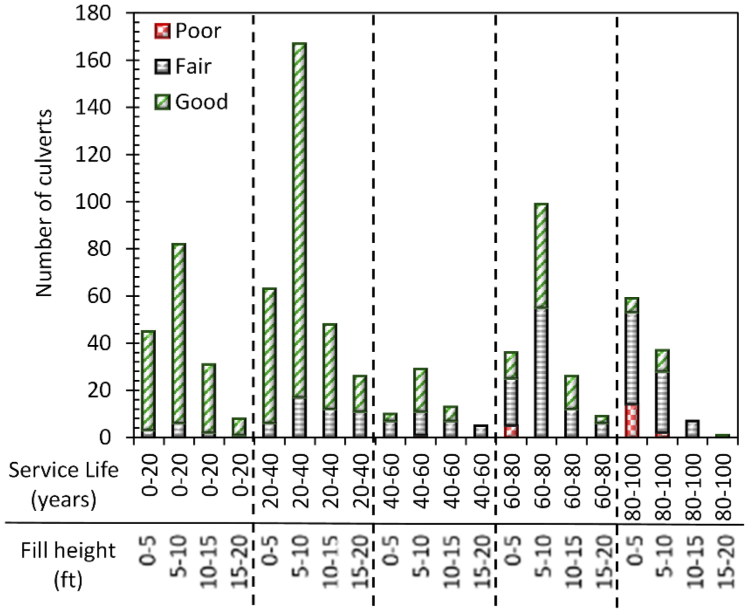

Figure 5.47: CIP RCBCs Condition Ratings vs. Service Life and Fill Height.

Table 5.22: Numerical Values of CIP RCBCs Condition Ratings vs. Service Life and Fill Height.

Service Life (years)	Fill Height (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-20	0-2	0	3	42	45
0-20	2-4	0	6	76	82
0-20	4-6	0	2	29	31
0-20	6-8	0	1	7	8
20-40	0-2	0	6	57	63
20-40	2-4	0	17	150	167
20-40	4-6	0	12	36	48
20-40	6-8	0	11	15	26
40-60	0-2	0	7	3	10
40-60	2-4	1	10	18	29
40-60	4-6	0	7	6	13
40-60	6-8	0	5	0	5
60-80	0-2	5	20	11	36
60-80	2-4	0	55	44	99
60-80	4-6	0	12	14	26
60-80	6-8	0	6	3	9
80-100	0-2	14	39	6	59
80-100	2-4	2	26	9	37
80-100	4-6	0	7	0	7
80-100	6-8	0	0	1	1

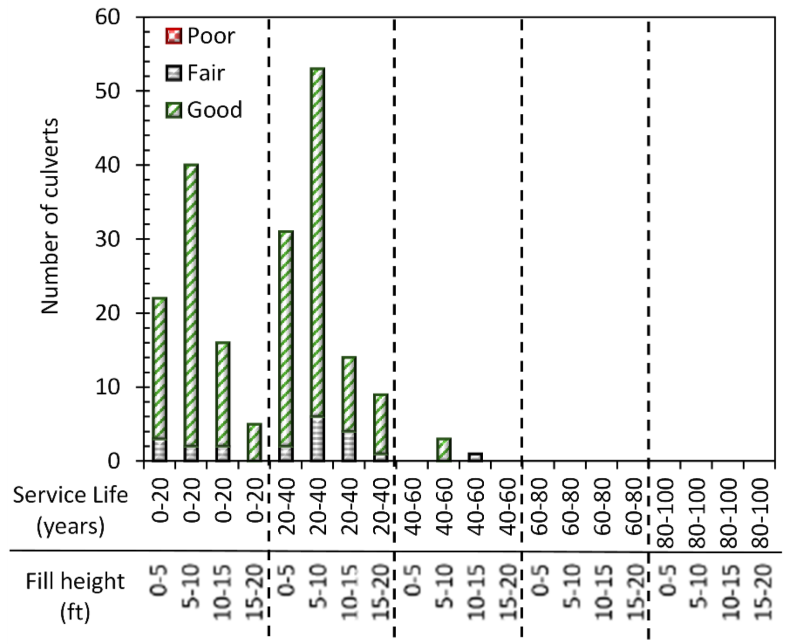

Figure 5.48: Precast RCBCs Condition Ratings vs. Service Life and Fill Height.

Table 5.23: Numerical Values of Precast RCBCs Condition Ratings vs. Service Life and Fill Height.

Service Life (years)	Fill Height (ft)	Poor Condition	Fair Condition	Good Condition	Total Culverts
0-20	0-2	0	3	19	22
0-20	2-4	0	2	38	40
0-20	4-6	0	2	14	16
0-20	6-8	0	0	5	5
20-40	0-2	0	2	29	31
20-40	2-4	0	6	47	53
20-40	4-6	0	4	10	14
20-40	6-8	0	1	8	9
40-60	0-2	0	0	0	0
40-60	2-4	0	0	3	3
40-60	4-6	0	1	0	1
40-60	6-8	0	0	0	0

5.2.1.3 Correlations Between Multiple Factors of the RCBCs

Figure 5.49 compares costs of precast and CIP RCBCs by length (a) and total open area (b). In both cases, precast culverts are consistently less expensive than CIP for comparable dimensions. While costs for both types increase with length or open area, the difference is most pronounced for larger culverts, where CIP costs can exceed $3,000,000, whereas precast options generally remain below $2,000,000. This cost advantage may be attributed to off-site manufacturing, faster installation, and reduced indirect costs such as road closures and weather-related delays. Data for these figures can be found in Appendix E.

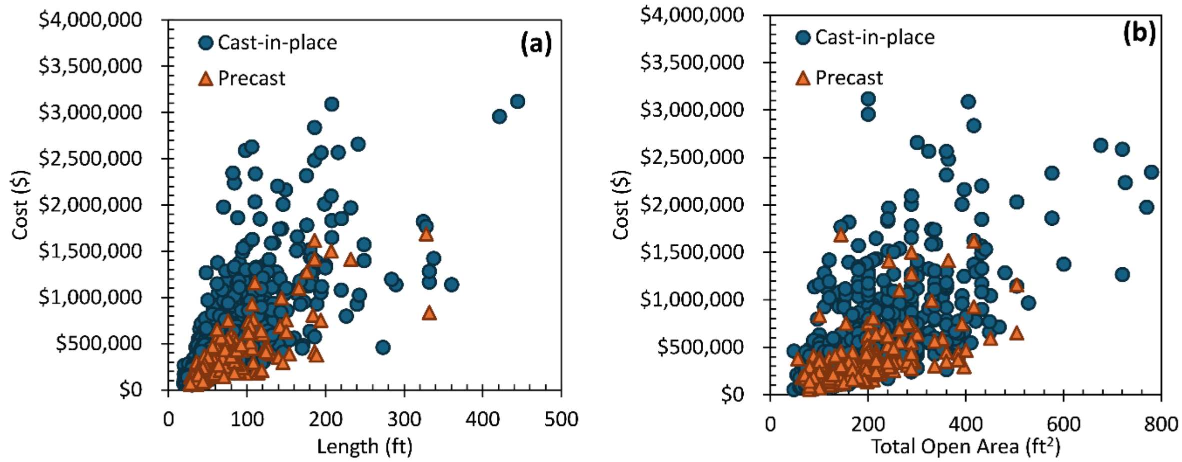

Figure 5.49: (a) Cost vs. Length. (b) Cost vs. Total Open Area.

Figure 5.50 compares fill height with total open area (a) and service life (b) for precast and CIP RCBCs. There is no clear relationship between fill height and open area, and values for both culvert types largely overlap, indicating that these parameters are more affected by other factors than by construction type. While both precast and CIP culverts are used in high-fill applications, only CIP culverts have proven long-term durability. Monitoring the performance of older precast culverts in these demanding conditions will be important to assess their long-term reliability. Data for these figures can be found in Appendix E.

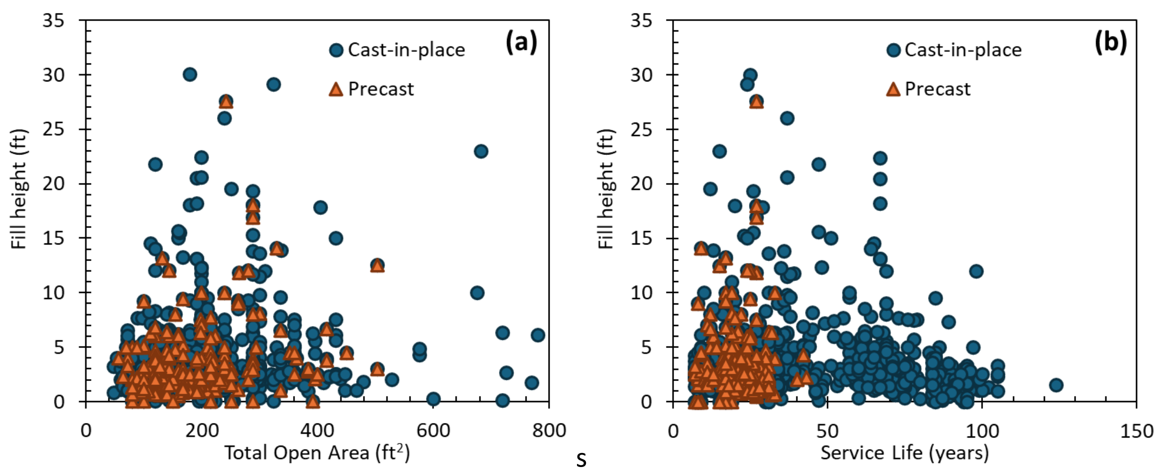

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Figure 5.50: (a) Fill Height vs. Total Open Area. (b) Fill Height vs. Service Life.

5.3 Criteria for the Selection of a Cast-In-Place or Precast RCBC Construction Type in South Dakota

Based on interview responses, survey feedback, and performance data from the SDDOT culvert database, the research team developed criteria to guide RCBC selection according to site conditions and project characteristics. The criteria outline scenarios where CIP culverts, precast culverts, or either type may be appropriate, providing the rationale for each recommendation.

5.3.1 Criteria when Selecting Box Culverts

1. Skew Angle

- **Recommended Action:** Use either precast or CIP culverts for skew angles up to 30 degrees. For skew angles between 30 degrees and 45 degrees, either type may be used with special approval, considering site-specific conditions and potential constructability or cost impacts. For skew angles greater than 45 degrees, we recommend that CIP culverts should be mandatory.
- **Reasoning:** SDDOT currently limits precast culverts to 10 degrees, but available data and practices in neighboring states indicate that higher skews can be accommodated without significant deterioration. Precasters typically manufacture standard skewed end sections at 15 degrees, 30 degrees, and 45 degrees. While SDDOT does not yet have approved precast details for skewed end sections, agencies such as MnDOT provide standard designs for 15 degrees, 30 degrees, and 45 degrees skews, which could serve as useful references for future development of SDDOT standards. Most surrounding states allow at least 30 degrees, and several permit up to 45 degrees (e.g., Iowa, Minnesota). While skews above 30 degrees may introduce constructability challenges, and higher costs, they are not uncommon in practice. Therefore, SDDOT could permit precast culverts up to 30 degrees by default, with the possibility of special approval for skews between 30 degrees and 45 degrees when justified by site conditions and supported by design detailing. For skews greater than 30 degrees, or those approved up to 45 degrees, additional requirements should address joint alignment, load distribution, and hydraulic performance. For skews above 45 degrees, CIP RCBC should remain the preferred option to ensure structural integrity.

2. Transportation and Installation Limitations

- **Recommended Action:** Use CIP culverts for large units when crane/installation equipment limitations exist.
- **Reasoning:** Oversized precast sections are difficult and costly to transport and install, requiring specialized cranes and permits. CIP avoids these logistical challenges by constructing the culvert directly on site, making it more practical and economical for large spans.

3. Availability of Ready-Mix Concrete

- **Recommended Action:** Use precast culverts when ready-mix concrete is not available within approximately a four-hour haul distance.

- **Reasoning:** Precast production in controlled environments ensures consistent quality and avoids risks associated with delayed deliveries, loss of workability, or compromised concrete quality during long-distance transport.

4. **Traffic Disruption and Tight Schedules**

- **Recommended Action:** Use precast culverts when minimizing traffic disruption or meeting tight construction schedules is critical.
- **Reasoning:** Precast units can be installed rapidly, reducing lane closures and overall project duration compared to CIP alternatives.

5. **Formwork Removal Issues**

- **Recommended Action:** Use precast culverts when the rise is 4 feet or less.
- **Reasoning:** Based on feedback from the technical panel, current practice limits precast selection to culverts with a rise of 4 feet or less, as cast-in-place form setup and removal become difficult in shorter rises due to limited access. 5

5.3.2 Supplemental Considerations

1. **Bedding Recommendations**

- **Recommended Action:** It is recommended to suggest a preferred bedding of a compacted layer of 3/4 inches crushed quarry aggregate such as limestone or quartz, topped with an uncompacted, screedable sand layer of 1 1/2-2 inches, following the recommendation of ASTM C1675 (American Society for Testing and Materials (ASTM), 2022). To mitigate potential migration of fines and ensure long-term separation between the sand and underlying aggregate (and/or native subgrade), a non-woven geotextile separator layer is recommended at the interface.
- **Reasoning:** Based on feedback from interviews and surveys conducted with SDDOT personnel, contractors, and consulting engineers, we propose the previous bedding preparation guidelines to support consistent and durable RCBC installations across the state. These practices support drainage, uniform bearing, and long-term structural performance. These recommendations were developed as they were recurring in stakeholder responses, where many emphasized the need for proper foundation preparation to prevent settlement, joint misalignment, or premature deterioration. We recommend formalizing these practices to enhance long-term RCBC performance across diverse field conditions in South Dakota.

2. **Joint Integration Recommendations**

- **Recommended Action:** Enhance joint protection practices by installing mastic rope material in the joint around the entire joint perimeter of the box section for all standard installations and require a mastic joint wrap at least 9" wide on top and sides of the box culvert joints for culverts exposed to higher water pressures or potential joint movement (e.g., under rivers or streams, skewed culverts, or areas with high groundwater). All sealants and gaskets should comply with ASTM C990 (American Society for Testing and Materials (ASTM), 2019), C877(American Society for Testing and Materials (ASTM), 2021), and C920 (American Society for Testing and Materials (ASTM), 2018)).

- **Reasoning:** Current SDDOT practice involves applying mastic up to 1 ft from the flowline, bolting sections together, and wrapping the exterior with drainage fabric. While effective for standard conditions, extending the mastic around the entire perimeter provides a more continuous and reliable seal without significant additional cost or installation complexity. For higher-stress environments, butyl gaskets provide a flexible, self-sealing barrier that accommodates joint movement and resists hydrostatic pressure, improving long-term durability. This approach is supported by the practices of 11 of the 19 states that responded to the survey. For instance, the Iowa DOT requires a 2-ft-wide fabric wrap and butyl gaskets for all precast culvert installations, a method shown to enhance joint leak resistance and service life.

3. **Hybrid Approach (Precast Barrel with CIP Ends)**

- **Recommended Action:** Encourage more frequent utilization of hybrid construction approaches using precast barrels with CIP ends when site-specific factors, such as skewed geometry, flared wingwalls, or restricted access, make full precast construction impractical. This option should be incorporated into design plans through a plan note and standardized detail, allowing contractors flexibility to propose hybrid solutions that best suit project conditions.
- **Reasoning:** Hybrid construction combines the speed, quality control, and durability of precast elements with the geometric adaptability of cast-in-place construction. This configuration improves constructability and cost-effectiveness, particularly for culverts with high skew angles or nonstandard end conditions. Survey and interview feedback highlighted the practicality of this approach, which is consistent with the trend in several surrounding states to use mixed precast/CIP systems under challenging field conditions. Incorporating detailed connection provisions for load transfer, joint alignment, and hydraulic performance will ensure structural integrity and facilitate broader implementation within SDDOT projects.

4. **Multiple Cells**

- **Recommended Action:** Specify single-cell precast units when feasible to simplify transportation, handling, and installation; double-units may be used where project conditions or contractor preference make them advantageous.
- **Reasoning:** Using multiple single-cell units reduces the need for oversized transport permits, specialized cranes, and complex lifting operations. This configuration enhances constructability and safety while minimizing installation time and logistical costs. Neighboring states, including Minnesota, and Iowa, commonly apply this approach to improve efficiency and reduce risks associated with large multi-cell precast components. Adopting this practice would bring SDDOT in line with regional standards and improve constructability for projects across varying site conditions.

5. **Partnership with regional box culvert producers**

- **Recommended Action:** Establish a formal partnership between SDDOT and regional precast producers to collaboratively address design and constructability challenges, especially those related to skewed configurations, variable fill heights, and transportation limitations. As part of this effort, SDDOT should request that fabricators statewide collaboratively develop and submit standardized details for review and approval by SDDOT/OBD. The partnership should include annual review meetings to discuss ongoing project feedback, evaluate performance, and update standard drawings or specifications as needed.
- **Reasoning:** Regular engagement between SDDOT and industry producers promotes consistency, innovation, and practical design development. Collaboration could support the creation of standardized skewed end details, variable-length precast sections, and more constructible, cost-effective solutions tailored to South Dakota's roadway conditions.

5.4 Recommendation for the SDDOT Bridge Manual

Based on survey results, interview feedback, and a review of neighboring state DOT practices, several updates are recommended for **SDDOT Bridge Manual Section 4.1.2.1.1** to better reflect current constructability considerations, material availability, hydraulic requirements, and industry capabilities. The proposed revisions modernize guidance on when to provide CIP and precast box culvert options and clarify the conditions under which each alternative is appropriate.

The final updated manual language would read (with **proposed changes highlighted in blue** and **relocated text in green**):

"…Normal practice for state highways is to provide plans for a cast-in-place box culvert installation and include an option for a precast concrete culvert installation unless the following conditions apply:

- **For skewed box culvert installation with skews 45 degrees or greater.**
- Special culvert end treatments that are not approved by the OBD and are determined necessary (flared wing walls, slope tapered aprons, side tapered inlets, skewed end sections, water control structures, etc.).
- **When rise exceeds 14 feet.**
- **When the proposed box culvert installation does not exceed 30 degrees, a precast box culvert option with an approved skewed end sections will be provided in the plans.**
- **When the proposed box culvert installation has a skew of 30 to 45 degrees, a precast box culvert option with an approved skewed end sections may be provided in plans after evaluating site-specific conditions, constructability challenges, cost impacts, availability, and at the discretion of the Chief Bridge Engineer.**

When specifically requested by the Region/Area office, plans may call for individual sites to be strictly precast type culvert installations (with no cast-in-place option) under the following circumstances:

- **Limited availability of ready-mix concrete.**
- **Need to minimize traffic impacts.**
- **Short-rise culverts (4 feet or less).**

Exceptions to these general rules may be considered where individual culvert site conditions allow. For instance, a culvert placed diagonally underneath a roadway intersection may fit better with zero skew (square) end sections and therefore a precast option could be viable there even though skew exceeds **30** degrees. Other site conditions such as depth of fill, size of culvert, channel configuration/depth, etc. may also be considered when evaluating viability of precast options. The decision whether to utilize options or not for locations with special conditions will be made during the structure TS&L inspection (with input from participants) and reflected in the site inspection report letter.

Individual culvert options may be composed of both precast and cast-in-place portions with the approval of the Chief Bridge Engineer.

Multiple barrel precast box culvert options maybe composed of the multiple precast single cell boxes with the approval of the Chief Bridge Engineer.(i.e.: Triples maybe composed of a double and a single side by side or three singles side by side)…”

6.0 RECOMMENDATIONS

This chapter presents key recommendations for updating the SDDOT Bridge Manual and improving decision-making for RCBCs. The recommendations are based on interviews and surveys with different stakeholders, and a review of neighbor state DOT practices. Each recommendation includes a concise statement followed by supporting justification.

6.1 Modify Skew Limits for Precast RCBCs

Update the SDDOT Bridge Manual to provide a precast culvert option for culverts up to 30 degrees skew, consider precast options for skews between 30 and 45 degrees subject to special approval, and restrict precast options for culverts exceeding 45 degrees in skew.

SDDOT currently limits precast culverts to 10 degrees, but available data and practices in neighboring states indicate that higher skews can be accommodated without significant deterioration. Precasters typically manufacture standard skewed end sections at 15 degrees, 30 degrees, and 45 degrees. While SDDOT does not yet have approved precast details for skewed end sections, agencies such as MnDOT provide standard designs for 15 degrees, 30 degrees, and 45 degrees skews, which could serve as useful references for future development of SDDOT standards. Most surrounding states allow at least 30 degrees, and several permit up to 45 degrees (e.g., Iowa, Minnesota). While skews above 30 degrees may introduce constructability challenges, and higher costs, they are not uncommon in practice. Therefore, SDDOT could permit precast culverts up to 30 degrees by default, with the possibility of special approval for skews between 30 degrees and 45 degrees when justified by site conditions and supported by design detailing. For skews greater than 30 degrees, or those approved up to 45 degrees, additional requirements should address joint alignment, load distribution, and hydraulic performance. For skews above 45 degrees, CIP RCBC should remain the preferred option to ensure structural integrity.

6.2 Joint Integration Recommendations

Enhance joint protection practices by installing mastic rope material around the entire perimeter of the box section joint for all standard installations and require a mastic joint wrap at least 9 in. wide on the top and sides of the box culvert joints for culverts exposed to higher water pressures or potential joint movement, such as those located under rivers or streams, skewed culverts, or areas with high groundwater. All sealants and gaskets should comply with ASTM C990, ASTM C877, and ASTM C920.

Current SDDOT practice involves applying mastic up to 1 ft from the flowline, bolting sections together, and wrapping the exterior with drainage fabric. While this approach performs adequately under standard conditions, extending the mastic around the full perimeter would provide a more continuous and reliable seal without significantly increasing installation complexity or cost. For installations subjected to higher stresses or hydrostatic pressures, butyl gaskets and wider joint wraps provide additional flexibility and sealing capacity, helping accommodate joint movement and improving long-term durability. Survey responses indicated that 11 of the 19 responding states currently use enhanced joint sealing practices for precast culvert installations. For example, the Iowa

Department of Transportation requires a 2-ft-wide fabric wrap and butyl gaskets for precast culvert joints, a practice reported to improve leak resistance and long-term service performance.

6.3 Allow Precast-Only Installations for Specific Project Constraints

Use precast culverts: (i) when closest ready-mix concrete plant is more than approximately four hours away; (ii) when minimizing traffic disruption or meeting tight construction schedules is critical; and (iii) when the rise is 4 feet or less.

Precast production in controlled environments ensures consistent quality and eliminates risks related to delayed deliveries, loss of workability, or reduced concrete performance during long-distance transport. Precast units can also be installed quickly, minimizing lane closures and shortening overall project duration compared to cast-in-place alternatives. Additionally, current practice typically limits precast selection to culverts with a rise of 4 feet or less, as setting up and removing formwork for cast-in-place construction becomes difficult in shorter rises due to restricted access. 6

6.4 Incorporate More Often Hybrid (Precast-CIP) Options

Encourage more frequent utilization of hybrid construction approaches using precast barrels with CIP ends when site-specific factors, such as skewed geometry, flared wingwalls, or restricted access, make full precast construction impractical.

Hybrid construction combines the speed, quality control, and durability of precast elements with the geometric adaptability of cast-in-place construction. This configuration improves constructability and cost-effectiveness, particularly for culverts with high skew angles or nonstandard end conditions. Survey and interview feedback highlighted the practicality of this approach, which is consistent with the trend in several surrounding states to use mixed precast/CIP systems under challenging field conditions. Incorporating detailed connection provisions for load transfer, joint alignment, and hydraulic performance will ensure structural integrity and facilitate broader implementation within SDDOT projects.

6.5 Prioritize Single-Cell Units for Multi-Barrel Precast Culverts

Specify single-cell precast units when feasible to simplify transportation, handling, and installation; double-units may be used where project conditions or contractor preference make them advantageous.

Using multiple single-cell units reduces the need for oversized transport permits, specialized cranes, and complex lifting operations. This configuration enhances constructability and safety while minimizing installation time and logistical costs. Neighboring states, including North Dakota, Minnesota, and Iowa, commonly apply this approach to improve efficiency and reduce risks associated with large multi-cell precast components. Adopting this practice would bring SDDOT in line with regional standards and improve constructability for projects across varying site conditions.

6.6 Incorporate Recommended Revisions into the SDDOT Bridge Manual

Incorporate the proposed revisions presented into the SDDOT Bridge Manual to provide clearer and more comprehensive guidance for the selection and design of CIP and precast RCBC installations.

The recommended revisions will improve the current manual language by clarifying when CIP and precast alternatives should be included, establishing updated skew limitations for precast applications, identifying conditions where precast-only installations are appropriate, and recognizing the use of hybrid precast/CIP systems and multiple single-cell precast configurations.

6.7 Partner with Precast Manufacturers

Encourage SDDOT to work directly with precast manufacturers to optimize unit design, joint detailing, and handling. Early collaboration can reduce installation errors, improve constructability, and streamline project schedules. Neighboring states, including Iowa and Minnesota, involve precasters during project planning to refine specifications and installation methods.

7.0 RESEARCH BENEFITS

The findings of this study on RCBC selection, design, and construction practices in South Dakota provide several concrete benefits for SDDOT, regional contractors, and the broader transportation community, particularly by improving cost efficiency, constructability, safety, and long-term performance of culverts.

- **Extended Service Life and Enhanced Durability:** By integrating decision-making criteria and design considerations, such as joint alignment and bedding practices, the research identifies strategies that improve culvert long-term performance. Condition ratings from the SDDOT RCBC database suggest that adherence to these criteria could extend service life, lower maintenance frequency, and reduce the occurrence of “Fair” or “Poor” ratings over time. Performance improvements can be tracked through periodic inspections and condition monitoring.
- **Direct Cost Savings:** Allowing both CIP and precast RCBC options, in combination with the research-based guidance on skew, rise, and multi-barrel configurations, enables contractors to select the most cost-effective alternative for each site. For example, longer or high-skew culverts can utilize CIP units to avoid expensive customization, while simpler configurations might be constructed as precast at lower cost. This flexibility is expected to reduce overall project costs.
- **Improved Work Efficiency and Reduced Construction Time:** The study demonstrates that hybrid systems and single-cell multi-barrel precast units could optimize installation, reduce on-site labor requirements, and minimize disruption to traffic. Field data from SDDOT and contractor interviews indicate that precast or hybrid installations can shorten construction schedules by several days to weeks per project compared to traditional CIP methods, particularly for short-rise and high-skew culverts.

