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Structural Engineering and Materials

**STATE OF INTERNAL DESIGN REVIEW PROCESS
IN STRUCTURAL ENGINEERING**

By

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Report No. CE/VPI-ST-23/02

May 2023

EXECUTIVE SUMMARY

Internal design reviews serve as a major quality control measure in structural engineering firms. The process differs among firms and may be formal (documented) or informal (undocumented). The motivation of this project was to understand the design review process as it typically exists in structural engineering firms. Topics included the review process, time spent on review, common errors caught during reviews, and improvements suggested by study participants.

Interviews were performed with 22 individuals from 16 structural engineering firms across the country. The study concluded that approximately 70% of firms have a formal internal design review process. A baseline process was established to occur before each submission to a client while each firm added their own unique practices to the process. Some practices, such as process scalability and the inclusion of design charrettes were mentioned by employees of multiple firms. Firms completing building design typically spent 5% of project hours on design review, however most employee suggestions related to expanding the time allowed for review or using it more efficiently. These factors alone cannot be used to indicate the quality of a design review, but the results of this paper may inform on different design review practices across the industry and aid firms in evaluating and improving their individual processes.

ACKNOWLEDGEMENTS

First and foremost, I am extremely grateful to my committee chairman, Dr. Matthew Eatherton for his willingness to explore this area of the structural engineering profession and for his guidance and support throughout the project and report process. I would also like to thank Dr. Carin Roberts-Wollmann and Professor Mike Biscotte for sharing their insights and sitting on my committee. Thank you to Dr. Scott Case for encouraging me and helping me to find such a wonderful team when I came to him with this research idea. My sincerest thanks go to the structural engineers who volunteered to participate in this study. I hope the contents of this report prove useful and are well worth the time they spent talking with me.

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1. INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION TO DESIGN REVIEW

Design reviews function as a check of structural design deliverables by experienced structural engineers prior to significant project milestones such as submission to the client or as construction documents. These design reviews can occur internally within a firm or externally by another engineering firm, called a peer review. Peer reviews are more common for extremely complicated or novel designs. Internal design reviews, however, are standard practice for projects of all types and sizes. The report focuses on reviews performed by structural engineers to include internal reviews, peer reviews, and reviews of contractor submissions, as highlighted in gray in Figure 1. The figure is a simplified depiction of the structural design process and should not be interpreted as applicable to every project or firm.

Depending on the firm and project, different products may be subject to internal design reviews. These can include drawing packages, BIM models, structural calculations, or reports compiled for the client.

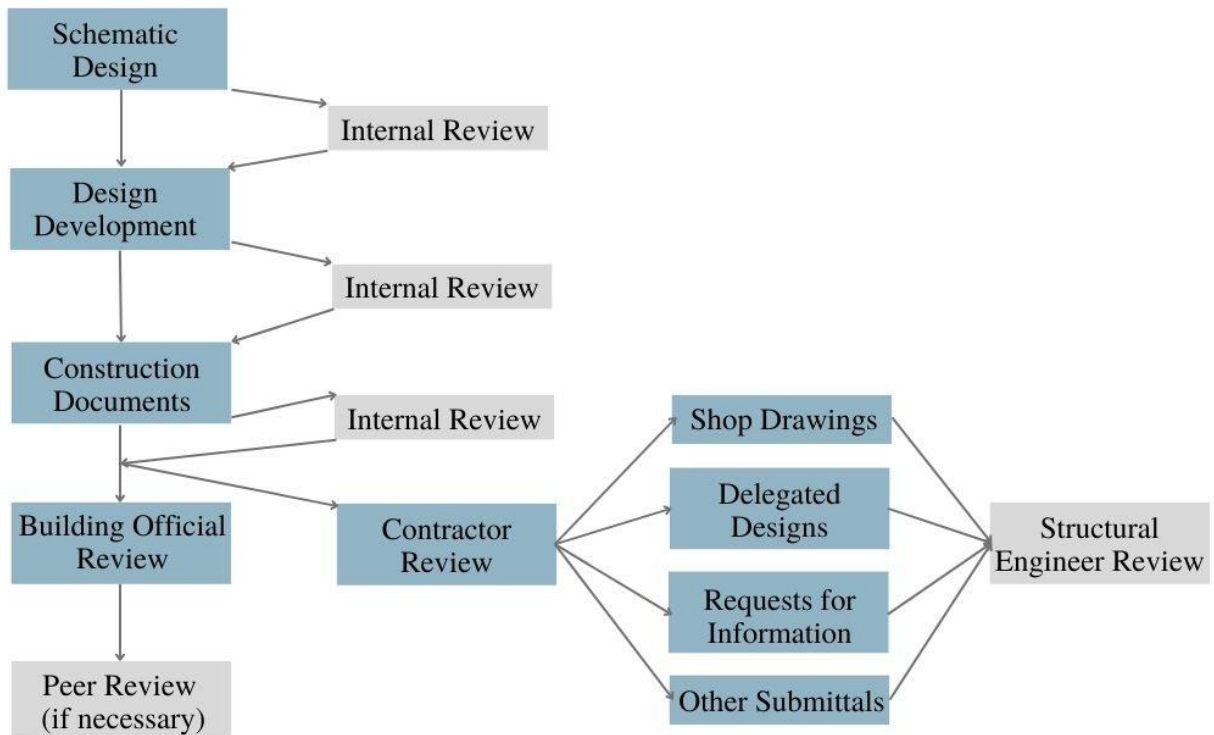


Figure 1: Opportunities for Design Review within Structural Design Process

1.2 PROJECT GOALS

The purpose of this project and report is to investigate the current state of the internal design review process within the structural design industry. Topics of interest include:

- Are formal or informal design review processes more prevalent?
- What are the characteristics of firms with formal design review processes?
- What are common steps of formal design review processes? Informal design review processes?
- How much time is dedicated to the review process on a typical project?
- Are engineers satisfied with the review process at their firm?

- What are common issues that engineers catch when performing design reviews?
- What are the characteristics of shop drawing and delegated design reviews?
- Are there overarching themes that can be used to help refine the review process?

1.3 OVERVIEW OF PROJECT

The project consisted of interviewing 22 design professionals with the aim of determining the state of design review within their firm. The overall questions categories included characteristics of the firm's internal design review process, common outcomes of that process, and characteristics of shop drawing, delegated design, and peer reviews. Answers to the questions detailed in Section 3.2 were transcribed and compiled for processing.

Processing of data took different forms depending on the format of the question. Questions with numerical answers were analyzed statistically and compared against firm characteristics. Questions without numerical answers were grouped by common themes or answers and compared against firm statistics and numerical answers when relevant.

2. REVIEW OF QUALITY MANAGEMENT METHODS

The existence of quality management systems such as internal design reviews is not a concept unique to the structural engineering community or even to engineering as a whole. Rather quality management systems are tools set in place by companies to ensure that the minimum standard for their goods and services is known and placed at a level above the minimum standards for the consumers in a market [1]. One method of setting such a minimum standard as a firm is to establish an internal system that is based on an accepted “good practice”, such as the ISO 9001 accreditation.

