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Impacts of a Dynamic Visualization Tool on Learning Lateral Loading Fundamentals and Applications

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ABSTRACT

Wind and seismic loading are one of the most integral and complex parts of structural engineering, with countless calculation and analysis methods possible. Their complexity poses a challenge in their education, making fundamental understanding of these loads and their most prevalent procedures an essential skill for any structural engineering student entering the industry. With the potential capabilities of Computer-Aided Learning providing an interactive environment and the benefits of visualization in learning, this thesis investigated the potential benefits of dynamic visualization of wind and seismic on the learning gains of student using a web tool in comparison to traditional teaching methods. Additionally, the different potential applications of such tools prompted the question of the effects of different input methods on the different applications of the tool.

The learning effects and input methods were investigated by conducting a study in an undergraduate structural engineering class in which wind and seismic loads are taught. The study comprised of three stages, each including a quiz and a survey. The questions and statements were created to form a hierarchy of granularity of the data, which can be separated into learning categories (Fundamentals, Design, and Analysis), and/or loads (Wind and Seismic).

The collected data was analyzed at multiple levels in hope of answering the questions identified by this thesis. The results show that the dynamic visualization tools helped student understanding of fundamental understanding, with no noticeable difference between the two tools. On the other hand, the input methods did not have an effect on one application over the other.

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Chapter 1 - Introduction

Wind and seismic load analysis is a key component to the field of structural engineering, as these loads form an integral part of building design and often are the controlling loading in many designs. Intuitively, the loads themselves are easy to explain and justify, but computing them is a much more complicated process, as there are various analysis methods available for engineers to take. Understanding the relationship between building parameters and lateral loads along with the ability to perform these analyses quickly makes for easier and more meaningful collaboration between the structural engineer and the rest of the design team. This thesis explores the pedagogical impact of having a quick dynamic tool that visualizes the loads and their change as input is changing. The aim is that tool can be helpful to undergraduate engineering students in associating the input parameters with the output loads by giving a didactic element to it. Iterations of the tool will allow the testing of different input methods (box vs. slider) for different applications (analysis vs. design/iteration). The iterations will be tested on structural engineering students.

1.1 Motivation

ASCE/SEI 7-16 – *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE, 2017) is the standard adopted by the *IBC - International Building Code 2021* (ICC, 2020) to compute lateral loads. Within ASCE 7, the most commonly used methods are the Equivalent Lateral Force Procedure (ELFP) for seismic loads (ASCE 7-16, Sec. 12.8), and Main Wind Force Resisting System (MWFRS) – Directional Procedure for wind loads on buildings (ASCE 7-16 - Ch. 27). These loads depend on several parameters across several equations. In some parts of the procedures, the parameter goes through five equations before the product can contribute directly and predictably to the final load. The processes the loads are computed by are at times complex, but intuition can be built based on performing iterative analyses between the numerical input and output, and over years of experience. While computer software is available to compute such loads, it is often slow, with complicated interface, and numerical values presented with little to no explanation of the relationship. The need for a fast, visual, and dynamic tool becomes apparent in cases where hand calculations are not quick enough or are too time intensive, and the computer analysis is not yet applicable, such as early conceptual design. This becomes particularly important when trying to teach these topics in packed curriculum where time for many iterations and explorations is limited to just a few lectures.

Structural engineering intuition is the skill with the potential to grow, the type of intuition is more complex. While the loads are calculated through a series of equations, there is several of them that an intuitive interpretation (Ji et. al, 2018) of the equations becomes more difficult. The tool can help build intuitive understanding (Ji et. al, 2018) through being able to relate between building structural characteristics (shape, stiffness, weight, etc.) and the resulting loads on the structure.

Chapter 2 – Background and Literature Review

Given the complexity of wind and seismic loads along with their applications in structural engineering, there exists a need to properly learn them. The educational background presented here focuses on Passive Learning, Active Learning, & Visualization along with Computer Aided Learning (CAL), centered around engineering education. The engineering background focuses on the educational side of Structural Loads and Analysis as well as the Importance of Wind and Seismic Loading in the profession. Lastly, the user interface background included an investigation of current User Interface Design and Input Methods

2.1 Importance of Wind & Seismic Loading

Lateral loading is one of the most important concepts in structural engineering, and on certain projects, lateral design can drive most design decisions. Wind and seismic loading on buildings are the most common always present structural lateral loads evaluated for buildings. As described in Section 1.1, the most used procedures are the MWFRS directional procedure for wind and ELF procedure for seismic, both defined by ASCE/SEI 7-16 – *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE, 2017). However, MWFRS and ELFP are the second most basic procedures, respectively, with the simplest procedures being done only when buildings meet certain criteria that prove they are uncomplicated. Furthermore, lateral loading within the codes and standards often requires further interpretation and questions always arise during application on real projects. STRUCTURE magazine (2021) has published articles about frequently asked wind and seismic questions, which are not necessarily specific to the procedures above, yet they show that these load types are often confusing to professionals the way they are written. For seismic, separate chapters within ASCE 7 (ASCE, 2017) are dedicated to

Nonlinear Response History Analysis (Ch. 16), seismically isolated structures (Ch. 17), structures with damping systems (Ch. 18), and soil interaction for seismic design (Ch. 19) all of which requires basic knowledge of seismic loading. For wind, complex structures and skyscrapers can constitute the need for wind tunnel testing, which is described in a separate standard; ASCE 49 (ASCE, 2022). Designing lateral resisting can also become sophisticated when a certain behavior and performance is desired of the structure, rather than meeting strength and serviceability limits. Chapter 18 of ACI 318-19 is dedicated to the design of seismic resisting lateral systems. Knowing this complexity, the fundamental understanding of lateral loading and developing intuition is critical. The skill can be learned by knowing simpler procedures early in a structural engineer's career and building off them. Understanding codes and the reasoning behind them helps advance these concepts to understand more special procedures for wind and seismic, and ultimately perform them well.

2.2 Passive Learning, Active Learning, & Visualization

Active and passive learning can be observed both in the style of teaching and in the student behavior as Petress (2008) describes. Petress (2008) further goes into describing the behavior of active learners such as asking clarification questions, furthering discussions with the instructor and among each other, which can still occur in a passive lecturing room. Active learning strategies are ones that promote or require discussions and questions to be asked in the classroom where they are more engaged in the moment, such as with Problem-Based Leading (PBL) and Case-Based Learning (CBL) (Gleason, 2011). Given that wind and seismic loading procedures and concepts investigated (in this study) are for full buildings, leveraging PBL and CBL are possible approaches. It is doable by incorporating PBL and CBL methods that give the information in the context of a project or a scenario where conditions change around a building. The use of active learning has also been combined with the use of technology to achieve visualization of the concepts in fields such as physics (Dori & Belcher, 2005). Visual thinking (VT) was also used as an active learning method in engineering courses, requiring modeling, or sketching of certain objects that helps them effectively see what they are evaluating (Olmedo-Torre et al., 2021). Physical demonstrations are an example of visually demonstrating and communicating structural concepts in structural engineering (Ji & Bell, 2014).

2.3 Teaching of Structural Loads & Analysis

Teaching structural loads and analysis takes different forms depending on the scope of structural engineering that is being taught, such as determining loads, establishing relevant code limits, load path analysis, or evaluating limit states (Phillips et al., 2021). The calculation of applied loads is also a task of navigating codes and standards to determine what is necessary. The most complex case of obtaining loads are wind and seismic loads as described in Section 2.1, but loads additionally include gravity loads (dead, live, snow, etc). ASCE 7 (ASCE, 2017) is the most popular resource used for building in the USA. Prescriptive design limits are also set or determined from codes, such as deflections limits, spacing, or size requirements for items such as rebar in concrete (ACI Committee 318 & American Concrete Institute, 2019). ABET (2021) states that for architectural engineering programs to include standards teaching, with students being able to use them at the design level (item 1.d). The teaching of said codes and standards has undergone some research regarding the parallels between students and professionals in structural engineering (Barner & Brown, 2021), and the incorporation of code teaching in the architectural engineering curriculums (Solnosky et al., 2017).

Upon obtaining loads, loads paths are studied and analyses are performed to obtain applied behavior (shear, moment, axial, etc.), and design the structural elements appropriately.

Additionally, overall structure behavior is dependent on structural design variations (braced frames vs. moments frames), which can both affect the loads calculated and the size of elements. As discussed in Section 2.2, building engineering intuition is often done through visualization. Meyer et al. (1996) used real physical to scale or smaller models to demonstrate both design behavior of lateral frames, limit states for built up steel sections, connection elements, or base plate behavior. Visualization through experiments can be used for connecting the theory to the physical reaction of structures (Lanning & Roberts, 2019). Additionally, computers along with interactive tutorials can be leveraged to further reinforce the concept of loads paths load paths. Lanning & Badrya (2021) explored this by creating applets that visualize such concepts. This is an example of Computer-Aided Learning (CAL) as discussed in Section 2.4.

2.4 Computer-Aided Learning (CAL)

Since computers became more accessible, CAL became a considered method for classroom delivery and assessment. CAL has shown benefits with results when used in varying topics including human biology (Devitt & Edward, 1999) and statistics (Aberson et al., 2003). Fields that rely heavily on mathematics and visualization of their results can benefit heavily from CAL. Additionally, engineering relies heavily on computers and complex software. An educational argument driving some CAL studies is that in engineering calculations, the speed and simplicity of such tools can help students more with fundamental understanding (Hart, 1993). Tasks that include individual use of tools that do engineering calculations given specific input have shown promising results in a civil engineering class, especially in asynchronous and independent learning (Chau, 2007). In engineering applications more related to building construction, visual CAL has been well received when used for the education of construction safety in a 3D video game environment that the user interacts with (Lin et al., 2011), and construction engineering in an excavation game (Sherif

& Mekkawi, 2010). Building Information Modeling (BIM), already popular industry wide, was evaluated for use in a design course that includes architecture and civil/structural engineering students (Károlyfi et al., 2021). In this case, BIM can be considered a form of CAL. In addition to the applets mentioned in Section 2.3 by Lanning & Badrya (2021), computer systems and applications have also been used in structural engineering in various capacities. Fuyama et al. (1997) developed a tool for conceptual design of steel structures, while Najafi (2003) used architectural input to automate aspects of structural design and report objectives to the users (aimed towards architects). A wind calculation program (based on ASCE 7) was studied, that performs calculations for flat roofs, gable roofs, and signs, which was meant for educational purposes, but is not meant to replace the need for familiarity with ASCE 7 (Estrada & Chiu, 2004).

2.5 User Interface Design and Input Methods

User interface design is the study of software interface, to help make the software easier to use and communicate the software use. User interface design includes several elements such as input, display, navigation, layout, interaction, and more. There has been little to no research done on the user interface design within a structural engineering software framework. Structural engineering software is often focused on the analysis theories used by the software to deliver results. Relevant user interface design work looks at different user interface items (Balagtas-Fernandez et al., 2009), with the item of interest being the input method comparison. The task was to change and specify a date using a touch screen, as well as some parameters like gender and relationship status. It was found that the non-modal method was preferred, but it was noted that the screen sensitivity was an issue. User input specifically is a complex category, because depending on the method, it can inherently provide guidance on the input itself, such as sliders providing guidance through their range (Eick, 1994). To apply this in structural engineering software, the user might not be aware of the limits, units, scale, or category of an input parameter without prior experience. The input is not easily understood, so non-modal input might cause invalid input more often, especially when the tool is being used in an educational setting. User Interface studies were done on small samples and include both explicit measures and surveys (Matsuno et al., 2019).

2.6 Summary

Given the importance of wind and seismic loads and their potential complexity, understanding the standard applied procedures in the code and its fundamentals is integral to any structural engineering graduate entering industry. While teaching of codes and loads has been explored in Architectural Engineering programs, the crossover between them in complex structural loading has been overlooked. Further understanding of load types on buildings and their impacts requires teaching methods to both teach analysis and visualize what is happening to help students understand. Active learning techniques (PBL and CBL) complement the topic being taught, while visualization provides a form of encouragement for the students to engage with hands-on activities that promote the behavior of an active learner. The use of CAL can expand on the use of active learning techniques and visualization and ventures away to provide an interactive environment that further engages the students. CAL in structural engineering has already been used through a wind program that was already developed for educational use, but without a statistical evaluation. In addition to that, complex software may not be the most ideal point to start for CAL and the use of simpler tools while evaluating the input methods was valuable to understand whether it impacts different applications of said tools. Establishing the benefits of CAL and the importance of lateral loading and structural analysis in general, dynamic visualization was chosen to implement along with active learning techniques to approach the teaching of lateral loading, while evaluating input methods in the process.

Chapter 3 – Research Hypothesis

The investigation into the background literature on CAL, structural loading, and dynamic tool interactivity, showed the importance of wind and seismic loads along with effective learning methods in engineering education. A lack of research covering input methods in engineering software was also identified. From this review, questions arose regarding the potential effects of a dynamic visualization tool on the students' ability to learn lateral loading, and the potential impacts of tool input methods on their knowledge structure. The following research questions were sought to be answered for this study:

1. *Does a dynamic visualization tool increase learning gains as compared to a traditional education teaching for lateral loading and to what extent?*
2. *For a dynamic visualization tool, did the input and interaction approach reflect in learning differences for different applications and to what extent?*
3. *Was there, and to what extent were the impacts on the relationship between fundamentals, analysis and design across wind and seismic loading on how students learned?*
4. *Was there, and to what extent were the impacts on the different input across wind and seismic loading on how students applied the tool for design and analysis?*
5. *Was there, and to what extent was the difference in performance between wind and seismic across the study dimensions?*

Given the formulated questions, there are two main leading hypotheses in this study. The first regarding learning with a tool, is that the tool(s) can provide learning gains in comparison. The second regarding the input methods, is that a flexible input method will help students perform better in changeable conditions questions, while a more precise input method helps students better with fixed conditions and precise questions. These hypotheses are to be tested across wind and seismic loading separately and jointly.