8.0 REFERENCES

American Association of State Highway and Transportation Officials (AASTHO), & South Dakota Department of Transportation (SDDOT). (2025). Bridge Management (BrM). Retrieved 7 May 2025 from https://brm.sd.gov/

American Society for Testing and Materials (ASTM). (2018). ASTM C920 - Standard Specification for Elastomeric Joint Sealants. In. West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM). (2019). ASTM C990 - Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants. In. West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM). (2021). ASTM C877 - Standard Specification for External Sealing Bands for Concrete Pipe, Manholes, and Precast Box Sections. In. West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM). (2022). ASTM C1675 - Standard Practice for Installation of Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers. In. West Conshohocken, PA: ASTM International.

Chris Chubb Cartography. (2025). South Dakota State Maps. Retrieved 23 May 2025 from https://www.cccarto.com/states/southdakota-maps/

Federal Highway Administration (FHWA). (2025). LTBP InfoBridge. Retrieved 7 May 2025 from https://infobridge.fhwa.dot.gov/Home

Iowa Department of Transportation. (2024a). Final Bridge Design Software. Retrieved 11/05/2024 from https://iowadot.gov/bridge/Automation-Tools/Final-Design-Software#446761464-cip-reinforced-concrete-box-culvert-program

Iowa Department of Transportation. (2024b). LRFD Bridge Design Manual. https://iowadot.gov/bridge/design-policies/lrfddesignmanual

Iowa Department of Transportation. (2024c). LRFD Culvert Standards. Retrieved 11/05/2024 from https://iowadot.gov/bridge/Bridge-and-Culvert-Standards/LRFD-Culvert-Standards

Iowa Department of Transportation. (2024d). LRFD Precast Culvert Standards. Retrieved 11/05/2024 from https://iowadot.gov/bridge/Bridge-and-Culvert-Standards/LRFD-Precast-Culvert-Standards

Iowa Department of Transportation. (2024e). Pedestrian Tunnels Standards. Retrieved 11/05/2024 from https://iowadot.gov/bridge/Bridge-and-Culvert-Standards/Pedestrian-Tunnel-Standards

Minnesota Department of Transportation. (2024). LRFD Bridge Design Manual. https://www.dot.state.mn.us/bridge/lrfd.html

National Oceanic & Atmospheric Administration (NOAA). (2025). U.S. Climate Normals. Retrieved 23 May 2025 from https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals

South Dakota Department of Transportation (SDDOT). (2021). Section 4 Design. In South Dakota Bridge Design Manual. Office of Bridge Design. https://search.library.wisc.edu/catalog/9910071548102121

South Dakota Department of Transportation (SDDOT). (2025). South Dakota Regions. Retrieved 23 May 2025 from https://dot.sd.gov/projects-studies/construction-projects/

Weather Spark. (2025). Compare the Climate and Weather in Sioux Falls, Rapid City, Aberdeen, and Pierre. Retrieved 23 May 2025 from https://weatherspark.com/compare/y/9059~4074~7277~5299/Comparison-of-the-Average-Weather-in-Sioux-Falls-Rapid-City-Aberdeen-and-Pierre

Appendix A: Preliminary Interviews Questions

DOT Personnel

1. What criteria do you consider when recommending either a cast-in-place or precast RCBCs during the TS&L site inspection?
2. What are the main advantages and disadvantages of cast-in-place culverts compared to precast culverts?
3. Are there precast RCBCs in your region with more the 10 degree skew, flared wing walls , or tapered/customized inlet or outlets with or without parapets? If so please describe the project. How are they performing?
4. How do you weigh the initial RCBC installation cost against long-term performance for cast-in-place versus precast RCBCs?
5. What are common issues you have encountered with cast-in-place RCBC during construction? How have you addressed them? What improvements can be made?
6. What are common issues you have encountered with pre-cast RCBC during installation? How have you addressed them? What improvements can be made?
7. How does the SDDOT monitor and evaluate the long-term performance of cast-in-place and precast RCBC across the state?
8. In your opinion, which type of culvert typically lasts longer? How long does a pre-cast RCBC last and how long for cast-in-place?
9. What are common issues you have encountered with cast-in-place RCBC over time? How have you addressed them? What improvements can be made?
10. What are common issues you have encountered with pre-cast RCBC over time? How have you addressed them? What improvements can be made?
11. Do you see more scour/undermining issues with pre-cast or cast-in-place RCBC? Where is the scour located (ie behind the wings, undermining the apron, etc)?
12. Are there any improvements you would suggest to the current RCBC guidelines specified in the Bridge Design Manual?
13. What typical maintenance repairs are required on pre-cast RCBC? What typical maintenance repairs are done on cast-in-place RCBC? Which type of culvert typically requires less maintenance? What are the main differences?
14. How does SDDOT incorporate feedback from ongoing projects into the Office of Bridge Design?
15. Have you ever faced availability issues when precast RCBCs are used?

MnDOT/Iowa DOT

1. Please summarize RCBC guidelines for MN/IA. How were they established and when?
2. How well are the guidelines working? What is working well and what are some opportunities for improvement?
3. Does MN/IA have a preference between pre-cast RCBC and cast-in-place. What is the preference based on?
4. In your opinion, what are the main advantages and disadvantages of cast-in-place culverts compared to precast culverts?

5. Are there site conditions or dimension limitations that influence the decision for each RCBC type?
6. Does MN/IA allow pre-cast RCBC with more the 10 degree skew, flared wing walls , or tapered/customized inlet or outlets with or without parapets? If so please describe the project. How are they performing?
7. What are common issues you have encountered with pre-cast RCBC during installation? How have you addressed them? What improvements can be made?
8. What are common issues you have encountered with cast-in-place RCBC during construction? How have you addressed them? What improvements can be made?
9. How do you weigh the initial RCBC installation cost against long-term performance for cast-in-place versus precast RCBCs?
10. How does the MN/IA monitor and evaluate the long-term performance of cast-in-place and precast RCBC across the state?
11. What are common issues you have encountered with pre-cast RCBC over time? How have you addressed them? What improvements can be made?
12. What are common issues you have encountered with cast-in-place RCBC over time? How have you addressed them? What improvements can be made?
13. How does MnDOT/Iowa DOT incorporate feedback from ongoing projects into the design guidelines?

Engineer Consultants

1. What are your criteria for choosing between cast-in-place and precast RCBCs designs? Do you have a preference? Why?
2. What are the main advantages and disadvantages of cast-in-place culverts compared to precast culverts?
3. Have you ever recommended a pre-cast RCBC with more than 10-degree skew? What is the maximum skew angle? Have you manufactured pre-cast RCBC with flared wing walls, or a tapered or customized inlet or outlets with or without parapets? If so please describe the project. How are they performing?
4. Are there site conditions, dimension limitations, or hydraulic considerations that influence the decision for pre-cast and cast-in-place RCBCs?
5. How do you weigh the initial installation cost against the potential long-term performance for cast-in-place versus precast RCBCs?
6. What are common issues you have encountered with pre-cast RCBC during installation? How have you addressed them? What improvements can be made?
7. What are common issues you have encountered with cast-in-place RCBC during construction? How have you addressed them? What improvements can be made?
8. Which factors most significantly impact the cost-effectiveness of precast or cast-in-place projects? Is one type typically less expensive?
9. What factors do you consider critical for ensuring the long-term performance of precast or cast-in-place RCBC?

10. What are common issues you have encountered with pre-cast RCBC over time? How have you addressed them? What improvements can be made?
11. What are common issues you have encountered with cast-in-place RCBC over time? How have you addressed them? What improvements can be made?
12. Based on your experience, what enhancements would you recommend for the SDDOT Bridge Design Manual to better guide the selection of RCBC construction types?
13. Do you currently use any decision-making framework to decide whether to design cast-in-place or precast RCBCs?

Precast Suppliers

1. What challenges do you face in transporting and installing large precast RCBC components? What is the maximum pre-cast RCBC length, width, and height?
2. Have you manufactured pre-cast RCBC with more the 10-degree skew? What is the maximum skew angle? Have you manufactured pre-cast RCBC with flared wing walls, or tapered or customized inlet or outlets with or without a parapet? If so please describe the project. How are they performing? Who was the owner?
3. What are common issues you have encountered with pre-cast RCBC during installation? How have you addressed them? What improvements can be made?
4. What are some of the common mistakes installation contractors make when installing precast RCBC?
5. What can the DOT do to ensure a high-quality installation of precast RCBC from the supplier's perspective?
6. Are there certain site conditions a pre-cast RCBC is not suited for?
7. What quality assurance protocols are used to ensure the integrity of pre-cast components fitting together?
8. What are common issues you have encountered with pre-cast RCBC over time? How have they been addressed? What improvements can be made?
9. How could you implement standard plates into your design and fabrication of precast box culverts for SDDOT to use?
10. What can be done to economize box culvert fabrication and speed fabrication?
11. What steps do you take to stay updated with industry design detailing changes? Are you aware of pre-cast RCBC details used by other producers to address skew or flared wingwall?
12. On SDDOT projects with an alternate for cast-in-place or Precast RCBC, is the playing field fair or does one of the products have a fair or unfair advantage? What is the advantage?
13. What are the challenges in supplying precast concrete RCBC in a timely fashion for construction projects? What can be done to improve the supply chain?
14. How has the demand for pre-cast RCBC changed over the years?

Highway Superintendents

1. What are your criteria for choosing between cast-in-place and precast RCBCs? Do you have a preference for cast-in-place or pre-cast? What is based on?

2. What are the main advantages and disadvantages of cast-in-place culverts compared to precast culverts?
3. Are there site conditions, dimension limitations, or hydraulic considerations that influence the decision for pre-cast and cast-in-place RCBCs?
4. Are there more pre-cast or cast-in-place RCBCs in your county?
5. Are there precast RCBCs in your county with more the 10-degree skew, flared wing walls, or tapered or customized inlets or outlets with or without parapets? If so please describe. How are they performing?
6. How do you weigh the initial installation cost against the potential long-term performance for cast-in-place versus precast RCBCs?
7. Which type of culvert typically lasts longer? How long does a pre-cast RCBC last and how long for cast-in-place?
8. What are common issues you have encountered with pre-cast RCBC over time, and how have you addressed them? What improvements can be made?
9. What are common issues you have encountered with cast-in-place RCBC over time, and how have you addressed them? What improvements can be made?
10. Have you seen more scour/undermining issues with pre-cast or cast-in-place RCBC? Where is the scour located (ie behind the wings, undermining the apron, etc)?
11. Which type of culvert typically requires less maintenance? What are the main differences?
12. Have you ever faced availability issues when precast RCBCs are used?

Structural Contractors

1. When given an option, what are your criteria for choosing between a cast-in-place and pre-cast RCBC
2. What are the main advantages and disadvantages of cast-in-place culverts compared to precast culverts?
3. In your opinion, which culvert type lasts longer? Which is a better product for the cost of installation?
4. Please describe the most common challenges you face during the installation of precast RCBCs. How have you addressed them? What improvements can be made? Please describe the advantages of pre-cast RCBC installation over cast-in-place
5. What quality control procedures do you implement when installing precast RCBCs?
6. Please describe the most common challenges you face during the construction of cast-in-place RCBCs. How have you addressed them? What improvements can be made? Please describe the advantages of cast-in-place RCBC installation over pre-cast.
7. Have you installed a precast RCBC with more than a 10 degree skew? What is the maximum skew angle? Have you ever installed a pre-cast RCBC with flared wing walls, or tapered /customized inlets or outlets with or without parapets? If so please describe the project. What, if any difficulties, were encountered? Who was the owner?
8. What advancements in technology have impacted precast RCBC installations most significantly in recent years?
9. Have you ever faced availability issues when precast RCBCs are used?

Appendix B: State DOT Survey Results

Q1. Does your state use precast RCBC? If so, what are the guidelines between choosing a precast RCBC and a Cast-in-place (CIP) RCBC? Would you please share a link to those guidelines in the space below?

- **Pennsylvania:** "Directly from our Design manual Part 4 policy section. Design manual Part 4. 7.3.2 Concrete Box Culvert Alternatives The procedure regarding concrete box culvert alternatives shall be as follows: (a) A precast concrete box culvert shall be prepared as a primary design, with a cast-in-place (CIP) concrete box culvert as a contractor-designed alternate, unless it can be documented that a precast concrete culvert is not suitable for a specific site, e.g., non-uniform bearing strata, cost ineffectiveness. If hydraulically and structurally feasible, both precast and CIP concrete box culverts shall be allowed as alternates for a CIP concrete arch and other small steel or concrete bridges, unless documented environmental restrictions for natural streambed preservation control. (b) The entire culvert, wingwalls, apron and incidental excavation and backfill for the box, wings and aprons shall be included in the lump sum culvert item, except for reinforcement bars which are "AND Items". List culvert length in feet, excavation and backfill in cubic yards, and concrete quantities for wings and aprons in terms of cubic yards in the quantity table as information items and on the Component Item Schedule in the Proposal."
- **Washington: "**Yes, we use precast reinforced concrete bridge culverts. We do not use CIP, but do not preclude them either. We give information on our buried structures in our Standard Specifications, section 6-20 as well as our Bridge Design Manual Section 8.3."
- **Illinois: "**IL uses precast concrete box culverts. The guidelines are general and are left up to district preference, unless settlement precludes a precast culvert. We also allow substitution of a precast box for a cast-in-place culvert unless the designer specifically precludes it via a note on the plans. The IDOT Culvert Manual is found here: IDOT Culvert Manual."
- **Missouri: "**Yes, we allow the use of Precast RCBC. It is to follow EPG 751.8.1.5 and Standard Specifications 733. Precast RCBC are not allowed on rock, when multiple bends are required or for multi-cell RCBC where USACE provisions require modifications to allow for passage of aquatic life. EPG 751.8.1.5. Standard Specifications 733."
- **Idaho (1): "**ITD primarily utilizes precast RCBC. While there isn't a strict policy dictating the choice between precast and CIP, ITD generally uses precast due to its ability to expedite construction and reduce traffic disruptions. In cases involving skews over 25 degrees, skewed structures built in stages, or those requiring longer spans, CIP may be chosen as a more suitable option."
- **Idaho (2): "**No, we do not have any written guidelines when selecting between a CIP or precast box culvert, however, the designer writes a report at concept and weighs different project considerations when making a selection. Factors include: limitations of culvert sizes and skews for the precasters, cost, construction schedule, and project location. After weighing the different factors, the engineer makes a selection that best meets the project needs."
- **Colorado: "**Yes. No defined guidelines but usually controlled by desire to shorten construction time and reduce traffic control. Contractor may value-engineer in precast for cast-in-place shown in plans."

- **Texas: "**Yes. No specific guidance. Always directed to provide both the precast and CIP standards in the plan set."
- **Kansas (1): "**Kansas allows a precast option. Guidelines are listed in Kansas' Bridge Design Manual. Precast RCBCs are not to be used when: the structure is on highly erodible soils or poor foundation materials; the top of the structure will be the wearing surface; the structure will be located within an MSE wall, extending an existing box structure; and there could be settlement of the base material. The Kansas Bridge Design Manual can be downloaded from KART after signing up for a free account. Information on RCBCs can be found in Section 12."
- **Kansas (2): "**Kansas allows a precast option. Guidelines are listed in Kansas' Bridge Design Manual. Precast RCBCs are not to be used when: the structure is on highly erodible soils or poor foundation materials; the top of the structure will be the wearing surface; the structure will be located within an MSE wall, extending an existing box structure; and there could be settlement of the base material. The Kansas Bridge Design Manual can be downloaded from KART after signing up for a free account. Information on RCBCs can be found in Section 12."
- **Wisconsin (1):** "Yes, but CIP is preferred. Contractors are given the option through a contract plan note if they want to use RCBC, the designer shall determine if the precast culvert is allowed. In general, the intent is for the use of Standard Design per ASTM C1577. Cost is a big factor as RCBC costs more, the note is given to provide more flexibility to contractors on CIP plans with the option to provide alternatives. Chapter 36, section 36.12 of the WisDOT bridge manual provides further guidance. Other factors on deciding if RCBC can be used include the structure skew, fill, hydraulic conditions, size, and if it's a pedestrian underpass."
- **Wisconsin (2): "**WisDOT allows the use of precast box culverts as an alternative to the designed cast-in-place concrete box culvert ""standard"". There are certain times where precast is mandated, but that decision is made on a case-by-case basis. One example of this is where a box culvert is being replaced under a railroad track that only has a limited outage window, so CIP won't allow that to happen. Box culvert design information can be found in our Bridge Manual here and in our Standard Details here.
- **Wyoming:** "Yes, we typically use precast box culverts for new structures."
- **North Carolina:** See Chapter 9 of the Structure Design Manual available via the following link: Chapter 9 of the Structure Design Manual"
- **Virginia: "**Yes, VDOT uses RCBC. We have design standard drawings for RCBC. These standards are for CIP RCBC. If the contractor chooses to use precast RCBC, they need to submit a request to VDOT for approval. Section 1000. section 302.03 (b)."
- **South Carolina:** "We do allow the use of precast box culverts. We do not have any written guidelines when to use one or the other. But we prefer cast-in-place when practical to do so."
- **North Dakota: "**Our standard practice is to use precast RCBCs. In the past we prepared plans containing both precast and CIP box culvert options and bid both alternates in the plans. We found that the CIP alternate was never being utilized, only the precast option was being bid, and we stopped bidding alternates and switched to using precast RCBCs only."
- **Arizona: "**Currently we are working with our Roadway Group to develop guidelines for choosing PC RCBC. Mainly construction cost and duration will be emphasized. Structural design details for precast culverts"

- **Nebraska: "**We allow submissions for precast box culvert alternates to CIP designs. We stipulate that precast substitutes can only be used for the culvert barrels and end treatments (wings etc.) will still be CIP per the original designs."
- **Rhode Island:** "We use precast RCBC in Rhode Island typically. We do have CIP as well. RIDOT standard details, Bridge Design manual, Road-Stream Crossing Design Manual and other information can be found on our web site at the following locations: RIDOT - Contractors and consultants and RIDOT – Natural Resources Unit"
- **Michigan:** "Yes. We primarily use precast. In recent years, we've included the option for the contractor to cast boxes in place due to challenges with lead times of precast elements. We have no official guidelines regarding this."

Q2. How well are the guidelines working? What is working well and what are some opportunities for improvement?

- **Pennsylvania:** "we in general do not expect to see contractors bidding cast in place box culverts , our state has significant capacity provided from our precast producers to fit precast culverts of various sizes and skews. we have had issues in the past during initiatives to replace large amounts of structures that have outstripped our capacity that had some projects go CIP due to lack of plant availability but that is not generally an issue. other hardships culverts with heavy skews greater then 15 degrees."
- **Washington**: "N/A"
- **Illinois:** "Everything is working well. Both precast and cast-in-place boxes are used regularly."
- **Missouri:** "They are working well."
- **Idaho (1):** "ITD guidelines are not formal. ITD has considered developing selection guidelines, however, the need has not been urgent to date."
- **Idaho (2):** "N/A"
- **Colorado:** "We could codify requirements. No objective measurements yet on when precast should be used over cast-in-place."
- **Texas:** "Guidelines are working fine. It allows the contractor to select which will work best for his schedule and equipment."
- **Kansas (1):** "In late March, Kansas is meeting with the Missouri/Kansas Concrete Pipe Association who also represent the precast culvert industry. We'll be discussing these questions."
- **Kansas (2):** "They are adequate."
- **Wisconsin (1):** "Yes, the guidelines seem to be working well. Recent inquiries into more size options have been asked from contractors. The department is working to improve on non-standard designs (beyond ASTM C1577)."
- **Wisconsin (2):** "These guidelines seem to be working well with our contracting community in Wisconsin. Historically, contractors wanted to keep the work to themselves so we were traditionally a heavy CIP box state, but precast has become more and more popular as of late as staffing shortages have hit the workforce locally. We still do approximately 2/3 CIP and 1/3 precast in the typical year."
- **Wyoming:** "This works well."

- **North Carolina:** “The guidelines are working well and have not required revisions or updating for several years.”
- **Virginia:** “Working very well. We also have the design guidelines for large culvert”
- **South Carolina:** “Again, no written guidelines are currently available on choosing between precast and cast-in-place.”
- **North Dakota:** “We do not have guidelines for choosing between CIP and precast RCBCs. We are currently in the process of updating all of our guidelines for the design of precast RCBCs. Our old process required the fabricator of the precast box to provide the design and rating per AASHTO LRFD. This design would then be checked by the Engineer as part of the shop drawing review process. Our new process will require the Engineer to complete the design and rating of the precast box and all details necessary to fabricate and install the box will be provided in the plans.”
- **Arizona:** “Not there yet, but we hope to be able to use more PC culverts to expedite construction and reduce construction time.”
- **Nebraska**: “We believe they are working relatively well, but don't have enough feedback from known precast alternate jobs.”
- **Rhode Island:** “Structure types are left to the discretion of the consultant designer for specific sites and are in accordance with RIDOT policies, design standards, and manuals, as well as in conjunction with our local environmental permitting agencies. We have had no issues to my knowledge. Our local permitting agencies due prefer natural stream beds, so they tend to prefer the 3 sided precast culverts rather than the standard box, unless a natural stream bed is provided within the box culvert. \We have also had some issues with inverts of four sided box culverts not being set properly during construction, causing issues with scour and undermining. Joints between segments of precast boxes tend to be the biggest issue with joint material failing.”
- **Michigan:** “Contractors have elected to cast in place on at least 2 projects, and projects went well."

Q3. Does your state consistently offer the option to choose between precast and CIP RCBC? If so, which option typically gets awarded?

- **Pennsylvania:** “CIP option is always available as a contractor designed alternate as stated above. the precast is almost always built.”
- **Washington**: “Yes. Precast is typically awarded.”
- **Illinois:** ” See previous answer. It seems to be around 50/50.”
- **Missouri:** “Yes. In general, the simpler the RCBC, the more likely it is for it to be awarded/selected to go precast.”
- **Idaho (1):** “ITD has not offered the option to choose between precast and CIP.”
- **Idaho (2):** “Yes, we typically do not prohibit the use of either option. Precast typically gets selected more often since these structures are most often used for canal crossings and construction has to occur during irrigation winter shutdown, thus a very short window. Precast culverts are typically much quicker to build especially if construction requires two different stages to maintain traffic.”
- **Colorado:** “No. Plans usually just show one option but we can include standards in the bid documents.”

- **Texas:** “Yes. For the smaller box sizes, precast is usually selected. Large boxes, ie 9' x 9', could be either.”
- **Kansas (1):** “Yes, the option to use precast is noted on the cast-in-place standard plans. Cast-in-place is chosen more than precast.”
- **Kansas (2):** “Yes, the option to use precast is noted on the cast-in-place standard plans. Cast-in-place is chosen more than precast.”
- **Wisconsin (1):** “Yes, with most if not all of the new culvert CIP designs being given the option to use RCBC. CIP is typically awarded with an uptick in contractors choosing the precast RCBC alternative.”
- **Wisconsin (2):** “Yes, in most box culvert plans we allow the precast alternative. Approximately 2/3 remain CIP and 1/3 go to precast.”
- **Wyoming:** ” No, we do not give the option.”
- **North Carolina:** “Generally, CIP RCBC are shown in the let plans. However, see Section 9.3.2 of the manual for criteria permitting optional precast RCBC.”
- **Virginia:** “Yes. Many CRBC were built with precast CRBC.”
- **South Carolina:** “We do not typically do not give options in the plans that are let. However, contractors sometimes value engineer the option in the plans and the VE alternate is sometimes allowed.”
- **North Dakota:** “No. See answer to question 1.”
- **Arizona:** “Our Roadway Group has been slow in adopting the SD 6.20 developed in Bridge Group, but we're hoping they start specifying PC in their designs.”
- **Nebraska**: “It is my understanding the precast alternate is available on every state job that includes CBCs; however, CIP is primarily chosen for most projects.”
- **Rhode Island:** “Yes. Precast would be the predominant type of box culvert called for on the design plans. CIP RCBC is not typically specified.”
- **Michigan:** “Yes. Most often, precast is used.”

Q4. Does your state use standard plates, base sheets, or tables for the design of CIP RCBC and/or precast RCBC? If so, how were they developed?

- **Pennsylvania:** “we use standard details, we do not have "preset design tables" anymore. they are archived.”
- **Washington**: “Yes, we have developed Standard Plans for our precast buried structures. Buried Structure Split Box - Standard Plan E-20, 10-00 and Buried Structure Split Box - Standard Plan E-20, 20-00 With some updates per a Design Memo: Buried Structure Standard Plan Updates. These were developed with help from a consultant in running a lot of analysis.”
- **Illinois:** ”We have standard base sheets for both. They were developed over years of use. The oldest version of the standards is from 1963. The current versions can be found here (scroll down to "culverts" and "culvert end sections"): Standard Base Sheets for Box Culverts”
- **Missouri:** “Yes. These were developed internally using Finite Element Models and Spreadsheets for design checks.”
- **Idaho (1):** “ITD does not use standard plates, base sheets, or tables.”

- **Idaho (2):** “No, each culvert, regardless of precast, or CIP, is designed per project. If precast is used, it is a contractor design so they are required to hire a design engineer and submit culvert shop drawings for review and approval.”
- **Colorado:** “Yes. Originally developed decades ago but updated for AASHTO LRFD requirements. Used a designer and design checker for standard designs.”
- **Texas:** “"Yes. TxDOT - Bridge Standards. Precast were developed based on ASTM C1577. CIP were designed in house and based on AASTHO LRFD. "”
- **Kansas (1):** “Kansas uses standard plans for cast-in-place box culverts that are generated by an in-house program that is a database of specific box culvert configurations. The standards were originally designed in LFD using the North Carolina Box Culvert program. When the standards were checked for LRFD an in-house design program was developed by one of our engineers. A table of available box configurations is shown in the Kansas Bridge Design Manual, Appendix A12.”
- **Kansas (2):** “Kansas uses standard plans for cast-in-place box culverts that are generated by an in-house program that is a database of specific box culvert configurations and details. The standards were originally designed using LFD. When the standards were checked for LRFD an in-house design program was developed by one of our engineers. A table of available box configurations is shown in the Kansas Bridge Design Manual, Appendix A12.”
- **Wisconsin (1):** “Yes, there are standards for both CIP RCBC and precast options with caveats that certain elements still need to be designed. They were developed based on ASTM C1577 and design calculations.”
- **Wisconsin (2):** “Yes, we have Standard Details for both CIP and precast box culverts. We developed these in the past in conjunction with industry research and input from other state DOT's, etc.”
- **Wyoming:** ”No, we design cast-in-place box culverts using BRASS Culvert software supplemented with hand calc's if needed. Precast box culverts are designed by the precaster.”
- **North Carolina:** “No. NCDOT has an in-house developed software program to design CIP RCBCs for the specific site conditions including length, skew, number and size of barrels, fill height, etc. NCDOT does not design precast RCBCs.”
- **Virginia:** “We have the standards for CIP RCBC as explain for Question 1. We do not have those for precast. The contractor needs to design the precast RCBC.”
- **South Carolina:** “Standard Drawings are available for both precast and CIP culverts. They are produced by our Roadway Standards Group. The drawings are not project specific and custom drawings are required in the plans.”
- **North Dakota:** “No standards are currently being used. Each box culvert is designed individually. Historically, we relied on in-house software to design/check box culverts. In 2023 we transitioned to Eriksson Culvert for the design/check of box culverts. We are currently exploring the standardization of our precast boxes.”
- **Arizona:** “Tables. We started using AASHTO M259, and by the time we were ready to start using the SD's ASTM C1577 was the go to standard. We depended on FDOT's and TxDOT's standard drawings while developing ours, and had help from the industry.”
- **Nebraska**: “Not currently.”