Organizations are able to define their own minimum standards. The standards chosen by a firm’s leadership may be more stringent than those required by law, but they should not fall below the industry standard of care or result in non-compliance with regulatory requirements. To that effect, organizations such as California’s Department of Health Care Access and Information (HCAI) and the Nuclear Regulatory Commission (NRC) exist to enforce quality management on buildings with high risk. Federal agencies and federal and state highway departments often have specific review requirements for their projects. Firms who work for these clients may be more likely to incorporate aspects of those requirements into their process for all projects.

2.1 ISO 9001 QUALITY MANAGEMENT STANDARD

The ISO 9001 management system published by the International Organization for Standardization (ISO) was first created in 1987 and was most recently updated in 2015 [1]. It is the most popular management system accreditation in the world, with over 1 million certifications issued [1]. ISO 9001:2015 focuses on quality management principles of customer focus, leadership, engagement

with people, process focus, improvement, evidence-based decision making, and relationship management [2].

The standard suggests the implementation of a Plan-Do-Check-Act (PDCA) cycle that is fueled by risk-based thinking. The PDCA cycle is essentially a method of establishing objectives or goals for the organization, likely driven by a desire to decrease risk, implementing a chosen method of establishing such a goal, monitoring the performance of the method, and making improvements as necessary. There is an emphasis placed on leadership involvement in the process throughout [2]. The ISO 9001 framework could be used to evaluate, improve, and accredit an existing design review process. One company interviewed for this project had achieved an ISO 9001 certification for their internal design review process.

2.2 DOCUMENTS TO AID INTERNAL QUALITY ASSURANCE

Documents to aid in the completion of internal quality assurance processes have been published by authors from different aspects of the building industry. Professional societies such as the Coalition of American Structural Engineers (CASE) have published documents with guidelines for performing peer reviews and implementing quality assurance plans. Additionally, state building agencies have published guides to review plans before submission for review by the publishing agency. For example, the Virginia Department of General Services published a Construction and Professional Services Manual with an Appendix Q dedicated to quality assurance checklists for designers to walk through prior to submitting drawings [3]. Such tools could prove beneficial to structural engineering firms, especially when working with an unfamiliar agency or if internal checklists have not been generated.

2.3 DEPARTMENT OF HEALTH CARE ACCESS AND INFORMATION (HCAI)

The Department of Health Care Access and Information (HCAI), formerly the Office of Statewide Planning and Development (OSHPD) is a government organization responsible for establishing building regulations, reviewing plans, and conducting construction inspections for work on new and existing healthcare facilities in California [4]. Engineers employed by HCAI review plans to ensure code compliance, a form of external quality management for structural design companies. In essence, HCAI is a quality management system enforcing the minimum standard of healthcare facility design in California. They have established several different processes to do so, scalable based on risk aspects of a project such as type, size, or complexity [4]. HCAI engineers are often involved early in the design process to establish special design considerations, situations requiring additional testing, and requirements for alternate design procedures [4].

2.4 NUCLEAR REGULATIONS

The Nuclear Regulatory Commission (NRC) is similar to HCAI in that it is an organization external to design firms which controls many of the requirements in place for a specific type of structure and is responsible for enforcing such requirements. Structural engineers are employed by the Division of Engineering and External Hazards (DEX), which provides technical expertise for the licensing and rulemaking functions of the NRC [5]. They also support oversight functions for nuclear facilities [5]. Structural engineers with the Division of Engineering are involved in the development of standards for design and construction of nuclear facilities [6]. The combination of these two offices both defines and enforces the minimum standard of structural design for nuclear facilities.

3. STUDY DESIGN

3.1 PROJECT IMPLEMENTATION

Experienced design professionals from different structural engineering companies were interviewed (30 min – 1 hour) and asked a series of pre-determined questions. Clarifying questions were asked if necessary. Interviews were conducted via Zoom video conference.

3.2 BACKGROUND ON DESIGN OF INTERVIEW TYPE STUDIES

There are three types of research approaches, qualitative, quantitative, and mixed method. Quantitative approaches rely on the collection of data and a comparison between selected variables. Qualitative approaches are more flexible in their method of collecting data, allowing for observations, interviews, and other data to be collected and analyzed to inform theories on social questions [7]. Mixed methods approaches combine both qualitative and quantitative data collection and analysis techniques to inform a research design that best addresses the study questions [8].

This study utilizes a mixed method approach that is informed by a pragmatic worldview. Pragmatism is a common worldview behind mixed methods research approaches because of its flexibility in approaching problems and finding the method that works rather than valuing one particular method of data gathering and analysis over another [7]. Specifically, this study will use a concurrent mixed methods approach. The defining characteristic of this approach is that both qualitative and quantitative data are collected at the same time and integrated during the analysis of the results [7]. In this case, questions aimed at gathering both qualitative and quantitative data (i.e., open-ended and close-ended questions) were asked of each interview participant.

3.3 IDENTIFYING PARTICIPANTS

Participants were identified by leveraging professor connections with former Virginia Tech students and professional committees. To encourage geographical diversity in participants, an online platform was used to conduct interviews. Multiple participants from the same firm were avoided unless each could offer a different perspective on the firm's process. Due to the methods of identification, the participants made up a non-probabilistic sample population representing structural design engineers. The intent was to complete a single-stage sampling procedure with known names within the structural engineering community. Single-stage sampling is feasible when the researcher knows the names of people within the population and can reach out directly to them [7]. Thanks to the abovementioned connections, this method was possible.

However, due to the non-random method of selection, there was a threat to the internal validity of the study due to characteristics of the participants that lead them to be selected [7]. In this project, such characteristics included participants likely being alumni of Virginia Tech or associates of Virginia Tech structural engineering faculty. As Virginia Tech has a highly ranked civil engineering program, its alumni and their associates are spread across many firms of various sizes and business areas. Since the focus of this project was on determining the design review methods of various firms, rather than specific individuals, this single-stage sampling was a valid method of determining participants for a study of this size.

3.4 PRIVACY AND DATA HANDLING

The identity of all participants is confidential, and responses are anonymously incorporated into this report. Furthermore, identifying information about the firm was discussed during the interview

solely for the purpose of correctly anonymizing the firm for the report. The session was recorded for purposes of data extraction. Identifying information and raw video footage is only available to the researcher and research advisor, both trained in IRB protocols.

The experimental protocol was approved for human subject research by the Virginia Tech Institutional Review Board and can be reviewed under IRB number 23-069.

3.5 EXPECTED ERRORS

It is important to note that there was an inherent bias due to participants who chose to participate versus non-participants. Participants were more likely to be employees who felt knowledgeable about their firm's design review process. Non-participants were more likely to be employees who felt less knowledgeable about the process or felt that their firm's process was inadequate. Participants were also likely to put a positive spin on their firm's design review process. These were systematic errors that are important to keep in mind when considering the results of this study.

Random errors in this study came from participants' accuracy and precision in answering interview questions. Answers varied given the uncertainty in measuring the true values of quantitative questions for a given firm. It was expected that the given answers varied both above and below the true values, rendering this a random error that trended toward the true value.

3.6 PLAN FOR DATA PROCESSING AND ANALYSIS

Data collection, processing, and analysis occurred in five steps, shown in Figure 2 below. It was essential to collect information unbiased by the researcher’s personal viewpoints and to recognize the biases that were inherent to the study.