3.1 Dynamic Visualization & Learning

The first (Q1) and the third (Q3) of the research questions discuss the effects of dynamic visualization on the students' in comparison to traditional teaching styles. These two questions are similar, with the difference being that Q1 evaluates lateral loading in general, while Q3 evaluates wind and seismic loading separately. Learning through software can have a negative effect on the overall understanding of concepts, because the students are unable to make direct connections if the software provides no relationship between input and output. Giving loads a changeable dynamic representation of the values could potentially help the understanding of the relationship between input and output, as well as the relevant parameters for each load. Testing the effect of dynamic visualization on the learning of the lateral loads combined and separate provides insights into the methods moving forwards with the instructions of these loads.

3.2 Input Methods & Applications

The second (Q2) and fourth (Q4) research questions investigate different input methods (sliders vs. text boxes), and their effect on learning. These questions are similar with Q2 evaluating the input methods for the overall data, while Q4 evaluates the same question with the loads separated into wind and seismic. The inherent difference between the two input methods is what is being evaluated, the dynamic change of the sliders against the precision of the text boxes. While sliders might be better to develop an understanding of the loads, as well as provide an easy platform to reiterate design, they might not work as well when precise analysis is being done where more exact answers are expected. On the other hand, the numerical box input would be helpful when performing a detailed analysis but lacks the dynamic change that helps the understanding of the loads, or the iterative design process.

3.3 Wind & Seismic Comparison

The fifth (Q5) question investigated the wind and seismic loads between the same categories to conclude if there is a difference in performance. This helps highlight the need (or not) for the separation of the data or even studies for future work.

3.4 Research Methodology

To test the hypotheses above to formulate answers for each research question, a study was developed in a classroom setting, in which a comparison is made between the traditional teaching method and two different tools. The study was performed in three stages, using both technical assessments (quizzes), and self-assessment surveys. For each stage, the teaching method is performed, then the quiz takes place, then the survey. The use of both quiz and survey helps to perform a comparison between student performance and perceived knowledge, as discussed further in Section 4.2. The study population is structural engineering students learning to compute wind and seismic loads. A breakdown of the most detailed categorization is shown in Table 3-1 below.

Table 3-1: Detailed Data Breakdown

		Traditional		Tool 1		Tool 2	
		W	S	W	S	W	S
Quiz	Analysis	-	-	WAQ1	SAQ1	WAQ2	SAQ2
	Design	-	-	WDQ1	SDQ1	WDQ2	SDQ2
	Fundamentals	WFQ0	SFQ0	WFQ1	SFQ1	WFQ2	SFQ2
Survey	Analysis	WAS0	SAS0	WAS1	SAS1	WAS2	SAS2
	Design	WDS0	SDS0	WDS1	SDS1	WDS2	SDS2
	Fundamentals	WFS0	SFS0	WFS1	SFS1	WFS2	SFS2

“-” signals that the data set in that slot does not exist.

Chapter 4 – Study Design

The study utilizes two data measuring techniques, a Technical Assessment (Quiz) and a Self-Assessment (Survey). The quiz was designed to produce entirely quantitative data, while the survey was mostly quantitative with a small portion being qualitative. The study was performed in three stages with the sample being the same group of students experiencing the different teaching methods. The quiz and the survey were performed after every teaching technique was performed.

4.1 Study Population and Setting

The targeted study population for this study is structural engineering students currently learning to compute wind and seismic loads using MWFRS and ELFP, respectively. Both methods are taught as part of the syllabus for the course AE 430 – Indeterminate Structures in the Architectural Engineering curriculum at Penn State. The study was deployed in AE 430 in the Fall semester, 2022. AE 430 focuses on teaching indeterminate analysis techniques (conjugate beams, moment distribution, etc.) and approximation methods for indeterminate systems (cantilever method). These methods are applied to lateral systems (Moment and Braced Frames), making calculating lateral load and their distribution to lateral elements relevant to this course. In addition to MWFRS and ELFP, center of mass and center of rigidity and lateral load distribution to lateral elements is part of this course.

Given that the study will be performed integral to the class, splitting the class into three groups; a Control, Tool 1, and Tool 2 could violate the principle of justice defined by The Belmont Report (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979). This is because if any of tool iterations happens to be an effective learning method, then the group that got that tool will have a possible grade advantage at the end of the semester. To avoid such injustice, this study was performed over time, where the entire class receives the tool in stages and goes through the same experience. For the technical assessment, the class had twelve quizzes, only ten of which contributed to the grade, with the lowest two dropped. The two related tool assessments were added to that total number, bringing the total to fourteen, with the four lowest dropped. This provided enough incentive for the students to take the technical assessments. The self-assessment surveys were an optional survey to take.

The number of enrolled students in AE 430 was 29. Table 4-1 below shows a breakdown of how many students participated in each of the six different data collection methods. Of the total 29, three were eliminated; One student did not consent to the release of grades, and two only participated in one of the six activities. A total of seven students participated in all six activities.

Table 4-1: Number of Student Participants in Each Activity

Stage	Technical Assessment	Survey
Traditional	23	15
Tool 1	18	21
Tool 2	19	25

4.2 Separation of Technical Assessment and Survey

Teaching methods are often evaluated through surveys taken by the students, and through students' formal grades (course overall or specific items). Multiple studies relating to flipped classroom teaching methods for engineering students used the approach of collecting information about the students' direct performance in the courses and surveys regarding their perceived confidence. One study was performed in structural engineering courses, where CUCEI surveys were implemented to evaluate different scales, and students' final grades were compared to the survey results (Solnosky & O'Halloran, 2023). This was also the case for a different flipped classroom study in an introductory statistics course for engineers, where various class performance indicators (different grades) were collected, as well as a survey that asked opinions of the teaching methods (Maldonado & Morales, 2019). Other studies evaluating different methods such as Design and Visual Thinking (Olmedo-Torre et al., 2021), Project-Based Learning (Solnosky, 2020), and Computer-Aided Learning (Chau, 2007) used a formal grade (overall grade or broken down) as well as surveys regarding the teaching methods.

As explained in Section 4.1, the course includes wind and seismic load calculations because they are occasionally the loads being analyzed on an indeterminate structure. Given the difference in fundamentals between indeterminate structures analysis techniques and calculations of lateral loads, using the overall course grade did not seem appropriate. This is also due to the teaching methods being applied to only one topic of the course. Since the surveys were designed with attention to certain categories, the opportunity to design the technical assessments in the same manner was taken.

4.3 The Quantitative (& Quantitative) Method

Engineering educational studies are known to prefer using quantitative methods (Borrego et al., 2009). As such, this study reviewed and assessed various factors to choose the data collection techniques. Qualitative and quantitative methods are said to be misinterpreted as dichotomy where, in fact, they are the ends of an interactive continuum (Newman et al., 1998). This study chose to implement quantitative methods entirely in the technical assessment, and mostly in the survey with some open-ended qualitative questions. The nature of the study is to determine which teaching method is better or which input method is more effective for which context. This is very similar to the deductive approach engineers usually apply in their work (Borrego et al., 2009). In addition to that, there was not a detailed "why" question that is being asked, which is what was described as the most use case for a qualitative study (Borrego et al., 2009). However, it was important to get verbal feedback on a teaching method (or an engineering task method) and how the end user feels about the product they used (Lin et al., 2011). The responses to the open-ended questions were eventually grouped for analysis, but it provided feedback for future work, and it informed the study in conjunction with the data evaluated.

4.4 Data Collection

Data collection included two methods, Technical Assessment Quizzes, and Self-Evaluation Surveys. Both quiz questions and survey statements were designed to contribute to different categories. The categories are as follows (notation shown and used in future sections):

- **Load Type:**
    - **Wind (W):** Quiz questions were considered contributing to this category always unless there was specific instruction to ignore wind loads. This is because recognizing that wind loads are not affected is part of understanding the load type. Survey statements were categorized by loads.
    - **Seismic (S):** Quiz questions were considered contributing to this category always unless there was specific instruction to ignore seismic loads. This is because recognizing that seismic loads are not affected is part of understanding the load. Survey statements were categorized by loads.
- **Learning/Utility Category:**
    - **Analysis (A):** Analysis questions/statements were defined as any quiz question or survey statement that implied unchangeable given conditions. This in engineering is considered "Analysis", which is evaluated a predetermined problem.

- **Design/Iteration (D):** Design questions/statements were defined as any quiz question or survey statement that implied changeable conditions or asked for different solutions to satisfy certain limits.
- **Fundamental Understanding (F):** Fundamental Understanding quiz questions not necessarily include numerical values but gave a changeable situation. These questions are meant to test the understanding between input and output, as well as the student comprehension of the loads. Survey statements that implied understanding of methods were included in this section.

4.4.1 Technical Assessments

The technical assessments included a list of questions that contribute to either wind loads, seismic loads, or both, that were each associated with the different learning categories described. The first assessment contained six questions including hypothetical scenarios with little to no numbers involved, mostly relating to fundamental understanding. These questions were graded as correct/incorrect where their value totally amounted to 20 points (3.33 for six questions; 1.67 for each of the loads). Each of the two remaining assessments had ten questions. The additional four questions had numerical and real values, two of which focused on design/iteration, and two focused on detailed analysis. These questions were graded at the professor's discretion as 0-5-10-15-20 points, based on analysis accuracy or design effort. It is important to note that Quiz 1 Q1 is the exact same question as Quiz 0 Q1. Assessment questions were created to fit certain learning categories but could contribute to more than they were intended for and were treated as such. Table 4-2 shows the relationship between the technical assessment questions relative to both loads and learning categories. The assessments are included in Appendix A. Examples of categorization are demonstrated after the table and the same logic can be extrapolated to other questions.

Table 4-2: Quiz Questions Load and Learning Categorization

Stage	Question	Load		Learning Category		
		Wind	Seismic	Analysis	Design	Fundamental Understanding
Traditional (Quiz 0)	1a	●	●			●
	1b	●	●			●
	1c	●	●			●
	1d	●	●			●
	1e	●	●			●
	1f	●	●			●
Tool 1 (Quiz 1)	1a	●	●			●
	1b	●	●		●	●
	1c	●	●		●	●
	1d	●	●	●		●
	1e	●	●		●	●
	1f	●	●	●		●
	2	●			●	
	3		●		●	
	4	●		●		
	5		●	●		
Tool 2 (Quiz 2)	1a	●	●		●	●
	1b	●	●	●		●
	1c	●	●	●		●
	1d	●	●	●		●
	1e	●	●	●		●
	1f	●	●	●		●
	2	●			●	
	3		●		●	
	4	●		●		
	5		●	●		

- **Question 1d from quiz 1:** In this case, the risk category changes from II to IV, increasing wind speed and ground motion parameter, and ultimately increasing both loads. This question was labeled as "Fundamental Understanding" because it calls on that understanding of the loads. It was also labeled as an "Analysis" question because risk category is not a design parameter, but design input.

> 1d. A structure was constructed as an outpatient public health center. The city is proposing new plans, and want to evaluate if the building can be designated as an essential facility. Consider the two cases to be the facility designated as non-essential vs essential.
> What lateral loads get affected?
>
> Wind loads increase
> Seismic loads increase

- **Question 1e from quiz 1:** In this case, the change affects the effective weight of the structure. This only affects seismic loads, as weight plays no effect in wind loads. This was labeled as "Fundamental Understanding" due to the same reason as 1d. However, it was labeled as a "Design" question because changing the weight or choosing different materials for weight can be done.

> 1e. A building is currently in the schematic design phase. A preliminary load estimate and a lateral system has already been proposed based on the design the architect provided. The architect is now proposing a change to the façade by decreasing the brick and increasing the curtain wall percentage of the total façade on the individual floors. Consider two cases, before and after the proposed façade change.
> Which loads (if any) need to be reconsidered?
>
> Wind loads do not change
> Seismic loads decrease

4.4.2 Self-Evaluation Surveys

The self-assessment surveys included a seismic, a wind, and an overall section. The same survey was used in all three stages. The wind and seismic sections are very similar, changed to fit the loads, each with twelve statements on a 1-5 Likert like scale measuring student agreement. There are four additional statements on what affects the load case in question, with a similar 1-5 scale with the scale representing effect on load (These questions are not used in analysis). The last section includes two statements of the same kind that are not specific to a load, along with open-ended questions that vary depending on the stage of the study and are meant to gather feedback and subject experience. These statements provide information in a "self-evaluation" manner, and each question is already linked to and can contribute to the three learning categories. Table 4-3 shows the relationship for each survey statement to the three learning categories. Here Table 4-3 did not include the overall evaluation questions, or the open-ended questions. Refer to Appendix B for the full quantitative portion of the survey. Open-ended questions are listed in Section 5.7

Example statements are shown below:

- **Statement 4 for wind:** The statement demonstrates confidence in the fundamental understanding of wind loads. The statement had no relation to "Analysis" or "Design".

4.	I can easily navigate the many parameters that influence wind loads	1	2	3	4	5

- **Statement 5 for wind:** This statement demonstrates lack of confidence in the fundamental understanding of wind loads. This is why it was labeled as a negative statement, where a lower score is better. This was reversed for analysis by subtracting the response from 6. The statement had no relation to "Analysis" or "Design".

5.	There are too many variables that affect wind loads	1	2	3	4	5

- **Statement 10 for seismic:** This statement provides the choice between two design tasks, one that signals to "Analysis" tasks, and the other to "Design" tasks. This statement naturally was positive for one of the two categories involved, and negative to the other. It had no relation to "Fundamental Understanding".

10.	I would rather calculate seismic loads on a predetermined building than reiterate calculations based on changing parameters	1	2	3	4	5

Table 4-3: Survey Statements Load and Learning Categorization

Load	Statement	Learning Category		
		Analysis	Design	Fundamental Understanding
Wind	1	●		
	2		●	
	3			●
	4			●
	5			○
	6			●
	7			●
	8		●	
	9	●		
	10	●	○	
	11	●		
	12	●		●
Seismic	1	●		
	2		●	
	3			●
	4			○
	5			●
	6			●
	7			●
	8		●	
	9	●		
	10	●	○	
	11	●		
	12	●		●

Hollow circles refer to negative statements, where a lower score portrays confidence. Scores for these statements was reversed for study results are analyzed.