- **Rhode Island:** “See the attached standard details at the above link for any applicable standard details or requirements. Consultant usually specified minimum design requirements and precast RCBC is designed by the precaster.”
- **Michigan:** “No. We refer to the ASTM standard, but also require that the RCBC be designed to accommodate our HL-93-Mod Loading, which is increased over HL-93 to account for our higher legal loads in Michigan. Our Standard Specifications require that the contractor design and load rate the new culvert prior to fabrication.”

Q5.a. Does your state place limitations on the use of precast RCBC due to: - a. Skew? If your state allows precast RCBCs with skew angles greater than 10 degrees, how have they performed in practice? Are they more economical than CIP RCBC?

- **Pennsylvania:** “we have a separate standard for skews greater then 15 degrees, they perform fine but have fabrication concerns. precast is again the preferred option”
- **Washington**: “45 degrees per our BDM 8.3.6.A.1.”
- **Illinois:** ”No limitation. Usage seems to be based more on district engineer preference than on a tangible study. They are more economical a lot of the time, but we don't directly compare the two costs very often.”
- **Missouri:** “MO”
- **Idaho (1):** “ITD allows up to 25 degrees.”
- **Idaho (2):** “It is typically dependent on the precasters capabilities at their plant. Most say, they can precast boxes up to 45 deg, but cost more since they require more time to reset forms. Typically we limit the precast section to 25 deg. Anything beyond that we provided square sections and then provide a CIP skewed end section. We have not noticed any issues in performance.”
- **Colorado:** “Performed well so far. Ends are typically cast in place”
- **Texas:** “Yes, skews are allowed. Box Culverts Precast Miscellaneous Details”
- **Kansas (1):** “No limit listed in the design manual. CIP end sections are used when the precast cells are used on skews.”
- **Kansas (2):** “No limit listed in the design manual.”
- **Wisconsin (1):** “Yes, allowed up to 30 degrees. No, they are not more economical than CIP but typically perform just as well.”
- **Wisconsin (2):** “We allow precast boxes up to 30 degrees in skew, and they've performed OK to date. That said, we don't have a long history with precast box culverts in our state.”
- **Wyoming:** ” no”
- **North Carolina:** “See manual for criteria.”
- **Virginia:** “No.”
- **South Carolina:** “No”
- **North Dakota:** “In the past we limited precast to 15 degree skews. Recently we have allowed precast boxes with skews of up to 30 degrees. Higher skew precast boxes have been in place for less than 5 years with no problems to date. We are working on new details for to construct and backfill the staggered ends of skewed precast boxes with straight wingwalls.”
- **Arizona:** “15 degrees max”

- **Nebraska**: "yes"
- **Rhode Island:** "See design manual for specific requirement. Yes, precast is more economical."
- **Michigan:** "No. We work with fabricators do determine what is a reasonable skew."

Q5.b. Does your state place limitations on the use of precast RCBC due to: - b. Flared Wingwalls? If flared wingwalls are used in your state, how have they performed? Can you share the details?

- **Pennsylvania:** "they have been standard details for considerable time and have performed well. Design standard"
- **Washington**: "Wingwalls are typically separate structures. We reference our Standard Plans (D-3.09 and D-20.10). We can also use our CIP reinforced concrete standard plans. See our D-10 series"
- **Illinois:** "No limitation. See previous response for base sheets. There are CIP wingwalls, sheet pile wingwalls, and soldier pile wall details on that website."
- **Missouri:** "MO"
- **Idaho (1):** "ITD allows flared wingwalls and the work well"
- **Idaho (2):** "Try to provide wingwalls at 45 deg to the culvert, but dependent on the topography and ROW limitations if adjustments need to be made."
- **Colorado:** "have not used precast wingwalls generally. cast-in-place have performed well"
- **Texas:** "No limit."
- **Kansas (1):** "Precast wings are not allowed at stream crossings. Flared wingwalls are used in Kansas for most of our box culverts and are preferred. They have performed adequately."
- **Kansas (2):** "Precast wings are not allowed at stream crossings. Flared wingwalls are used in Kansas for most of our box culverts and are preferred. They have performed adequately."
- **Wisconsin (1):** "Precast wings are relatively new and appear to be performing well."
- **Wisconsin (2):** "Yes, they have performed well in most cases. The link to our Standards was shared in a previous question."
- **Wyoming:** " Yes we use flared wingwalls and they have performed well. We have standard designs for these wingwalls from zero to 45 degree skew."
- **North Carolina:** "See Section 9.4.9"
- **Virginia:** "No."
- **South Carolina:** "Flared wingwalls are typically used. No data on their performance. We can provide example plans upon request."
- **North Dakota:** "Flared wingwalls were our standard until 2023. In 2023, due to supply issues, we changed to straight wingwalls. Design and details of the precast flared wings was the responsibility of the fabricator. We have no known issues with the flared wings."
- **Arizona:** "They fared well. They have to be CIP for PC culverts."
- **Nebraska**: "yes"
- **Rhode Island:** "See attached design guidance at links provided above. RIDOT does use flared wingwalls and they have performed well. See attached links for any standard details."
- **Michigan:** "No limitation on flared wingwalls"

Q5.c. Does your state place limitations on the use of precast RCBC due to: - c. Span/Rise?

- **Pennsylvania:** "spans over 40' have been done we do not limit"
- **Washington**: "N/A"
- **Illinois:** " We follow the ASTM standards. If a larger box is required, we allow it but it requires a structural engineer seal. This is not common."
- **Missouri:** "16 feet (max span of state standards)"
- **Idaho (1):** "Span limited to 20' unless coordination with fabricator allow greater."
- **Idaho (2):** "No limits. Just dependent of precast capabilities."
- **Colorado:** "limited to ASTM C1577 without special design"
- **Texas:** "No limit."
- **Kansas (1):** "None listed in the design manual. This is typically dictated by the fabricators."
- **Kansas (2):** "None listed in the design manual."
- **Wisconsin (1):** "Span/Rise limits are typically based on ASTM C1577 (12ft span max/12ft rise max). Draft specifications are looking at prohibiting precast box spans greater than 15-ft. Other designs may be considered with approval."
- **Wisconsin (2):** "We follow ASTM C1577."
- **Wyoming:** "max precast span we've used is 20 ft."
- **North Carolina:** "See manual"
- **Virginia:** "No.
- **South Carolina:** "No."
- **North Dakota:** "Span/Rise is limited only by what the precast suppliers can fabricate and ship."
- **Arizona:** "Yes"
- **Nebraska**: "possibly"
- **Rhode Island:** "See design guidance at links provided above."
- **Michigan:** "Limited based on available fabricator limitations and hauling requirements. no standard limitations on this."

Q5.d. Does your state place limitations on the use of precast RCBC due to: - d. Depth of fill?

- **Pennsylvania:** "50' + requires an additional review step but is allowed, we have records of culverts at 80' of fill depth."
- **Washington**: "up to 30 feet for some of our design spans"
- **Illinois:** " No limits"
- **Missouri:** "50 feet (max design fill of state standards)"
- **Idaho (1):** "No limits"
- **Idaho (2):** "No limits."
- **Colorado:** "no limits, but may require special design"
- **Texas:** "Different standards are designed to different fill heights."
- **Kansas (1):** "Requirements listed in the Kansas specifications for Precast Reinforced Concrete Box"
- **Kansas (2):** "Requirements listed in the Kansas specifications for Precast Reinforced Concrete Box."
- **Wisconsin (1):** "Minimum of 2'-0" of fill."

- **Wisconsin (2):** “No.”
- **Wyoming:** ” We try go get a min of 18 inches over the top of a culvert, but do have some that are at grade box culverts”
- **North Carolina:** “See manual”
- **Virginia:** “No.”
- **South Carolina:** “No”
- **North Dakota:** “No current limitations.”
- **Arizona:** “Yes. 2' min. 20' max.”
- **Nebraska**: “possibly”
- **Rhode Island:** “See design guidance at links provided above.”
- **Michigan:** “NO”

Q5.e. Does your state place limitations on the use of precast RCBC due to: - e. Hydraulic Conditions/Scour? What type of RCBC (precast or cast-in-place) is typically preferred for high-flow areas, and why?

- **Pennsylvania:** “no preference based on flow”
- **Washington**: “See BDM 8.3.3.D which refers to BDM 7.1.7 and 8.1.10 for scour.”
- **Illinois:** ” We use vague language like "not recommended in scour conditions for precast culverts." See Culvert Manual, linked above, and do a word search for "scour."”
- **Missouri:** “not aware of any”
- **Idaho (1):** “ITD has not specified type due to scour.”
- **Idaho (2):** “We do not distinguish between CIP vs precast for high-flows. Which ever is selected, countermeasures have to be met for scour mitigations usually in the way of a cut-off wall.”
- **Colorado:** “no limitations at this time”
- **Texas:** “no preference”
- **Kansas (1):** “None listed in the design manual.”
- **Kansas (2):** “Cast-in-place is preferred for high-flow/scour conditions. Precast Boxes do not tolerate scour and undermining erosion as well as cast in place RCBs. When the local support is gone the box segments settle, opening joints, thus allowing road fill to escape.”
- **Wisconsin (1):** “CIP”
- **Wisconsin (2):** “No recommendations given in our guidance.”
- **Wyoming:** ” Either precast or cast-in-place is allowed”
- **North Carolina:** “See manual”
- **Virginia:** “The designer needs to assess.”
- **South Carolina:** “No. No preference.”
- **North Dakota:** “We do not have any limitations on the use of precast boxes based on hydraulic criteria. Precast RCBCs are specified anywhere a concrete box culvert is a hydraulically viable structure.”
- **Arizona:** “If hydraulics recommend an RCBC; the designer can choose either”
- **Nebraska**: “.”
- **Rhode Island:** “See design guidance at links provided above.”
- **Michigan:** “RCBC are generally sized such that ordinary high water stream width is accommodated.”

Q5.f. Does your state place limitations on the use of precast RCBC due to: - f. Other Limitations?

- **Pennsylvania:** “no”
- **Washington**: “See our BDM 8.3.6.A.1”
- **Illinois:** ” Settlement and clogging from debris”
- **Missouri:** “Not that I can think of”
- **Idaho (1):** “Stage of skewed structures sometimes precludes precast”
- **Idaho (2):** “none”
- **Colorado:** “none”
- **Texas:** “none”
- **Kansas (1):** “None”
- **Kansas (2):** “none”
- **Wisconsin (1):** “Pedestrian or Cattle pass use.”
- **Wisconsin (2):** “36.12 in the WisDOT Bridge Manual covers different limitations for use of precast.”
- **Wyoming:** ” None”
- **North Carolina:** “See manual”
- **Virginia:** “We do not the segment size during the design phase. The segment size affects the design.”
- **South Carolina:** “Geotechnical. Sometimes we prefer CIP over precast in soft soils. We believe CIP will bridge over areas of differential settlement better.”
- **North Dakota:** “None”
- **Arizona:** “None”
- **Nebraska**: “number of barrels”
- **Rhode Island:** “See design guidance at links provided above.”
- **Michigan:** “NO.”

Q6. How does your state ensure joint integrity in precast RCBC? What, if any, failures have you experienced during installation or over time? What sealing materials or methods do you recommend for the joints?

- **Pennsylvania:** “"we use a ship lap joint with neoprene material and waterstop. Design standard sheets 6-7 cut off wall and rock lining"”
- **Washington**: “See our BDM Section 8.3.6.A.3. Shear transfer is addressed in Section 8.3.5.A.2.”
- **Illinois:** ”Mastic joints and sealing bands are used. Neither are very popular with contractors. Sealing bands are less messy but cannot be installed on the bottom of the culvert very easily.”
- **Missouri:** “By inspection during construction. We're not seeing failures over time. Joints are as Specified in Standard Spec. 733.”
- **Idaho (1):** “ITD has typically used a z joint or grouted key. We have seen leaking of these type of joints. ITD has discussed using UHPC joint connections, but has not used this connection yet.”
- **Idaho (2):** “"We require the precaster do a complete fit up in the yard to ensure all joints line up and then each segment must be labeled so they can be placed in the same order in the field. We require a male/female joint fit-up at each segment. A joint sealant that meets the requirements of ASTM C990 is provided at the center of the joint on all four sides. If the joint is required to be

water tight, as is our requirement for pedestrian pathways, then non-shrink grout is placed above the joint sealant to fill the remaining opening of the joint. We then place a 12"" wide joint wrap (ASTM C877) over the joints along the walls and top slab. Finally we apply a waterproofing system on top of the top slab before backfilling the culvert. Waterproofing system is a pre-coated, preformed membrane sheet that is either self-adhesive or uses a separate bonding agent to adhere to the concrete surface. Joints typically hold up well as long they are constructed properly. Contractor must exercise care when constructing the precast culvert. Often times, if the ground is not level, then there are fit-up issues, or when setting the segments they damage the joint keys. Both cause irregular joints that could cause leakage issues."

- **Colorado:** "Require Joint Material per C990 6.1 or 2 or Rubber Gaskets per C1677. Over time they can start leaking and cause deterioration. Rubber Gaskets may be most durable?"
- **Texas:** ""Joints are covered by spec items 464 and 462. We occasionally see leaking joints. This is handled by sealing at later date. If concerned about a tight seal, rubber gaskets may be the way to go. This is what we do when we need a water tight seal. "
- **Kansas (1):** "Details are shown in bridge standard BR031 which can be provided."
- **Kansas (2):** "Details are shown in bridge standard BR031."
- **Wisconsin (1):** ""All joints are sealed with a preformed butyl rubber sealant in conformance with ASTM C990 section 6.2. A 2'-0" strip of geotextile type DF schedule A is placed over the joints on the top and sides of the culvert. The geotextile conforms to section 645.2.2.4 of the standard specification. Some spalling or settlement has been observed but performs well overall. Joint ties are required on skewed end sections. The designer may require use of joint ties throughout the culvert length."
- **Wisconsin (2):** "We require joints on all sides of the culvert to be sealed with a preformed butyl rubber sealant in conformance with ASTM C990 Section 6.2. A 2' strip of geotextile type DF schedule A is then placed over the joints on the top and sides of the culvert, in conformance with our standard specifications."
- **Wyoming:** "AASHTO M198 joint filler supplied by the precaster. We've had pretty good success with this material."
- **North Carolina:** ""See special provision available via the following link: Special provision""
- **Virginia:** ""The contractor usually provides tongue-groove joints and uses sealant or gasket we approved. We use sealing materials from List 14. ""
- **South Carolina:** "Visual inspection. No data available on failures. Use flexible preformed joint material meeting ASTM C990."
- **North Dakota:** ""Below is our spec for sealing joints. The main issue we have had with the precast box culvert joints is the gaps between segments are larger than 3/4"". This is sometimes due to poor construction methods and sometimes poor control of fabrication tolerances. Install the barrel sections so that joints between sections fit as tight as possible, with a maximum gap of 3/4 inch wide. Connect each section using the approved ties before setting the next section. Provide watertight joints on the floor, on the exterior walls, and roof using a preformed mastic meeting ASTM C 990. Use a waterproof membrane that is a minimum of 12 inches wide. Prepare the walls and roof exterior surface of the joint according to the waterproof membrane manufacturer's recommendation. Roll the membrane to the surface keeping it free of wrinkles and bubbles. Lap

waterproof membrane joints a minimum of 2.5 inches. Seal the joints and exposed edges with a joint sealing mastic recommended by the manufacturer of the membrane"”

- **Arizona:** “Our experience is limited. We depended on the manufacturer's expertise with joint material type”
- **Nebraska**: “We require complience with ASTM C1677 for tongue-and-groove connections.”
- **Rhode Island:** "See attached design guidance at links provided above. Issues tend to be with the joint filler material falling out over time between the precast segments. We usually call for a high quality waterproofing membrane or waterproofing material placed on the top and sides of the culvert, sealing any joints, prior to any fill material being placed on top.”
- **Michigan:** “Our standard specifications call for standard tongue and groove joints per ASTM C1577 with C990 closed cell butyl rubber extrusion type gaskets. The joint is then covered with a 12 inch wide external rubber gasket strip centered over the joint, meeting ASTM C877. Gasket is adhered to the surface. Joints are then treated with cold applied culvert joint sealer and a 24 inch wide strip of geotextile blanket. Once installed, the entire culvert is covered a 40mil pvc liner.”

Q7. Does your state specify the type of bedding material provided for RCBC construction and provide inspection during installation? What is that specification? In your opinion could settlement issues in RCBCs be resolved through proper bedding?

- **Pennsylvania:** “Design standard. 1' of bedding material (#8's or 2a) unless on rock which is 2' with geo potentially."”
- **Washington**: “"Yes. See our Standard Specifications Section 6-20.3(6) and our BDM Section 8.3.4.C. Proper bedding definitely helps with settlement issues. "”
- **Illinois:** ”IL requires 6" of porous granular material as bedding. It's typically a CA 6 mix. IL also will require rockfill if settlement is an issue. In rarer cases, we have required geotextile reinforcement under the culvert to avoid settlement and spreading.”
- **Missouri:** “"Yes. they are to follow Standard Specifications 206 (excavation and backfilling) & 1007 (bedding material). We are not seeing a lot of settlement of our culverts that have been place in accordance with our spec."”
- **Idaho (1):** “This is based on the geotechnical recommendations.”
- **Idaho (2):** “Bedding material depends on the recommendations of the geotechnical engineer. The typical recommendation is a compacted subbase layer (depth varies per geotech recommendations, but typically 1.0'-2.0') or we provide a nonstructural concrete leveling course (1.0' min - 2.0' max). Yes, settlement concerns can be resolved through proper bedding.”
- **Colorado:** “Yes & Yes. 6" aggregate base course (Class 6) compacted to 95% max. density or 3" lean concrete. Not all settlement issues can be resolved through proper bedding but it will probably solve most of them.”
- **Texas:** “Bedding is covered by spec item 464 in the TxDOT specifications, which references you back to Item 400. Proper bedding is critical to help manage differential settlement.”
- **Kansas (1):** “Yes, the details are shown on bridge standard BR020B which is attached. The foundation stabilization is a sand or other aggregate that contains sufficient binder and moisture to allow compaction and limit the flow of water through the material. Kansas has inspectors at the jobsite.”

- **Kansas (2):** “Yes, the details are shown on bridge standard BR020B. Kansas has inspectors at the jobsite.”
- **Wisconsin (1):** “Yes, structural backfill Type B is required, with a 6" minimum undercut prior to placing backfill, this ensures a solid base for placing reinforcement in the bottom slab. In general, inspection of the culvert installation is performed to all other construction activities. WisDOT provides foundation improvements, as required to mitigate settlement issues. Typically, this may include an undercut and backfilled with breaker run and geotextile type C lining.”
- **Wisconsin (2):** “Precast concrete sections shall be placed on a bedding of "structure backfill type B" per our standard specifications, at a minimum depth of 6". Some site specific changes of this are required at times for certain projects.”
- **Wyoming:** ”Bedding rec's are recommended by our Geology Program. These rec's are typically based on limiting settlement to one inch. Often times subexcavation is required, and may consist of layers of crushed base with biaxial grid.”
- **North Carolina:** “See Section 9.4.4.2 on Foundation Conditioning Material.”
- **Virginia:** “"yes. please see [Installation of Box Culvert Bedding and Backfill]. Bedding can mitigate settlement.”
- **South Carolina:** “Yes, by Standard Specification Sections 204 and 722 and by geotechnical analysis of soils. Proper bedding is a key factor to culvert structural performance. Proper bedding is essential. #57 stone is typically used in layers determined by geotechnical analysis.”
- **North Dakota:** “Yes. We provide details in the plans for bedding and backfill at all box culverts. We also have inspection staff on site during installation. We specify a 2' depth of Foundation Aggregate to be installed beneath the boxes. The spec for foundation aggregate is shown below. We have not seen any widespread settlement issues in our precast box culverts. C. Box Culvert Foundation Aggregate. Provide material that meets the following requirements: Sieve Size or Testing Method / % Passing: 2 inch / 100%, 1.5 inch / 80% - 100%, 3/8 inch / 20% - 60%, No. 10 / 0% - 10%, ND T 113, Shale (max %) - 12%, AASHTO T 96, L.A. Abrasion (max %) - 40%, NDDOT 4, Fractured Faces (See Note 1, min %) - 75%. Note 1: Minimum weight percentage allowable for the portion of the aggregate retained on a No. 4 sieve having at least 1 fractured face"
- **Arizona:** “Yes. ITEM 6017105 – PRECAST REINFORCED CONCRETE BOX CULVERT: General: The work under this item shall consist of furnishing and constructing precast reinforced concrete box culverts to the size and dimensions shown on the plans and as directed by the Engineer. Materials: Precast reinforced concrete box sections shall be monolithic 4-sided sections and conform to the requirements of ASTM C1577. Alternate designs that differ in member sizes, strength and reinforcement will not be acceptable, unless specified herein. The joint sealant material shall be a long lasting silicone, mastic, asphalt, tar or other material that is acceptable to the culvert manufacturer. Joint material shall conform to the requirements of ASTM C990. The contractor shall submit all joint sealer specifications to the Engineer for approval prior to construction. Design Requirements: Design for member sizes and spans shall be as shown on the plans. Design for member sizes and spans not shown on the plans, shall be designed and detailed per the applicable ASTM C1577 specification for governing fill height and live load. For designs not shown on the plans, the contractor shall submit to the Engineer calculations signed and sealed by a Professional Engineer meeting the requirements of the specifications for review and approval. The sealed and signed calculations shall accompany the shop drawing submittal.

Construction Requirements: Each precast unit shall be clearly marked on an inside face. The markings shall show the manufacture date and the manufacturer's name or symbol. The top of each precast unit shall be clearly identified on either an inner or outer surface. Precast reinforced concrete box culverts shall be installed in accordance with the requirements of ASTM C1675 and the manufacturer's recommendation. Headwalls, wingwalls, and other special features shall be constructed using cast-in-place methods. Precast headwalls, wingwalls, and cut-off walls will not be acceptable. A minimum of a 3 inch gap shall be provided between all adjacent precast units. The gap shall be backfilled with cement-treated slurry backfill conforming to the requirements of Subsection 501-3.02(A)(3) of the specifications or non-shrink grout listed on the Department's Approved Product List (APL). Temporary shoring may be required and shall be provided in accordance with Subsection 105 of the Specifications. The cost of shoring shall be included in the contract unit price of the precast reinforced concrete box culvert item. The foundation underneath the leveling course shall be prepared in accordance with Subsection 501-3.01 of the specifications. A minimum 6" leveling course shall be constructed directly below the culverts and extending 12" on both sides of the exterior culverts. The leveling course material shall be granular, with 100 percent passing a 3/8 inch sieve and not more than 10 percent passing a No. 200 sieve. Backfilling and compacting shall conform to the requirements of Subsection 501-3.04 of the specifications. Structural excavation and backfill shall be per Subsection 203-5 of the specifications. A 2 foot minimum width wide strip of geocomposite wall drain fabric shall be securely placed and centered over all joints in the walls and top slab. The geocomposite wall drain fabric length shall be sufficient to ensure a minimum overlap of 24 inches, with the fabric extending a minimum of 12 inches beyond each side of the joint. The fabric shall be tightly secured against the box culvert with metal or plastic strapping. Shop Drawing Submittal: The contractor shall submit shop drawings for precast box culvert sections and shall include details of connections to cast-in-place elements, such as wingwalls, cut-off-walls and headwalls. Additional reinforcement as required in the plans shall be included. Optional use of mechanical connections shall be designated on the shop drawings and meet the requirements of Subsection 605-3.02 of the specifications. Shop drawing submittals shall be provided in accordance with Section 105 of the specifications. The submittal shall include a letter signed and sealed by a Professional Engineer, which states the selected precast box culvert meets the design parameters of live load and fill height, per ASTM C1577 for the specific box culvert site. Certifications and Inspection: Precast elements shall be fabricated at a National Precast Concrete Association (NPCA), American Concrete Pipe Association (ACPA) or Precast/Prestressed Concrete Institute (PCI) certified plant. The fabricator shall submit certification for their respective association to the Engineer prior to fabrication. The Department shall be notified a minimum of 2 weeks prior to precast box fabrication to allow for inspection of precast box manufacturing. Method of Measurement: Precast culverts will be measured by the linear foot along the central axis of the culvert per barrel, and shall include the length of joints and connections. Wingwalls, cut-off-walls, headwalls, and closure pours will be measured and paid for under the respective contract items. Basis of Payment: The accepted quantities of precast reinforced concrete box culvert, measured as provided above, will be paid for at the contract unit price per linear foot, which price shall be full compensation for the work, complete in place, including bedding, wall drain fabric, and slurry backfill. Payment for the removal of rock, hard pan, other unyielding material, or soft, spongy or other unstable soil below the vertical limits as shown on the plans, and the backfilling of these over-excavated areas, as specified herein and as directed by the Engineer, will be paid for in accordance with the requirements of Subsection 104.02 of the specifications."

- **Nebraska**: "6" layer of crushed rock base course"
- **Rhode Island:** "Yes. This would be specified by the design consultant and it would be project specific in conjunction with any environmental permitting requirements. Typically our local permitting agencies prefer a natural stream bottom so if a four sided box is used, natural stream bed material is placed within the culvert, site specific."
- **Michigan:** ""Yes. Bedding is specified for all culverts. Class IIIA aggregate is used, per our standard specs. The thickness is prescribed by our geotechnical unit based on the suitability of the subgrade. Bedding is fully wrapped in a geotextile fabric. Below is the link to our standard specifications.