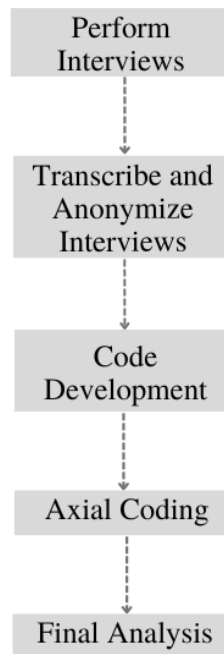


Figure 2: Data Analysis Process

3.6.1 Perform Interviews

Participants were asked questions during the interview in accordance with Section 4.2 of this document. The interviewer asked clarifying questions as necessary to guide the participant to answer the question completely. Answers to quantitative questions were not expected to be precise, but rather to reflect as accurately as possible the participant’s views on a given question.

3.6.2 Transcribe and Anonymize Interviews

After the interview was completed, the Canvas platform was used to generate an initial transcription of the conversation. It was expected that this transcription was 80-90% accurate. If

necessary for data analysis, the raw video footage was referenced to clarify transcription ambiguity. All identifying information of the participant was removed and replaced with a unique alphanumeric identifier for the purposes of this report. Participant names matched to the identifiers were kept on a separate list, accessible only to trained personnel.

3.6.3 Code Development

The interviews resulted in both qualitative and quantitative data, requiring mixed-method analysis support. This project used Dedoose, a cloud-based mixed-method analysis software. The process of using such a software required the development of codes, or sorting bins. For example, the question “Who stamps drawings at your firm?” could have had codes for the participant, firm principal, project manager, non-principal engineer with 10 years of experience, etc. A particular answer could have been coded multiple times. If the participant was a principal at their firm and also stamps drawings, the response was coded into both the participant and firm principal codes. If the participant was an entry level engineer whose project manager was the Engineer of Record and had 10 years of experience, the response was coded into the project manager and non-principal engineer with 10 years of experience codes. The essential characteristic of a code was that it either applied or it did not, it was not arbitrary.

The development of these codes was based on an inductive grounded theory approach. Such an approach relied on the participant responses to organically develop codes as analysis progressed rather than the researcher introducing their own biases by developing their expected codes in advance and trying to fit the responses into what was expected [7]. As the researcher was also a structural engineer, this step was considered necessary to mitigate the possibility of researcher bias at this stage of the process.

3.6.4 Axial Coding

After all interviews were transcribed and coded, the process of axial coding was used to combine similar codes or split codes that contained multiple types of responses. This process was guided by the fundamental idea that codes were binary, either applying or not applying. Codes for which all entries meant the same thing could be combined under a larger code. Codes whose entries, upon further analysis, diverged to mean multiple things, were broken up into multiple codes. The end goal of this step was to simplify the results as much as possible to allow for drawing conclusions. This step also served as a reliability check to ensure that the meaning of a code did not change through the coding process [7].

3.6.5 Final Analysis

Analysis of the interview data included a comparison of descriptors to code results for the questions asked in the interview. Descriptors resulted from questions in Part 1: Questions about firm designation. These represented variables expected to influence the review process at a firm. Relevant code results were compared to the descriptors or to each other. These comparisons informed further statistical analysis and led to conclusions regarding the impact of descriptors on different code results. Below is a list of descriptors and code results that was useful in evaluating the robustness of the design review process. Any generalizations or theories that were posed were formed by the complete data analysis process rather than posed beforehand and supported by evidence from the data analysis.

Descriptors Affecting Review Process:

- Firm size

Code Results for Evaluating Robustness of Design Review Process

- Ratio of design to review hours
- Percentage of the projects when the total review process is completed
- When the process happens
- Formal or informal review process

4. INTERVIEW DESIGN

4.1 INTERVIEW OVERVIEW

Each participant was interviewed according to the outline starting in section 4.2. Clarifying questions were asked as needed to ensure proper answers to the questions are received. Interviews lasted 30-60 minutes. The interview consisted four parts as outlined in Figure 3 below.

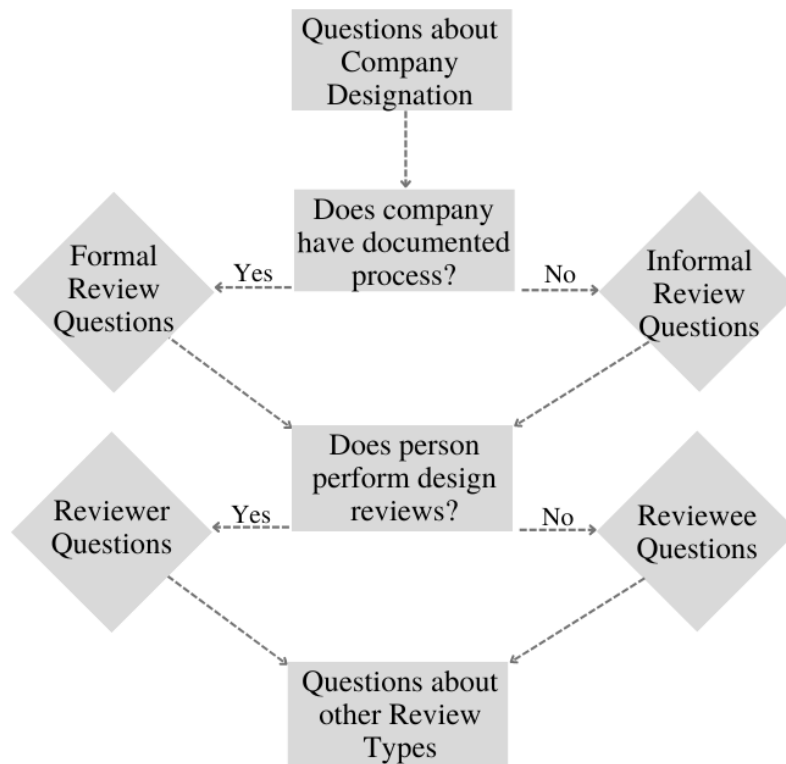


Figure 3: Flowchart of the Interview Process

4.2 INTERVIEW QUESTIONS

Interview introduction and questions obtaining participant consent must be read and voluntary consent obtained before the interview may proceed.

*Introduce interviewer. **The purpose of this interview is to obtain an understanding of the design review process at your structural engineering firm. If, at any point in the interview or***

afterwards, you wish to withdraw your participation, simply state that is the case and the recording of your interview and any transcriptions will be deleted. Have you read and understood the consent form included in the scheduling email? *Participant responds. If yes, proceed. If no, allow them to read the form and ask again. Do you consent to participate in this research project? If yes, proceed. If no, thank them for their time and end the interaction.*

For this first portion of the interview, we will be discussing review of internally generated designs specifically. Later in the interview, we will discuss peer reviews and review of delegated designs, shop drawings, and other submittals. Do you have any questions regarding the terminology or subject of these first questions? *If participant has questions, clarify. Once all questions are answered, proceed to 3.1.1.*

Part 1: Questions about Firm Designation

1. Which firm do you work for?
2. Approximately how many people does your firm employ?
3. Is your firm purely structural or are there other disciplines as well?
 - a. If no to (3), how large is your structural engineering department?
 - b. How large is your office? How many structural engineers work in your office?
 - c. Do you work closely with other offices? How many structural engineers are there among the collaborating offices?
4. Where is your office located? *City and state.*
5. What types of structures do you work on? (Commercial, industrial, academic, high-rise, bridges, etc.)
6. Who is the Engineer of Record who stamps drawings at your firm?