4.5 Learning Methods Documentation

This section documents each of the learning methods used to introduce wind and seismic loads. This included the Traditional Teaching Method and the Tools Teaching Methods (Slider vs. Text Input).

4.5.1 Traditional Teaching Methods of Wind and Seismic

The traditional learning method was taught in a lecture format. Here, each load type was taught in separate lectures but followed a similar lecture process.

Wind loads were taught assuming familiarity with the simplified procedure (taught in a prior course in AE). The lecture followed the flow of the process of finding wind loads referencing equations and tables from ASCE 7 -16 in the process, starting with main input parameters such as Risk Category and Wind Speed. From that, the equations for K-factors, velocity pressure (q), pressure coefficients (C_p), and wind pressure. Gust factor (G_f) was discussed theoretically and was assumed to be 0.85. A few practice problems were shown solved using spreadsheets. General questions were asked about the meaning of the building's natural frequency. A small undocumented quiz was given for this. Wind loading was taught over 1-2 50-minutes lectures.

Seismic loads were taught in a similar manner. Applicability of the Equivalent Lateral Force Procedure was introduced, along with other procedures where ELFP is not applicable. From there, parameters such as Risk Category and ground motion parameters were determined (S_S, S_1). Other parameters (S_{DS}, S_{D1}) were found by hand. Response Modification Coefficient (R) was then found, and finally Seismic Response Coefficient (C_s). Example walkthroughs were done to help with the process as well as provide familiarity with calculating effective weight. Seismic loading was taught over 1-2 50-minutes lectures.

4.5.2 Tool Description

The tool used in the Tool teaching methods was developed in Google Collaboratory, and it had a cleaner interface than that of a coding block like one would see when functionally using python. Figure 4-1 below shows the entire tool. It requires scrolling through on any computer screen, but the input was separated so scrolling is minimally needed. Figures 4-2, 4-3, and 4-4 subsequently show **Story Data**, **Procedural Step**, and the **Guide for the controlling C_s equation.**

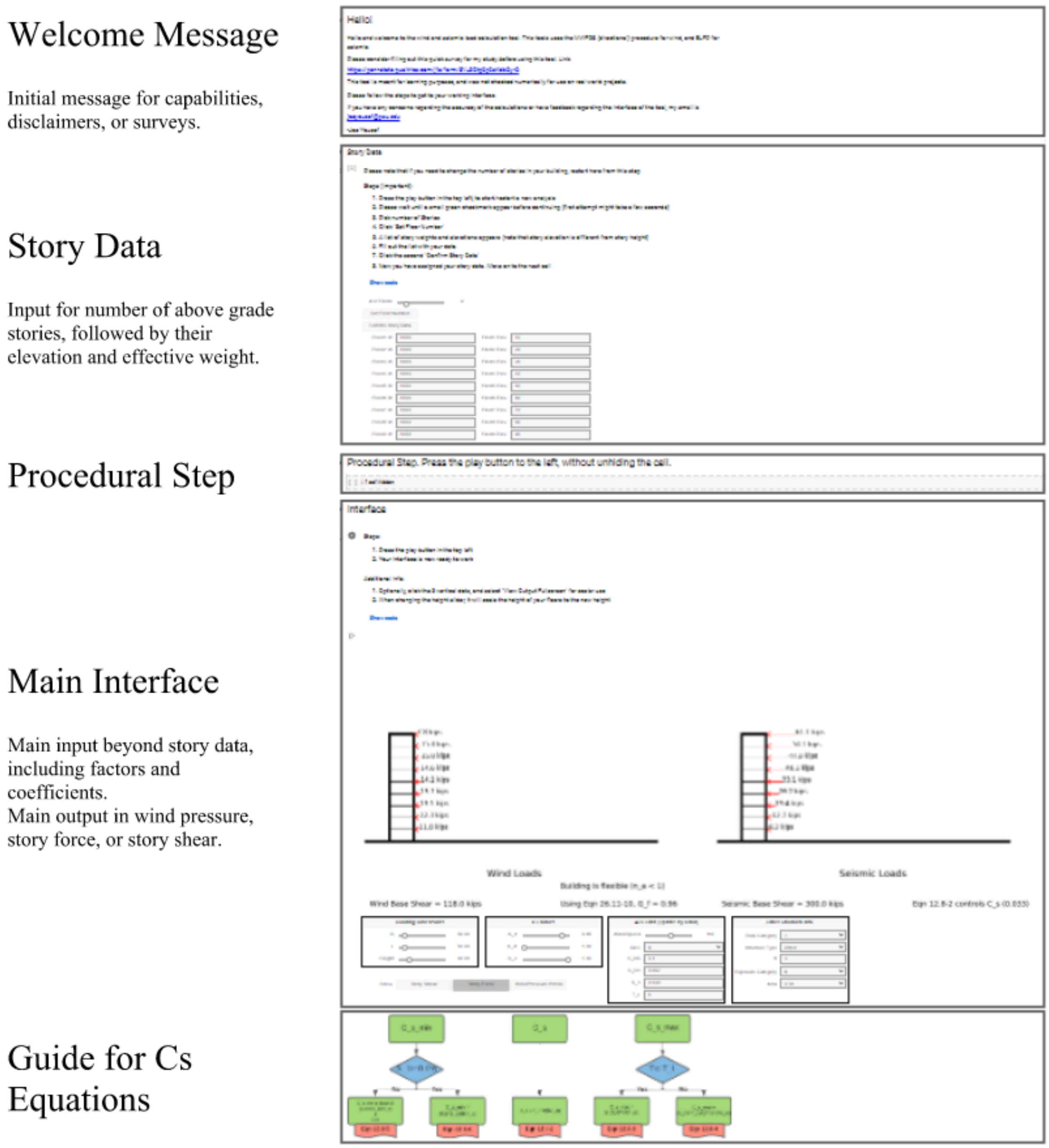

Figure 4-1: Tool Overview

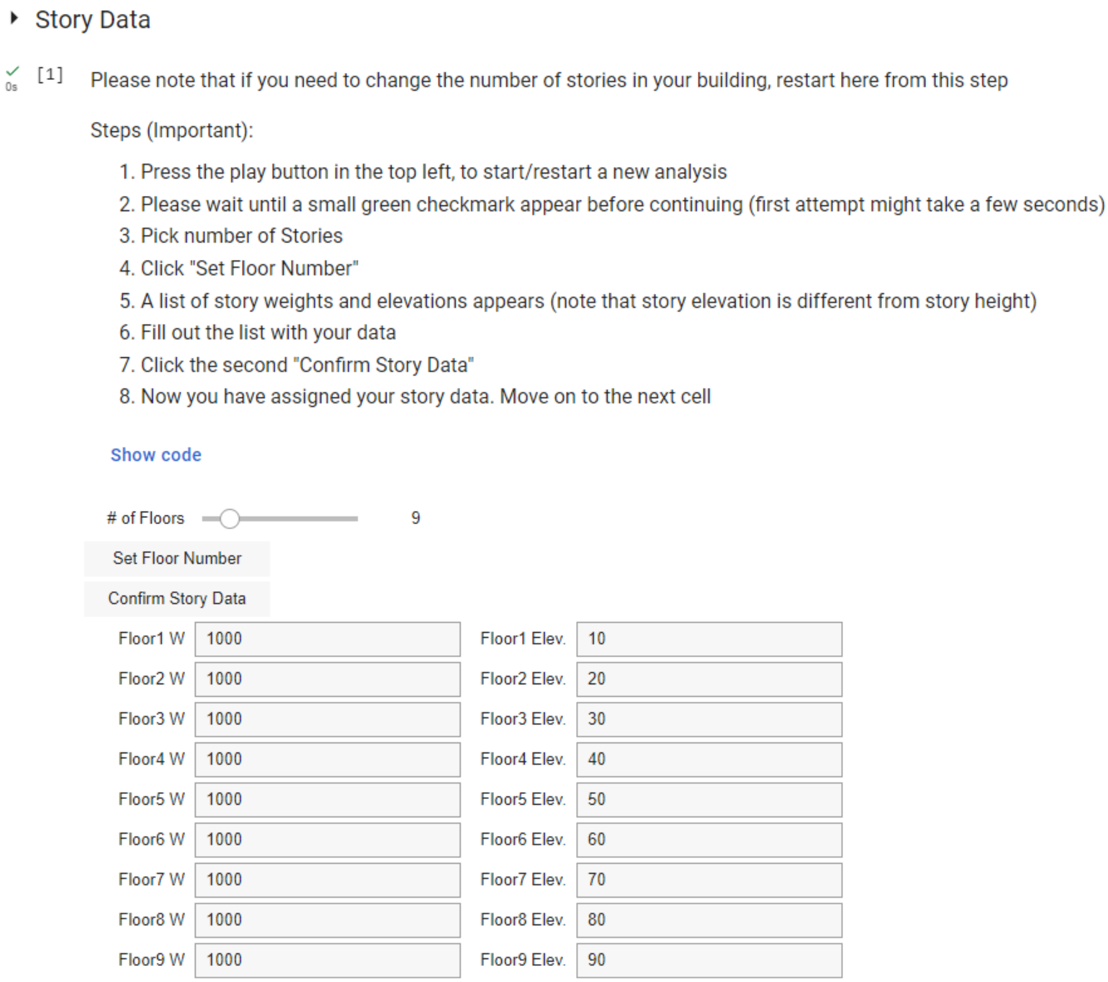

Figure 4-2: Story Data Window

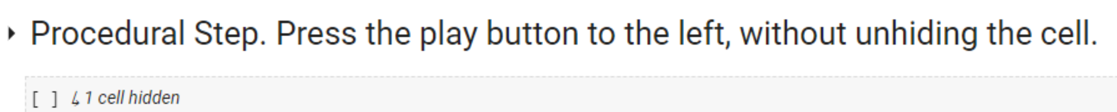

Figure 4-3: Procedural Step Window

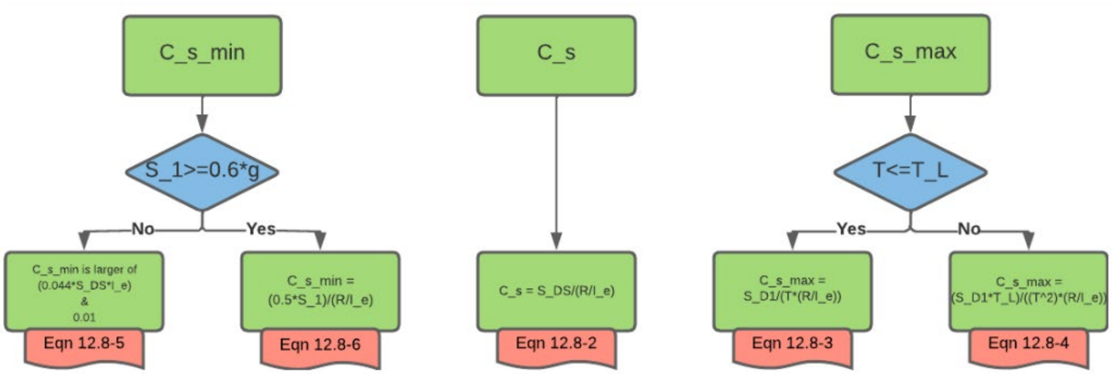

Figure 4-4: Cs Equation Guide

The main tool interface is shown in Figure 4-5 below. The input items are contained in rectangles grouping them into relating input, and include:

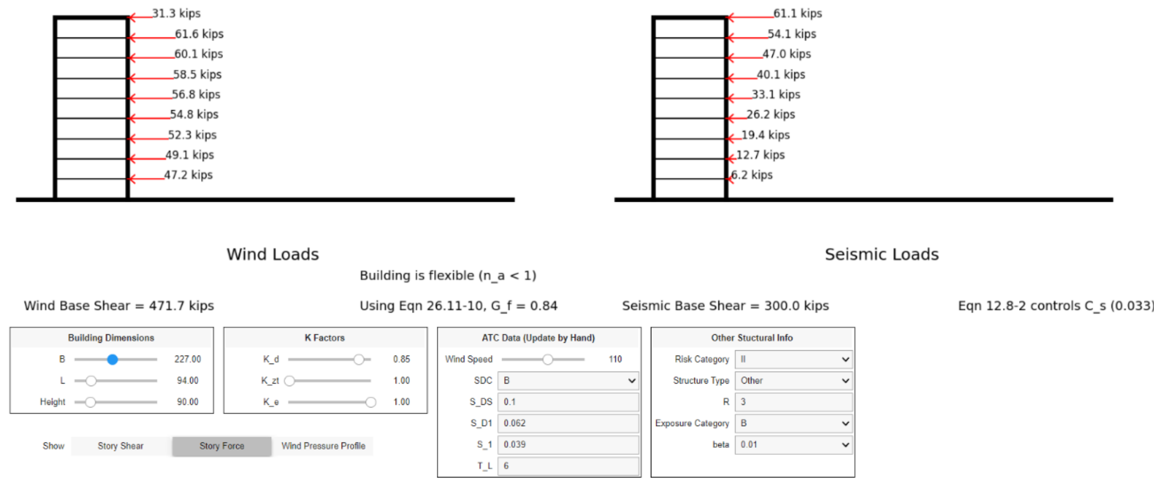

Figure 4-5: Main Interface Window

- **Building Dimensions:** Relevant geometric dimensions, in feet and to two decimal places.
- **K Factors:** All K factors used in wind calculations that are not K_z. All ranges are within code limits, and to two decimal places.
- **ATC Data:** All input coming directly from ASCE 7 or ATC Hazards by Location. This is design input that depends on uncontrolled conditions (location, site, etc.). Wind speed is to the nearest integer (similar to ATC Hazards by Location output). Seismic Design Category has no computational effects, but it is listed to keep track of. Ground motion parameters are to the third decimal place, as it is usually significant.
- **Other Information:** Includes relevant information.
  - **Risk Category:** Automatically dictates seismic importance factor, but wind speed and ground motion parameters must be adjusted manually.
  - **Structure Type:** Refers to lateral system type used to estimate building natural frequency (ASCE 7-16, Sec 26.11.2 & Sec 26.11.3) for wind loads, and building period (ASCE 7-16, Sec 12.8.2.1) for seismic loads.
  - The rest depends on lateral system, surrounding environment, or designer choice.