Q8. Does your state use multiple-barrel precast RCBC? What is your opinion of using several single precast RCBCs instead of a single larger multiple-box configuration (e.g., using two single boxes instead of one double box)? What are the potential advantages or challenges of this approach in terms of installation, performance, and cost?

- **Pennsylvania:** "we have used and avoid use of twin or multi cell box's , they tend to become maintenance issues overtime as the one cell will often become impacted with debris and siltation. we prefer to use larger single cell boxes or box alternatives such as the arch culvert systems (BeBo, Conspan by Contech) where applicable if the span is excessive."
- **Washington**: "No we do not use multiple-barrel precast RCBC. Our Hydraulics office does not want them."
- **Illinois:** "We use two single boxes next to each other, and not a multiple box. We fill the space between the single boxes with grout. It is easier to ship and install the single boxes separately."
- **Missouri:** "We allow our precast fabricators to make that decision on whether to use a multi-barrel precast RCBC or to use two single boxes when the project requires a double barrel RCBC."
- **Idaho (1):** "ITD does not use multiple-barrel precast RCBC. Side by side boxes have been used, but we feel a different structure type should be evaluated for this situation."
- **Idaho (2):** "We have used side-by-side boxes in the past but try to refrain from using them. We would try to do a larger singular box or change to a different structure type like 3-sided frame or small bridge vs. using side-by-side boxes. They are typically a maintenance concern especially when used for canal structures whose maintenance crews have to go in and clear them out annually. Two boxes is twice the work and makes access harder. They also are more prone to catch debris at the center wall which causes other maintenance issues."
- **Colorado:** "Yes, they are allowed. These have been accepted in the past and part of the standard. Advantages are you can lift smaller pieces to get larger capacities. Potential disadvantage is differential settlement between barrels. Cost could be affected since the interior walls are doubled."
- **Texas:** ""Yes, Smaller single boxes are easier to ship and handle over using a large single box. How to use precast singles for multi box is covered on Box Culvert Precast Miscellaneous Details. Since

single boxes in a multi box situation are placed further apart this can impact whether or not a the culvert is a bridge class culvert. Just something that needs to be considered."

- **Kansas (1):** "Kansas allows the use of multiple-barrel precast RCBC."
- **Kansas (2):** "Kansas allows the use of multiple-barrel precast RCBC."
- **Wisconsin (1):** ""Yes, multiple precast barrels are allowed per Standard 36.05. WisDOT has not evaluated the condition."
- **Wisconsin (2):** "Our preference is to not use multi-cell precast box culverts and haven't done so in most cases."
- **Wyoming:** " Yes, we use multi-cell box culverts. We leave it up to the contractor during the bidding process to select if they wish to use single cell culverts or multi-cell culverts."
- **North Carolina:** "Precast culverts are not commonly used. Contractors often do not select precast culverts when they have the option."
- **Virginia:** "Very rare to see this type. For small size RCBC, it may be doable. But the transportation is an issue for large RCBC."
- **South Carolina:** "Yes. Our multiple barrel precast boxes are singe barrels laid adjacent to each other. They are lighter to handle than multiple barrels cast together. We have no known issues with doing this. Multiple barrels could be quicker to construct entire culvert."
- **North Dakota:** "Yes. The total number of barrels at a site may be between 1 and 4 barrels. Precast boxes may be fabricated as single or double barrels. For a quad box, we permit either 4 single barrel precast RCBCs to be used, or 2 double barrel precast RCBCs. The advantage of using single barrel precast RCBCs is they are lighter and easier to handle and set, and, if used for skewed boxes with straight wingwalls, there is less of a stagger between ends compared to a dual precast RCBC. The disadvantage is our fabricator has told us he can fabricate the total amount of box required for a multi barrel box more quickly and cheaper if using dual line precast RCBSs."
- **Arizona:** "No. Single only."
- **Nebraska**: "We have only seen using multiple single-barrel configurations for precast alternates of multi-barrel CIP designs. Adjustments have to be made for widening interior walls when transitioning to our required CIP end treatments. We also require maintaining continuous, uniform contact between adjacent box sections to ensure positive lateral bearing."
- **Rhode Island:** "Yes, we do and have both types in RI. Typically though, they are of the multiple box configuration and not two or more single box culverts."
- **Michigan:** "Very rarely are these allowed due to concerns with debris buildup."

Q9. Has your state ever used a hybrid approach in constructing RCBCs, such as combining precast box culvert barrels with CIP wing walls? In your opinion, what are the potential advantages or challenges of this approach?

- **Pennsylvania:** ""we have this as a Design standard. cip wall allow more freedom when setting flares. we have a hybrid of precast wings with cast in place coping for additional wall height as well."
- **Washington**: ""Yes, our contractors have that option. We reference various retaining wall options adjacent to our buried structures. D-3.09: Also, any of our D-10 series would be allowed. These are in addition to a precast option"""

- **Illinois:** ”Yes, regularly. See previous replies and standard base sheets. This approach allows designers to use the most cost-effective wingwalls.”
- **Missouri:** “We try not to mix and match. It is either a precast system or a CIP system.”
- **Idaho (1):** “Yes. It allows for the expedited construction within traffic, and a more traditional construction method where traffic is not significantly impacted.”
- **Idaho (2):** “Yes, we have done hybrid. We sometimes use precast main segments with CIP end segments and have done both CIP and precast wingwalls with precast culverts. The main factor is based on the skew and the angle of the wall relative to the wingwall. The main advantage is the simplifies the culvert segment by allowing them to be square and can also simplify the connection of the wingwall to culvert when just using CIP.”
- **Colorado:** “Yes, this is our standard approach. Helpful on skewed culverts. Details are always challenging.”
- **Texas:** “This is our current approach. It works well and allows the precast to be used with any skew.”
- **Kansas (1):** “Yes, Kansas shows the hybrid approach on Bridge Standard BR031 and in some instances the hybrid approach is required (boxes in streams or skewed).”
- **Kansas (2):** “Yes, Kansas shows the hybrid approach on Bridge Standard BR031 and in some instances the hybrid approach is required (boxes in streams).”
- **Wisconsin (1):** “Yes, typically the apron and wingwalls are CIP.”
- **Wisconsin (2):** “Typically, our box culverts and their wings are either all CIP or all precast.”
- **Wyoming:** ” Yes, all our precast box culverts utilize a cast-in-place headwall, cutoffwall, and wingwalls.”
- **North Carolina:** “NCDOT does not permit use of precast wings.”
- **Virginia:** “Very rare to see this type of hybrid. I do not see any advantages to do so.”
- **South Carolina:** “Our policy is to always use CIP headwalls, wingwalls, aprons, and cut-off walls. We believe precast wingwalls, headwalls, etc. are not as durable.”
- **North Dakota:** “I am not aware of this having been done in North Dakota, but we don't have any guidelines that would prohibit this. The advantage of using CIP wingwalls seems to be that you could construct end sections at skewed ends or for unique site conditions to better fit the channel and conform to what is desired at each end of the box culvert.”
- **Arizona:** “Only hybrid we would consider is extending an existing CIP RCBC with a PC culvert.”
- **Nebraska**: “Yes”
- **Rhode Island:** “Yes. It has been done. Could be proposed by the Contractor as a Value Engineering proposal. It would depend on site specifics and the need to control water flow at the site to determine the advantages of challenges with that approach. However, diversion of the stream flow during construction would be the biggest issue/concern.”
- **Michigan:** “We use precast wingwalls whenever possible.”

Q10. Have inspection results in your state shown any significant trends in failure rates or performance differences between precast and CIP RCBC? What are those failures? How old are the boxes when they fail?

- **Pennsylvania:** “none that have been brought to our attention.”

- **Washington**: “We use precast.”
- **Illinois:** ” We used to see the boxes pull apart from settlement. We started installing positive connections on the last three precast segments to preclude this. The boxes tend to be young when this occurs because the settlement happens very early in the life of the structure.”
- **Missouri:** “I don't believe so.”
- **Idaho (1):** “The only failures I am aware of are linking joints, and deterioration adjacent to the joints.”
- **Idaho (2):** “I do not recall any failures of box culverts. Most hold up really well.”
- **Colorado:** “No. the big difference is how long the joints last for precast.”
- **Texas:** “No. We have not see significant differences between the performance of precast and CIP. Joints can leak, proper construction, regular inspection, and repair can reduce these impacts. The precast boxes in general have greater control on construction and quality in the fabrication plant. We have seen more issues with the thinner top decks used in CIP developing punching shear or corrosion issues. Common issues with both types is the wingwall to box connection splitting when the wingwalls rotate, this is usually due to loss of bedding under the wingwall.”
- **Kansas (1):** “We only have 27 bridge-sized precast culverts in Kansas. There are 50 that are inspected. 49 are in good condition, 1 in fair. Kansas would not call them failures or performance differences, more of an issue: Separations at the construction joints between the precast sections but not bad enough that ratings are dropping.”
- **Kansas (2):** “KDOT has 50 precast boxes on the state system with 27 being bridge size. 49 are in good condition and 1 is in fair condition. We do not have a lot of issues except we do see separations at the construction joints between the precast sections. These are not bad enough to drop the ratings.”
- **Wisconsin (1):** “No, seem to perform similarly. Typical failures with settlement or spalling at precast joints.”
- **Wisconsin (2):** “We don't have a long enough history of using precast box culverts to have a good comparison between the two.”
- **Wyoming:** ” No trends in failure. Many old cast-in-place box culverts are still performing well. Many of these do not pass today's design standards and have minimal amount of reinforcing steel in them.”
- **North Carolina:** “No. Both appear to perform well using the design policies provided in the Design Manual.”
- **Virginia:** “Some joint leaking and concrete spalling because of the leaking were reported for precast RCBC. These started about 20 years after construction.”
- **South Carolina:** “Not sure. No known issues.”
- **North Dakota:** “We have only been installing precast RCBCs on our state system since the early 1990s. CIP box culverts were used almost exclusively before that time. Many of our CIP box culverts are much older than any precast boxes on our system. For boxes of comparative age, we do not see any performance difference between precast and CIP RCBCs.”
- **Arizona:** “No PC culvert inspections have occured yet.”
- **Nebraska**: “...”

- **Rhode Island:** “No. Overall, our box culverts (both precast and CIP) have performed very well. Issues we have seen is typically with the construction joint material failing between segments of the precast units.”
- **Michigan:** “No.”

Q11. If construction speed and traffic impact are not factors, what is the preferred construction method for RCBC, and why?

- **Pennsylvania:** “precast, its normally cheaper, less permeable concrete and higher strength .”
- **Washington**: “We use precast.”
- **Illinois:** ”Contractors seem to favor precast because there aren't issues with having the concrete delivered and then cured.”
- **Missouri:** “Yes. Reduction in joints increases longevity of the culverts”
- **Idaho (1):** “For this situation, we base it on cost.”
- **Idaho (2):** “It is all driven by cost. We primarily would have selected a precast box since it was similar in cost to CIP but offered the advantage of faster construction. However, we have seen a large increase in price for the precast boxes the last couple of years and have been starting to use more CIP when speed and traffic are not factors.”
- **Colorado:** “Cast-in-place. Avoids the joint issues and is familiar to all contractors.”
- **Texas:** “We do not have a preference. We leave the selection to the contractor.”
- **Kansas (1):** “Cast-in-place is the preferred method for reinforced concrete box culverts.”
- **Kansas (2):** “Cast-in-place is the preferred method for reinforced concrete box culverts.”
- **Wisconsin (1):** “I’d say CIP due to costs and its ability to address site-specific challenges with less joints.”
- **Wisconsin (2):** “We don't have a strong preference at this time, but historically our contracting community has gone CIP and they have held up well over a long time in Wisconsin.”
- **Wyoming:** ”Both are good options and have their pros and cons.”
- **North Carolina:** “CIP RCBC. Cost, quality and durability.”
- **Virginia:** “CIP.”
- **South Carolina:** “CIP. We believe it is a more durable solution and not as susceptible to differential settlement.”
- **North Dakota:** “We believe precast RCBCs provide an end product that is equal to CIP box culverts even if we do not account for the added benefits of speeding construction and reducing traffic impacts. Precast alternatives have historically been cheaper and have always won the bid when alternates have been provided in our plans. However, the speed of construction is by far the biggest advantage of precast RCBCs.”
- **Arizona:** “CIP. Traffic impacts can't be ignored, as the public has no patience for construction, and the longer it take the more they contact their local representatives.”
- **Nebraska**: “...”
- **Rhode Island:** “Precast because it is more economical, better quality control, and less overall impact to the stream crossing during installation as long term dewatering measures needed for CIP would not have to be in place but only a short term diversion.”
- **Michigan:** “I dont understand the question.”

Appendix C: Precast Suppliers Survey Results

Q1.a. Has your company provided precast RCBC with any of the following details? Who was the owner? - a. End Sections with skew angles greater than 10 degrees on single or multicell RCBC. If so, what challenges did you face, and how were they resolved? Is there any substantial cost increase?

- **Shea:** "Yes. If the skew is too large then custom forming is required which greatly increases the cost. A small skew can be easily poured in standard culvert forms. The cost increases is $500 to $5000 for the skew."
- **McPherson:** "Yes. Most precast RCB / RFBs are produced with a drycast mix and vibration. We typically build all special end sections with a combination of handset forms and wood. An SCC mix design is used (self leveling and no vibration required). The cost is comparable to cast-in-place."
- **S&M:** "Yes, for a skewed angle greater that 10 deg, last year we did a job for City of Indianapolis Department of public works. Biggest challenge was the structural rebar design. Yes, caused a substantial cost increase due to labor/engineering for the 19x9 skewed end section."
- **Gillespie:** "Yes. When the long leg skew gets over 12' it is a challenge for our plant team to work that high in the air. Scaffolding and harnesses are needed as required. The price is not affected substantially but extra forming costs are added."
- **Engineered Concrete Products:** "Yes, NDDOT, Weight and Hauling Dimension, Cost was More than Conventional."
- **Garden State:** "The challenges are all based upon the span. Short span culverts we have skewed up to 60 degrees. We specify a minimum of 3' on the short segment. This is then based with shipping requirements to generate a maximum skew by span. If we fail at this, then the next approach is to make every section a skew. While this increases the design span, it does extend the size of material able to be precast."

Q1.b. Has your company provided precast RCBC with any of the following details? Who was the owner? - b. Precast inlet or outlet with flared wing walls. If so, what challenges did you face, and how were they resolved? Is there any substantial cost increase? Can you share the details?

- **Shea:** "Precast wing walls are standard and cost $2500 to $10,000. However large retaining wall block is usually a better choice for onsite changes, ease of install and aesthetics."
- **McPherson:** "Yes. Please reference my answer in the above section. All precast RCB end sections should be restrained and/or include a toe wall to help prevent the end section separation due to erosion / scour."
- **S&M:** "We build them everyday. Standard pricing applied."
- **Gillespie:** "No challenges. Like with the skews there is additional forming needed for the structures. We pour wingwalls in two pours. First the stem with rebar and PVC pipe left out for the second pour for the footing."
- **Engineered Concrete Products:** "Yes, NDDOT, No Issues. Cost about the Same."
- **Garden State:** "We can either pour with the last segment for smaller spans, or set up and pour 2 wings on a footing that matches the last segment"

Q1.c. Has your company provided precast RCBC with any of the following details? Who was the owner? - c. Monolithic parapet at inlet or outlet. If so, what challenges did you face, and how were they resolved? Is there any substantial cost increase?

- **Shea:** “Parapet walls are standard and cost from $500 to $2500. However large retaining wall block is usually a better choice for onsite changes, ease of install and aesthetics.”
- **McPherson:** “I don't understand the term "parapet" in relation to this topic. If this is a toe wall, soil saver, or hub guard then we do not ever produce them monolithically. Generally, it is more economical to build them as a secondary pour with rebar dowels, epoxied into the end section.”
- **S&M:** “Yes, we pour them every week. These go along with runs that require wing walls. Standard pricing is applied.”
- **Gillespie:** “N/A”
- **Engineered Concrete Products:** “Yes, WYDOT, No Issues, Cost was Little More.”
- **Garden State:** “we often pour monolithic and/or integral poured parapets. These are usually in the less than 30” height range. Large heights are poured as an L shape and bolted atop the culvert. The cost impacts for projects in our area are minimal due to the very high prevailing wage, (85.00 plus $/hr for basic site labor)”

Q2. What steps does your company take to stay updated with industry design detailing changes? Are you aware of pre-cast RCBC details used by other producers to address skew or flared wingwall?

- **Shea:** “We do not take any specific steps to stay updated.”
- **McPherson:** “We do not typically share our details or production practices with other precast producers. However, generic details of our standard products can be found on our website. I am not aware of any other producer's details at this time.”
- **S&M:** “We currently use BOXCAR, AutoCAD and SolidWorks to create production drawings and rebar drawings. We are unaware of any software that is specific to RCBC design. The automated software we have demoed, has not sufficiently created rebar mats for wing walls or box sections.”
- **Gillespie:** “Our company is a certified NPCA plant. This provides us with upsets on industry design. We also have outside sales representatives that are involved with DOT's/conferences/shows. Yes we are aware of some.”
- **Engineered Concrete Products:** “We really don't design around anything in particular or follow other precasters. We will work with what the Engineer is wanting.”
- **Garden State:** “We participate in ASTM C27, NPCA Committee work, and audit various engineering/industry publications. We do work within 5 states and have an engineer that is licensed in 30+ states that has extensive commercial precast design experience.”

Q3. Does your company provide or use standard plates, base sheets, or tables with pre-approved RCBC designs or is each RCBC designed by a structural engineer? How can this affect the cost and lead times of precast RCBC production?

- **Shea:** “Each RCBC is designed by a structural engineer. lead time is 1 to 2 weeks for engineering and cost is $800 to $2500.”

- **McPherson:** “All precast RCBs / RFBs that we produce are individually designed by our engineering team for the specific project. We do not have generic tables nor do we follow the ASTM C1577 design tables.”
- **S&M:** “Yes, up to a certain size, we are allowed to use standard designs. In Indiana, if the run requires wingwalls, it always has to be stamped by a PE.”
- **Gillespie:** “If it is a DOT project that provides that design they want, we usually follow that layout/design. If we believe we can design a better option (ex. lighter reinforcement) we will have our structural engineer design. This does not affect our cost or lead times as we include pricing for drawings & calculations when quoting."”
- **Engineered Concrete Products:** “No we don't, each is designed specifically for a job. Lead times dont seem to be an issue with us.”
- **Garden State:** “All culverts in NJ are individually designed. This is due to HEC 3 requirements. Most culverts are sized to replace or handle a very specific flow. Culvert standardization does not really apply. We have made a few culverts to ASTM C1433 standards as well, but only a handful.”

Q4. What are some of the common mistakes contractors make when installing precast RCBC?

- **Shea:** “Unlevel base. Pick position adjustments for the sections to help aid in placement."
- **McPherson: “**Most of the contractors that install precast RCBs in our market do a good job with installation. I'm not aware of any common mistakes. As an engineer, I would be most concerned with the contractor building a suitable base upon which to place the RCB. Additionally, I would worry about adequate erosion control on the upstream and downstream ends. If the precast RCB experiences differential settlement, the joints could separate and allow soil into the joints which would negatively impact the road (surface) above. If proper erosion control is not established on the ends, scour also cause joint separation.”
- **S&M:** “Rock bedding under the culvert is the biggest issues we see. If the rock is not properly graded and compacted, this will keep the culvert from assembling properly. Setting the bell end first is another issue we have seen. Mastic installation can be a challenge as well. There can be a lot of customer training needed to utilize the best practices.”
- **Gillespie:** “Not being prepared. Our company has a box culvert install guide that is sent to all of our clients before delivery as well as a list of questions that need to be answered be for delivery takes place. Communication and being prepared with the right tools and site conditions is key.”
- **Engineered Concrete Products:** “Uneven grades, compacted top lift in the grade, crane size, experience, speed (too fast), etc.”
- **Garden State:** “Common mistakes include, backward installation, not putting a barrier at the joint to avoid subbase material hilling into the joint, drawing the culvert away from field cast wingwalls.”

Q5. What best practices and recommendations do you suggest to ensure joint integrity and prevent alignment issues during installation?

- **Shea:** “Level base, proper rigging, compression of sealant”
- **McPherson:** “The contractor must build a stable foundation with adequate bearing capacity to prevent settlement. The contractor must backfill the RCB and compact evenly on both sides to prevent alignment issues. If joint separation is a major concern, there are a wide variety of

mechanical joint restraints available to purchase. We sell thousands of feet of precast RCBs every year, and during my 16 years with MCC, we have not had a failure of any type during this time period. We have had to coach some newer contractors on how to properly install and ensure proper seating and sealing of the joints on a few occasions. In these occasions, we were notified by the project inspector who had concerns about the installation."

- **S&M:** "Compacted and level rock bedding. Clean a little rock out where the joints will come together so that rock doesn't get picked up and prevent the culvert sections coming together to the proper joint gap. When using a puller, leave the crane tensioned so that the puller doesn't have to pull the entire weight of the culvert section. If you push on the culvert with a piece of equipment, use a wooden block to prevent spalling."
- **Gillespie:** "Bolt pocket connection"
- **Engineered Concrete Products:** "Coach the contract onsite to make sure they are addressing my concerns."
- **Garden State:** "To avoid issues we usually send an install office to the job. They review details, installation, sequence etcetera with the client. This usually occurs a day or so before start of deliveries. We also observe the installation and provide technical support. Approximately 90% of New Jersey culverts are post tensioned. This is not to transfer load across the joint like in PA, but simply to tighten up the joints. This is limited to short run culvers of say 100 lf or less due to friction. We sometimes tension multiple days. We also occasionally produce culverts with a rubber single offset gasket. This allows installation very similar to RCP."

Q6. Does your company recommend a specific type of bedding material, compaction requirements, or joint details to enhance the overall performance of precast RCBCs? If so, can you share the details?

- **Shea:** "crushed stone compacted level bed. Shiplap joint (Bell & spigot) with butyl resin"
- **McPherson:** "If we are asked to recommend bedding materials, compaction requirements, or joint details, we reference KDOT standards. These standards are tried and true.
- **S&M:** "This is always defined by the civil engineering firm for the project. We absolutely do not advise what type of bedding material to install."
- **Gillespie:** "1' neoprene on the inside of the joint and 9" joint wrap on the outside of the joints when installed"
- **Engineered Concrete Products:** "The top 2" of the bed must be loose and regraded as needed."
- **Garden State:** "Bedding is designed by site/geotechnical engineers based upon reactive loads in the culvert design. This is usually on a case by case basis as site conditions vary wildly across our area."

Q7. What is your opinion of producing several single-cell precast RCBCs instead of a multiple-cell precast RCBC? (e.g., using two single boxes instead of one double box)? What are the potential advantages or challenges of this approach in terms of installation, performance, and cost?

- **Shea:** "Double box could cost less as long as the overall size is not too heavy."
- **McPherson:** "We do not own the tooling to provide precast multi-cell RCBs. We regularly supply single-cell RCBs for multi-cell applications. The advantage is faster production and lighter weights (smaller construction equipment for installation). The single-cell RCBs must be installed

approximately 1.5" apart and the contractor must fill that space with sand or flowable fill. We always recommend flowable fill. Once the space between the cells is filled, the contractor must backfill and compact evenly on both sides."

- **S&M:** "We always try to keep the weight down so that the pieces fit on a semi-truck. And can easily be maneuvered on the jobsite."
- **Gillespie:** ""Single cells can use up less forming. Twin cells use up more forms for the plant that can hold up production for other clients. Some situations it makes sense when installing to use twin, triple, or quad box culverts. This can be an advantage for the contractor.""
- **Engineered Concrete Products:** "When trucking weight is an issue that is an option but for the most part double cells are less expensive than single cell. I have seen contractors struggle with both."
- **Garden State:** "Most constraints in culvert design are about freight. Single cell culverts allow longer section lengths, dual cell are shorter section lengths. Some states have a high GVWR on trucking, thus dual cells can be longer. Performance should be the same. Some benefits in using single cell include, no crane?, install within trench shield, radius construction, bend or elbow construction to name a few."

Q8. Do you or have you ever implemented match casting into your production process? What considerations was the decision based on?

- **Shea:** "We had a sharp skew in the middle of the box culvert so we did a match cast which worked excellent and guaranteed seams to match."
- **McPherson:** "The only time we have practiced match casting is when we are providing an RCB bend for a multi-cell application. We pour the outside bend and then match cast the consecutive bends to ensure a proper fit."
- **S&M:** "Yes. This is job specific."
- **Gillespie:** "Yes. Depending on the project. We use this mostly on big wingwalls that need to be split into several pieces due to size. We match cast to make sure the wall flows as one when installing in the field."
- **Engineered Concrete Products:** "We have but it was too labor intensive, and we could not be competitive."
- **Garden State:** "Match casting is an integral part of our production process. We make culvert extensions this way. We also pour elbows and bends this way. Occasionally we match cast skewed sections as well. Consideration is based on tolerance, form work needs, and number of pours. A match cast section will be to the same tolerances ie -if the diagonal is ¾" out, then the matching piece will be out the same amount in the same way. This eliminates pieces being out of tolerance as a group, but in tolerance as a piece."

Q9. What challenges do you face in transporting and installing large precast RCBC components? What is the maximum pre-cast RCBC length, width, and height?

- **Shea:** "We commonly ship oversize loads up to 14ft wide and weigh up to 100,000lbs"
- **McPherson:** "The maximum precast RCB size that we can dry-cast is 12' wide x 10' tall. This is due to the overhead crane capacity and the concrete feeder system. The largest precast RCB that

we have ever produced was 20' wide x 10' tall. This was a wet-cast RCB and we had to pour it outside, under our large gantry crane."

- **S&M:** "We are really just limited by over width and overweight restrictions for the semi-trucks. This is set by the DOT and the permitting process."
- **Gillespie:** "If it can ship, we can precast it. All states are different with restrictions but anything over 8'-6"" wide, 13'-6"" tall, and 80,000 lbs. require additional permits. Including permit costs when quoting and any additional labor like flipping the pieces or escorts needs to be determined during the quoting phase"
- **Engineered Concrete Products:** "Pilot cars can be expensive to purchase, and the weight can be a challenge in finding enough trucks capable of hauling them.""
- **Garden State:** "We have access to trucking up to about 75 tons with reasonable cost. Crossing major bridges, state lines, and night deliveries are cost centers. A good rule of thumb we use is 16' wide x 38' long x 10.5' high cargo volume at 50 tons or less. Most all culverts of this size will be shipping on their sides. Rotating the piece erect is a challenge that requires some thought. Another challenge is the number of loads required per day at an install. If the travel distance is great, then a large amount of specialty trucks is required. As our long haul is usually less than 60 miles, multiple runs per day can be made with the same truck. As to maximum size, we have shipped 3 sided spans up to 38 feet."