Part 2: Questions about Design Review Process

1. Does your firm have a formal internal design review process?

If yes, proceed to Part 2a. If the process is informal, proceed to Part 2b.

Part 2a: Formal Review Process

2. Could you describe your firm's design review process? *Ask initial question and let them answer. If their answer does not address a-g, ask the remaining questions as follows.*

- a. How is the process documented?
- b. What steps are included?
- c. How many reviewers? Who are the reviewers? What experience level are they?
- d. Are there face-to-face meetings to discuss feedback?
- e. How long has it been in place?
- f. Why was it put in place?
- g. Is there an informal feedback process as well?

3. Is there anything that changes the process or timeline? *Ask initial question and let them answer. If their answer does not address a-e, ask the remaining questions as follows.*

- a. Delivery method
- b. Building type
- c. Complexity
- d. Client type
- e. Building official or external reviewing agency

4. How involved is the Engineer of Record who stamps drawings in implementing and enforcing the design review process?
5. What percentage of projects would you say the process is implemented as it was intended?
6. What is a typical ratio of design to review hours for a standard project?
7. On average, what percentage of the documented process is completed?
8. When does a design review happen?
9. If there is informal feedback, when does this happen? How often do these occur? *Do not ask if participant answered no to Question 2g of this section.*
10. What steps are most valuable? Least valuable? Are there any steps you feel should be added or deleted? *Ask all questions at once and then allow participant to answer.*
11. If you have process documentation, are there any resources (checklists, etc.) that you can share with me? The purpose of gathering these resources is to compile a list of common steps to be included as an appendix to the report.

Part 2b: Informal Review Process

2. Could you describe your firm's informal design review process? *Ask initial question and let them answer. If their answer does not address a-e, ask the remaining questions as follow ups.*
 - a. How does it work?
 - b. Who do you go to for feedback?
 - c. Are there face-to-face meetings to discuss feedback?
 - d. How often do you get feedback?
 - e. Who initiates the review?

3. When does an informal review happen?
4. Is there anything that changes the process or timeline? *Ask initial question and let them answer. If their answer does not address a-e, ask the remaining questions as follow ups.*
 - a. Delivery method
 - b. Building type
 - c. Complexity
 - d. Client type
 - e. Building official or external reviewing agency
5. How involved is the Engineer of Record who stamps drawings in reviewing designs?
6. What is a typical ratio of design to review hours for a standard project?
7. If you could establish a formal review process for your firm, what would it look like?
Ask initial question and let them answer. If their answer does not address a-c, ask the remaining questions as follow ups.
 - a. What steps are included?
 - b. Who is involved?
 - c. When does it happen?

Part 3: Questions about Outcomes of Design Review

1. Do you complete design reviews? Or are your designs the ones that are reviewed?

If reviewer, proceed to Part 3a. If reviewee, use Part 3b.

Part 3a: Reviewer Reflections

2. Are there common things that you catch when completed design reviews? Common errors that newer structural engineers make?
3. What is your process of completing a design review?
4. Are there areas of design that you focus on when completing design reviews?
5. Are there any areas of designs that prompt your close attention due to consequential impacts of a mistake?

Part 3b: Reviewee Reflections

2. Are there common things that are caught when your design is reviewed? Common errors that you or newer structural engineers make?
3. Are there any areas of your designs that prompt close attention due to consequential impacts of a mistake (maybe an area that you ask for an informal review of first)?
4. Do you find that feedback you receive from design reviews is clear, helpful, and relevant?

We are now no longer referring to review of internal designs, but review of others' work.

Identify to participant that the interview is transitioning from internal to external review.

Part 4: Questions about Other Types of Reviews

1. Do you complete peer reviews? What is that process like? How is it different from your internal process? *Ask questions on at a time. Desired responses are only from participants who have actually participated in a peer review.*
2. How are delegated design submissions reviewed?
3. How are shop drawings and other project submittals reviewed?

That concludes the interview. Thank you for participating in the study. If you wish to be notified of the findings of this project, I can make a note of that at this time.

5. STUDY IMPLEMENTATION

Recruiting for this study yielded 20 interviews with 22 individuals. These individuals worked for 16 independent structural engineering firms in 11 different states and the District of Columbia as shown in Figure 4. Most participant offices were located on the East Coast, but there was also representation from the West Coast and Midwest. The figure shows the locations of the office where each individual works, but it is important to note that in many cases the processes described by the individual were applicable to other firm offices across the country as well.

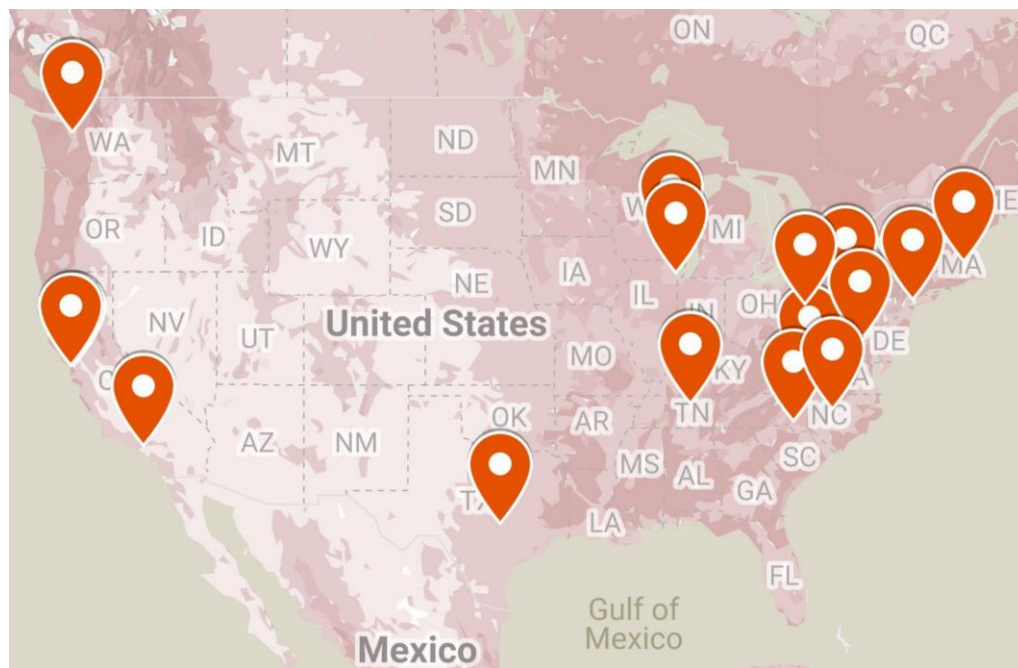


Figure 4: Locations of Structural Engineering Offices Interviewed

During the course of the interviews, it became apparent that a few of the questions intended to be asked were not understood by the participants. For example, the intent behind question 2a-7 was not easily understood and the answers were not relevant. Some questions, for example questions

3a-4 and 3a-5 had answers that merged together such that the individual questions were essentially redundant.