For the tool output shown in Figure 4-5, the option to show story forces, story shears, or wind pressure is available. Both wind and seismic load figure output has the base shear listed on the bottom left of the respective figures, and relevant information to that load in the bottom right.

For wind formulation within the tool, the program estimated natural frequency and gust factor are listed. Gust effect is listed because it is an important indicator in wind design of building stability, but it is also an input value in ETABS and it does not automatically calculate it. In theory, the tool can be used to just calculate the gust factor and used that value in ETABS. Natural frequency is listed as it affects gust factor and dictates whether the building is considered rigid or flexible. However, if the code limits that allow natural frequency to be estimated are violated, a warning is displayed as Figure 4-6 shows, but the loads are still calculated, and it is the designer's responsibility to make a choice regarding this.

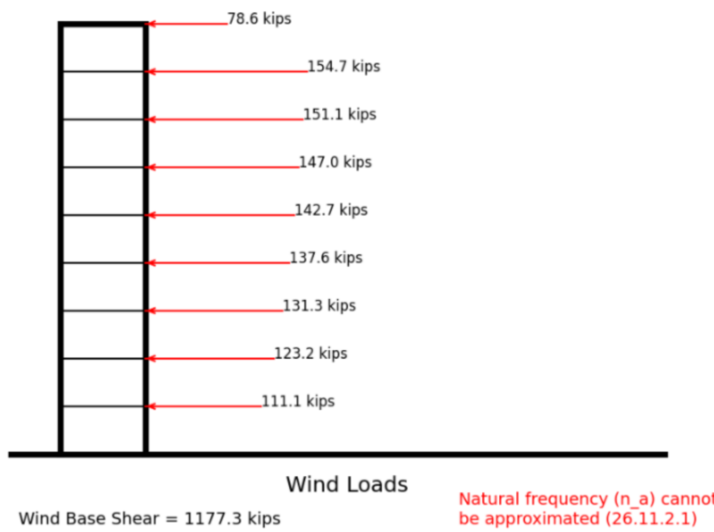

Figure 4-6: Natural Frequency Approximation Error

For seismic loads, the main displayed item is the value of C_s, and the controlling equation, as it has five possible equations. The value of C_s is relevant because it is what effective weight is multiplied by, making it the main important output. The controlling equation is listed because it helps the designer understand the values affecting C_s when attempting to reduce seismic loads.

4.5.3 Tool 1 and Tool 2 Variation

As the study looked to see if the input method of the tool influenced application of the tool, the main and only variation between the two tools is the input methods. The first tool's main input method used sliders for most of the input, while the second tool used text boxes. Figure 4-7 below shows the two input panels. The input that changed is often one that is iterated. This is the reason motion parameters were text input in the first tool and not sliders. Wind speed is inconsistent with this rule, but it was done in that manner (went from slider to text box). Others such as risk category and exposure category are items from a limited list of choices, which is why they were dropdown menus.

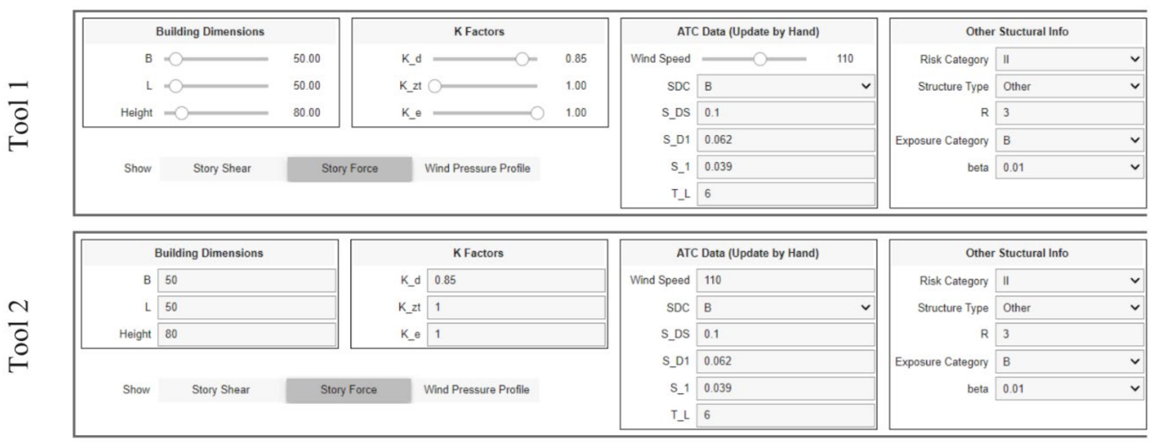

Figure 4-7: Tool 1 vs. Tool 2 Input Variation

4.5.4 Class Tool Introduction

The tool was introduced in class, where it was used to perform several practice problems that are similar in style to the quiz questions. This was done over one 50-minute lecture period. This was the opportunity to interact directly with the users of the tool, so they can ask questions or clarifications on how to use the tool, or to troubleshoot issues. The lecture where the tool was introduced was the first time it was available to the students to interact with.

4.6 Tool Accuracy Check

The tools computations were checked for accuracy by evaluating the same hypothetical building both in the tool and using ETABS autogenerated load cases.

4.6.1 Main Assumptions

The building was assumed to be a six-story office building (Risk Category LL) in State College, PA. Site Class D (Default) was assumed. Floor-to-floor height is 12'-0" (72'-0" overall), and the building is 75'x75'. The lateral system was chosen to be a non-seismically detailed steel moment frame. Total deadload was set to 105 PSF (20 SDL, 10 Framing Allowance, and 75 Generic Slab). The façade load was generically set to 25 PSF (of wall).

4.6.2 Input in Tool & ETABS

Figure 4-8 shows the story data input for the tool, and Figure 4-9 shows the main interface. Figure 4-10 shows the ETABS model, while Figures 4-11 and 4-12 shows the lateral load data used in ETABS.