Q10. How has the demand for pre-cast RCBC changed over the years?

- **Shea:** "As flooding seems to occur more often and bridges begin to fail we have seen an increase in RCBC"
- **McPherson:** "The demand for precast has steadily increased over my 16 years in the industry."
- **S&M:** "This has drastically increased in our area. Due to aging road infrastructure and increased runoff volume from impervious surfaces, demand for RCBC has increased."
- **Gillespie:** "Increased. I was hired to project manage the box culverts because the demand was so high."
- **Engineered Concrete Products:** "They have stayed stagnate in SD but we see them more in Municipalities and boarding states, WY MT ND."
- **Garden State:** "During meetings between the New Jersey Precast Concrete Association and the NJDOT, information was shared that precast culvert and bridge ratings are trending better as compared to cip. In addition, effective lifespan of precast is trending longer. The NJDOT is looking to design first with culverts as large as they can, then to bridges. This is especially important due to the number of secondary road bridges that need replacement. This is also being used as a partial accelerated bridge construction process. Some projects require that the culvert be ready to ship before the site starts work. This minimizes the actual road detour/closure. We are seeing more skew culverts and more hybrid pedestal/top culverts as well."

Appendix D: Data for Figure 5.28

Table D.1 shows the data used in Figure 5.28.

Table D.1. Data used in Figure 5.28.

Region	Month	Hour	Band	Estimated Temperature (°F)
Mitchell	January	12:00 AM	Freezing	25
Mitchell	January	2:00 AM	Frigid	5
Mitchell	January	4:00 AM	Frigid	5
Mitchell	January	6:00 AM	Frigid	5
Mitchell	January	8:00 AM	Freezing	25
Mitchell	January	10:00 AM	Freezing	25
Mitchell	January	12:00 PM	Cold	50
Mitchell	January	2:00 PM	Cold	50
Mitchell	January	4:00 PM	Cold	50
Mitchell	January	6:00 PM	Freezing	25
Mitchell	January	8:00 PM	Freezing	25
Mitchell	January	10:00 PM	Freezing	25
Mitchell	February	12:00 AM	Freezing	25
Mitchell	February	2:00 AM	Frigid	5
Mitchell	February	4:00 AM	Frigid	5
Mitchell	February	6:00 AM	Frigid	5
Mitchell	February	8:00 AM	Freezing	25
Mitchell	February	10:00 AM	Freezing	25
Mitchell	February	12:00 PM	Cold	50
Mitchell	February	2:00 PM	Cold	50
Mitchell	February	4:00 PM	Cold	50
Mitchell	February	6:00 PM	Freezing	25
Mitchell	February	8:00 PM	Freezing	25
Mitchell	February	10:00 PM	Freezing	25
Mitchell	March	12:00 AM	Freezing	25
Mitchell	March	2:00 AM	Freezing	25
Mitchell	March	4:00 AM	Freezing	25
Mitchell	March	6:00 AM	Very Cold	40
Mitchell	March	8:00 AM	Very Cold	40
Mitchell	March	10:00 AM	Very Cold	40
Mitchell	March	12:00 PM	Cool	60
Mitchell	March	2:00 PM	Cool	60
Mitchell	March	4:00 PM	Cool	60
Mitchell	March	6:00 PM	Very Cold	40
Mitchell	March	8:00 PM	Freezing	25
Mitchell	March	10:00 PM	Freezing	25
Mitchell	April	12:00 AM	Very Cold	40
Mitchell	April	2:00 AM	Very Cold	40

Region	Month	Hour	Band	Estimated Temperature (°F)
Mitchell	April	4:00 AM	Very Cold	40
Mitchell	April	6:00 AM	Cold	50
Mitchell	April	8:00 AM	Cold	50
Mitchell	April	10:00 AM	Cold	50
Mitchell	April	12:00 PM	Comfortable	70
Mitchell	April	2:00 PM	Comfortable	70
Mitchell	April	4:00 PM	Comfortable	70
Mitchell	April	6:00 PM	Cold	50
Mitchell	April	8:00 PM	Very Cold	40
Mitchell	April	10:00 PM	Very Cold	40
Mitchell	May	12:00 AM	Cold	50
Mitchell	May	2:00 AM	Cold	50
Mitchell	May	4:00 AM	Cold	50
Mitchell	May	6:00 AM	Cool	60
Mitchell	May	8:00 AM	Cool	60
Mitchell	May	10:00 AM	Cool	60
Mitchell	May	12:00 PM	Warm	80
Mitchell	May	2:00 PM	Warm	80
Mitchell	May	4:00 PM	Warm	80
Mitchell	May	6:00 PM	Cool	60
Mitchell	May	8:00 PM	Cold	50
Mitchell	May	10:00 PM	Cold	50
Mitchell	June	12:00 AM	Cool	60
Mitchell	June	2:00 AM	Cool	60
Mitchell	June	4:00 AM	Cool	60
Mitchell	June	6:00 AM	Comfortable	70
Mitchell	June	8:00 AM	Comfortable	70
Mitchell	June	10:00 AM	Comfortable	70
Mitchell	June	12:00 PM	Warm	80
Mitchell	June	2:00 PM	Hot	90
Mitchell	June	4:00 PM	Hot	90
Mitchell	June	6:00 PM	Comfortable	70
Mitchell	June	8:00 PM	Cool	60
Mitchell	June	10:00 PM	Cool	60
Mitchell	July	12:00 AM	Comfortable	70
Mitchell	July	2:00 AM	Comfortable	70
Mitchell	July	4:00 AM	Comfortable	70
Mitchell	July	6:00 AM	Comfortable	70
Mitchell	July	8:00 AM	Warm	80
Mitchell	July	10:00 AM	Warm	80
Mitchell	July	12:00 PM	Hot	90
Mitchell	July	2:00 PM	Hot	90
Mitchell	July	4:00 PM	Hot	90

Region	Month	Hour	Band	Estimated Temperature (°F)
Mitchell	July	6:00 PM	Warm	80
Mitchell	July	8:00 PM	Comfortable	70
Mitchell	July	10:00 PM	Comfortable	70
Mitchell	August	12:00 AM	Comfortable	70
Mitchell	August	2:00 AM	Comfortable	70
Mitchell	August	4:00 AM	Comfortable	70
Mitchell	August	6:00 AM	Comfortable	70
Mitchell	August	8:00 AM	Warm	80
Mitchell	August	10:00 AM	Warm	80
Mitchell	August	12:00 PM	Hot	90
Mitchell	August	2:00 PM	Hot	90
Mitchell	August	4:00 PM	Hot	90
Mitchell	August	6:00 PM	Warm	80
Mitchell	August	8:00 PM	Comfortable	70
Mitchell	August	10:00 PM	Comfortable	70
Mitchell	September	12:00 AM	Cool	60
Mitchell	September	2:00 AM	Cool	60
Mitchell	September	4:00 AM	Cool	60
Mitchell	September	6:00 AM	Comfortable	70
Mitchell	September	8:00 AM	Comfortable	70
Mitchell	September	10:00 AM	Comfortable	70
Mitchell	September	12:00 PM	Warm	80
Mitchell	September	2:00 PM	Warm	80
Mitchell	September	4:00 PM	Warm	80
Mitchell	September	6:00 PM	Comfortable	70
Mitchell	September	8:00 PM	Cool	60
Mitchell	September	10:00 PM	Cool	60
Mitchell	October	12:00 AM	Cold	50
Mitchell	October	2:00 AM	Cold	50
Mitchell	October	4:00 AM	Cold	50
Mitchell	October	6:00 AM	Cool	60
Mitchell	October	8:00 AM	Cool	60
Mitchell	October	10:00 AM	Cool	60
Mitchell	October	12:00 PM	Comfortable	70
Mitchell	October	2:00 PM	Comfortable	70
Mitchell	October	4:00 PM	Comfortable	70
Mitchell	October	6:00 PM	Cool	60
Mitchell	October	8:00 PM	Cold	50
Mitchell	October	10:00 PM	Cold	50
Mitchell	November	12:00 AM	Freezing	25
Mitchell	November	2:00 AM	Freezing	25
Mitchell	November	4:00 AM	Freezing	25
Mitchell	November	6:00 AM	Very Cold	40

Region	Month	Hour	Band	Estimated Temperature (°F)
Mitchell	November	8:00 AM	Very Cold	40
Mitchell	November	10:00 AM	Very Cold	40
Mitchell	November	12:00 PM	Cool	60
Mitchell	November	2:00 PM	Cool	60
Mitchell	November	4:00 PM	Cool	60
Mitchell	November	6:00 PM	Very Cold	40
Mitchell	November	8:00 PM	Freezing	25
Mitchell	November	10:00 PM	Freezing	25
Mitchell	December	12:00 AM	Freezing	25
Mitchell	December	2:00 AM	Frigid	5
Mitchell	December	4:00 AM	Frigid	5
Mitchell	December	6:00 AM	Frigid	5
Mitchell	December	8:00 AM	Freezing	25
Mitchell	December	10:00 AM	Freezing	25
Mitchell	December	12:00 PM	Cold	50
Mitchell	December	2:00 PM	Cold	50
Mitchell	December	4:00 PM	Cold	50
Mitchell	December	6:00 PM	Freezing	25
Mitchell	December	8:00 PM	Freezing	25
Mitchell	December	10:00 PM	Freezing	25
Rapid City	January	12:00 AM	Freezing	25
Rapid City	January	2:00 AM	Freezing	25
Rapid City	January	4:00 AM	Freezing	25
Rapid City	January	6:00 AM	Freezing	25
Rapid City	January	8:00 AM	Freezing	25
Rapid City	January	10:00 AM	Freezing	25
Rapid City	January	12:00 PM	Very Cold	40
Rapid City	January	2:00 PM	Very Cold	40
Rapid City	January	4:00 PM	Very Cold	40
Rapid City	January	6:00 PM	Very Cold	40
Rapid City	January	8:00 PM	Freezing	25
Rapid City	January	10:00 PM	Freezing	25
Rapid City	February	12:00 AM	Freezing	25
Rapid City	February	2:00 AM	Freezing	25
Rapid City	February	4:00 AM	Freezing	25
Rapid City	February	6:00 AM	Freezing	25
Rapid City	February	8:00 AM	Freezing	25
Rapid City	February	10:00 AM	Freezing	25
Rapid City	February	12:00 PM	Very Cold	40
Rapid City	February	2:00 PM	Very Cold	40
Rapid City	February	4:00 PM	Very Cold	40
Rapid City	February	6:00 PM	Very Cold	40
Rapid City	February	8:00 PM	Freezing	25

Region	Month	Hour	Band	Estimated Temperature (°F)
Rapid City	February	10:00 PM	Freezing	25
Rapid City	March	12:00 AM	Freezing	25
Rapid City	March	2:00 AM	Freezing	25
Rapid City	March	4:00 AM	Freezing	25
Rapid City	March	6:00 AM	Freezing	25
Rapid City	March	8:00 AM	Freezing	25
Rapid City	March	10:00 AM	Freezing	25
Rapid City	March	12:00 PM	Cold	50
Rapid City	March	2:00 PM	Cold	50
Rapid City	March	4:00 PM	Cold	50
Rapid City	March	6:00 PM	Very Cold	40
Rapid City	March	8:00 PM	Freezing	25
Rapid City	March	10:00 PM	Freezing	25
Rapid City	April	12:00 AM	Freezing	25
Rapid City	April	2:00 AM	Freezing	25
Rapid City	April	4:00 AM	Freezing	25
Rapid City	April	6:00 AM	Very Cold	40
Rapid City	April	8:00 AM	Very Cold	40
Rapid City	April	10:00 AM	Very Cold	40
Rapid City	April	12:00 PM	Cool	60
Rapid City	April	2:00 PM	Cool	60
Rapid City	April	4:00 PM	Cool	60
Rapid City	April	6:00 PM	Cold	50
Rapid City	April	8:00 PM	Freezing	25
Rapid City	April	10:00 PM	Freezing	25
Rapid City	May	12:00 AM	Very Cold	40
Rapid City	May	2:00 AM	Very Cold	40
Rapid City	May	4:00 AM	Very Cold	40
Rapid City	May	6:00 AM	Cold	50
Rapid City	May	8:00 AM	Cold	50
Rapid City	May	10:00 AM	Cold	50
Rapid City	May	12:00 PM	Comfortable	70
Rapid City	May	2:00 PM	Comfortable	70
Rapid City	May	4:00 PM	Comfortable	70
Rapid City	May	6:00 PM	Cool	60
Rapid City	May	8:00 PM	Very Cold	40
Rapid City	May	10:00 PM	Very Cold	40
Rapid City	June	12:00 AM	Cold	50
Rapid City	June	2:00 AM	Cold	50
Rapid City	June	4:00 AM	Cold	50
Rapid City	June	6:00 AM	Cool	60
Rapid City	June	8:00 AM	Cool	60
Rapid City	June	10:00 AM	Cool	60

Region	Month	Hour	Band	Estimated Temperature (°F)
Rapid City	June	12:00 PM	Warm	80
Rapid City	June	2:00 PM	Warm	80
Rapid City	June	4:00 PM	Warm	80
Rapid City	June	6:00 PM	Comfortable	70
Rapid City	June	8:00 PM	Cool	60
Rapid City	June	10:00 PM	Cold	50
Rapid City	July	12:00 AM	Comfortable	70
Rapid City	July	2:00 AM	Comfortable	70
Rapid City	July	4:00 AM	Comfortable	70
Rapid City	July	6:00 AM	Comfortable	70
Rapid City	July	8:00 AM	Warm	80
Rapid City	July	10:00 AM	Warm	80
Rapid City	July	12:00 PM	Hot	90
Rapid City	July	2:00 PM	Hot	90
Rapid City	July	4:00 PM	Hot	90
Rapid City	July	6:00 PM	Warm	80
Rapid City	July	8:00 PM	Comfortable	70
Rapid City	July	10:00 PM	Comfortable	70
Rapid City	August	12:00 AM	Comfortable	70
Rapid City	August	2:00 AM	Comfortable	70
Rapid City	August	4:00 AM	Comfortable	70
Rapid City	August	6:00 AM	Comfortable	70
Rapid City	August	8:00 AM	Warm	80
Rapid City	August	10:00 AM	Warm	80
Rapid City	August	12:00 PM	Hot	90
Rapid City	August	2:00 PM	Hot	90
Rapid City	August	4:00 PM	Hot	90
Rapid City	August	6:00 PM	Warm	80
Rapid City	August	8:00 PM	Comfortable	70
Rapid City	August	10:00 PM	Comfortable	70
Rapid City	September	12:00 AM	Cool	60
Rapid City	September	2:00 AM	Cool	60
Rapid City	September	4:00 AM	Cool	60
Rapid City	September	6:00 AM	Comfortable	70
Rapid City	September	8:00 AM	Comfortable	70
Rapid City	September	10:00 AM	Comfortable	70
Rapid City	September	12:00 PM	Warm	80
Rapid City	September	2:00 PM	Warm	80
Rapid City	September	4:00 PM	Warm	80
Rapid City	September	6:00 PM	Comfortable	70
Rapid City	September	8:00 PM	Cool	60
Rapid City	September	10:00 PM	Cool	60
Rapid City	October	12:00 AM	Cold	50

Region	Month	Hour	Band	Estimated Temperature (°F)
Rapid City	October	2:00 AM	Cold	50
Rapid City	October	4:00 AM	Cold	50
Rapid City	October	6:00 AM	Cool	60
Rapid City	October	8:00 AM	Cool	60
Rapid City	October	10:00 AM	Cool	60
Rapid City	October	12:00 PM	Comfortable	70
Rapid City	October	2:00 PM	Comfortable	70
Rapid City	October	4:00 PM	Comfortable	70
Rapid City	October	6:00 PM	Cool	60
Rapid City	October	8:00 PM	Cold	50
Rapid City	October	10:00 PM	Cold	50
Rapid City	November	12:00 AM	Freezing	25
Rapid City	November	2:00 AM	Freezing	25
Rapid City	November	4:00 AM	Freezing	25
Rapid City	November	6:00 AM	Very Cold	40
Rapid City	November	8:00 AM	Very Cold	40
Rapid City	November	10:00 AM	Very Cold	40
Rapid City	November	12:00 PM	Cool	60
Rapid City	November	2:00 PM	Cool	60
Rapid City	November	4:00 PM	Cool	60
Rapid City	November	6:00 PM	Very Cold	40
Rapid City	November	8:00 PM	Freezing	25
Rapid City	November	10:00 PM	Freezing	25
Rapid City	December	12:00 AM	Freezing	25
Rapid City	December	2:00 AM	Freezing	25
Rapid City	December	4:00 AM	Freezing	25
Rapid City	December	6:00 AM	Freezing	25
Rapid City	December	8:00 AM	Freezing	25
Rapid City	December	10:00 AM	Freezing	25
Rapid City	December	12:00 PM	Very Cold	40
Rapid City	December	2:00 PM	Very Cold	40
Rapid City	December	4:00 PM	Very Cold	40
Rapid City	December	6:00 PM	Freezing	25
Rapid City	December	8:00 PM	Freezing	25
Rapid City	December	10:00 PM	Freezing	25
Aberdeen	January	12:00 AM	Frigid	5
Aberdeen	January	2:00 AM	Frigid	5
Aberdeen	January	4:00 AM	Frigid	5
Aberdeen	January	6:00 AM	Frigid	5
Aberdeen	January	8:00 AM	Frigid	5
Aberdeen	January	10:00 AM	Freezing	25
Aberdeen	January	12:00 PM	Freezing	25
Aberdeen	January	2:00 PM	Freezing	25

Region	Month	Hour	Band	Estimated Temperature (°F)
Aberdeen	January	4:00 PM	Freezing	25
Aberdeen	January	6:00 PM	Freezing	25
Aberdeen	January	8:00 PM	Frigid	5
Aberdeen	January	10:00 PM	Frigid	5
Aberdeen	February	12:00 AM	Frigid	5
Aberdeen	February	2:00 AM	Frigid	5
Aberdeen	February	4:00 AM	Frigid	5
Aberdeen	February	6:00 AM	Frigid	5
Aberdeen	February	8:00 AM	Frigid	5
Aberdeen	February	10:00 AM	Freezing	25
Aberdeen	February	12:00 PM	Freezing	25
Aberdeen	February	2:00 PM	Freezing	25
Aberdeen	February	4:00 PM	Freezing	25
Aberdeen	February	6:00 PM	Freezing	25
Aberdeen	February	8:00 PM	Frigid	5
Aberdeen	February	10:00 PM	Frigid	5
Aberdeen	March	12:00 AM	Freezing	25
Aberdeen	March	2:00 AM	Freezing	25
Aberdeen	March	4:00 AM	Freezing	25
Aberdeen	March	6:00 AM	Freezing	25
Aberdeen	March	8:00 AM	Very Cold	40
Aberdeen	March	10:00 AM	Very Cold	40
Aberdeen	March	12:00 PM	Cold	50
Aberdeen	March	2:00 PM	Cold	50
Aberdeen	March	4:00 PM	Cold	50
Aberdeen	March	6:00 PM	Freezing	25
Aberdeen	March	8:00 PM	Freezing	25
Aberdeen	March	10:00 PM	Freezing	25
Aberdeen	April	12:00 AM	Freezing	25
Aberdeen	April	2:00 AM	Freezing	25
Aberdeen	April	4:00 AM	Freezing	25
Aberdeen	April	6:00 AM	Very Cold	40
Aberdeen	April	8:00 AM	Very Cold	40
Aberdeen	April	10:00 AM	Very Cold	40
Aberdeen	April	12:00 PM	Cool	60
Aberdeen	April	2:00 PM	Cool	60
Aberdeen	April	4:00 PM	Cool	60
Aberdeen	April	6:00 PM	Very Cold	40
Aberdeen	April	8:00 PM	Freezing	25
Aberdeen	April	10:00 PM	Freezing	25
Aberdeen	May	12:00 AM	Very Cold	40
Aberdeen	May	2:00 AM	Very Cold	40
Aberdeen	May	4:00 AM	Very Cold	40

Region	Month	Hour	Band	Estimated Temperature (°F)
Aberdeen	May	6:00 AM	Cold	50
Aberdeen	May	8:00 AM	Cold	50
Aberdeen	May	10:00 AM	Cold	50
Aberdeen	May	12:00 PM	Comfortable	70
Aberdeen	May	2:00 PM	Comfortable	70
Aberdeen	May	4:00 PM	Comfortable	70
Aberdeen	May	6:00 PM	Cool	60
Aberdeen	May	8:00 PM	Very Cold	40
Aberdeen	May	10:00 PM	Very Cold	40
Aberdeen	June	12:00 AM	Cold	50
Aberdeen	June	2:00 AM	Cold	50
Aberdeen	June	4:00 AM	Cold	50
Aberdeen	June	6:00 AM	Cool	60
Aberdeen	June	8:00 AM	Cool	60
Aberdeen	June	10:00 AM	Cool	60
Aberdeen	June	12:00 PM	Comfortable	70
Aberdeen	June	2:00 PM	Comfortable	70
Aberdeen	June	4:00 PM	Comfortable	70
Aberdeen	June	6:00 PM	Cool	60
Aberdeen	June	8:00 PM	Cold	50
Aberdeen	June	10:00 PM	Cold	50
Aberdeen	July	12:00 AM	Comfortable	70
Aberdeen	July	2:00 AM	Comfortable	70
Aberdeen	July	4:00 AM	Comfortable	70
Aberdeen	July	6:00 AM	Comfortable	70
Aberdeen	July	8:00 AM	Warm	80
Aberdeen	July	10:00 AM	Warm	80
Aberdeen	July	12:00 PM	Warm	80
Aberdeen	July	2:00 PM	Warm	80
Aberdeen	July	4:00 PM	Warm	80
Aberdeen	July	6:00 PM	Comfortable	70
Aberdeen	July	8:00 PM	Comfortable	70
Aberdeen	July	10:00 PM	Comfortable	70
Aberdeen	August	12:00 AM	Comfortable	70
Aberdeen	August	2:00 AM	Comfortable	70
Aberdeen	August	4:00 AM	Comfortable	70
Aberdeen	August	6:00 AM	Comfortable	70
Aberdeen	August	8:00 AM	Warm	80
Aberdeen	August	10:00 AM	Warm	80
Aberdeen	August	12:00 PM	Warm	80
Aberdeen	August	2:00 PM	Warm	80
Aberdeen	August	4:00 PM	Warm	80
Aberdeen	August	6:00 PM	Comfortable	70

Region	Month	Hour	Band	Estimated Temperature (°F)
Aberdeen	August	8:00 PM	Comfortable	70
Aberdeen	August	10:00 PM	Comfortable	70
Aberdeen	September	12:00 AM	Cool	60
Aberdeen	September	2:00 AM	Cool	60
Aberdeen	September	4:00 AM	Cool	60
Aberdeen	September	6:00 AM	Cool	60
Aberdeen	September	8:00 AM	Comfortable	70
Aberdeen	September	10:00 AM	Comfortable	70
Aberdeen	September	12:00 PM	Comfortable	70
Aberdeen	September	2:00 PM	Comfortable	70
Aberdeen	September	4:00 PM	Comfortable	70
Aberdeen	September	6:00 PM	Cool	60
Aberdeen	September	8:00 PM	Cool	60
Aberdeen	September	10:00 PM	Cool	60
Aberdeen	October	12:00 AM	Cold	50
Aberdeen	October	2:00 AM	Cold	50
Aberdeen	October	4:00 AM	Cold	50
Aberdeen	October	6:00 AM	Cool	60
Aberdeen	October	8:00 AM	Cool	60
Aberdeen	October	10:00 AM	Cool	60
Aberdeen	October	12:00 PM	Cool	60
Aberdeen	October	2:00 PM	Cool	60
Aberdeen	October	4:00 PM	Cool	60
Aberdeen	October	6:00 PM	Cold	50
Aberdeen	October	8:00 PM	Cold	50
Aberdeen	October	10:00 PM	Cold	50
Aberdeen	November	12:00 AM	Freezing	25
Aberdeen	November	2:00 AM	Freezing	25
Aberdeen	November	4:00 AM	Freezing	25
Aberdeen	November	6:00 AM	Very Cold	40
Aberdeen	November	8:00 AM	Very Cold	40
Aberdeen	November	10:00 AM	Very Cold	40
Aberdeen	November	12:00 PM	Cold	50
Aberdeen	November	2:00 PM	Cold	50
Aberdeen	November	4:00 PM	Cold	50
Aberdeen	November	6:00 PM	Very Cold	40
Aberdeen	November	8:00 PM	Freezing	25
Aberdeen	November	10:00 PM	Freezing	25
Aberdeen	December	12:00 AM	Frigid	5
Aberdeen	December	2:00 AM	Frigid	5
Aberdeen	December	4:00 AM	Frigid	5
Aberdeen	December	6:00 AM	Frigid	5
Aberdeen	December	8:00 AM	Frigid	5

Region	Month	Hour	Band	Estimated Temperature (°F)
Aberdeen	December	10:00 AM	Freezing	25
Aberdeen	December	12:00 PM	Freezing	25
Aberdeen	December	2:00 PM	Freezing	25
Aberdeen	December	4:00 PM	Freezing	25
Aberdeen	December	6:00 PM	Freezing	25
Aberdeen	December	8:00 PM	Frigid	5
Aberdeen	December	10:00 PM	Frigid	5
Pierre	January	12:00 AM	Freezing	25
Pierre	January	2:00 AM	Freezing	25
Pierre	January	4:00 AM	Freezing	25
Pierre	January	6:00 AM	Freezing	25
Pierre	January	8:00 AM	Freezing	25
Pierre	January	10:00 AM	Freezing	25
Pierre	January	12:00 PM	Very Cold	40
Pierre	January	2:00 PM	Very Cold	40
Pierre	January	4:00 PM	Very Cold	40
Pierre	January	6:00 PM	Very Cold	40
Pierre	January	8:00 PM	Freezing	25
Pierre	January	10:00 PM	Freezing	25
Pierre	February	12:00 AM	Freezing	25
Pierre	February	2:00 AM	Freezing	25
Pierre	February	4:00 AM	Freezing	25
Pierre	February	6:00 AM	Freezing	25
Pierre	February	8:00 AM	Freezing	25
Pierre	February	10:00 AM	Freezing	25
Pierre	February	12:00 PM	Cold	50
Pierre	February	2:00 PM	Cold	50
Pierre	February	4:00 PM	Cold	50
Pierre	February	6:00 PM	Cold	50
Pierre	February	8:00 PM	Freezing	25
Pierre	February	10:00 PM	Freezing	25
Pierre	March	12:00 AM	Very Cold	40
Pierre	March	2:00 AM	Very Cold	40
Pierre	March	4:00 AM	Very Cold	40
Pierre	March	6:00 AM	Very Cold	40
Pierre	March	8:00 AM	Very Cold	40
Pierre	March	10:00 AM	Very Cold	40
Pierre	March	12:00 PM	Cold	50
Pierre	March	2:00 PM	Cold	50
Pierre	March	4:00 PM	Cold	50
Pierre	March	6:00 PM	Cold	50
Pierre	March	8:00 PM	Very Cold	40
Pierre	March	10:00 PM	Very Cold	40