To classify the firms interviewed by size, it was necessary to create labels ranging from small to extremely large. With the interviewed firms ranging from 13 to 52000 employees, bins fitting a logarithmic scale were chosen. Thus, a small firm had fewer than 100 employees, a medium firm fewer than 1000 employees, etc. Table 1 below details the breakdown of firms interviewed and what size descriptor was applied to them. Three of the 20 interviews were with bridge engineers. The remaining 17 interviews were with engineers who worked on buildings. Of these, three firms also did work on existing buildings and one firm solely worked on existing buildings.

Table 1: Size Characteristics of Firms Interviewed

Size Descriptor	Employee Number	Number of Firms Interviewed
Small	1-100	6
Medium	101-1,000	5
Large	1,001-10,000	4
Extremely Large	10,001-100,000	1

6. RESULTS

The first topic of interest in the project was determining whether formal or informal review processes dominated the internal review field. As shown in Figure 5, over two-thirds of the participants said their firm used a formal review process. For purposes of this report, a formal review process is assumed to be a documented process that is decided on by the firm and applied to all projects. An informal review process would be one that is carried out largely the same way on each project but has not been documented either because the firm is small enough that it is taught by word of mouth or simply because everyone knows the process.

Of the five companies with informal design review processes, four were classified as small companies with the remaining firm being classified as medium. In three cases, the engineer of record was the project manager. For the others it was a principal or associate in the firm. The remaining 11 firms reported having a formal internal design review process.

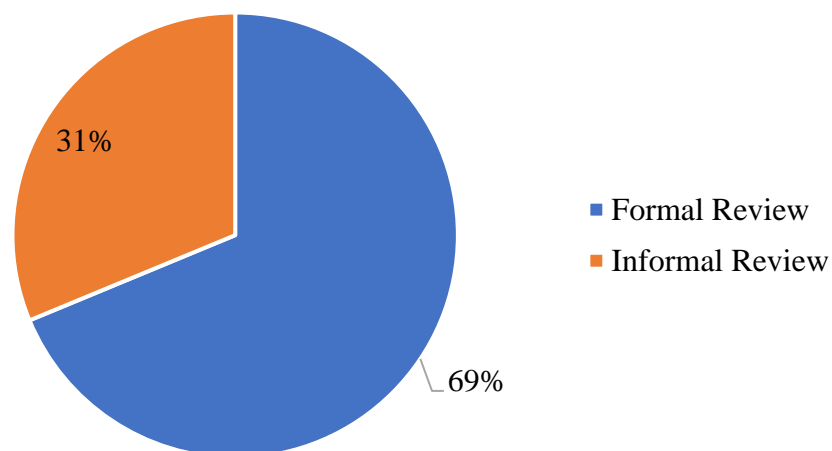


Figure 5: Percentage of Formal vs Informal Review Processes Among Firm Surveyed

In order to determine what was unique about each firm's internal design review process, a baseline process first had to be established, as shown in Figure 6. The process starts with completion of a design milestone, assuming that the process occurs before each milestone submittal to the client. The figure includes reviews by the originator and reviewer, a period for the originator to make changes as needed, and an option for discussion with the reviewer if there is a disagreement about a comment. This meeting between the originator and reviewer is less likely to be in person post-Covid but most participants indicated that it was a common occurrence in the case of disagreements or misunderstandings. Table 2 lists unique aspects of the design review process identified by at least one respondent as well as a count of how many participants mentioned that particular practice. These unique practices would be incorporated with the baseline process to describe a specific firm's process. A firm can have multiple unique practices in their process.

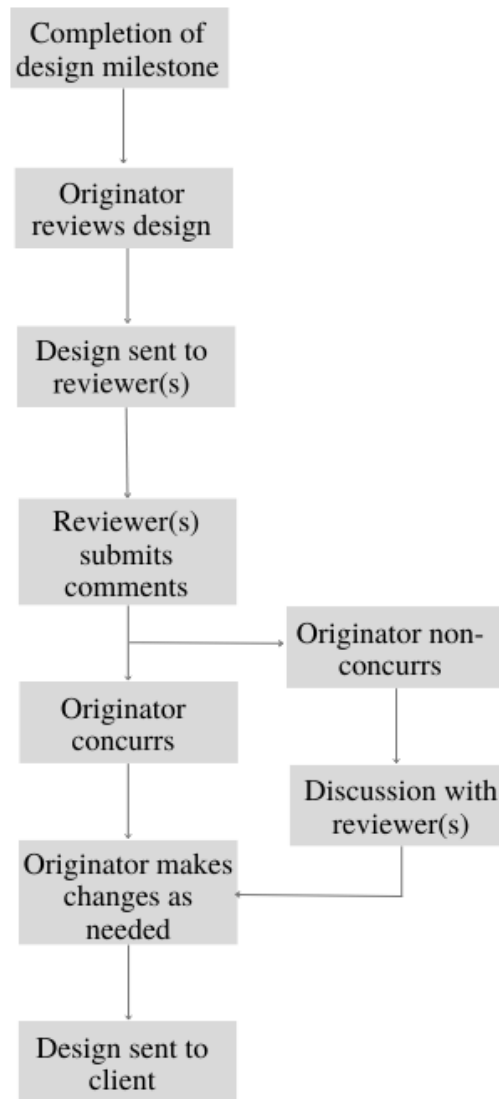


Figure 6: Baseline Internal Design Review Process

Table 2: Reported Unique Practices of Internal Design Review Processes

UNIQUE PRACTICES	OCCURRENCE COUNT (out of 20)	RELATIVE OCCURRENCE
Design Charrette	7	35%
Complex Projects	4	20%
Charrette as Design Review	1	5%
Office Monthly Charrette of Sample Project	1	5%
Senior Assessment Early On	1	5%
Scalable Process	6	30%
Inter-discipline Review	5	25%
Firm Has QA/QC Role to Enforce Process	4	20%
Checklist of Items to Check	3	15%
Color Coding of Comments	3	15%
Review Team Includes Younger Engineers	3	15%
List Critical Comments	2	10%
Team Meeting Weekly to Review Design	2	10%
Constructability Review	1	5%
Document Lessons Learned	1	5%
Focus on Quality of Written Work	1	5%
Formal Escalation Process	1	5%
Office Invited to Look at Drawings Before Issued	1	5%
Principle Develops System Within Parameters	1	5%
Project Advisor	1	5%
Project Audits	1	5%
Senior Technical Review	1	5%
Visual Check	1	5%

Practices that occurred with high frequency included design charrettes, scalable processes, and inter-discipline reviews. A design charrette is a meeting of the engineers on a project with engineers who have experience with similar projects to go over lessons learned, stumbling blocks that popped up in previous designs, solutions utilized on previous projects, etc. Essentially, it is a meeting of minds within the firm to brainstorm the best solutions to an issue and look ahead at

possible issues. Several different applications of a design charrette were noted, including implementing them for particularly complex projects, monthly as a learning experience for all employees, or simply involving a senior engineer early on.

An additional common practice was the implementation of a scalable review process. This comment came from firms who did a large range of work, with a wide range of project budgets. The idea is to have a formal process that does not overwhelm the budget of smaller projects and recognizes that there are fewer hours available for review overall. It is a good way to ensure that a known process is implemented even on small projects where the tendency might be to drop review steps because the project simply cannot afford it. Scalability would also be applicable on projects with different risk levels. For example, several participants mentioned that condominium projects were always under close scrutiny due to the probability of litigation, so the design review measures on those projects were never scaled down.