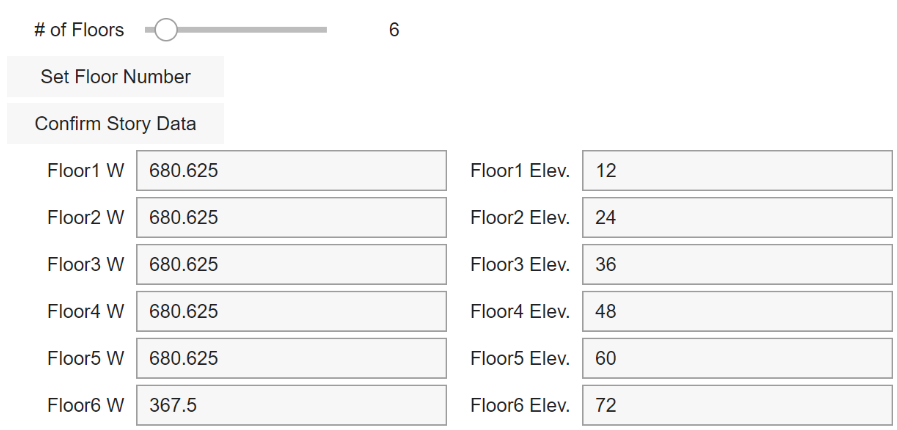

Figure 4-8: Story Data Input in Tool

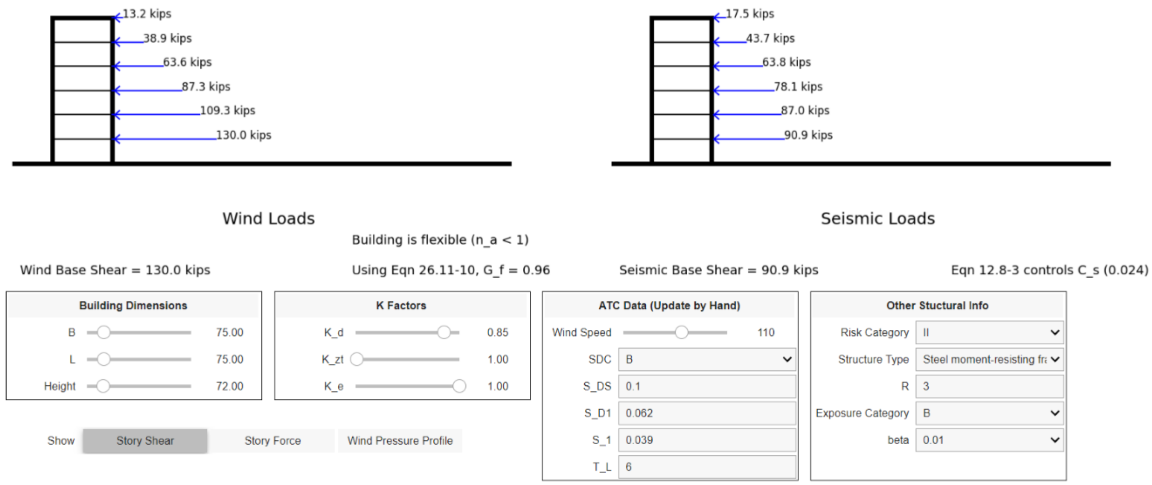

Figure 4-9: Interface Input in Tool

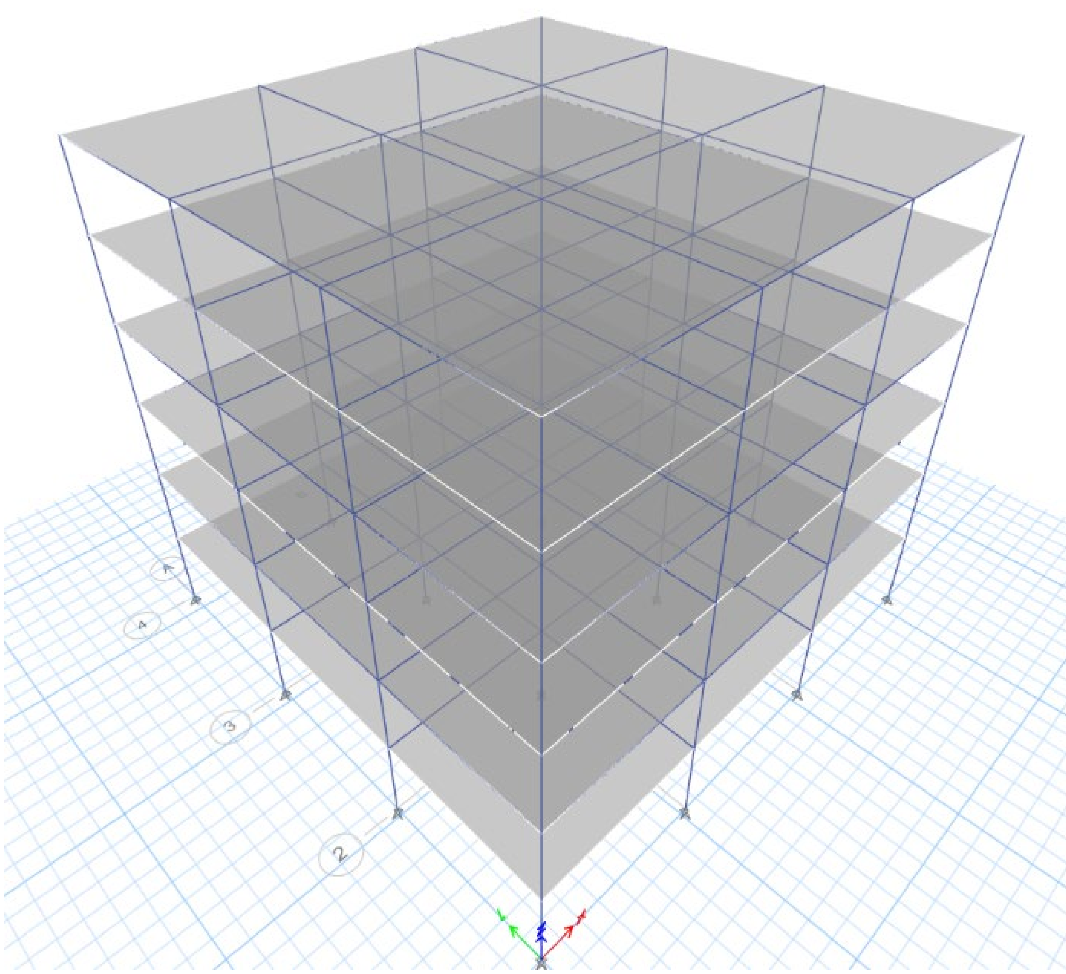

Figure 4-10: ETABS Model

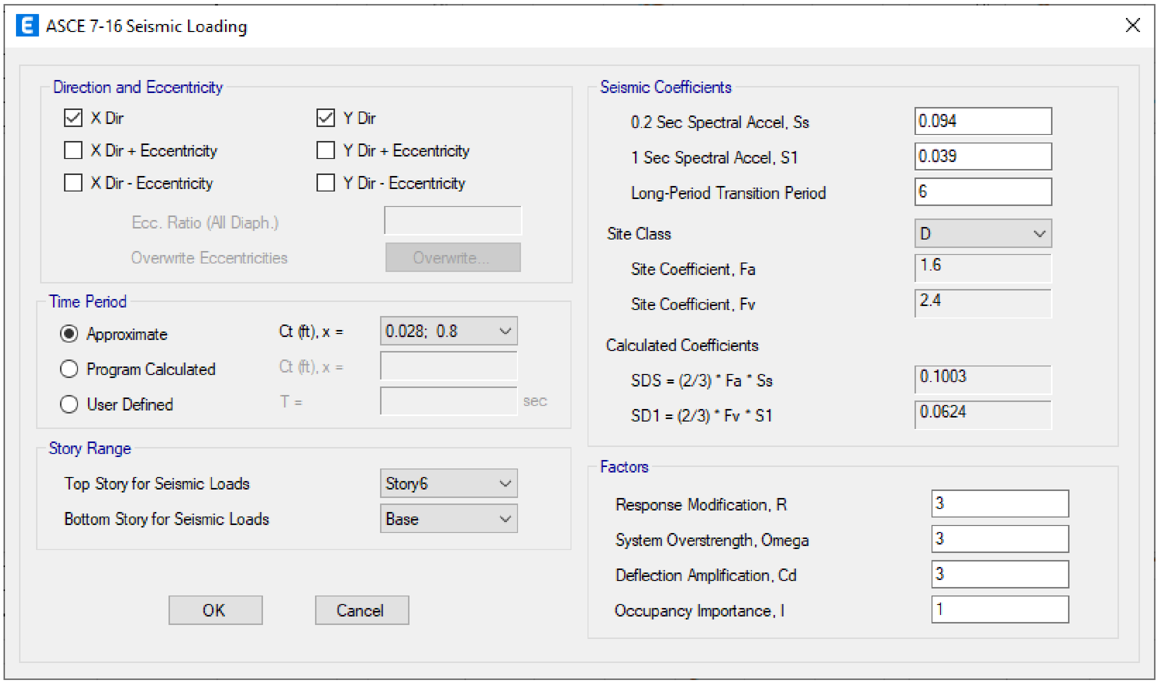

Figure 4-11: ETABS Auto Seismic Load Input

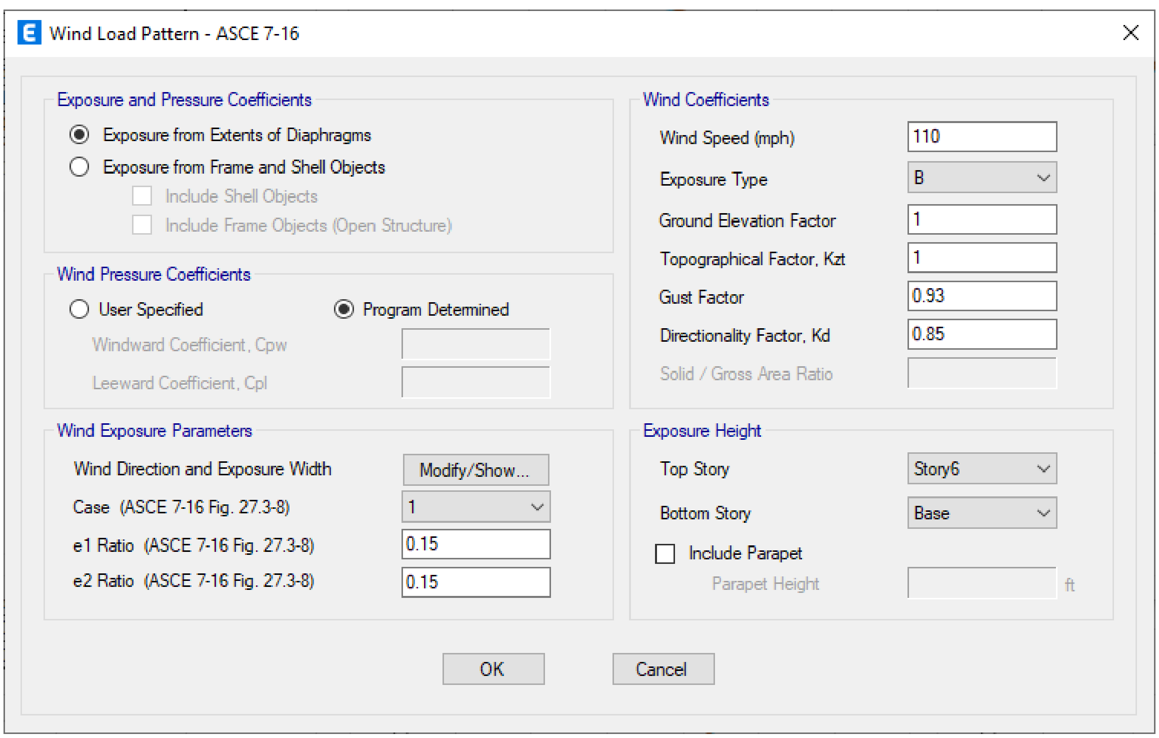

Figure 4-12: ETABS Auto Wind Load Input

4.6.3 Output Comparison

Figure 4-13 below shows a visual comparison between wind and seismic story forces and story shears. Tables 4-4 and 4-5 show a numerical evaluation with percentage differences. All the story forces and shears are within 5% of the calculated values, which means they are reliable.

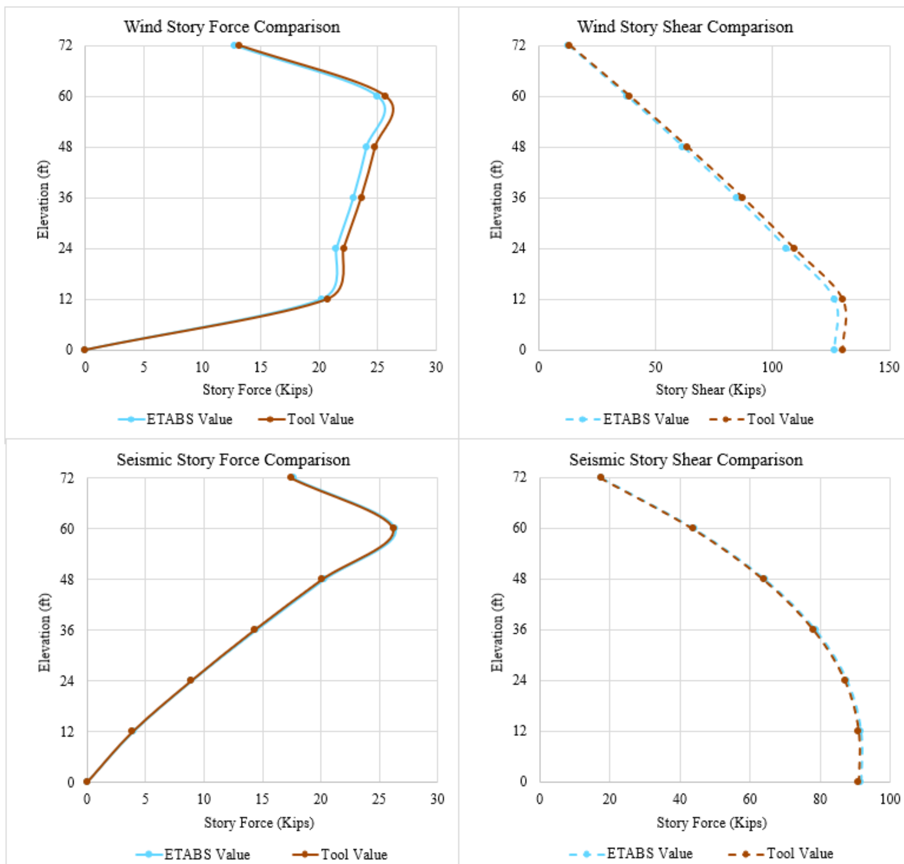

Figure 4-13: Wind and Seismic Story Forces and Story Shears Visual Comparison

Table 4-4: Wind Story Forces and Story Shears Comparison

Floor	Elevation	Force			Shear		
	ft	Tool	ETABS	% Diff	Tool	ETABS	% Diff
Roof	72	13.2	12.758	3.35%	13.2	12.758	3.35%
5th	60	25.7	24.96	2.88%	38.9	37.718	3.04%
4th	48	24.8	24.025	3.13%	63.6	61.743	2.92%
3rd	36	23.6	22.901	2.96%	87.3	84.644	3.04%
2nd	24	22.1	21.457	2.91%	109.3	106.101	2.93%
1st	12	20.7	20.195	2.44%	130	126.296	2.85%
Base	0	0	0	N/A	130	126.296	2.85%

Table 4-5: Seismic Story Forces and Story Shears Comparison

Floor	Elevation	Force			Shear		
	ft	Tool	ETABS	% Diff	Tool	ETABS	% Diff
Roof	72	17.5	17.624	-0.71%	17.5	17.624	-0.71%
5th	60	26.2	26.329	-0.49%	43.7	43.953	-0.58%
4th	48	20.1	20.241	-0.70%	63.8	64.193	-0.62%
3rd	36	14.3	14.42	-0.84%	78.1	78.614	-0.66%
2nd	24	8.9	8.942	-0.47%	87	87.556	-0.64%
1st	12	3.9	3.951	-1.31%	90.9	91.507	-0.67%
Base	0	0	0	N/A	90.9	91.507	-0.67%

4.7 Tools Necessary to Undertake the Research

The tools were created in and students utilized the tool using Google Colaboratory. Google Colaboratory was also used subsequently used for data analysis. Since the technical assessment are part of the course, they will be performed similarly to the category they are fitting in, which is Canvas quizzes. Lastly, the self-assessment surveys will be performed using Penn State Qualtrics, which is a safe platform that can be used to collect survey data.

4.7.1 Google Colaboratory/Python

Google Colaboratory (Google Colab) is a web-based programming site that uses Python 3.8. The tool itself was developed in Google Colab. Colab was used as it has little to no barrier to accessing the tool, besides a working computer and internet connection. It also utilizes Google servers to run the code rather than the user computer, minimizing difference in experience. The input methods are being iterated using the library "ipywidgets" (Jupiter Widgets, 2022). The output graphs are being shown using the visual library Matplotlib (Hunter, 2007). Plotly (Plotly

Technologies Inc., 2015) was evaluated as it has interactive plots itself, but due to this complexity, it was not fluid in comparison to Matplotlib.

Figure 4-14 shows a comparison of the visuals from the two plotting libraries.

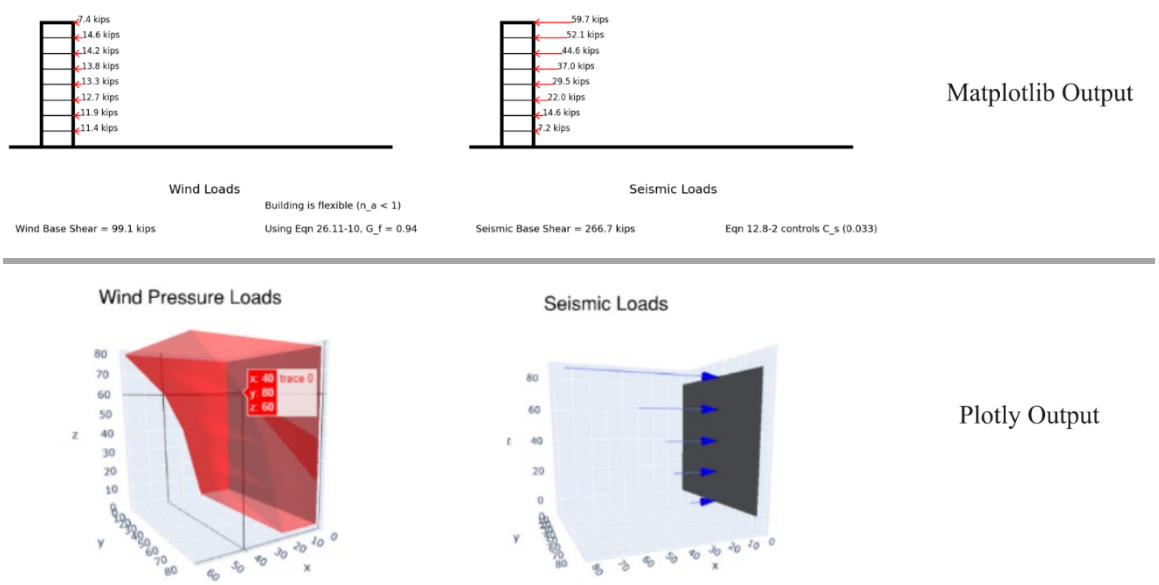

Figure 4-14: Plotting Libraries Comparison

4.7.2 PSU Canvas

PSU Canvas is an online teaching platform used by Penn State. It is used by almost every class, and it is where assignments get posted and submitted, as file submission or Canvas quizzes. It can also be used as a communications platform between the instructor and the students. The quiz feature was used to provide the technical assessments, as that is the method being used in the class where the study was performed. The Canvas communication capabilities were also used in announcing the study.

Chapter 5 – Study Analysis

The data collected during the study was analyzed using different statistical tests to compare different knowledge areas to draw conclusions regarding the research questions (Chapter 3). Based on information such as sample size, normality, and other characteristics of the study and data, appropriate statistical tests were utilized. As a result, the data was studied in a hierarchical manner at three different levels of detail. Once the statistical tests and strategies are established, the data was studied with the teaching methods being considered the variables, evaluating the tools in learning categories, then the variable was changed to be the learning categories to evaluate how each tool helped the categories. Lastly, qualitative responses were analyzed and tabulated. The quantitative data was analyzed as aggregated, then separated into learning categories, then loads.

5.1 Statistical Analysis Tests

Given the data collected, several statistical tests needed to be performed to either find statistical significance between groups, or a step to guide towards the correct test to be performed next. The first test that was looked at was an Analysis of Variance (ANOVA). ANOVA is a statistical test used to analyze sets of data with three or more groups. A Repeated Measures (RM) ANOVA is a variation used when the study subjects are the same for all observations and is the standard procedure in various fields using this kind of study design (Park et al., 2009). A Repeated Measures ANOVA has three assumptions to be suitable:

- **Independence:** Satisfied as the quizzes and surveys were performed individually.
- **Normality:** Must be tested. While Anderson-Darling is a good test to use for small samples, Shapiro-Wilk is the most "omnibus indicator of nonnormality" (Yazici, 2007). Data that is not normally distributed used a Friedman test instead, which is the non-parametric equivalent of

an RM ANOVA (Demšar, 2006). When the data analysis was performed, all available points in each data grouping were used regardless of participation in others.

- **Sphericity:** Must be tested for RM ANOVA data. A Mauchly test was performed (Part et al., 2009). If sphericity failed, a Greenhouse-Geisser correction was applied to the RM ANOVA.