Region	Month	Hour	Band	Estimated Temperature (°F)
Pierre	April	12:00 AM	Cold	50
Pierre	April	2:00 AM	Cold	50
Pierre	April	4:00 AM	Cold	50
Pierre	April	6:00 AM	Cold	50
Pierre	April	8:00 AM	Cold	50
Pierre	April	10:00 AM	Cold	50
Pierre	April	12:00 PM	Cool	60
Pierre	April	2:00 PM	Cool	60
Pierre	April	4:00 PM	Cool	60
Pierre	April	6:00 PM	Cool	60
Pierre	April	8:00 PM	Cold	50
Pierre	April	10:00 PM	Cold	50
Pierre	May	12:00 AM	Cold	50
Pierre	May	2:00 AM	Cold	50
Pierre	May	4:00 AM	Cold	50
Pierre	May	6:00 AM	Cold	50
Pierre	May	8:00 AM	Cool	60
Pierre	May	10:00 AM	Cool	60
Pierre	May	12:00 PM	Comfortable	70
Pierre	May	2:00 PM	Comfortable	70
Pierre	May	4:00 PM	Comfortable	70
Pierre	May	6:00 PM	Comfortable	70
Pierre	May	8:00 PM	Cool	60
Pierre	May	10:00 PM	Cool	60
Pierre	June	12:00 AM	Comfortable	70
Pierre	June	2:00 AM	Comfortable	70
Pierre	June	4:00 AM	Comfortable	70
Pierre	June	6:00 AM	Comfortable	70
Pierre	June	8:00 AM	Cool	60
Pierre	June	10:00 AM	Cool	60
Pierre	June	12:00 PM	Warm	80
Pierre	June	2:00 PM	Warm	80
Pierre	June	4:00 PM	Warm	80
Pierre	June	6:00 PM	Comfortable	70
Pierre	June	8:00 PM	Comfortable	70
Pierre	June	10:00 PM	Comfortable	70
Pierre	July	12:00 AM	Comfortable	70
Pierre	July	2:00 AM	Comfortable	70
Pierre	July	4:00 AM	Comfortable	70
Pierre	July	6:00 AM	Comfortable	70
Pierre	July	8:00 AM	Warm	80
Pierre	July	10:00 AM	Warm	80
Pierre	July	12:00 PM	Hot	90

Region	Month	Hour	Band	Estimated Temperature (°F)
Pierre	July	2:00 PM	Hot	90
Pierre	July	4:00 PM	Hot	90
Pierre	July	6:00 PM	Warm	80
Pierre	July	8:00 PM	Comfortable	70
Pierre	July	10:00 PM	Comfortable	70
Pierre	August	12:00 AM	Comfortable	70
Pierre	August	2:00 AM	Comfortable	70
Pierre	August	4:00 AM	Comfortable	70
Pierre	August	6:00 AM	Comfortable	70
Pierre	August	8:00 AM	Warm	80
Pierre	August	10:00 AM	Warm	80
Pierre	August	12:00 PM	Hot	90
Pierre	August	2:00 PM	Hot	90
Pierre	August	4:00 PM	Hot	90
Pierre	August	6:00 PM	Warm	80
Pierre	August	8:00 PM	Comfortable	70
Pierre	August	10:00 PM	Comfortable	70
Pierre	September	12:00 AM	Cool	60
Pierre	September	2:00 AM	Cool	60
Pierre	September	4:00 AM	Cool	60
Pierre	September	6:00 AM	Cool	60
Pierre	September	8:00 AM	Cool	60
Pierre	September	10:00 AM	Cool	60
Pierre	September	12:00 PM	Warm	80
Pierre	September	2:00 PM	Warm	80
Pierre	September	4:00 PM	Warm	80
Pierre	September	6:00 PM	Cool	60
Pierre	September	8:00 PM	Cool	60
Pierre	September	10:00 PM	Cool	60
Pierre	October	12:00 AM	Cold	50
Pierre	October	2:00 AM	Cold	50
Pierre	October	4:00 AM	Cold	50
Pierre	October	6:00 AM	Cold	50
Pierre	October	8:00 AM	Cold	50
Pierre	October	10:00 AM	Cold	50
Pierre	October	12:00 PM	Cool	60
Pierre	October	2:00 PM	Cool	60
Pierre	October	4:00 PM	Cool	60
Pierre	October	6:00 PM	Cold	50
Pierre	October	8:00 PM	Cold	50
Pierre	October	10:00 PM	Cold	50
Pierre	November	12:00 AM	Freezing	25
Pierre	November	2:00 AM	Freezing	25

Region	Month	Hour	Band	Estimated Temperature (°F)
Pierre	November	4:00 AM	Freezing	25
Pierre	November	6:00 AM	Freezing	25
Pierre	November	8:00 AM	Very Cold	40
Pierre	November	10:00 AM	Very Cold	40
Pierre	November	12:00 PM	Cold	50
Pierre	November	2:00 PM	Cold	50
Pierre	November	4:00 PM	Cold	50
Pierre	November	6:00 PM	Very Cold	40
Pierre	November	8:00 PM	Freezing	25
Pierre	November	10:00 PM	Freezing	25
Pierre	December	12:00 AM	Freezing	25
Pierre	December	2:00 AM	Freezing	25
Pierre	December	4:00 AM	Freezing	25
Pierre	December	6:00 AM	Freezing	25
Pierre	December	8:00 AM	Freezing	25
Pierre	December	10:00 AM	Freezing	25
Pierre	December	12:00 PM	Very Cold	40
Pierre	December	2:00 PM	Very Cold	40
Pierre	December	4:00 PM	Very Cold	40
Pierre	December	6:00 PM	Freezing	25
Pierre	December	8:00 PM	Freezing	25
Pierre	December	10:00 PM	Freezing	25

Appendix E: Data for Figures 5.49 and 5.50

Table E.1 shows the data used in Figures 5.49 and 5.50.

Table E.1. Data used in Figures 5.49 and 5.50.

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
8245060	Precast	20	59.0	249,089	168	5.2
10099380	Precast	17	64.0	256,696	192	1.0
10341100	Precast	42	70.0	246,204	140	4.3
10531320	Precast	8	52.5	184,706	140	2.3
15067061	Precast	26	64.0	212,331	132	2.0
17377212	Precast	21	186.0	1,414,337	364	4.0
24257097	Precast	27	74.0	327,493	176	2.0
25357240	Precast	17	80.0	588,262	352	4.5
26210006	Precast	20	49.0	275,827	224	2.4
26210043	Precast	24	54.0	195,411	144	4.0
26310183	Precast	24	66.0	199,060	120	6.0
30160021	Precast	23	84.0	325,082	154	4.8
32268030	Precast	9	59.6	448,216	360	4.5
34145100	Precast	17	84.0	557,283	264	9.3
45380164	Precast	29	84.0	202,624	96	2.8
45380183	Precast	29	84.0	252,655	144	2.7
46109164	Precast	18	84.0	405,297	192	1.5
47560162	Precast	26	52.0	344,985	264	1.1
50270121	Precast	17	39.0	192,094	196	1.2
52221445	Precast	27	232.0	1,410,838	242	27.6
52226438	Precast	27	176.0	1,275,768	288	18.0
52231439	Precast	27	207.1	1,501,011	288	16.9
52232439	Precast	27	166.0	1,102,281	264	11.8
53323060	Precast	17	50.0	281,456	224	2.3
53349240	Precast	21	44.0	185,761	168	2.3
57228471	Precast	19	102.0	639,234	300	8.1
69181173	Precast	32	41.6	111,155	128	0.6
2180167	Precast	18	110.0	199,030	72	4.0
6080044	Precast	8	58.0	145,754	100	2.8
6168200	Precast	15	86.0	323,377	180	2.0
6201050	Precast	8	58.0	174,905	120	1.5
6201170	Precast	18	46.0	194,205	168	2.0
6242010	Precast	19	58.0	314,829	216	2.5
6320143	Precast	20	58.0	174,905	120	1.5
7079480	Precast	19	50.0	158,764	152	2.0
10093178	Precast	14	54.0	162,842	120	2.5
10100213	Precast	14	60.0	150,780	100	5.0
10144013	Precast	9	36.0	60,163	80	2.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
10220291	Precast	27	51.2	185,206	144	2.7
10230291	Precast	27	74.2	268,328	144	2.8
10230318	Precast	28	45.9	138,507	120	1.0
10236380	Precast	27	46.0	184,957	160	0.5
10250309	Precast	28	70.5	248,174	140	2.2
10260295	Precast	28	52.5	184,670	140	2.7
10270314	Precast	29	77.0	270,901	140	1.5
10280399	Precast	30	88.0	265,373	120	4.7
10325310	Precast	28	75.5	265,624	140	1.5
10429196	Precast	21	44.0	185,761	168	2.5
10538320	Precast	8	46.7	351,203	360	2.5
11200095	Precast	19	84.0	354,635	168	4.3
11200097	Precast	19	84.0	295,529	140	4.7
14090065	Precast	23	39.0	137,210	140	1.6
15190137	Precast	40	40.0	125,309	150	2.1
16310313	Precast	18	62.0	448,721	288	3.5
16354116	Precast	9	76.0	748,673	392	0.0
17377209	Precast	21	186.0	411,328	88	2.2
17382180	Precast	21	186.0	1,616,385	416	3.8
18040208	Precast	22	46.0	178,021	154	1.6
18044210	Precast	17	150.0	753,900	200	10.0
18070097	Precast	16	32.0	112,582	140	0.7
18070173	Precast	22	34.0	102,530	120	0.8
18090177	Precast	17	45.0	271,404	240	1.8
18090209	Precast	19	86.0	518,683	240	10.0
18110026	Precast	20	36.0	303,972	336	1.0
18120114	Precast	25	40.0	144,749	144	2.5
18120146	Precast	16	82.0	395,647	192	4.0
18122230	Precast	22	40.0	132,686	132	2.2
18132200	Precast	24	39.0	219,536	224	1.0
18139190	Precast	24	39.0	164,652	168	0.8
18140114	Precast	24	40.0	168,874	168	1.4
18170175	Precast	27	34.5	104,038	120	0.7
20213111	Precast	25	52.0	219,536	168	2.1
22212040	Precast	31	46.5	140,105	120	2.2
22240144	Precast	22	46.0	101,726	88	2.1
24200222	Precast	25	106.0	447,515	168	9.4
24377200	Precast	25	36.0	158,016	210	0.9
24382200	Precast	25	48.0	180,602	180	1.0
24405201	Precast	23	48.0	210,571	210	4.0
24416219	Precast	12	184.0	807,190	210	5.0
24420273	Precast	12	194.0	750,784	154	8.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
26220070	Precast	17	60.0	301,560	200	4.0
26230218	Precast	25	40.6	81,662	80	2.1
26243190	Precast	25	74.0	297,459	160	6.2
26300202	Precast	9	50.0	301,560	240	4.3
26325222	Precast	7	54.0	341,969	252	3.0
26330195	Precast	8	42.0	227,979	216	2.8
26330196	Precast	8	42.0	227,979	216	2.8
26340196	Precast	8	36.0	297,808	396	2.1
26363170	Precast	20	52.0	182,946	140	3.5
27476330	Precast	33	102.0	738,219	288	3.9
27482325	Precast	22	76.0	550,045	288	8.0
28032309	Precast	27	82.0	407,961	198	7.5
28200416	Precast	19	51.0	184,555	144	2.9
28222380	Precast	18	68.0	205,061	120	4.2
28337150	Precast	31	52.0	182,946	140	3.2
28390383	Precast	25	108.0	759,931	280	12.0
29230017	Precast	25	48.0	144,749	120	2.0
30160045	Precast	23	84.0	455,959	216	4.5
31169110	Precast	22	34.5	124,846	144	2.8
32010197	Precast	13	72.0	260,548	144	6.0
32040192	Precast	24	48.0	289,498	240	5.0
32040196	Precast	10	49.4	278,079	224	2.0
32067483	Precast	26	57.4	277,001	192	2.5
32082122	Precast	19	30.0	60,312	80	0.0
32091120	Precast	22	44.0	265,373	240	3.0
32110308	Precast	21	44.0	309,602	280	2.9
32178310	Precast	17	48.0	270,198	224	1.5
32305028	Precast	9	63.3	595,052	450	4.5
32360305	Precast	17	48.0	270,198	224	1.5
32482340	Precast	19	48.0	236,423	196	2.1
33110029	Precast	17	54.0	216,588	192	1.0
33110037	Precast	9	48.0	120,624	100	0.0
33114126	Precast	24	62.0	373,995	240	1.7
33380021	Precast	17	94.0	424,151	216	0.0
34040012	Precast	21	62.0	349,062	224	6.0
34040096	Precast	24	34.4	86,497	100	1.2
34060050	Precast	25	114.0	183,348	64	2.3
34175200	Precast	20	62.5	263,865	168	2.9
34200171	Precast	15	110.0	1,158,142	504	12.5
34212160	Precast	21	28.3	140,863	198	1.5
34252118	Precast	21	67.0	565,642	336	6.5
35030363	Precast	19	70.0	197,019	112	6.2

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
35062427	Precast	24	122.0	441,520	144	12.0
35097434	Precast	24	86.0	345,749	160	6.0
35150152	Precast	21	47.7	201,382	168	3.0
35150472	Precast	16	69.0	339,858	196	1.5
36436111	Precast	19	84.0	405,297	192	3.7
40077128	Precast	28	84.0	379,028	216	3.9
40083127	Precast	28	98.3	177,878	72	3.3
40150210	Precast	11	142.0	685,234	231	2.0
42090004	Precast	21	129.5	390,520	120	2.9
42090014	Precast	24	188.5	377,166	56	4.0
42144019	Precast	11	54.0	189,983	140	3.5
42144026	Precast	11	120.0	603,120	200	7.0
43160265	Precast	20	84.0	253,310	120	3.6
44003000	Precast	22	48.0	216,588	216	3.0
45361150	Precast	11	86.0	259,342	120	1.9
47009426	Precast	19	64.0	160,435	120	2.5
47033449	Precast	20	154.0	387,002	100	1.8
47040384	Precast	24	54.0	265,976	196	1.0
47040395	Precast	24	56.0	343,933	294	5.0
47048310	Precast	28	107.9	292,953	108	1.0
47050311	Precast	25	70.0	190,140	108	3.1
47060301	Precast	21	44.0	106,149	96	1.5
47064310	Precast	30	86.0	259,311	120	2.8
47080307	Precast	29	70.5	212,720	120	2.1
47109579	Precast	17	90.0	199,030	88	2.2
47110335	Precast	20	54.0	162,842	120	3.8
47110580	Precast	17	140.0	351,820	100	9.2
47110581	Precast	17	94.0	236,222	100	3.2
47111581	Precast	17	48.0	115,799	96	0.9
47130385	Precast	11	74.0	468,624	252	1.5
47136612	Precast	17	332.0	834,316	100	5.1
47147513	Precast	25	76.2	413,348	216	5.8
47151389	Precast	15	40.0	253,310	252	0.0
47210515	Precast	43	48.0	144,749	120	2.2
47210569	Precast	8	58.0	294,424	243	3.0
47484360	Precast	7	58.0	314,829	216	2.5
47504100	Precast	26	58.0	320,714	220	3.7
47560198	Precast	31	72.0	253,240	140	6.4
47720153	Precast	26	50.0	361,872	288	3.5
49125230	Precast	22	48.0	202,648	168	2.9
49167127	Precast	31	42.0	177,275	168	1.6
50130231	Precast	9	58.0	209,886	144	2.8

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
50168190	Precast	12	106.6	926,380	416	6.7
50170188	Precast	11	55.0	441,197	384	2.8
50240239	Precast	13	150.0	626,700	200	2.0
50266120	Precast	26	32.0	154,399	192	0.9
50319060	Precast	17	64.0	192,998	120	6.8
50330192	Precast	21	34.5	124,846	144	3.0
50330205	Precast	30	46.0	166,461	144	4.0
50331180	Precast	25	88.0	275,748	150	2.1
50335090	Precast	15	46.0	369,001	384	3.0
50338140	Precast	16	46.0	194,205	168	3.0
51014150	Precast	32	104.2	518,273	198	6.3
51080187	Precast	22	56.0	467,819	400	2.5
52391328	Precast	31	62.0	186,967	120	2.0
52420267	Precast	17	84.0	303,972	144	3.0
52423312	Precast	18	328.0	1,687,599	144	1.5
52445281	Precast	16	68.7	344,434	240	3.0
52445286	Precast	19	145.7	292,915	80	5.0
52457310	Precast	27	126.2	456,610	144	4.2
52490281	Precast	24	59.0	177,920	120	3.8
52500282	Precast	13	50.0	351,820	280	2.0
52719310	Precast	19	66.0	212,298	128	3.2
53079290	Precast	17	124.0	411,328	132	13.2
53210139	Precast	21	44.0	176,915	160	2.9
54170087	Precast	22	84.0	405,297	192	4.0
55068120	Precast	7	72.0	433,175	288	0.0
55112270	Precast	8	40.0	125,340	150	0.0
55170361	Precast	40	36.5	91,674	100	2.0
55220399	Precast	8	40.0	217,123	216	0.0
56069060	Precast	23	46.0	276,751	288	2.9
56090096	Precast	17	62.0	652,771	504	3.0
57183411	Precast	14	118.8	209,034	70	5.0
57204425	Precast	14	84.0	185,761	88	5.0
57252473	Precast	9	144.0	992,693	330	14.1
59062400	Precast	33	90.0	452,290	200	10.0
60172240	Precast	19	64.0	270,198	168	3.0
61023084	Precast	22	64.0	270,198	168	2.5
61350076	Precast	31	44.0	238,836	216	2.4
61442120	Precast	25	40.0	180,891	180	2.5
63002220	Precast	33	28.3	56,854	80	0.7
63127220	Precast	31	27.8	69,836	100	1.2
63224170	Precast	7	80.0	360,979	216	3.2
64012207	Precast	8	104.0	689,969	264	9.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
65180063	Precast	26	38.0	160,388	168	1.2
65357140	Precast	31	44.0	88,458	80	1.3
68110185	Precast	23	87.0	428,517	196	2.6
68138194	Precast	28	70.4	141,552	80	1.3
68160042	Precast	13	92.7	487,999	252	2.5
68180072	Precast	17	102.0	615,182	240	3.5
69002640	Precast	20	118.0	640,513	216	7.7
2239155	Cast-in-place	74	122.5	1,010,717	225	2.6
3000169	Cast-in-place	85	28.0	196,322	200	1.6
3041190	Cast-in-place	86	32.4	178,216	150	1.3
3130213	Cast-in-place	85	25.5	178,787	200	1.0
3151060	Cast-in-place	86	36.4	102,068	80	1.5
3287040	Cast-in-place	85	25.5	179,145	200	0.6
3290299	Cast-in-place	86	24.0	184,432	210	5.0
3300011	Cast-in-place	77	31.3	100,649	92	1.3
4310137	Cast-in-place	71	30.0	105,574	96	1.0
5099060	Cast-in-place	90	63.0	332,670	144	3.3
5138210	Cast-in-place	25	248.9	1,571,206	180	30.0
5230085	Cast-in-place	105	40.0	168,336	120	3.3
6156080	Cast-in-place	63	44.4	208,356	128	3.0
6230106	Cast-in-place	16	38.0	334,430	240	2.1
6246160	Cast-in-place	29	92.0	971,503	288	6.3
6278160	Cast-in-place	29	92.0	455,392	135	6.4
6310193	Cast-in-place	35	59.4	471,041	216	2.0
7018140	Cast-in-place	85	25.5	112,166	120	1.0
7201400	Cast-in-place	85	48.0	1,267,315	720	0.1
7312340	Cast-in-place	53	208.0	1,647,510	216	1.5
7319342	Cast-in-place	53	182.0	1,201,309	180	2.8
7320053	Cast-in-place	90	26.0	109,334	120	1.0
8192030	Cast-in-place	66	27.5	72,580	72	3.0
8245060	Cast-in-place	20	59.0	347,614	168	5.2
9065074	Cast-in-place	63	57.0	501,558	240	3.5
9290108	Cast-in-place	65	49.0	129,372	72	2.0
10099380	Cast-in-place	17	64.0	450,601	192	1.0
10101267	Cast-in-place	59	66.0	370,227	160	3.2
10221010	Cast-in-place	93	30.0	105,210	100	0.8
10239010	Cast-in-place	93	25.0	105,210	120	1.5
10310296	Cast-in-place	63	54.0	296,862	150	2.8
10310314	Cast-in-place	63	70.0	441,756	180	4.5
10310336	Cast-in-place	63	36.0	189,939	144	2.4
10321339	Cast-in-place	69	61.0	256,670	120	2.4
10341100	Cast-in-place	42	70.0	343,588	140	4.3

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
10421200	Cast-in-place	27	35.1	295,430	240	1.9
10429212	Cast-in-place	63	40.0	269,338	192	3.4
10487212	Cast-in-place	69	76.8	344,617	128	3.0
10531320	Cast-in-place	8	52.5	257,765	140	2.3
11074020	Cast-in-place	45	106.0	535,157	144	8.2
11182020	Cast-in-place	64	54.0	296,862	150	1.3
12376240	Cast-in-place	84	44.0	308,616	200	2.0
12519290	Cast-in-place	57	132.0	929,364	192	4.5
13030314	Cast-in-place	76	42.0	443,455	288	2.5
13030336	Cast-in-place	76	42.0	443,455	288	2.5
14090125	Cast-in-place	95	36.0	100,974	80	0.6
15067061	Cast-in-place	26	64.0	296,318	132	2.0
15208010	Cast-in-place	84	25.3	70,982	80	0.7
15209180	Cast-in-place	55	360.4	1,137,436	90	7.7
15230125	Cast-in-place	71	30.2	211,683	200	2.1
17354071	Cast-in-place	98	70.0	811,565	310	12.0
17365064	Cast-in-place	36	112.4	1,134,955	288	8.5
17377212	Cast-in-place	21	186.0	2,482,706	364	4.0
17381195	Cast-in-place	68	185.0	1,297,590	200	4.8
17420106	Cast-in-place	68	241.6	2,658,062	300	4.1
18074200	Cast-in-place	80	23.8	100,118	120	0.3
18125030	Cast-in-place	71	38.0	418,038	300	1.8
18130148	Cast-in-place	46	65.0	500,546	210	1.5
18147095	Cast-in-place	49	55.0	362,967	180	2.0
18150116	Cast-in-place	105	25.4	71,234	80	2.3
18160142	Cast-in-place	79	116.7	1,847,904	432	7.5
18160171	Cast-in-place	79	85.4	375,706	120	2.2
19000108	Cast-in-place	91	25.0	70,140	80	1.0
19031060	Cast-in-place	95	54.0	113,627	60	2.0
19070012	Cast-in-place	55	84.0	589,106	200	
19099060	Cast-in-place	90	26.0	70,647	78	2.0
20100038	Cast-in-place	54	123.0	517,633	120	2.4
20100151	Cast-in-place	34	82.1	552,748	192	3.9
20176040	Cast-in-place	85	24.0	242,202	288	4.0
20200035	Cast-in-place	72	32.0	84,461	72	2.0
21138120	Cast-in-place	65	38.0	546,247	410	1.7
22063050	Cast-in-place	102	25.7	113,046	120	1.3
23330217	Cast-in-place	39	114.0	799,456	200	11.8
23380039	Cast-in-place	33	91.0	638,274	200	6.3
24174064	Cast-in-place	92	39.9	251,873	180	2.3
24200253	Cast-in-place	34	104.1	729,947	200	9.0
24257097	Cast-in-place	27	74.0	457,030	176	2.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
24293039	Cast-in-place	57	108.1	832,215	210	3.6
24326052	Cast-in-place	15	274.4	6,867,484	683	23.0
24334083	Cast-in-place	69	219.8	1,079,321	140	8.0
24356012	Cast-in-place	19	421.5	2,956,401	200	11.0
24459200	Cast-in-place	73	124.5	427,820	98	7.7
25090177	Cast-in-place	85	22.2	74,674	96	0.9
25240177	Cast-in-place	84	22.0	111,001	144	0.1
25280013	Cast-in-place	85	25.3	106,473	120	0.0
25290048	Cast-in-place	87	22.2	124,456	160	0.1
25294050	Cast-in-place	94	25.5	187,878	201	0.4
25357240	Cast-in-place	17	80.0	1,032,627	352	4.5
26022120	Cast-in-place	33	42.0	212,053	144	1.0
26055040	Cast-in-place	94	29.2	102,404	100	0.0
26060084	Cast-in-place	86	44.0	444,407	288	2.5
26060089	Cast-in-place	85	52.0	364,518	200	4.5
26085074	Cast-in-place	49	120.0	841,540	200	7.2
26090071	Cast-in-place	89	22.0	92,501	120	2.1
26169010	Cast-in-place	84	24.5	171,703	200	2.0
26171040	Cast-in-place	31	116.0	813,484	200	10.0
26180008	Cast-in-place	37	86.0	482,507	160	6.2
26180020	Cast-in-place	37	180.8	1,431,829	216	3.0
26183047	Cast-in-place	28	92.1	710,511	220	4.3
26194059	Cast-in-place	28	138.6	544,320	112	7.2
26205100	Cast-in-place	95	25.4	142,468	160	2.5
26210006	Cast-in-place	20	49.0	384,928	224	2.4
26210043	Cast-in-place	24	54.0	272,704	144	4.0
26222069	Cast-in-place	28	102.0	386,217	108	4.0
26230106	Cast-in-place	75	25.0	175,350	200	2.1
26260112	Cast-in-place	87	25.4	124,660	140	3.0
26260124	Cast-in-place	87	25.4	106,851	120	3.0
26264150	Cast-in-place	69	58.0	318,864	150	2.9
26270185	Cast-in-place	94	36.0	252,434	200	3.0
26270221	Cast-in-place	95	24.8	69,495	80	1.5
26298150	Cast-in-place	59	49.0	343,546	200	1.9
26310183	Cast-in-place	24	66.0	277,796	120	6.0
26330231	Cast-in-place	124	21.5	75,401	100	1.5
26370150	Cast-in-place	59	118.0	529,608	128	5.4
26381150	Cast-in-place	59	49.0	309,191	180	1.7
27038080	Cast-in-place	54	121.0	305,530	72	2.0
27050135	Cast-in-place	68	76.0	668,861	240	5.3
28186480	Cast-in-place	71	56.0	615,726	300	2.5
28410472	Cast-in-place	44	93.0	939,113	288	6.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
29100098	Cast-in-place	89	24.5	103,022	120	0.8
29102100	Cast-in-place	84	24.0	101,002	120	0.8
29140176	Cast-in-place	95	25.0	70,140	80	1.0
29270094	Cast-in-place	99	23.0	64,529	80	1.0
30110206	Cast-in-place	72	24.0	211,043	240	4.0
30157242	Cast-in-place	23	85.0	1,122,234	360	4.3
30160021	Cast-in-place	23	84.0	453,666	154	4.8
30160111	Cast-in-place	23	90.1	1,374,908	416	3.9
30160122	Cast-in-place	23	84.0	665,340	216	3.3
30160150	Cast-in-place	23	198.8	2,007,912	288	15.3
30160181	Cast-in-place	23	88.1	1,860,207	576	4.3
30160203	Cast-in-place	23	86.0	1,248,834	396	4.4
30160345	Cast-in-place	97	60.0	336,504	160	5.0
30190222	Cast-in-place	33	54.0	264,982	140	1.3
30190232	Cast-in-place	95	48.0	202,003	120	0.9
30250236	Cast-in-place	65	27.0	207,919	210	2.2
32122467	Cast-in-place	64	45.0	315,490	200	4.0
32268030	Cast-in-place	9	59.6	786,792	360	4.5
33112125	Cast-in-place	30	104.0	875,347	240	3.8
33119112	Cast-in-place	31	94.1	1,490,521	432	6.1
34096180	Cast-in-place	85	40.0	168,336	120	2.5
34140129	Cast-in-place	90	29.5	103,562	100	1.0
34145100	Cast-in-place	17	84.0	777,712	264	9.3
34200223	Cast-in-place	85	64.0	492,845	210	9.5
35110164	Cast-in-place	61	50.0	280,560	160	2.3
35110279	Cast-in-place	66	65.0	364,672	160	3.5
35110397	Cast-in-place	66	64.0	225,300	96	4.3
36086179	Cast-in-place	66	98.8	1,564,976	432	2.5
36147110	Cast-in-place	57	178.0	1,123,580	180	3.5
36148111	Cast-in-place	69	78.0	411,825	144	3.7
36156007	Cast-in-place	71	56.0	431,008	210	1.5
36171317	Cast-in-place	13	134.0	1,588,390	338	13.9
36301184	Cast-in-place	71	66.0	370,227	160	5.0
36320338	Cast-in-place	13	95.0	1,532,806	440	2.1
38276173	Cast-in-place	84	42.0	461,932	300	1.3
39047000	Cast-in-place	95	25.8	72,384	80	0.5
40010100	Cast-in-place	87	32.0	211,153	180	2.0
40022130	Cast-in-place	42	84.0	565,609	192	5.2
40130138	Cast-in-place	25	122.8	945,877	210	1.8
41084057	Cast-in-place	51	249.0	1,397,189	160	15.0
41084060	Cast-in-place	85	42.0	294,518	200	4.0
41161038	Cast-in-place	27	84.0	2,236,017	726	2.6