The baseline internal design review process was assumed to be applicable at the completion of each client submittal. Data gathered regarding the timing of internal design reviews within each firm supports this baseline, with over 80% of firms implementing a review prior to each client submittal as shown in Figure 7. All companies that did not have a review before each client submittal were small companies with informal processes. Therefore, the assumption of a baseline process as presented in Figure 6 held true for all formal design review processes.

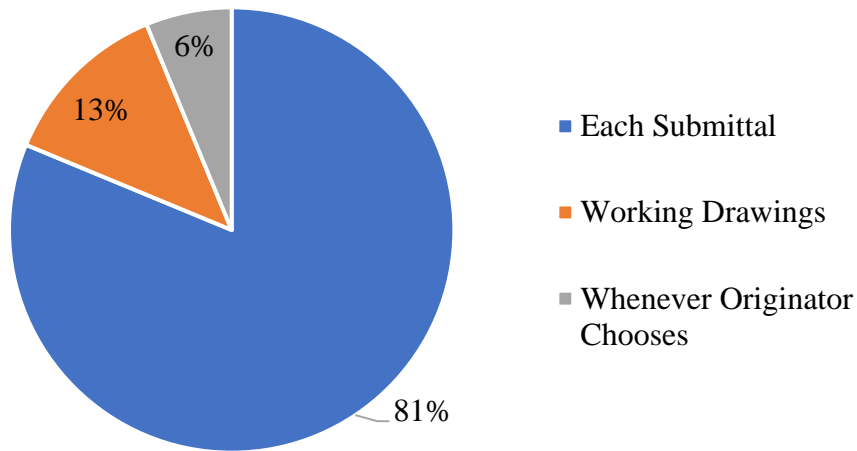


Figure 7: Timing of Internal Design Review Across Firms

Along with determining when each review happened, it was important to determine how long of a period was allotted for review of designs. This was accomplished by gathering data on the ratio of review hours to design hours for a typical project at each firm. The results in Figure 8 show a large amount of scatter, but with the majority of firms falling in the range of 3-20% of the design hours. Notably, the bridge engineers interviewed provided the 40% and two 15% data points. The firm with the 40% review to design ratio was focused on complex bridges. Excluding those from the graph, it can be assumed that the review hours for a typical project range from 3-10% for buildings as shown in Figure 9. The scatter increases for medium sized (100-1000 employees) companies. Small companies, though they were more likely to have an informal process, were very consistent with a 5% ratio reported. Large and extremely large companies varied a bit more but still stayed around the 5% mark.

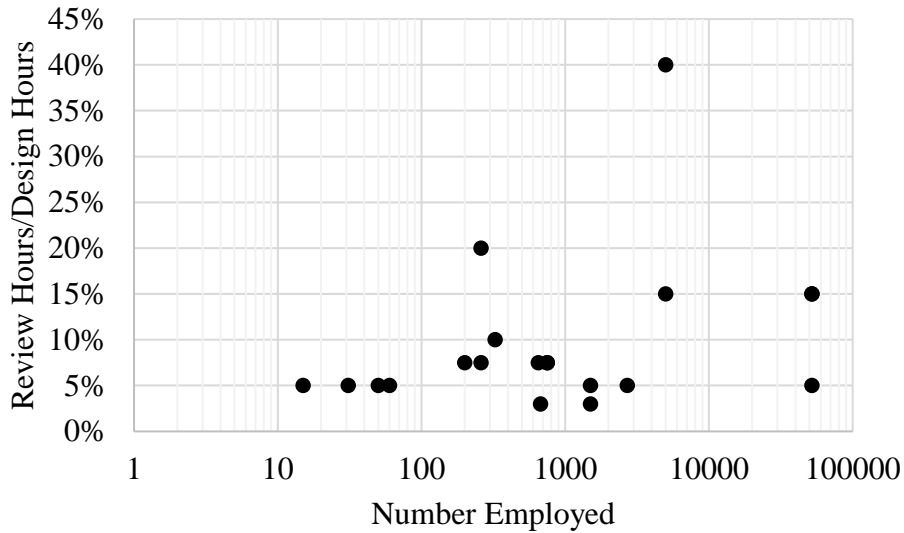


Figure 8: Ratio of Review to Design Hours by Firm Size

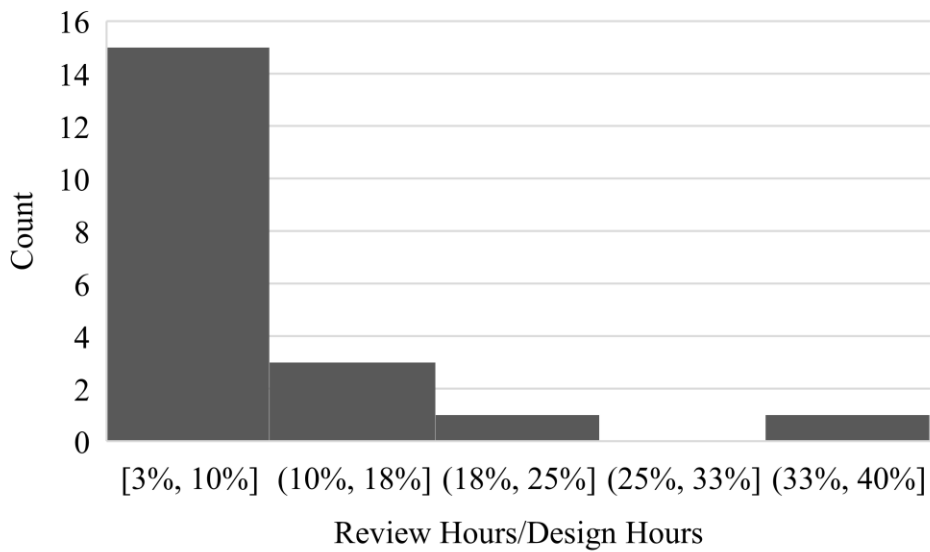


Figure 9: Distribution of Ratio of Review Hours to Design Hours

The remaining quantitative data point that was collected from each interview was an estimate of what percentage of projects had the firm’s formal design review process fully implemented, shown in Figure 10. Answers ranged from 50-100% of projects with the average being 83%. There was not an apparent correlation between the size of the firm and the percentage of projects which had a design review fully completed. Data points in red indicate firms with QA/QC teams or positions

intended to enforce the formal firm processes. The minimum value for this data collection was 50% which was applied when a firm indicated that the process was rarely fully applied.