RM ANOVA and Friedman were performed on the data from individuals who were part of all three groups available, and if they yielded that at least one of the groups' means are different (p-value is statistically significant), then post-hoc tests were needed to compare pairs of groups. For normally distributed data, a pairwise t-test was used as the post hoc test with a Bonferroni correction to account for potential Type I errors (Park et al., 2009). For non-normal sets, a Nemenyi test was performed as it is the non-parametric equivalent of a t-test (Demšar, 2006). Figure 5-1 below shows a flow chart of the tests and sequence they were performed in. A few data sets that only included two groups skipped the group difference tests and were immediately evaluated using the pair difference, in which case, they case still yield to be indifferent. Additionally, correlation between individuals quiz and survey responses were examined using a Spearman's rank correlation coefficient, as Pearson's r is sensitive to skewness (Frey, 2018). Table 5-1 shows the null hypotheses, alternative hypotheses, and significant p-values used for each test. Spearman's rho interpretation will be adapted from Dancey and Reidy (2004), and is shown in Table 5-2.

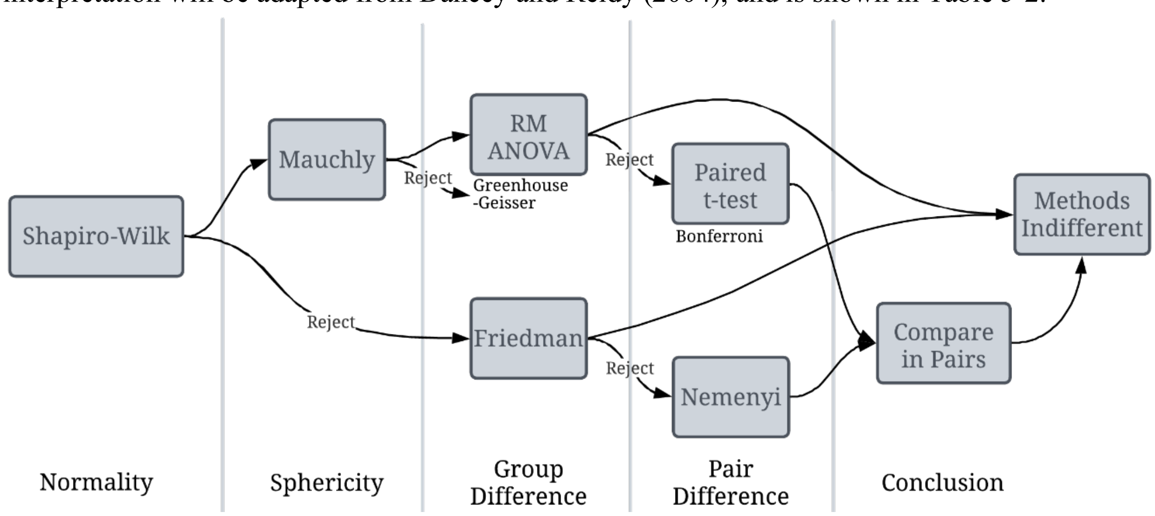

Figure 5-1: Group Comparison Statistical Tests Flowchart

Table 5-1: Statistical Tests Null & Alternative Hypotheses, & Significant p-values

Test	Null Hypothesis	Alternative Hypothesis	Significant p-value
Shapiro-Wilk	Data is normally distributed	Data is not normally distributed	0.05
Mauchly	The variance of difference is equal	The variance of difference is not equal	0.05
RM ANOVA	Group means are not different	At least one groups is different	0.05
Friedman	Group means are not different	At least one groups is different	0.05
Pairwise t-test	Difference is between pairs is 0	Significant difference	0.0167 or 0.05*
Nemenyi	Difference is between pairs is 0	Significant difference	0.05

*0.05 was used when only 2 groups (1 pair) are compared, while 0.0167 was used for 3 groups (3 pairs)

Table 5-2: Spearman's Rank Correlation Coefficient Scale Interpretation

Spearman's ρ	Interpretation
0.70≤	Very strong relationship
0.40-0.69	Strong relationship
0.30-0.39	Moderate relationship
0.20-0.29	Weak relationship
0.01-0.19	No/Negligible relationship

5.2 Statistical Analysis Strategy and Data Overview

The methods in which the quiz and the survey were created provided the opportunity to study the effects of the tools and their input methods in detail (Section 4.4), separating them by learning categories and load types. Given the small sample (n = ~12 to ~25) and the number of questions (5 in quiz, 24 in survey), the implemented strategy was to analyze the data in a hierarchical manner, starting at the aggregated level first then learning categories, and finally loads. This breakdown of the data is shown in Figure 5-2, along with how many groups were considered in each set. Given the quiz and survey, a total of 20 sets were examined. The data analysis used the tests describer in Sec. 5.1 and followed the flowchart in Figure 5-1.

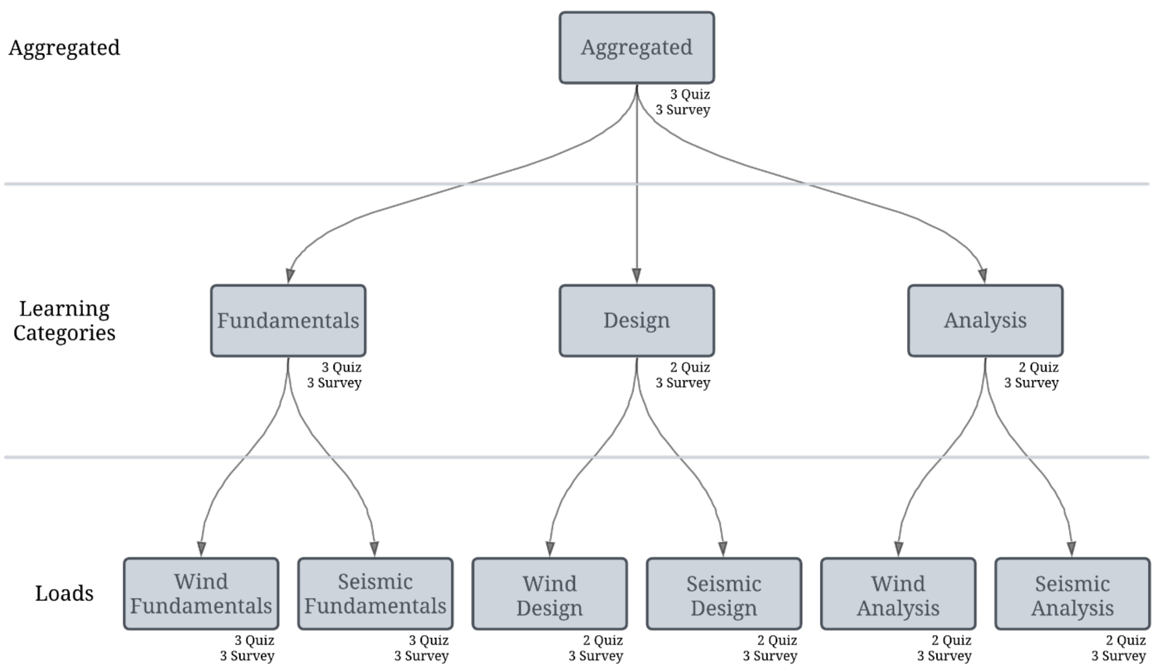

Figure 5-2: Data Granulation and Data Sets

5.3 Aggregated Analysis

The first level that was analyzed is the total aggregated data set. For the quiz, this refers to the overall score received on all the questions combined out of 100%. For the survey, this was computed as the average of all the statements in the survey, or the reverse score of negative statements as explained in Sec. 4.4.2. If statements contributed to more than one category, it was only counted once in the aggregated analysis. If statements contributed positively to one category and negatively to another, the statement was not included in this data set.

The first step performed a group difference test. Table 5-3 shows the results of the normality test, sphericity test (if needed), and the group difference test used as applicable. All the survey groups and the Traditional quiz had $P > 0.05$, which means that these have normally distributed data when observing the null hypothesis. The Tool 1 and Tool 2 quizzes had a non-normal distribution due to the statistically significant p-value ($P < 0.05$). The surveys' normal distribution can be explained by the high number of statements (24) contributing to well defined curve, as well as the use of the 5-point Likert scale. The difference between the quizzes could be explained by the fact that the Traditional method quiz comprised of binary grading (multiple choices with 3 options), where the responses were either correct or incorrect. Tool 1 and Tool 2 quizzes included four additional questions each (2 design and 2 analysis), which made up 80% of the grade. Subsequently, a sphericity test was performed for the survey data that resulted in a statistically insignificant p-value ($P > 0.05$), which meant that the data is spherical and that a RM ANOVA is satisfied without corrections needed. Sphericity was not tested for the quiz data because non-normality required a Friedman test, which makes no assumptions regarding sphericity. For quiz and survey data using the Friedman and RM ANOVA respectively, both yielded a statistically significant p-value (Quiz: $P = 0.0244$, Survey: $P = 0.0108$), which means at least one of the groups is different, therefore requiring a post hoc.

Table 5-3: Aggregated Data Normality, Sphericity, and Group Difference Tests p-values

	Normality Test (Shapiro-Wilk)			Sphericity (Mauchly)	Group Difference	Conclusion
	Traditional	Tool 1	Tool 2			
Quiz	**0.5677**	0.0041	≈0.0000	N/A	0.0244 Friedman	Perform Nemenyi Post Hoc
Survey	**0.3714**	**0.7851**	**0.1466**	**0.2722**	0.0108 ANOVA	Perform t-test Post Hoc

"N/A" signals that the test is not needed due to subsequent tests not requiring it

The post-hoc analysis data is shown in Table 5-4. The Nemenyi post hoc test was performed for the quiz data, and it yielded a statistically significant p-value (P = 0.0222) for only one of the three pairs of groups, which is the Traditional-Tool 2 comparison where Tool 2 had a high mean score (X_2 = 71.46, X_0 = 56.88) as Table 5-5 shows. Scores for Tool 1 were better than the Traditional method, but worse than Tool 2, but neither of these differences was statistically significant. The t-test performed for the survey data showed a statistically significant p-value for that same pair of Traditional-Tool 2 (P = 0.0021), with Tool 2 having the better score (X_2 = 3.344, X_0 = 2.864). The Traditional-Tool 1 and Tool 1-Tool 2 comparisons for the survey followed the same trend of the quizzes. While the difference can be explained by the exposure to the same material for the third time, observing the p-value for Traditional – Tool 1 (P = 0.1416), which is lower than that of Tool 1 – Tool 2 (P = 0.7111), shows that there may have been some meaningful jump in their score. This can also be due to the difference in quiz style, where the first quiz did not include design or analysis questions. The survey on the other hand shows that the difference between Tool 1 – Tool 2 was nearly significant (P = 0.0509) and could indicate that the students have more confidence in their ability after the second use of the tool, but not after the first.

Table 5-4: Aggregated Data Post Hoc Resulting p-values for Pairs of Groups

Pairs Compared	Quiz (Nemenyi)	Survey (Pairwise t-test[1])
Traditional – Tool 1	**0.1416**	**0.3011**
Traditional – Tool 2	0.0222	0.0021
Tool 1 – Tool 2	**0.7111**	**0.0509**

1 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.

Table 5-5: Aggregated Quiz and Survey Overall Means, Mins, & Maxes

		Traditional	Tool 1	Tool 2
Quiz (points/100)	Mean	56.88	60.19	71.46
	Min	16.67	15.00	8.33
	Max	91.67	88.33	91.67
Survey (points/5)	Mean	2.864	3.126	3.344
	Min	1.955	2.091	2.364
	Max	3.818	4.318	4.682

Lastly, Spearman's rank correlation coefficient was used to test correlation in Table 5-6. For all study stages, all the correlation coefficients are negligible (0.01-0.19) (some close to being considered weak). The means yielded a perfect 1.0 for the correlation coefficient, which can be due to that set including only three points.

Table 5-6: Aggregated Quiz and Survey Spearman's Rank Correlation Coefficient

	Traditional	Tool 1	Tool 2	Means Correlation
Survey-Quiz Correlation	0.1784	0.0858	0.0308	1.0

5.4 Learning Categories Analysis

The second level of analysis separated the data by the learning categories to get a better understanding of the effects of the different tools. Table 5-7 shows the results of the normality test, sphericity test (if needed), and the group difference test used as applicable. The observation regarding normality of the quizzes in Sec. 5.3 seems to differ here. All learning categories yielded non-normal data in Tool 1 and Tool 2 quizzes ($P < 0.05$), while Fundamentals for Traditional quizzes stayed the same as it is the entire quiz. The survey data continued to be normal and spherical in all learning categories and tool types ($P > 0.05$), which can still be explained by the magnitude of questions still contributing to each value. The Friedman test for the Fundamental quiz scores yielded a statistically significant p-value ($P = 0.0004$), and therefore required a Nemenyi post hoc. The Design and Analysis data will automatically perform a Nemenyi test because Friedman (or ANOVA) are not often performed for only two groups. As for the surveys that met the RM ANOVA assumptions, the Fundamentals and Design categories yielded a high p-value (Fund: $P = 0.1394$, Design: $P = 0.3694$), meaning there was no statistical difference between the groups, while the analysis category yielded a low p-value ($P = 0.0100$) and requiring a t-test post hoc.

The post hoc analyses were performed with results shown in Table 5-8. When observing the p-values in conjunction with means (Table 5-9), the performance of the Fundamentals category has improved with significant p-values from Traditional ($X_0 = 56.88$) to both Tool 1 ($P = 0.0095$, $X_1 = 78.70$) and Tool 2 ($P = 0.0010$, $X_2 = 82.87$). Tool 1-Tool 2 showed some improvement in all categories but was not statistically significant ($P > 0.05$). For the surveys, the analysis category was the only one requiring post hoc analysis. The increase in the responses was steady from Traditional to Tool 1 to Tool 2 but was statistically significant for Traditional – Tool 2 ($P = 0.0157$), and Tool 1 – Tool 2 ($P = 0.0124$) ($X_2 = 3.448$, $X_1 = 3.143$, $X_0 = 2.947$). This conveys that the students may have gained confidence in their ability in analysis only after Tool 2, but the correlation with the analysis questions is negligible (Table 5-10: Spearman's Key), and the Analysis questions means are generally poor in comparison to Design and Fundamentals in Tool 1 and Tool 2. Further comparison of the categories performance under each tool is performed in Sec. 5.6.