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
41195226	Cast-in-place	68	35.0	122,640	100	2.0
41294313	Cast-in-place	71	45.3	498,125	300	3.3
42020057	Cast-in-place	78	40.0	140,813	96	3.0
42020065	Cast-in-place	77	43.0	473,043	300	3.0
42070198	Cast-in-place	25	76.4	514,098	192	2.0
42080154	Cast-in-place	87	45.8	201,538	120	1.5
42103260	Cast-in-place	78	35.0	461,646	360	2.0
42150027	Cast-in-place	26	150.7	856,178	162	15.5
42167260	Cast-in-place	95	38.5	338,655	240	3.3
42172260	Cast-in-place	95	36.0	475,111	360	2.7
43160204	Cast-in-place	78	86.0	603,204	200	2.0
43230288	Cast-in-place	62	33.0	115,661	100	2.0
43470478	Cast-in-place	93	32.5	142,925	120	2.0
44200225	Cast-in-place	85	19.4	65,281	96	2.8
44213088	Cast-in-place	68	40.0	280,490	200	1.5
44213106	Cast-in-place	66	73.0	321,229	120	2.2
45050073	Cast-in-place	71	74.0	407,147	150	0.8
45170035	Cast-in-place	92	46.6	196,069	120	0.9
45380164	Cast-in-place	29	84.0	282,771	96	2.8
45380183	Cast-in-place	29	84.0	443,508	144	2.7
45438150	Cast-in-place	68	66.0	462,784	200	3.9
46108230	Cast-in-place	45	86.0	434,256	144	6.6
46109163	Cast-in-place	48	86.0	579,076	192	1.5
46109164	Cast-in-place	18	84.0	565,609	192	1.5
46110141	Cast-in-place	48	86.0	180,940	60	1.1
46140100	Cast-in-place	83	86.0	621,489	197	4.5
46170029	Cast-in-place	65	53.0	233,221	120	1.2
46170084	Cast-in-place	65	54.0	340,691	180	1.8
47045458	Cast-in-place	78	180.2	1,516,455	240	7.5
47068503	Cast-in-place	69	189.0	927,952	140	5.6
47070306	Cast-in-place	71	67.8	372,824	150	4.4
47107576	Cast-in-place	68	147.0	1,030,918	200	6.3
47117558	Cast-in-place	74	33.3	224,022	192	2.5
47188373	Cast-in-place	69	59.0	259,492	120	2.3
47468330	Cast-in-place	52	123.0	1,353,123	300	7.4
47560162	Cast-in-place	26	52.0	481,441	264	1.1
47661070	Cast-in-place	63	36.0	303,005	240	2.7
47759141	Cast-in-place	38	96.1	674,045	200	7.8
48282111	Cast-in-place	63	36.0	190,097	144	3.5
50090158	Cast-in-place	73	40.5	142,034	100	3.2
50116164	Cast-in-place	76	69.5	917,483	360	7.5
50176122	Cast-in-place	62	164.0	1,035,266	180	5.7

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
50180166	Cast-in-place	25	137.8	1,273,665	252	5.0
50194237	Cast-in-place	66	273.0	459,557	48	3.2
50220091	Cast-in-place	87	25.5	71,543	80	2.7
50250065	Cast-in-place	85	25.5	71,543	80	0.0
50270121	Cast-in-place	17	39.0	268,075	196	1.2
50290225	Cast-in-place	73	42.0	147,294	100	4.0
50310015	Cast-in-place	62	82.0	601,388	200	2.0
50315130	Cast-in-place	87	25.3	212,945	240	2.8
51050105	Cast-in-place	100	41.0	143,717	100	1.0
51086100	Cast-in-place	48	177.1	1,242,390	200	12.3
51099240	Cast-in-place	86	32.3	79,244	70	1.5
51148170	Cast-in-place	69	23.0	141,693	168	1.5
52221445	Cast-in-place	27	232.0	1,968,885	242	27.6
52221447	Cast-in-place	27	148.8	2,162,864	396	5.5
52226438	Cast-in-place	27	176.0	1,780,390	288	18.0
52226438	Cast-in-place	27	176.0	1,780,390	288	18.0
52231439	Cast-in-place	27	207.1	2,094,725	288	16.9
52232439	Cast-in-place	27	166.0	1,538,281	264	11.8
52307300	Cast-in-place	67	98.5	663,177	192	20.5
52310301	Cast-in-place	67	77.0	518,273	192	13.1
52310303	Cast-in-place	67	77.0	518,273	192	13.1
52375262	Cast-in-place	78	118.7	914,073	210	1.5
52430449	Cast-in-place	28	208.0	1,830,302	240	6.5
52462326	Cast-in-place	17	146.0	2,007,126	392	2.2
52489339	Cast-in-place	75	131.0	735,067	160	2.4
52613396	Cast-in-place	61	64.0	269,253	120	3.2
52768500	Cast-in-place	66	60.0	316,829	144	6.4
52833552	Cast-in-place	42	90.1	951,437	288	6.9
52940382	Cast-in-place	67	444.7	3,119,056	200	22.4
53190299	Cast-in-place	62	49.8	335,123	192	2.7
53323060	Cast-in-place	17	50.0	392,784	224	2.3
53349240	Cast-in-place	21	44.0	259,237	168	2.3
54170077	Cast-in-place	22	104.0	525,208	144	4.0
54285000	Cast-in-place	73	39.0	273,406	200	0.9
54288000	Cast-in-place	73	44.0	484,044	300	2.0
55009050	Cast-in-place	65	54.0	296,862	150	3.3
55060103	Cast-in-place	88	26.0	127,557	140	1.3
55060106	Cast-in-place	88	25.5	125,151	140	1.3
55074190	Cast-in-place	28	115.9	520,181	128	6.5
55090192	Cast-in-place	84	42.0	424,207	288	4.0
55091197	Cast-in-place	84	41.0	180,460	120	3.0
55100279	Cast-in-place	84	39.0	273,616	200	2.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
55100289	Cast-in-place	84	42.0	294,518	200	2.0
55115267	Cast-in-place	47	337.5	1,420,335	120	21.8
55115282	Cast-in-place	47	172.5	948,671	150	3.1
55115312	Cast-in-place	47	324.3	1,819,600	160	15.6
55130309	Cast-in-place	94	45.0	284,130	180	1.5
55180386	Cast-in-place	37	74.0	569,698	210	3.7
55180419	Cast-in-place	37	113.2	1,245,203	300	9.8
55189190	Cast-in-place	90	40.5	356,344	240	2.5
55303010	Cast-in-place	96	25.0	105,210	120	1.0
56007010	Cast-in-place	63	51.0	286,171	160	2.8
56039100	Cast-in-place	89	86.5	424,698	140	2.0
56051030	Cast-in-place	15	50.0	528,048	288	2.9
57228471	Cast-in-place	19	102.0	1,122,102	300	8.1
58002330	Cast-in-place	36	74.0	1,171,950	432	2.5
58020302	Cast-in-place	36	98.0	1,006,225	280	9.3
58044290	Cast-in-place	36	74.0	518,896	200	4.6
58222420	Cast-in-place	12	163.0	1,506,257	252	19.5
58297060	Cast-in-place	67	55.0	193,582	96	3.9
58300062	Cast-in-place	70	48.0	126,732	72	1.0
58303340	Cast-in-place	91	37.0	244,222	180	2.0
59048279	Cast-in-place	105	20.0	112,112	160	1.0
59234176	Cast-in-place	55	60.0	660,060	300	5.5
61431020	Cast-in-place	20	180.3	1,138,162	180	18.0
61485010	Cast-in-place	9	82.0	2,345,413	780	6.1
62028270	Cast-in-place	37	98.0	2,587,435	720	6.3
62075270	Cast-in-place	37	181.0	1,269,324	200	20.6
62081270	Cast-in-place	37	128.0	1,408,018	300	11.5
62179273	Cast-in-place	60	180.0	631,225	100	2.9
62270372	Cast-in-place	77	44.0	232,341	144	2.0
62270414	Cast-in-place	77	44.0	338,831	210	1.0
62310270	Cast-in-place	54	135.1	473,690	100	3.0
62315270	Cast-in-place	54	135.1	473,690	100	2.5
63160150	Cast-in-place	60	108.0	712,865	180	3.2
63160198	Cast-in-place	62	118.7	798,990	192	5.8
63181090	Cast-in-place	57	94.0	593,384	180	5.4
63192090	Cast-in-place	57	133.3	935,036	200	9.6
64016050	Cast-in-place	65	39.0	218,725	160	3.0
64025030	Cast-in-place	75	35.8	200,825	160	1.3
64030136	Cast-in-place	75	24.0	84,098	100	2.3
64070179	Cast-in-place	70	36.0	126,696	96	2.2
64070210	Cast-in-place	77	37.0	325,454	240	3.0
64115160	Cast-in-place	75	25.6	125,642	140	2.5

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
65150039	Cast-in-place	60	38.0	278,619	200	0.3
65172080	Cast-in-place	66	40.0	211,166	144	2.5
65180077	Cast-in-place	66	42.0	184,773	120	2.0
65210003	Cast-in-place	91	26.0	114,322	120	1.5
65210004	Cast-in-place	91	26.0	114,322	120	1.5
65290030	Cast-in-place	72	76.2	267,163	100	0.6
65320160	Cast-in-place	56	90.0	201,981	64	2.0
69181173	Cast-in-place	32	41.6	195,120	128	0.6
2007220	Cast-in-place	21	50.0	396,036	216	2.7
2012240	Cast-in-place	26	50.0	484,044	264	2.8
2180042	Cast-in-place	66	62.0	341,031	150	3.2
2180116	Cast-in-place	65	54.0	189,378	100	2.5
2180167	Cast-in-place	18	110.0	208,316	54	4.0
2223165	Cast-in-place	60	160.0	561,120	100	4.0
3050116	Cast-in-place	7	55.0	653,459	324	0.0
3220197	Cast-in-place	20	88.1	426,249	132	4.5
3231199	Cast-in-place	20	114.2	552,778	132	4.2
3300045	Cast-in-place	86	75.0	263,025	100	2.5
3350281	Cast-in-place	8	43.0	253,346	168	2.1
3399240	Cast-in-place	7	48.0	316,829	180	2.5
4305130	Cast-in-place	71	29.9	105,258	96	1.0
5065060	Cast-in-place	61	75.0	526,050	200	5.9
5164060	Cast-in-place	59	73.8	414,107	160	3.1
5184060	Cast-in-place	59	54.0	142,573	72	2.1
5230017	Cast-in-place	17	131.1	1,586,696	330	5.0
5230027	Cast-in-place	13	84.0	589,176	200	6.0
5248180	Cast-in-place	20	86.0	567,652	180	2.2
5260172	Cast-in-place	46	86.0	331,762	110	2.5
6080044	Cast-in-place	8	58.0	203,406	100	#VALUE!
6103080	Cast-in-place	63	40.0	290,426	198	2.5
6105110	Cast-in-place	19	40.0	185,170	132	2.5
6120005	Cast-in-place	8	60.3	477,699	216	2.5
6130202	Cast-in-place	17	55.0	423,539	210	2.3
6139100	Cast-in-place	29	40.0	493,214	336	2.0
6141170	Cast-in-place	25	39.9	526,728	360	2.0
6150073	Cast-in-place	35	59.4	392,600	180	2.0
6151070	Cast-in-place	21	40.0	492,845	336	2.0
6158060	Cast-in-place	29	40.0	422,755	288	2.0
6160057	Cast-in-place	20	40.0	422,438	288	2.5
6168200	Cast-in-place	15	86.0	567,652	180	2.0
6171100	Cast-in-place	23	40.0	440,040	300	3.0
6181010	Cast-in-place	22	42.6	562,767	360	2.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
6183210	Cast-in-place	59	49.3	203,097	112	2.5
6201050	Cast-in-place	8	58.0	244,087	120	1.5
6201170	Cast-in-place	18	46.0	271,021	168	2.0
6202190	Cast-in-place	17	44.0	290,426	180	2.2
6203202	Cast-in-place	22	56.8	900,269	432	2.5
6220079	Cast-in-place	18	38.0	292,627	210	2.5
6220113	Cast-in-place	20	40.0	387,235	264	3.0
6220143	Cast-in-place	28	40.0	351,944	240	2.0
6220201	Cast-in-place	22	57.0	627,057	300	2.5
6233100	Cast-in-place	26	49.0	387,719	216	2.5
6242010	Cast-in-place	19	58.0	439,357	216	2.5
6245030	Cast-in-place	36	46.0	232,497	144	3.0
6260123	Cast-in-place	35	42.0	265,036	180	2.5
6260176	Cast-in-place	36	46.0	486,209	288	2.0
6270175	Cast-in-place	26	48.7	599,915	336	2.5
6290177	Cast-in-place	16	38.0	535,089	384	2.2
6300183	Cast-in-place	35	42.0	332,591	216	2.5
6310186	Cast-in-place	35	42.0	147,406	100	2.5
6320143	Cast-in-place	20	58.0	244,087	120	1.5
7079480	Cast-in-place	19	50.0	274,365	150	2.0
7119340	Cast-in-place	35	62.5	1,375,125	600	0.3
7130323	Cast-in-place	30	70.0	654,372	255	0.0
7180387	Cast-in-place	25	56.0	517,487	252	1.5
7340389	Cast-in-place	23	42.0	277,225	180	2.0
7341390	Cast-in-place	23	44.5	293,727	180	2.0
8302135	Cast-in-place	61	171.0	479,758	80	3.0
8310161	Cast-in-place	76	84.8	297,253	100	3.5
9142081	Cast-in-place	26	164.0	1,656,426	288	19.3
9315080	Cast-in-place	73	50.0	330,030	180	2.0
10093178	Cast-in-place	14	54.0	227,254	120	2.5
10100213	Cast-in-place	14	60.0	210,420	100	5.3
10144013	Cast-in-place	9	36.0	105,610	80	2.0
10219010	Cast-in-place	93	30.0	165,015	150	1.3
10220291	Cast-in-place	27	51.2	258,463	144	2.7
10220321	Cast-in-place	63	38.0	133,772	96	1.4
10222010	Cast-in-place	93	30.0	52,805	48	0.8
10230291	Cast-in-place	27	74.2	374,463	144	2.8
10230318	Cast-in-place	28	45.9	193,292	120	1.0
10236380	Cast-in-place	27	46.0	258,115	160	0.5
10237366	Cast-in-place	23	114.3	1,006,019	240	6.6
10250309	Cast-in-place	28	70.5	346,337	140	2.2
10254300	Cast-in-place	31	74.7	366,615	140	1.5
10260295	Cast-in-place	28	52.5	257,715	140	2.7

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
10270314	Cast-in-place	29	77.0	378,055	140	1.5
10274390	Cast-in-place	29	74.0	374,373	138	2.9
10280399	Cast-in-place	30	88.0	370,339	120	4.7
10325310	Cast-in-place	28	75.5	370,690	140	1.5
10328334	Cast-in-place	69	61.7	173,049	80	3.9
10428207	Cast-in-place	63	34.0	214,628	180	2.0
10429196	Cast-in-place	21	44.0	259,237	168	2.5
10440187	Cast-in-place	63	34.0	166,933	140	2.1
10538320	Cast-in-place	8	46.7	616,496	360	2.5
11200095	Cast-in-place	19	84.0	494,908	168	4.3
11200097	Cast-in-place	19	84.0	412,423	140	4.7
12079000	Cast-in-place	41	64.0	269,338	120	2.5
12091000	Cast-in-place	41	64.0	323,205	144	4.0
12092020	Cast-in-place	22	48.0	237,622	135	3.5
12183080	Cast-in-place	62	74.0	467,132	180	6.5
12300206	Cast-in-place	71	66.0	232,341	96	3.8
12389243	Cast-in-place	20	84.0	589,176	200	3.5
12394244	Cast-in-place	20	88.1	370,634	120	3.8
12508210	Cast-in-place	16	63.0	332,670	144	3.2
12530290	Cast-in-place	57	154.0	1,080,156	200	10.0
13010266	Cast-in-place	13	44.0	619,576	384	1.0
13010323	Cast-in-place	8	40.0	657,126	448	1.0
13020053	Cast-in-place	69	40.0	175,972	120	2.0
13020127	Cast-in-place	69	40.0	168,294	120	2.0
13020159	Cast-in-place	69	40.0	140,245	100	2.0
13020172	Cast-in-place	69	40.0	263,958	180	2.5
13030269	Cast-in-place	13	46.0	387,173	240	1.0
13031310	Cast-in-place	7	60.0	404,006	192	4.2
13060278	Cast-in-place	7	60.0	252,504	120	3.0
14051050	Cast-in-place	78	38.5	80,970	60	3.0
14060014	Cast-in-place	21	47.8	268,384	160	2.0
14060032	Cast-in-place	16	76.0	533,064	200	8.0
14065000	Cast-in-place	42	36.0	126,252	100	2.5
14066030	Cast-in-place	21	58.5	410,319	200	4.7
14068010	Cast-in-place	14	44.0	271,582	176	2.6
14072020	Cast-in-place	16	52.0	514,847	270	3.3
14075063	Cast-in-place	29	65.1	410,887	180	3.5
14090065	Cast-in-place	23	39.9	195,901	140	1.6
14095130	Cast-in-place	47	24.0	164,832	196	0.1
14108010	Cast-in-place	21	47.8	561,256	320	1.7
14110020	Cast-in-place	28	46.0	310,384	192	2.4
14110056	Cast-in-place	8	57.0	399,798	200	3.5

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
14141070	Cast-in-place	13	49.3	332,026	192	2.5
15179165	Cast-in-place	35	75.0	792,072	288	2.4
15179183	Cast-in-place	13	73.0	1,284,917	480	1.8
15184186	Cast-in-place	13	70.0	1,976,513	770	1.7
15190019	Cast-in-place	26	50.1	462,689	252	4.0
15190137	Cast-in-place	40	40.0	219,965	150	2.1
15200052	Cast-in-place	34	42.0	176,711	120	2.0
15250061	Cast-in-place	27	46.0	193,586	120	2.1
16310313	Cast-in-place	18	62.0	626,210	288	3.5
16354116	Cast-in-place	9	76.0	1,044,805	392	0.0
17161088	Cast-in-place	37	90.1	442,324	140	4.9
17234172	Cast-in-place	33	84.0	1,293,564	420	2.2
17244068	Cast-in-place	61	72.0	505,008	200	5.1
17261068	Cast-in-place	61	74.0	519,036	200	4.9
17302039	Cast-in-place	20	64.0	291,782	130	2.9
17304045	Cast-in-place	20	69.1	377,876	156	2.7
17309046	Cast-in-place	20	90.8	496,924	156	2.9
17332067	Cast-in-place	38	67.0	626,524	250	2.8
17340072	Cast-in-place	38	111.6	1,325,691	324	3.9
17363066	Cast-in-place	36	194.3	2,564,861	360	6.2
17364065	Cast-in-place	36	126.0	1,272,418	288	13.8
17377209	Cast-in-place	21	186.0	574,026	88	2.2
17382180	Cast-in-place	21	186.0	2,837,378	416	3.8
18040208	Cast-in-place	22	46.0	248,436	154	1.6
18040213	Cast-in-place	23	66.0	356,451	154	4.7
18044210	Cast-in-place	17	150.0	1,052,100	200	10.0
18070097	Cast-in-place	16	32.0	157,114	140	0.7
18070173	Cast-in-place	22	34.0	143,086	120	0.8
18090152	Cast-in-place	12	54.0	475,243	240	3.2
18090177	Cast-in-place	17	45.0	378,756	240	1.8
18090209	Cast-in-place	19	86.0	723,845	240	10.0
18110026	Cast-in-place	20	36.0	424,207	336	1.0
18120114	Cast-in-place	25	40.0	202,003	144	2.5
18120146	Cast-in-place	16	82.0	552,142	192	4.0
18122230	Cast-in-place	22	40.0	185,170	132	2.2
18132200	Cast-in-place	24	39.0	306,372	224	1.0
18139190	Cast-in-place	24	39.0	229,779	168	0.8
18140114	Cast-in-place	24	40.0	235,670	168	1.4
18149096	Cast-in-place	24	216.0	2,566,313	324	29.1
18154098	Cast-in-place	35	96.0	528,048	150	2.0
18161100	Cast-in-place	37	220.0	1,851,696	240	26.0
18170175	Cast-in-place	27	34.5	145,190	120	0.7

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
19019060	Cast-in-place	95	56.0	196,287	100	1.5
19030019	Cast-in-place	25	56.5	198,146	100	2.5
19030032	Cast-in-place	21	42.0	247,454	168	2.1
19040180	Cast-in-place	30	42.0	353,421	240	3.0
19060089	Cast-in-place	19	42.0	226,833	154	1.3
19062090	Cast-in-place	19	42.0	226,833	154	1.5
19066090	Cast-in-place	19	42.0	226,833	154	1.7
19080043	Cast-in-place	16	46.2	285,223	176	2.5
19346040	Cast-in-place	14	44.0	240,720	156	1.5
20010295	Cast-in-place	22	40.0	435,640	297	2.1
20013210	Cast-in-place	23	44.0	542,129	336	2.0
20056220	Cast-in-place	21	45.1	189,925	120	2.0
20200041	Cast-in-place	72	34.0	119,656	96	2.0
20213111	Cast-in-place	25	52.0	306,372	168	2.1
20213121	Cast-in-place	33	49.7	376,256	216	2.1
21136060	Cast-in-place	17	59.2	406,718	196	0.0
22212040	Cast-in-place	31	36.4	153,017	120	2.2
22230178	Cast-in-place	36	54.3	190,430	100	2.1
22231080	Cast-in-place	65	56.0	235,670	120	2.2
22240144	Cast-in-place	22	46.0	141,963	88	2.1
23380002	Cast-in-place	33	86.0	227,034	72	4.2
23380005	Cast-in-place	33	84.0	235,642	80	3.2
23380093	Cast-in-place	33	92.0	607,189	180	6.2
24188247	Cast-in-place	34	84.0	412,374	140	5.4
24200222	Cast-in-place	25	106.0	624,527	168	9.4
24293026	Cast-in-place	43	132.0	1,110,933	240	3.4
24377200	Cast-in-place	25	36.0	277,379	210	0.9
24382200	Cast-in-place	25	48.0	317,027	180	1.0
24405201	Cast-in-place	23	48.0	369,634	210	4.0
24416219	Cast-in-place	12	184.0	1,416,929	210	5.0
24420273	Cast-in-place	12	194.0	1,047,751	154	8.0
25379190	Cast-in-place	89	26.0	91,112	100	0.5
26220070	Cast-in-place	17	60.0	420,840	200	4.0
26230218	Cast-in-place	25	40.6	113,963	80	2.1
26243190	Cast-in-place	25	74.0	415,117	160	6.2
26250040	Cast-in-place	19	65.3	439,694	192	4.1
26270037	Cast-in-place	15	42.6	458,839	294	2.1
26270068	Cast-in-place	26	48.0	563,603	320	2.5
26300202	Cast-in-place	9	50.0	420,840	240	4.3
26325222	Cast-in-place	7	54.0	477,233	252	3.0
26330195	Cast-in-place	8	42.0	318,155	216	2.8
26330196	Cast-in-place	8	42.0	344,668	234	2.8