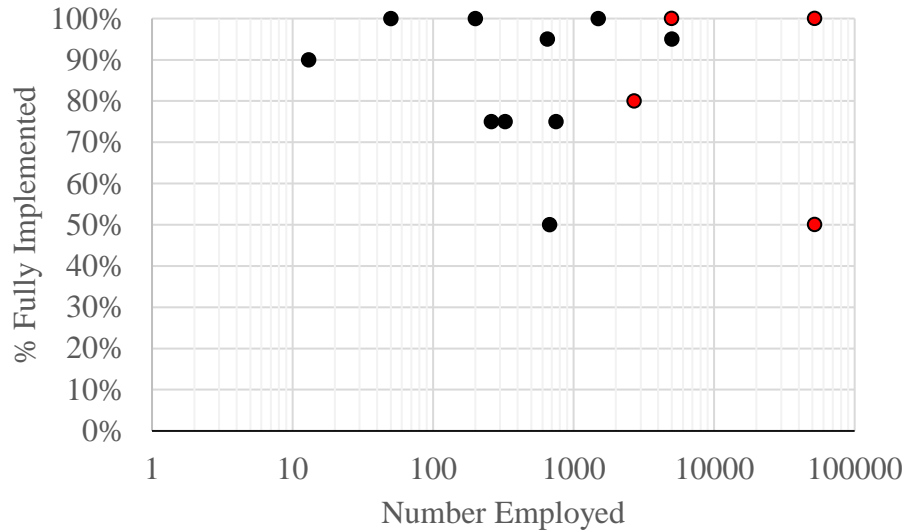


Figure 10: Percentage of Projects with Process Fully Implemented

Participants seemed happy with the overall internal design review process at their firms, but there were several process changes suggested by participants to improve the quality of reviews, outlined in Table 3. The most popular suggested change was a request for more time to complete the reviews. Other suggestions included removing unnecessary checks (software verification) to save time, finding a more efficient way to check calculations, allowing more time earlier in the process to put in effort, and putting documents together more efficiently to save time. Overall, the emphasis was on having the time to complete a quality review and some potential solutions were presented to achieve that goal. It is likely the case that this lack of time is caused by needing to send out a deliverable before a deadline. There could be several solutions to this problem, two of which will be presented here. The first option would be to protect the review time by ensuring the submittal is ready well ahead of time. This may prove difficult in practice. The other option, practiced by one of the firms interviewed, is to complete the review after the submittal is sent to the client if

sufficient time was not allowed beforehand. This is perhaps not the ideal timing, especially for construction documents, but it would still allow for discrepancies to be found and addressed on the next submittal.

Table 3: Process Changes Recommended by Participants

PROCESS CHANGES	OCCURRENCE COUNT (out of 20)	RELATIVE OCCURRENCE
More Time	2	10%
Better Process to put Documents Together Efficiently	1	5%
Automate Process	1	5%
Check Calculations more Efficiently	1	5%
More Independent Checking	1	5%
Put in More Effort Earlier	1	5%
Remove Software Verification Requirement	1	5%
Teach Differently	1	5%

In Part 3 of the interview, participants were asked about their personal experiences with reviewing designs or having their designs reviewed. The results reduced to topics that were often commented on during design reviews and areas that were subject to increased attention during design reviews, outlined in Table 4 and Table 5 respectively. Table 4 lists topics that resulted in review comments either because mistakes were caught, the design intent was not adequately communicated, or because the reviewer noticed there was a better way to solve the problem. Table 5 addresses topics that come under close scrutiny during design review because the reviewer knows that a mistake made in that specific area would be extremely costly or impactful.

Table 4: Common Topics of Comment on Internal Design Reviews

TOPIC	OCCURRENCE COUNT (out of 20)	RELATIVE OCCURRENCE
Load Path	5	25%
Additional Communication Needed	4	20%
Software	4	20%
Modeling Assumptions	1	5%
Not Understanding Software Processes	1	5%
Over Reliance on Software	1	5%
Software Upgrades	1	5%
Constructability	3	15%
Detailing	3	15%
Better Solutions Available	2	10%
Stability Analysis	2	10%
Seismic Design for Non-Structural Elements	1	5%
Spelling	1	5%
Basic Mechanics	1	5%
Design Capacity Ratio	1	5%
Limit States	1	5%

While not all participants named common topics of comment for drawing reviews, there were several categories that were mentioned multiple times. The most common topics of comment on internal design reviews included load path issues or overcomplications, lack of communication on drawings, and software issues. Slightly less common were topics such as constructability, detailing, finding the best solution, and stability analysis.

The areas that came under scrutiny due to their potential impact were similarly distributed, with lateral systems being the most common concern that 40% of participants said they paid close attention to when reviewing. Other common concerns included unique or complicated areas of the design, coordination efforts, and connection viability. Load path and detailing were frequently mentioned on both lists, meaning that they were often checked and often commented on in designs.

Repeated items make sense to be on this list because getting the design wrong for something that is repeated 50-100 times in a building would have a huge impact down the line if it needed to be reordered or repaired.

Table 5: Areas Under Close Attention During Internal Design Reviews

TOPIC	OCCURRENCE COUNT (out of 20)	RELATIVE OCCURRENCE
Lateral System	8	40%
Load Path	4	20%
Unique or Complicated Areas	4	20%
Coordination	3	15%
Connection Viability	2	10%
Detailing	2	10%
Loads	2	10%
Stability	1	5%
Foundation	1	5%
Repeated Items	1	5%
Lessons Learned from the Past	1	5%
Geometry	1	5%
Existing Conditions	1	5%
Brittle Failures	1	5%
Composite Steel Beams	1	5%
OSHPOD Designs	1	5%
Big Picture Items for Expert Witness Work	1	5%

The final section of interview questions addressed approaches to reviewing shop drawings, delegated designs, and completing peer reviews. Comments on peer reviews were varied in what type of peer review the firm was asked to do, how they completed it, etc. that it was impossible to form many conclusions. Generally, however, there were types of peer review that were undertaken similarly to the design review process and there were more formal types of peer review, often seismic review for tall buildings, that were described as more formal and very paperwork heavy. It is a complicated topic with many facets that was not the main focus of this project. An examination of the mechanics of peer reviews could comprise the scope of a project similar to this one.

The predominant concern when reviewing delegated designs was that they comply with the design intent of the structural engineering firm. Items of interest are detailed in Table 6. A quarter of participants went on to evaluate if the submitted designs were consistent with what was expected, ensure the loads placed on the structure were within allowable limits, and spot check a few designs. Fewer went on to check design assumptions and review the design process. The relatively limited number of respondents indicating that they conduct detailed checks of the delegated design is due to the delegated designs being signed and sealed under the liability of another engineering firm. One firm interviewed completed delegated design work and they had their own internal design review process for each design in a package. Therefore, the in-depth review by the structural engineer of record would essentially be a second or third review of the delegated designs depending on the depth of the delegated designer’s process. Depending on the project, that could make them one of the most deeply reviewed items in a design package.

Table 6: Items of Interest During Delegated Design Review

ITEMS OF INTEREST	OCCURRENCE COUNT (out of 20)	RELATIVE OCCURRENCE
Complies with Design Intent	12	60%
Consistent with Expected	5	25%
Interface with Structure	5	25%
Spot Check a Few Designs	5	25%
Check Assumptions	4	20%
In Correct Locations	2	10%
Sealed and Complete	2	10%
Review Design Process	2	10%

An evaluation was also completed for shop drawing review procedures and is detailed in Table 7. Similarly to delegated designs, the most important item of interest was that the designs were consistent with the design intent. A quarter of participants then went on to review each drawing in

a detailed manner such as checking the size and spacing of rebar in reinforced concrete designs, reviewing each drawing, or performing a detailed review of the package. 10% of participants paid close attention to unique and cluttered areas and one participant flagged details that were known to be complicated to ensure they were reviewed in depth when shop drawings came in. Overall, it was found that the processes for reviewing delegated designs and shop drawings were similar, with more attention to detail placed on shop drawings.