Table 5-7: Learning Cat. Data Normality, Sphericity, and Group Difference Tests p-values

		Normality Test (Shapiro-Wilk)			Sphericity (Mauchly)	Group Difference	Conclusion
		Traditional	Tool 1	Tool 2			
Quiz	Aggregated	**0.5677**	0.0041	≈0.0000	N/A	0.0244 Friedman	Perform Nemenyi Post Hoc
	Fundamentals	**0.5677**	≈0.0000	0.0007	N/A	0.0004 Friedman	Perform Nemenyi Post Hoc
	Design	**-**	0.0030	≈0.0000	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
	Analysis	**-**	0.0359	0.0031	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
Survey	Aggregated	**0.3714**	**0.7851**	**0.1466**	**0.2722**	0.0108 ANOVA	Perform t-test Post Hoc
	Fundamentals	**0.4401**	**0.9849**	**0.2567**	**0.2428**	**0.1394** ANOVA	Methods Indifferent
	Design	**0.9589**	**0.4256**	**0.2291**	**0.2915**	**0.3694** ANOVA	Methods Indifferent
	Analysis	**0.6351**	**0.3826**	**0.2872**	**0.6026**	0.0100 ANOVA	Perform t-test Post Hoc

"N/A" signals that the test is not needed due to subsequent tests not requiring it.
"-" signals that the data set in that slot does not exist.

Table 5-8: Learning Categories Post Hoc Resulting p-values for Pairs of Groups

Pairs Compared	Quiz (Nemenyi)				Survey (Pairwise t-test[1])			
	Agg	Fund.	Design	Analysis	Agg	Fund.	Design	Analysis
Traditional – Tool 1	**0.1416**	0.0095	-	-	**0.3011**	N/A	N/A	**0.5238**
Traditional – Tool 2	0.0222	0.0010	-	-	0.0021	N/A	N/A	0.0157
Tool 1 – Tool 2	**0.7111**	**0.7651**	**0.2850**	**0.6020**	**0.0509**	N/A	N/A	0.0124

1 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.
"N/A" signals that the test is not needed due to subsequent tests not requiring it.
"-" signals that the data set in that slot does not exist.

Table 5-9: Learning Categories Quiz and Survey Data Means, Mins, & Maxes

		Traditional				Tool 1				Tool 2			
		Agg.	F.	D.	A.	Agg.	F.	D.	A.	Agg.	F.	D.	A.
Quiz (points/100)	Mean	56.88	56.88	-	-	60.19	78.70	66.56	50.91	71.46	82.87	80.47	64.58
	Min	16.67	16.67	-	-	15.00	0.00	10.00	10.71	8.33	41.67	7.69	8.82
	Max	91.67	91.67	-	-	88.33	91.67	93.33	89.29	91.67	100.0	100.0	97.06
Survey (points/5)	Mean	2.864	2.900	2.778	2.947	3.126	3.020	3.056	3.143	3.344	3.180	3.133	3.448
	Min	1.955	2.000	1.500	1.600	2.091	1.917	2.333	1.500	2.364	2.250	2.333	2.200
	Max	3.818	4.000	3.833	4.000	4.318	4.167	3.833	4.100	4.682	4.417	4.000	5.000

"-" signals that the data set in that slot does not exist.

Spearman's rank correlation coefficient was used to test correlation in Table 5-10. All the correlations have negligible relationships (0.01-0.19) between survey and quiz, except for the Fundamental learning category in the Traditional and Tool 1 stages. The Traditional stage shows a moderate relationship (ρ = 0.3022), and the Tool 1 stage shows a strong (ρ = 0.4092) relationship. Design Tool 1 had a negligible negative relationship (ρ = -0.1646).

Table 5-10: Learning Cat. Quiz and Survey Spearman's Rank Correlation Coefficient

	Traditional	Tool 1	Tool 2	Means Correlation
Survey-Quiz Correlation	0.1784	0.0858	0.0308	1.0000
Fundamentals	0.3022	0.4092	0.0078	1.0000
Design	-	-0.1646	0.0270	N/A
Analysis	-	0.1368	0.0427	N/A

"N/A" signals that the test is not needed due to subsequent tests not requiring it.
"-" signals that the data set in that slot does not exist.

5.5 Learning Categories for Loads Analysis

This section investigates the learning categories after splitting the performance for the wind and seismic loads.

5.5.1 Fundamentals

For the fundamental learning category, when separated to wind and seismic loads, the surveys followed the same path of normality, sphericity, and yielded that the methods were indifferent using a RM ANOVA (Table 5-11). The quizzes for Tool 1 and Tool 2 remained to be non-normal. However, for the Traditional stage, the earlier result was normal and yet became non-normal for seismic and close to non-normal for wind. This conveys that the two loads showed skewness in opposite directions and further observation of the means in Table 5-13 supports alternated skews. It can be due to the data becoming more detailed. Both loads showed a statistically significant p-value (Wind: $P = 0.0004$, Seismic: $P = 0.0038$), and required Nemenyi post hoc test. Survey separated data matched the earlier results with statistically insignificant p-values ($P > 0.05$) for ANOVA.

Table 5-11: Fund. Loads Data Normality, Sphericity, and Group Difference Tests p-values

		Normality Test (Shapiro-Wilk)			Sphericity (Mauchly)	Group Difference	Conclusion
		Traditional	Tool 1	Tool 2			
Quiz	Fundamentals	**0.5677**	≈0.0000	0.0007	N/A	0.0004 Friedman	Perform Nemenyi Post Hoc
	Wind	**0.0684**	≈0.0000	≈0.0001	N/A	0.0004 Friedman	Perform Nemenyi Post Hoc
	Seismic	0.0166	≈0.0000	0.0028	N/A	0.0038 Friedman	Perform Nemenyi Post Hoc
Survey	Fundamentals	**0.4401**	**0.9849**	**0.2567**	**0.2428**	**0.1394** ANOVA	Methods Indifferent
	Wind	**0.2761**	**0.8263**	**0.7417**	**0.2440**	**0.3588** ANOVA	Methods Indifferent
	Seismic	**0.9300**	**0.8392**	**0.0733**	**0.4088**	**0.0771** ANOVA	Methods Indifferent

“N/A” signals that the test is not needed due to subsequent tests not requiring it.

Observing Table 5-12 for the post hoc test, the Traditional – Tool 2 (P = 0.0169) and Tool 1 – Tool 2 (P = 0.0052), comparison were significant in the same manner. Using Table 5-13 and observing the means, they followed the same steady increase or were equal going from Traditional to Tool 1 to Tool 2, but they did not decrease. Traditional – Tool 1 was significant for wind (P = 0.0014) but was not for seismic ($\rho < 0.20$)which can mean that the tool was not as helpful the first time for seismic load understanding. This could be due to the method in which seismic loads are calculated and having minimums and maximums that can make the process less intuitive unless the students make use of the figure attached in the tool and compares the equation that reports the $C_s$value.

Table 5-12: Fund. Loads Post Hoc Resulting p-values for Pairs of Groups

Pairs Compared	Quiz (Pairwise t-test[1])		
	Fund.	Wind	Seismic
Traditional – Tool 1	0.0095	0.0014	**0.2051**
Traditional – Tool 2	0.0010	0.0169	0.0052
Tool 1 – Tool 2	**0.7651**	**0.7111**	**0.3325**

1 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.

Table 5-13: Fund. Loads Quiz and Survey Fundamentals Data Means, Mins, & Maxes

		Traditional			Tool 1			Tool 2		
		Fund	Wind	Seismic	Fund	Wind	Seismic	Fund	Wind	Seismic
Quiz (points/100)	Mean	56.88	52.90	60.87	78.70	84.26	73.15	82.87	84.26	81.48
	Min	16.67	16.67	16.67	0.00	0.00	0.00	41.67	33.33	50.00
	Max	91.67	100.0	83.33	91.67	100.0	100.0	100.0	100.0	100.0
Survey (points/5)	Mean	2.900	2.822	2.978	3.020	3.032	3.008	3.180	3.087	3.273
	Min	2.000	1.500	2.000	1.917	2.000	1.667	2.250	2.000	2.167
	Max	4.000	4.000	4.000	4.167	4.167	4.167	4.417	4.333	4.500

Spearman's rank correlation coefficient was used to test correlation in Table 5-14. For the Traditional learning method, the correlation slightly decreased, but a weak correlation was still observed for both loads ($0.20 < \rho < 0.29$). Tool 1 has strong correlation ($0.40 < \rho < 0.69$) overall for Fundamentals, but further investigation shows that it mainly came from the wind loads, which had strong correlation ($0.40 < \rho < 0.69$) as well while seismic had negligible correlation ($\rho < 0.20$). For Tool 2, the correlation was negligible for Fundamentals and continued to be negligible for both loads ($\rho < 0.20$).

Table 5-14: Fund. Loads Quiz and Survey Spearman's Rank Correlation Coefficient

	Traditional	Tool 1	Tool 2	Means Correlation
Fundamentals	0.3022	0.4092	0.0078	1.0000
Wind	0.2532	0.5357	0.0217	0.5000
Seismic	0.2883	-0.0617	-0.0556	1.0000

5.5.2 Design

Observing Table 5-15 for the Design learning category, the quiz design data was non-normal and that did not change when separated to wind and seismic. The Nemenyi test was performed because there are only two groups for the quizzes. For the surveys, most of the data remained normal when separated, except for Tool 1 Wind data and Tool 2 Seismic data ($P < 0.05$), making an ANOVA unusable, so a Friedman test was performed instead. The Friedman test for the survey still yielded an unsignificant p-value ($P > 0.05$) for wind and seismic in comparison to the overall Design, which meant there is no statistically significant difference in the means of the survey results.

Table 5-16 includes the comparison between Tool 1 – Tool 2 for the quiz data, since other pairs of groups do not exist for the quizzes and the survey data required no post hoc analysis. The change was statistically insignificant for the overall Design category, and it was the same for each of the wind and seismic groups ($P > 0.05$). Even though the increase in means of the quizzes is notable as Table 5-17 shows across design (~14 pt increase), wind (~12 pt increase), and seismic (~15 pt increase), it was not statistically significant. This could be due to the small sample size.

Table 5-15: Des. Loads Data Normality, Sphericity, and Group Difference Tests p-values

		Normality Test (Shapiro-Wilk)			Sphericity (Mauchly)	Group Difference	Conclusion
		Traditional	Tool 1	Tool 2			
Quiz	Design	-	0.0030	≈0.0000	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
	Wind	-	0.0113	≈0.0000	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
	Seismic	-	0.0002	0.0002	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
Survey	Design	**0.9589**	**0.4256**	**0.2291**	**0.2915**	**0.3694** ANOVA	Methods Indifferent
	Wind	**0.7703**	0.0436	**0.1223**	N/A	**0.2231** Friedman	Methods Indifferent
	Seismic	**0.6695**	**0.6182**	0.0159	N/A	**0.9092** Friedman	Methods Indifferent

"N/A" signals that the test is not needed due to subsequent tests not requiring it
"-" signals that the data set in that slot does not exist.

Table 5-16: Design Loads Post Hoc Resulting p-values for Pairs of Groups

Pairs Compared	Survey (Pairwise t-test[1])		
	Design	Wind	Seismic
Traditional – Tool 1	-	-	-
Traditional – Tool 2	-	-	-
Tool 1 – Tool 2	**0.2850**	**0.2850**	**0.6020**

1 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.
"-" signals that the data set in that slot does not exist

Table 5-17: Design Loads Quiz and Survey Design Wind & Seismic Data Summary

		Traditional			Tool 1			Tool 2		
		Design	Wind	Seismic	Design	Wind	Seismic	Design	Wind	Seismic
Quiz (points/100)	Mean	-	-	-	66.56	70.15	62.96	80.47	82.56	78.38
	Min	-	-	-	10.00	13.33	6.67	7.69	7.69	7.69
	Max	-	-	-	93.33	100.0	100.0	100.0	100.0	100.0
Survey (points/5)	Mean	2.778	2.844	2.711	3.056	3.127	2.984	3.133	3.187	3.080
	Min	1.500	1.667	1.333	2.333	2.000	2.000	2.333	2.333	2.333
	Max	3.833	4.000	3.667	3.833	4.000	4.000	4.000	4.333	4.000

"-" signals that the data set in that slot does not exist.

The computed Spearman's Rank Correlation Coefficient for the overall Design category was negligible for both Tool 1 and Tool 2 ($0.01 < \rho < 0.19$) (when the comparison is possible), and that was the same through for wind and seismic through both tools, except for Tool 2 seismic where a weak relationship was observed ($0.20 < \rho < 0.29$)

Table 5-18: Design Loads Quiz and Survey Spearman's Rank Correlation Coefficient

	Traditional	Tool 1	Tool 2	Means Correlation
Design	-	-0.1646	0.0270	N/A
Wind	-	0.0382	0.0321	N/A
Seismic	-	-0.0920	0.2877	N/A

"N/A" signals that the test is not needed due to subsequent tests not requiring it
"-" signals that the data set in that slot does not exist

5.5.3 Analysis

Like the Design quiz data, Analysis learning category (Table 5-19) was non-normal and there was no change when separated into wind and seismic loads. There were also only two groups, so the Nemenyi test was performed. However, the survey Analysis data continued to be normally distributed, spherical, and yielded an insignificant p-value (*P* > 0.05) for both wind and seismic, similar to the overall Analysis category.