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
26340196	Cast-in-place	8	46.0	667,981	396	2.1
26363170	Cast-in-place	20	52.0	255,310	140	3.5
27019100	Cast-in-place	7	36.0	84,488	64	1.4
27030252	Cast-in-place	21	45.1	221,579	140	2.5
27050241	Cast-in-place	29	82.7	626,311	216	3.5
27168174	Cast-in-place	28	64.0	538,507	240	4.5
27230339	Cast-in-place	20	56.1	346,391	176	4.6
27476330	Cast-in-place	33	102.0	1,030,216	288	3.9
27482325	Cast-in-place	22	76.0	767,612	288	8.0
28032309	Cast-in-place	27	82.0	569,327	198	7.5
28200416	Cast-in-place	19	51.0	257,554	144	2.9
28222380	Cast-in-place	18	68.0	286,171	120	4.2
28337150	Cast-in-place	31	52.0	255,310	140	3.2
28390383	Cast-in-place	25	108.0	1,060,517	280	12.0
29100148	Cast-in-place	7	52.1	550,226	288	2.1
29153155	Cast-in-place	23	42.0	332,670	216	2.5
29228054	Cast-in-place	11	44.0	185,170	120	2.3
29230017	Cast-in-place	25	48.0	202,003	120	2.0
29270039	Cast-in-place	8	48.8	434,402	243	2.0
29270104	Cast-in-place	19	42.0	117,835	80	1.5
29300034	Cast-in-place	20	54.0	185,590	98	2.3
30100188	Cast-in-place	30	60.0	403,804	192	4.5
30154255	Cast-in-place	34	42.0	323,352	210	2.1
30160045	Cast-in-place	23	84.0	636,310	216	4.5
30224330	Cast-in-place	95	28.0	78,557	80	3.0
30291210	Cast-in-place	30	62.3	524,638	240	3.3
31169110	Cast-in-place	22	34.5	174,228	144	2.8
32010197	Cast-in-place	13	72.0	363,606	144	6.0
32040192	Cast-in-place	24	48.0	404,006	240	5.0
32040196	Cast-in-place	10	49.4	388,071	224	2.0
32050101	Cast-in-place	64	39.0	273,953	200	1.5
32067483	Cast-in-place	26	57.4	386,567	192	2.5
32082122	Cast-in-place	19	30.0	84,168	80	0.0
32091120	Cast-in-place	22	44.0	370,339	240	3.0
32110308	Cast-in-place	21	44.0	432,062	280	2.9
32178310	Cast-in-place	17	48.0	377,073	224	#VALUE!
32305028	Cast-in-place	9	63.3	1,044,545	450	4.5
32360305	Cast-in-place	17	48.0	377,073	224	1.5
32369280	Cast-in-place	31	128.0	1,408,018	300	13.6
32482340	Cast-in-place	19	48.0	329,939	196	2.1
33110029	Cast-in-place	17	54.0	380,195	192	1.0
33110037	Cast-in-place	9	48.0	168,336	100	0.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
33114126	Cast-in-place	24	62.0	521,842	240	1.7
33170107	Cast-in-place	30	42.0	424,106	288	1.8
33256103	Cast-in-place	58	55.0	387,165	192	2.5
33290064	Cast-in-place	63	72.0	408,943	162	4.0
33380021	Cast-in-place	17	94.0	744,548	216	0.0
33380121	Cast-in-place	31	94.0	744,548	216	0.0
34040012	Cast-in-place	21	62.0	487,052	224	6.0
34040096	Cast-in-place	24	34.4	120,746	100	1.2
34060005	Cast-in-place	25	84.0	1,016,492	330	2.4
34060050	Cast-in-place	25	114.0	255,871	64	2.3
34060079	Cast-in-place	33	96.0	1,182,828	336	3.6
34060091	Cast-in-place	25	84.0	848,413	288	3.5
34060107	Cast-in-place	25	84.0	176,753	60	3.7
34060119	Cast-in-place	25	84.0	294,588	100	4.0
34070007	Cast-in-place	35	50.3	774,690	420	2.3
34070205	Cast-in-place	41	86.0	422,243	140	3.0
34081180	Cast-in-place	85	40.0	140,813	96	2.0
34135050	Cast-in-place	63	26.0	262,604	288	1.5
34175200	Cast-in-place	20	62.5	368,235	168	2.9
34200171	Cast-in-place	15	110.0	2,032,985	504	12.5
34202187	Cast-in-place	13	100.0	926,126	264	8.5
34212160	Cast-in-place	21	28.3	196,581	198	1.5
34252118	Cast-in-place	21	67.0	789,378	336	6.5
34270100	Cast-in-place	67	30.0	210,420	200	5.2
34300222	Cast-in-place	34	62.0	613,658	270	5.7
35030363	Cast-in-place	19	70.0	962,321	392	6.2
35062427	Cast-in-place	24	122.0	616,160	144	12.0
35097434	Cast-in-place	24	86.0	482,507	160	6.0
35150152	Cast-in-place	21	47.7	281,037	168	3.0
35150472	Cast-in-place	16	69.0	474,287	196	1.5
36105212	Cast-in-place	13	84.0	1,330,681	432	5.6
36436111	Cast-in-place	19	84.0	565,609	192	3.7
37054080	Cast-in-place	73	54.0	475,243	240	2.9
37190104	Cast-in-place	62	47.3	166,546	96	2.0
37190118	Cast-in-place	62	42.0	110,864	72	2.0
37273090	Cast-in-place	62	58.0	446,641	210	2.1
39005080	Cast-in-place	38	48.0	211,219	120	1.6
39052010	Cast-in-place	33	42.0	141,402	96	1.2
40077128	Cast-in-place	28	84.0	665,340	216	3.9
40083127	Cast-in-place	28	98.3	248,237	72	3.3
40083127	Cast-in-place	28	98.3	248,237	72	3.3
40120042	Cast-in-place	71	54.0	475,243	240	3.2

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
40127127	Cast-in-place	22	58.0	292,905	144	2.4
40131131	Cast-in-place	22	49.0	247,454	144	3.0
40132131	Cast-in-place	22	50.0	294,765	168	3.2
40150210	Cast-in-place	11	142.0	1,202,849	231	2.0
41068069	Cast-in-place	25	90.0	833,171	264	2.0
41100088	Cast-in-place	31	90.0	441,833	140	5.8
41106086	Cast-in-place	31	126.8	557,839	120	4.9
41111086	Cast-in-place	31	118.8	705,736	162	4.0
41150030	Cast-in-place	62	70.0	490,840	200	4.0
42004270	Cast-in-place	9	42.5	589,104	378	1.6
42016140	Cast-in-place	10	76.4	907,477	324	2.0
42022260	Cast-in-place	12	48.3	382,571	216	4.8
42024120	Cast-in-place	72	82.0	541,249	180	3.1
42026260	Cast-in-place	13	56.5	447,521	216	4.0
42027070	Cast-in-place	34	44.7	245,817	150	1.0
42031260	Cast-in-place	75	30.0	126,252	120	1.5
42035120	Cast-in-place	72	82.0	517,633	180	3.0
42040262	Cast-in-place	9	43.0	253,346	168	1.5
42049170	Cast-in-place	7	87.1	1,149,825	360	3.7
42050169	Cast-in-place	26	58.9	466,451	216	3.0
42050207	Cast-in-place	9	46.0	258,115	160	1.3
42059220	Cast-in-place	23	46.0	154,869	96	1.5
42065047	Cast-in-place	67	168.0	924,084	150	2.7
42065177	Cast-in-place	65	170.3	449,554	72	5.0
42065278	Cast-in-place	65	289.5	1,137,110	112	14.5
42090004	Cast-in-place	21	130.0	401,201	88	4.5
42090014	Cast-in-place	24	188.5	1,382,150	196	4.0
42100109	Cast-in-place	38	86.0	868,614	288	3.8
42103270	Cast-in-place	29	54.0	272,553	144	4.5
42110175	Cast-in-place	7	50.0	252,504	144	2.3
42111210	Cast-in-place	31	60.6	344,289	162	3.5
42120117	Cast-in-place	27	44.7	432,639	264	2.0
42120209	Cast-in-place	10	50.0	392,784	224	3.0
42121210	Cast-in-place	10	52.0	350,139	192	4.1
42138280	Cast-in-place	35	48.5	272,143	160	2.0
42140281	Cast-in-place	35	48.5	272,143	160	1.5
42142019	Cast-in-place	10	54.0	415,838	210	3.5
42144019	Cast-in-place	11	54.0	265,129	140	3.5
42144026	Cast-in-place	11	120.0	841,680	200	7.0
42150143	Cast-in-place	20	110.0	694,386	180	9.3
42150155	Cast-in-place	20	98.3	1,297,810	360	7.0
42170163	Cast-in-place	8	64.0	675,901	288	4.5

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
42225271	Cast-in-place	28	56.0	738,871	360	2.0
42225281	Cast-in-place	28	54.0	181,702	96	2.0
43025323	Cast-in-place	24	139.0	2,202,119	432	15.0
43041130	Cast-in-place	17	50.0	280,560	160	1.3
43090122	Cast-in-place	57	46.0	193,586	120	3.0
43120038	Cast-in-place	39	44.0	406,597	252	1.7
43160265	Cast-in-place	20	84.0	353,506	120	3.6
44003000	Cast-in-place	22	48.0	380,195	216	3.0
44015030	Cast-in-place	24	47.6	489,148	280	1.5
44015182	Cast-in-place	89	55.5	389,277	200	7.3
44040197	Cast-in-place	89	43.7	306,722	200	3.5
44110025	Cast-in-place	78	74.0	651,259	240	4.5
44119210	Cast-in-place	27	118.3	298,712	72	6.5
44130037	Cast-in-place	20	48.0	282,804	168	2.5
44137040	Cast-in-place	20	55.5	604,886	297	2.0
44152210	Cast-in-place	27	119.5	301,742	72	2.8
44199040	Cast-in-place	17	50.0	968,088	528	2.0
44209051	Cast-in-place	68	42.0	184,773	120	2.0
44210071	Cast-in-place	69	44.0	193,618	120	2.2
44210137	Cast-in-place	66	44.0	387,235	240	3.2
44212105	Cast-in-place	78	84.0	221,780	72	5.7
45050039	Cast-in-place	37	74.0	259,518	100	2.6
45361150	Cast-in-place	11	86.0	361,922	120	1.9
46305166	Cast-in-place	32	84.0	494,849	168	2.5
47009426	Cast-in-place	19	64.0	281,626	120	2.5
47010424	Cast-in-place	62	27.5	151,209	150	3.0
47031438	Cast-in-place	46	195.0	1,116,185	153	0.8
47031439	Cast-in-place	46	200.0	1,346,760	180	1.0
47033449	Cast-in-place	20	154.0	540,078	100	1.8
47040384	Cast-in-place	24	54.0	424,207	224	1.0
47040395	Cast-in-place	24	56.0	603,735	294	5.0
47048310	Cast-in-place	28	107.9	408,829	108	1.0
47050311	Cast-in-place	25	70.0	265,348	108	3.1
47059340	Cast-in-place	71	26.2	86,402	90	0.8
47060301	Cast-in-place	21	44.0	148,136	96	1.5
47064310	Cast-in-place	30	86.0	361,880	120	2.8
47068501	Cast-in-place	69	226.4	797,071	96	5.2
47068510	Cast-in-place	9	240.0	925,848	110	4.5
47080307	Cast-in-place	29	70.5	296,861	120	2.1
47082542	Cast-in-place	9	85.0	459,066	154	5.0
47095556	Cast-in-place	10	91.8	386,457	120	3.6
47109579	Cast-in-place	17	90.0	277,754	88	2.2

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
47110335	Cast-in-place	20	40.0	168,336	120	3.8
47110580	Cast-in-place	17	140.0	490,980	100	9.2
47110581	Cast-in-place	17	94.0	329,658	100	3.2
47111581	Cast-in-place	17	48.0	161,603	96	0.9
47115560	Cast-in-place	74	30.0	197,952	180	1.5
47122558	Cast-in-place	75	32.0	337,951	288	0.3
47130385	Cast-in-place	11	74.0	653,985	252	1.5
47131612	Cast-in-place	68	199.7	1,318,404	180	2.3
47136612	Cast-in-place	17	332.0	1,164,324	100	5.1
47136612	Cast-in-place	17	332.0	1,280,756	110	5.1
47137612	Cast-in-place	17	75.0	263,025	100	4.9
47147513	Cast-in-place	25	76.2	576,845	216	5.8
47151389	Cast-in-place	15	40.0	353,506	252	0.0
47167559	Cast-in-place	75	44.0	444,407	288	2.0
47170612	Cast-in-place	22	68.3	1,082,446	432	2.3
47178382	Cast-in-place	69	56.0	353,316	180	2.3
47182379	Cast-in-place	69	75.0	526,050	200	4.9
47192610	Cast-in-place	21	76.0	936,405	336	7.8
47210515	Cast-in-place	43	48.0	202,003	120	2.2
47210569	Cast-in-place	8	58.0	516,827	243	3.0
47230373	Cast-in-place	10	106.0	2,627,626	676	10.0
47448330	Cast-in-place	52	99.0	694,386	200	6.0
47484360	Cast-in-place	7	58.0	439,357	216	2.5
47504100	Cast-in-place	26	58.1	448,265	220	3.7
47560198	Cast-in-place	31	72.0	353,407	140	6.4
47660121	Cast-in-place	65	41.0	258,817	180	1.5
47720153	Cast-in-place	26	50.0	505,008	288	3.5
47760068	Cast-in-place	38	110.9	1,306,792	336	9.6
47761044	Cast-in-place	38	120.0	1,211,817	288	11.7
48440241	Cast-in-place	21	98.3	344,738	100	2.1
49000078	Cast-in-place	19	46.0	546,530	324	1.5
49010071	Cast-in-place	24	48.5	426,751	240	2.7
49054220	Cast-in-place	16	40.0	316,829	216	1.0
49091030	Cast-in-place	35	42.0	226,779	154	1.5
49094050	Cast-in-place	35	42.0	147,259	100	1.3
49094200	Cast-in-place	20	42.0	542,129	352	1.7
49097070	Cast-in-place	32	42.0	176,711	120	1.2
49097170	Cast-in-place	23	42.0	554,450	360	2.0
49098130	Cast-in-place	39	89.4	1,180,187	360	5.0
49125230	Cast-in-place	22	48.0	282,804	168	2.9
49127220	Cast-in-place	17	47.6	565,896	324	2.0
49166120	Cast-in-place	24	42.0	332,591	216	1.4

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
49167127	Cast-in-place	31	42.0	247,395	168	1.6
49181190	Cast-in-place	28	42.0	282,737	192	1.6
49209220	Cast-in-place	30	42.0	207,869	135	2.0
49231050	Cast-in-place	22	50.8	536,602	288	1.3
50002210	Cast-in-place	30	84.0	353,506	120	3.5
50026210	Cast-in-place	30	128.4	540,527	120	8.3
50130231	Cast-in-place	9	59.0	297,955	144	2.8
50139210	Cast-in-place	36	90.1	1,110,503	336	2.4
50147170	Cast-in-place	76	66.0	444,407	192	3.5
50152170	Cast-in-place	76	68.0	748,068	300	5.0
50161170	Cast-in-place	76	86.0	756,869	240	3.3
50168190	Cast-in-place	12	106.6	1,626,153	416	6.7
50170188	Cast-in-place	11	55.0	774,470	384	2.8
50174222	Cast-in-place	29	208.0	3,089,081	405	17.8
50176175	Cast-in-place	24	74.0	651,259	240	3.4
50183240	Cast-in-place	28	175.5	2,316,811	360	4.1
50240069	Cast-in-place	12	37.3	480,095	351	2.8
50240073	Cast-in-place	12	41.6	713,921	468	1.0
50240239	Cast-in-place	13	150.0	1,100,100	200	2.0
50266120	Cast-in-place	26	32.0	215,470	192	0.9
50280106	Cast-in-place	21	88.0	611,060	198	6.3
50284100	Cast-in-place	20	94.0	527,453	160	4.7
50319060	Cast-in-place	17	64.0	269,338	120	6.8
50327180	Cast-in-place	37	84.0	776,231	252	3.0
50330192	Cast-in-place	21	34.5	174,228	144	3.0
50330205	Cast-in-place	30	46.0	232,304	144	4.0
50331180	Cast-in-place	25	88.0	484,044	150	2.1
50335090	Cast-in-place	15	46.0	647,739	384	3.0
50338140	Cast-in-place	16	46.0	271,021	168	3.0
51014150	Cast-in-place	32	104.2	723,272	198	6.3
51020159	Cast-in-place	20	57.4	483,124	240	3.0
51039170	Cast-in-place	20	46.8	769,331	448	2.5
51080187	Cast-in-place	22	56.0	821,203	400	2.5
51164130	Cast-in-place	15	88.0	784,240	243	5.5
51199130	Cast-in-place	15	84.0	499,005	162	3.0
52309299	Cast-in-place	67	102.0	686,609	192	18.2
52312307	Cast-in-place	69	80.0	538,608	192	4.6
52313311	Cast-in-place	69	90.0	605,942	192	9.0
52391328	Cast-in-place	31	62.0	260,921	120	2.0
52393325	Cast-in-place	34	131.1	865,141	180	2.7
52417298	Cast-in-place	24	100.0	420,840	120	5.0
52419296	Cast-in-place	45	95.0	386,605	116	2.0

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft²)	Fill height (ft)
52420267	Cast-in-place	17	84.0	424,207	144	3.0
52423312	Cast-in-place	18	328.0	1,766,949	144	1.5
52445281	Cast-in-place	16	68.7	604,615	240	3.0
52445286	Cast-in-place	19	145.7	408,776	80	5.0
52457310	Cast-in-place	27	126.2	637,219	144	4.2
52490281	Cast-in-place	24	59.0	248,296	120	3.8
52500279	Cast-in-place	23	96.0	528,048	150	3.2
52500282	Cast-in-place	13	50.0	490,980	280	2.0
52609290	Cast-in-place	99	19.7	82,905	120	2.0
52719310	Cast-in-place	19	66.0	296,271	128	3.2
52861552	Cast-in-place	42	84.0	443,508	144	3.6
52913550	Cast-in-place	42	82.0	721,578	240	2.5
52923550	Cast-in-place	42	20.0	264,024	360	5.1
52925490	Cast-in-place	44	20.0	168,336	240	5.1
52929550	Cast-in-place	42	65.1	801,982	336	4.3
52960359	Cast-in-place	35	71.2	249,663	100	4.1
52993480	Cast-in-place	63	34.0	187,017	150	2.2
53072290	Cast-in-place	17	96.0	580,853	165	4.6
53079290	Cast-in-place	17	124.0	574,026	132	13.2
53112290	Cast-in-place	17	143.0	842,522	168	13.2
53150289	Cast-in-place	31	62.0	490,926	216	2.8
53161290	Cast-in-place	42	62.0	490,926	216	2.8
53210139	Cast-in-place	21	44.0	246,893	160	2.9
53380083	Cast-in-place	7	82.0	694,603	231	2.3
53410597	Cast-in-place	9	110.6	2,336,084	576	4.8
54155160	Cast-in-place	85	84.0	235,642	80	4.0
54170087	Cast-in-place	22	84.0	565,609	192	4.0
54230201	Cast-in-place	89	34.0	149,614	120	0.5
54230204	Cast-in-place	89	32.0	140,813	120	1.0
54306040	Cast-in-place	34	42.0	388,115	252	1.8
54307080	Cast-in-place	33	42.0	184,817	120	2.5
55020044	Cast-in-place	21	42.7	239,374	160	1.7
55060173	Cast-in-place	21	54.0	475,243	240	2.7
55062120	Cast-in-place	16	40.0	202,003	144	2.0
55068120	Cast-in-place	7	72.0	760,389	288	0.0
55070126	Cast-in-place	31	72.0	760,389	288	0.0
55070169	Cast-in-place	19	42.0	457,422	297	3.0
55070190	Cast-in-place	28	132.5	594,697	128	5.4
55095100	Cast-in-place	11	56.4	237,354	120	1.0
55100233	Cast-in-place	84	55.5	194,674	100	2.5
55100315	Cast-in-place	84	44.0	484,044	300	2.5
55108270	Cast-in-place	96	34.0	95,362	80	2.8

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
55112270	Cast-in-place	8	40.0	220,020	150	0.0
55138270	Cast-in-place	34	74.0	233,629	90	1.3
55140372	Cast-in-place	20	42.0	353,506	240	3.0
55143300	Cast-in-place	33	42.0	318,079	216	2.0
55160216	Cast-in-place	29	42.0	424,106	288	2.5
55170361	Cast-in-place	40	36.5	127,935	100	2.0
55180352	Cast-in-place	14	44.0	387,235	240	1.3
55220399	Cast-in-place	8	40.0	303,005	216	0.0
56069060	Cast-in-place	23	46.0	485,804	288	2.9
56090096	Cast-in-place	17	62.0	1,145,864	504	3.0
56190100	Cast-in-place	20	118.0	1,090,419	252	1.4
57183411	Cast-in-place	14	118.8	291,716	70	5.0
57204425	Cast-in-place	14	84.0	259,237	88	5.0
57252473	Cast-in-place	9	144.0	1,742,558	330	14.1
58007330	Cast-in-place	33	43.6	288,050	180	4.0
58356420	Cast-in-place	12	87.0	689,103	216	6.8
59062400	Cast-in-place	33	90.0	631,190	200	10.0
59402306	Cast-in-place	35	114.1	800,087	200	12.3
60172240	Cast-in-place	19	64.0	377,073	168	3.0
61023084	Cast-in-place	22	64.0	377,073	168	2.5
61350076	Cast-in-place	31	44.0	333,305	216	2.4
61442120	Cast-in-place	25	40.0	252,441	180	2.5
62222460	Cast-in-place	67	77.0	508,048	180	2.5
63002220	Cast-in-place	33	28.3	79,342	80	0.7
63024070	Cast-in-place	64	84.0	295,707	96	3.1
63127220	Cast-in-place	31	27.8	97,460	100	1.2
63140043	Cast-in-place	26	83.3	350,686	120	3.0
63160075	Cast-in-place	12	29.8	167,214	160	1.0
63160108	Cast-in-place	60	90.8	318,541	100	2.8
63160223	Cast-in-place	62	107.0	270,179	72	6.0
63224170	Cast-in-place	7	80.0	633,658	216	3.2
64006104	Cast-in-place	64	243.0	1,022,641	120	3.6
64006108	Cast-in-place	64	284.0	1,195,186	120	14.0
64006115	Cast-in-place	64	167.5	1,174,845	200	7.8
64010175	Cast-in-place	70	46.0	161,935	96	1.5
64012207	Cast-in-place	8	104.0	962,882	264	9.0
64020218	Cast-in-place	19	53.3	448,615	240	2.1
64032147	Cast-in-place	75	24.5	103,022	120	1.7
64038040	Cast-in-place	15	48.0	665,340	378	1.4
64038147	Cast-in-place	18	102.0	701,119	196	3.2
64046010	Cast-in-place	17	53.3	246,507	132	3.5
64050082	Cast-in-place	16	54.0	265,129	140	3.1

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
64056150	Cast-in-place	18	78.5	440,704	160	2.0
64070217	Cast-in-place	77	46.7	410,909	240	2.4
64076040	Cast-in-place	21	44.0	200,600	130	2.5
64077223	Cast-in-place	65	84.2	531,521	180	4.1
64086100	Cast-in-place	75	34.0	89,742	72	3.3
64089010	Cast-in-place	41	50.0	336,672	192	2.5
64090022	Cast-in-place	60	72.3	381,832	144	3.1
64090120	Cast-in-place	56	68.0	476,952	200	5.8
64091020	Cast-in-place	21	49.3	172,930	100	2.0
64160011	Cast-in-place	71	85.0	357,840	120	3.1
65145150	Cast-in-place	69	34.0	143,044	120	12.0
65180063	Cast-in-place	26	38.0	223,828	168	1.2
65210129	Cast-in-place	20	98.2	648,179	180	2.4
65240184	Cast-in-place	34	56.0	211,990	108	3.0
65240188	Cast-in-place	34	42.0	415,739	270	1.6
65302100	Cast-in-place	39	84.0	554,384	180	2.8
65357140	Cast-in-place	31	44.0	123,446	80	1.3
68061206	Cast-in-place	20	118.0	455,209	110	8.2
68079202	Cast-in-place	37	141.2	1,739,742	336	4.0
68100170	Cast-in-place	16	54.1	364,481	192	3.3
68110185	Cast-in-place	23	87.0	598,014	196	2.6
68138194	Cast-in-place	28	70.4	197,542	80	1.3
68160042	Cast-in-place	13	92.7	856,626	252	2.5
68180072	Cast-in-place	17	102.0	858,514	240	3.5
69002640	Cast-in-place	20	118.0	893,864	216	7.7
69360425	Cast-in-place	31	84.0	294,553	100	5.5
4045180	Cast-in-place	93	25.6	179,488	200	0.3
4060178	Cast-in-place	93	25.5	280,415	300	0.3
6307140	Cast-in-place	95	28.3	119,014	120	1.7
7044230	Cast-in-place	93	21.5	75,365	100	2.5
16687258	Cast-in-place	60	77.3	341,575	126	1.5
18070198	Cast-in-place	100	31.0	272,825	240	2.5
18080007	Cast-in-place	65	25.6	125,691	140	1.0
18090017	Cast-in-place	80	25.8	173,723	192	1.8
20170004	Cast-in-place	95	20.0	92,585	132	0.4
23371100	Cast-in-place	51	108.0	454,381	120	3.3
28421469	Cast-in-place	84	54.0	227,127	120	3.6
29221020	Cast-in-place	95	24.0	67,334	80	0.0
34120127	Cast-in-place	90	25.0	70,140	80	1.2
35070262	Cast-in-place	91	24.1	158,942	180	1.2
35110414	Cast-in-place	66	72.3	506,972	200	1.2
35110475	Cast-in-place	62	83.0	638,927	210	8.5

Structure #	Type	Service life (years)	Length (ft)	Cost ($)	Total Open Area (ft^2)	Fill height (ft)
37282100	Cast-in-place	88	21.5	90,439	120	1.0
39004120	Cast-in-place	92	32.0	253,463	216	1.6
42186250	Cast-in-place	85	44.8	113,071	72	1.0
42200287	Cast-in-place	84	29.7	228,711	210	1.5
47050322	Cast-in-place	90	23.0	161,322	200	0.8
47375253	Cast-in-place	63	34.2	143,885	120	1.3
50290149	Cast-in-place	87	25.5	89,429	100	0.3
51146180	Cast-in-place	105	24.0	134,557	160	2.5
58300162	Cast-in-place	67	50.5	333,264	180	1.3