Table 7: Items of Interest During Shop Drawing Review

ITEMS OF INTEREST	OCCURRENCE COUNT (out of 20)	RELATIVE OCCURRENCE
Consistent with Design Intent	11	55%
Size and Spacing RC Reinforcement	5	25%
Review each Drawing	5	25%
Detailed Review	5	25%
Consistent with Expected	4	20%
Unique/Cluttered Areas of Design	2	10%
Special Attention to Flagged Details	1	5%

7. CONCLUSIONS AND RECOMMENDATIONS

Interviews with 22 individuals from 16 structural engineering companies allowed for conclusions regarding the internal design review process at typical structural engineering firms to be drawn. It was determined that over two-thirds of firms have a formal, or documented design review process. While smaller companies were more likely to have an informal process, it does not necessarily follow that the quality of their review is less robust than a formal review. Firms with an informal process or who allow principals and project managers to decide their own process are more likely to have a harder time teaching their process to new hires or explaining it to a client. The baseline internal review process consists of a review before each submittal to the client, which was evident in the majority of firm processes. However, an individual firm's process also consists of practices unique to that firm. Notably, more than 30% of firms identified the importance of a scalable process and included a design charrette in some form. For over 80% of firms, this process was proved to be applicable before each client submittal. The development of a firm's process may be impacted by the clients the firm has and their expectations for review. For example, a firm that completes a great deal of work for the Army Corps of Engineers and is familiar with the review procedures for that organization may decide to apply a similar or the same process to all of their work because it is effective.

Examining the ratio of review hours to design hours practiced by each firm suggested that bridge design firms spent more time on design review than firms doing work on buildings. Additional data from bridge firms would be needed to conclusively compare building and bridge firms. Firms focusing on buildings spent 3% - 10% of project hours on review with 5% being typical. Building engineers with review times greater than 10% may be able to make their process more efficient.

This analysis is only applicable to firms who do building work, the review hours for bridge firms proved to be higher as a group and are not comparable to the ratios for building design firms.

The percentage of projects with the process allowed to be fully implemented varied from 50-100%. While larger companies were more likely to have a dedicated QA/QC enforcing role, it was not shown to greatly improve the percentage of projects with the process fully implemented. This is likely due to a lack of time to complete the process, as most process changes suggested by participants related to buying more time to review a design before its submission to the client. In several instances, it was mentioned that timelines did not accurately reflect the length of time it would take to thoroughly review a product and reviews often felt rushed. One participant who worked on existing buildings noted, “Design firms tend to take on a lot of liability relative to what their fees are. It seems to me that the margins are so low that it’s hard to find a firm that says, ‘We spent exactly as much amount of time as we wanted to on this project.’” While the participant did admit their view was likely influenced by working on existing buildings with problems, it seems to be an opinion that is reflected by employees in the structural design field as well.

Recommendations to improve upon current internal design review processes include the following:

1. Create internal deadlines for each design submittal before the actual deadline to allow for design review. Ensure all parties on the project team understand when the review is to happen, what is under review, and how long the review will take.
2. Create a formal review process. It can be as simple as a basic procedure and identity of a typical reviewer put in writing. Documentation and predictability aid in communicating the review process to newer engineers and clients. Additional practices such as checklists or design charettes can be added later or on a case-by-case basis.

3. Make the review process scalable in companies that are involved in a range of project sizes. A process that is effective in a large project will overwhelm the budget of a smaller one, but a scalable process will be applicable to projects of all sizes.
4. Include newer engineers in the process. A culture that puts emphasis on producing a quality product will benefit from the inclusion of engineers of all levels. Being part of a review team will help newer engineers to learn and apply their experiences to their own designs.
5. Talk about how to achieve a 100% implementation rate. Protected design review deadlines and a scalable process may help, but employee suggestions and buy-in are also essential.
6. Ensure fully implementing the process is achievable. The problem with a given process may not be that it is too short or vague, but rather that it has grown unwieldy and engineers are unable to implement it effectively.

Future work on the topic of design reviews should include an investigation on the topic of peer reviews. A deeper look at the processes and timings behind review of shop drawings and delegated designs would also be warranted. Interviews with additional bridge firms would allow for comparison between building and bridge firms. Finally, an interesting subject would be the role of professional liability insurance in determining the role of engineer of record at structural design firms.

8. REFERENCES

- [1] Watkins, S., & Orchiston, N. (2016). *ISO 9001:2015: A Pocket Guide*. IT Governance Publishing. <http://www.jstor.org/stable/j.ctt1bj4t23>
- [2] ISO (2015). *ISO 9001:2015 Quality Management Systems - Requirements*.
- [3] Commonwealth of Virginia, Department of General Services, Division of Engineering and Buildings (2004). *Construction and Professional Services Manual*.
<https://ris.dls.virginia.gov/uploads/6VAC35/DIBR/ab622001330~2.pdf>
- [4] Office of Statewide Health Planning and Development, Facilities Development Division (2013). *Guide for Working on Project Under OSHPD Jurisdiction - Tips from the Experts*.
<https://hcai.ca.gov/wp-content/uploads/2020/10/Guide-Working-on-Projects-OSHPD-Jurisdiction-Tips-from-Experts.pdf>
- [5] *Nuclear Reactor Regulation*. United States Nuclear Regulatory Commission. (n.d.).
<https://www.nrc.gov/about-nrc/organization/nrrfuncdesc.html>
- [6] *Nuclear Regulatory Research*. United States Nuclear Regulatory Commission. (n.d.).
<https://www.nrc.gov/about-nrc/organization/resfuncdesc.html>
- [7] J. W. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 3 ed., Thousand Oaks, California: SAGE Publications, Inc., 2009.
- [8] J. W. Creswell and V. L. P. Clark, *Designing and Conducting Mixed Methods Research*, SAGE Publications, Inc., 2017.

APPENDIX 1

Table 8: Firm Designation Summary

Interview Number	Company	Purely Structural?	Firm Size	Structure Type	Engineer of Record
1	A	no	Extremely Large	Bridge	PM (Direct Charge)
2	A	no	Extremely Large	Bridge	PM (Direct Charge)
4	A	no	Extremely Large	Buildings	PM (Direct Charge)
3	B	yes	Small	Buildings	Principal
5	C	no	Large	Bridge	PM (Direct Charge)
6	D	no	Small	Buildings	PM (Direct Charge)
7	E	no	Medium	Buildings	PM (Direct Charge)
8	F	yes	Medium	Existing and New Buildings	PM (Direct Charge)
17	F	yes	Medium	Existing and New Buildings	Principal
9	G	yes	Medium	Buildings	Direct Charge
10	H	no	Large	Existing and New Buildings	Principal
14	H	no	Large	Existing and New Buildings	Principal
11	I	no	Large	Buildings	PM (Direct Charge)
12	J	no	Large	Bridge	Direct Charge
13	K	yes	Small	Existing Buildings	Principal (PM)
15	L	yes	Small	Delegated Design and Buildings	Principal
16	M	yes	Medium	Existing and New Buildings	Principal
18	M	no	Medium	Existing and New Buildings	Principal
19	N	no	Small	Buildings	Principal
20	O	yes	Small	Buildings	Associate
21	P	no	Medium	Buildings	Principal or PM
22	P	no	Medium	Buildings	Principal or PM