Table 5-19: Aggregated Data Normality, Sphericity, and Group Difference Tests p-values

		Normality Test (Shapiro-Wilk)			Sphericity (Mauchly)	Group Difference	Conclusion
		Traditional	Tool 1	Tool 2			
Quiz	Analysis	-	0.0359	0.0031	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
Quiz	Wind	-	0.0235	0.0028	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
Quiz	Seismic	-	0.0088	0.0025	N/A	N/A (2 groups)	Perform Nemenyi Post Hoc
Survey	Analysis	**0.6351**	**0.3826**	**0.2872**	**0.6026**	0.0100 ANOVA	Perform t-test Post Hoc
Survey	Wind	**0.2997**	**0.0620**	**0.1611**	**0.8901**	0.0158 ANOVA	Perform t-test Post Hoc
Survey	Seismic	**0.7306**	**0.3437**	**0.0511**	**0.3193**	0.0138 ANOVA	Perform t-test Post Hoc

"N/A" signals that the test is not needed due to subsequent tests not requiring it
"-" signals that the data set in that slot does not exist

For the post hoc tests, the quiz data revealed the same p-value for wind and seismic as it did for overall Analysis (*P* > 0.05). The survey data gave different results for the Traditional – Tool 2 comparison, while Tool 1 – Tool 2 had a significant p-value for seismic only (*P* > 0.05). If the

Bonferroni correction was not implemented, then all of these values would be considered statistically significant. This also reverts the wind survey data to having the methods indifferent as all pairs of groups were considered insignificant. It is important to note that (even though statistically insignificant, $P > 0.05$), the means increase of the quiz scores for wind more than double that of the increase of seismic (~19 pts wind to ~8 pts seismic), and the increase for overall Analysis was in between. This means that the improvement was similar to that of Design, except for Seismic Analysis.

Table 5-20: Aggregated Data Post Hoc Resulting p-values for Pairs of Groups

Pairs Compared	Quiz (Nemenyi)			Survey (Pairwise t-test[1])		
	Analysis	Wind	Seismic	Analysis	Wind	Seismic
Traditional – Tool 1	**-**	**-**	**-**	**0.5238**	**0.6671**	**0.4550**
Traditional – Tool 2	**-**	**-**	**-**	0.0157	**0.0192**	**0.0182**
Tool 1 – Tool 2	**0.6020**	**0.6020**	**0.6020**	0.0124	**0.0220**	0.0105

1 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.
"-" signals that the data set in that slot does not exist

Table 5-21: Quiz and Survey Analysis Wind & Seismic Data Summary

		Traditional			Tool 1			Tool 2		
		Analysis	Wind	Seismic	Analysis	Wind	Seismic	Analysis	Wind	Seismic
Quiz (points/100)	Mean	-	-	-	50.91	53.73	48.10	64.58	72.68	56.47
	Min	-	-	-	10.71	7.14	14.29	8.82	5.88	11.76
	Max	-	-	-	89.29	100.0	100.0	97.06	100.0	100.0
Survey (points/5)	Mean	2.947	3.013	2.880	3.143	3.229	3.057	3.448	3.480	3.416
	Min	1.600	1.600	1.600	1.500	1.200	1.800	2.200	2.000	2.400
	Max	4.000	4.000	4.000	4.100	4.200	4.200	5.000	5.000	5.000

"-" signals that the data set in that slot does not exist.

The computed Spearman's Rank Correlation Coefficient for the overall Analysis category was negligible (0.01 < ρ < 0.19) for Tool 1 and Tool 2. That was the same through for wind and seismic through both tools, except for Tool 1 wind which had weak relationship (0.20 < ρ < 0.29).

Table 5-22: Analysis Loads Quiz and Survey Spearman's Rank Correlation Coefficient

	Traditional	Tool 1	Tool 2	Means Correlation
Analysis	-	0.1368	0.0427	N/A
Wind	-	0.2508	0.1082	N/A
Seismic	-	0.0491	0.0567	N/A

"-" signals that the data set in that slot does not exist.

5.6 Tool Application for Design and Analysis

The evaluation of the different input methods, and whether that has an impact on student learning gains tested as shown in Figure 5-1. The groups in this evaluation are the quiz and survey scores for the Fundamentals, Design, and Analysis within each tool. Table 5-23 shows the first evaluation done before separation into wind and seismic. Normality tests were performed in Table 5-7 and were not repeated here. Using the Friedman test for both types of input, the test yielded in statistically significant p-value for both (P < 0.05) and required a Nemenyi post hoc. Table 5-9 shows that both tools resulted in the highest score being in the Fundamentals category, followed by Design, then Analysis, but the difference varied in magnitude. The post hoc performed in Table 5-23 of the quiz data, showed that the Fundamentals – Design pair difference was not statistically significant for both tools (P > 0.05), and the Fundamentals – Analysis pair was statistically significant for both tools (P < 0.05). The Design – Analysis pair was statistically significant for the Text Input (P = 0.0058) but was not for the Slider Input (P = 0.0513). Survey data for the Slider Input had no statistically significant p-value with ANOVA (P = 0.2266), which means the averages among groups were not statistically significant. Text Input survey data on the other hand had a non-spherical data set (*P* = 0.0025) and had a statistically significant ajusted p-value (*P* = 0.0108). Post hoc t-test yielded that the only pair to be statistically significant is the Fundamentals – Analysis (*P* = 0.0011) comparison with Analysis having the higher average.

Table 5-23: Tool Comparison Data Sphericity, and Group and Pair Difference Tests p-values

		Sphericity (Mauchly)	Group Difference	Conclusion	Post Hoc		
					F-D	F-A	D-A
Quiz	Slider Input	N/A	0.0010 Friedman	Perform Nemenyi Post Hoc	**0.3779**	0.0010	**0.0513**
Quiz	Text Input	N/A	0.0022 Friedman	Perform Nemenyi Post Hoc	**0.9000**	0.0099	0.0058
Survey	Slider Input	**0.2266**	**0.5726** ANOVA	Methods Indifferent	N/A	N/A	N/A
Survey	Text Input	0.0025	0.0108[1] ANOVA	Perform t-test[2] Post Hoc	**0.6037**	0.0011	**0.0177**

1 Greenhouse-Geisser Correction was implemented, and the corrected p-value is shown. See Sec. 5.1.
2 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.
"N/A" signals that the test is not needed due to subsequent tests not requiring it.

Further analysis after separation to wind (Table 5-24) and seismic (Table 5-25), showed slight variation in the tests. For wind, the Slider Input quiz yielded the same results as the combined data, while Text Input Fundamentals – Analysis pair p-value became statistically insignificant (*P* = 0.1123). Survey Wind data outcomes were similar except for the violation of normality ($P < 0.05$) of the Slider Input data that required a Friedman test instead.

For Seismic, the Slider Input quiz data showed a statistically insignificant p-value (*P* = 0.1062)., meaning that the category means are not different, while Text Input showed the same results. Survey results of the Slider Input also matched the data above. Seismic Text Input survey results showed a statistically significant p-value for Design – Analysis (*P* = 0.0105) pair, and a statistically insignificant for the Fundamentals – Analysis pair (*P* = 0.3722).

Table 5-24: Wind Tool Comparison Data Sphericity, and Group and Pair Difference Tests p-values

		Sphericity (Mauchly)	Group Difference	Conclusion	Post Hoc		
					F-D	F-A	D-A
Quiz	Slider Input	N/A	0.0245 Friedman	Perform Nemenyi Post Hoc	**0.4750**	0.0265	**0.3327**
	Text Input	N/A	0.0220 Friedman	Perform Nemenyi Post Hoc	**0.8575**	**0.1123**	0.0333
Survey	Slider Input	N/A	**0.1062** Friedman	Methods Indifferent	N/A	N/A	N/A
	Text Input	**0.0682**	0.0060 ANOVA	Perform t-test[1] Post Hoc	**0.3729**	0.0008	**0.0555**

1 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.
"N/A" signals that the test is not needed due to subsequent tests not requiring it.

Table 5-25: Seismic Tool Comparison Data Sphericity, and Group and Pair Difference Tests p-values

		Sphericity (Mauchly)	Group Difference	Conclusion	Post Hoc		
					F-D	F-A	D-A
Quiz	Slider Input	N/A	**0.1192** Friedman	Methods Indifferent	N/A	N/A	N/A
	Text Input	N/A	0.0002 Friedman	Perform Nemenyi Post Hoc	**0.8575**	0.0033	0.0010
Survey	Slider Input	**0.4705**	**0.8105** ANOVA	Methods Indifferent	N/A	N/A	N/A
	Text Input	N/A	0.0055 Friedman	Perform Nemenyi Post Hoc	**0.2655**	**0.3722**	0.0105

1 Greenhouse-Geisser Correction was implemented, and the corrected p-value is shown. See Sec. 5.1.
2 Bonferroni Correction was implemented to avoid Type I errors. See Sec. 5.1. Significant p-value is 0.0167 here.
"N/A" signals that the test is not needed due to subsequent tests not requiring it.

5.7 Qualitative Evaluation

As explained in Chapter 4, the study included a qualitative evaluation portion of the survey open-ended response questions to collect feedback on the tools. There was a total of five questions, three on Survey 1 after Tool 1, and two on Survey 2 after Tool 2:

- Survey 1 questions:
    1. Have you used a similar parametric/computational tool before?
    2. Are familiar with structural software?
    3. What suggestions do you have on the user interface of the tool?
- Survey 2 questions:
    1. Between hand calculations, the first tool, and the second tool, which one is your preferred method for analysis? Which one is your preferred method for design? Please elaborate.
    2. What suggestions do you have on the user interface of the tool?

Figure 5-3 below shows the response breakdown about the use of a similar tool. Most of the students (16/22) have not used a similar computational or parametric tool before. However,

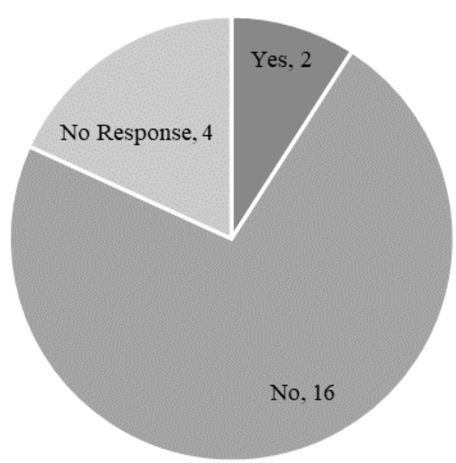

Figure 5-3: Use of Parametric/Computational Tools

when asked about experience with structural engineering software in Figure 5-4, more than half (11/21) responded with “Yes” or at least had some experience with structural software.

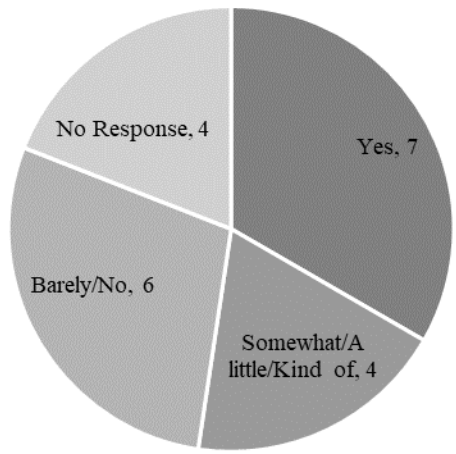

Figure 5-4: Experience with Structural Software

Tables 5-26 and 5-27 show the response breakdown on Tool 1 and Tool 2 respectively. Most of the students (16/21 for Slider Tool, 14/25 for Text Tool) either did not respond to the optional question or responded with “None” or something similar in meaning. Between the two, none of the feedback was specific to the input methods (sliders and boxes). Instead, comments centered on the tool overall. Between the two feedback questions, a few of the responses (4) asked for the story data and story information to be closer, or easier to change than to be separated early in the tool. Another popular response between the two qusetions (3) was automatically fill in some of the location related input (presumably wind speed and motion parameters). The rest of the responses asked for more abbreviations, less steps to operate the tool, guidance to ASCE 7 sections, and more clarity overall in the tool (one for each).

Table 5-26: Feedback on Tool after Slider Input Tool

Preference	Quantity
Automate location related values	1
Reduce intermediate steps	1
Better and easier story control	1
Replace with visual programming software, helps associating the relationships	1
Guide to ASCE 7 sections to help input	1
No Suggestions	6
No Response	10

Table 5-27: Feedback on Tool after Text Input Tool

Preference	Quantity
Better and easier story control	3
Clearer interface/steps	3
Automate location related values	2
Guide to ASCE 7 sections to help input	1
Note abbreviations	1
More interactive	1
No Suggestions	5
No Response	9

When asked regarding their preference, Figure 5-4 shows majority of the responses (10/25) preferred the second tool with the text input over the first tool with the slider input (5/25). There was a portion that preferred any tool or software over hand calculations, some noticing the different applications, and one student who preferred hand calculations.

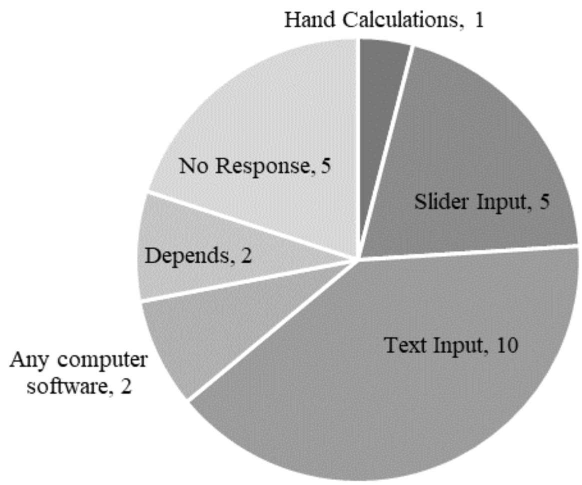

Figure 5-5: Preference for Lateral Load Calculation

5.8 Wind & Seismic Comparison

While other sections of the study compare means and values across variables, either teaching methods or learning categories, this section compares groups at the lowest level (e.g. Fundamentals Wind vs. Fundamentals Seismic). These comparisons examine the behavior of the data across wind and seismic loads to eventually draw conclusions for future work on the necessity of separating the loads or the study in general (two settings instead of one). This was done by performing the post hoc methods used previously (Nemenyi and t-test depending on normality), as well as Spearman’s rank correlation coefficient for each student’s score across the categories.

Table 5-28 shows both tests performed. The Nemenyi test was conducted for nine of the 16 pairings, and the t-test was conducted for the remaining seven. Of the 16 pairings, only three

(Tool 1 Quiz Fundamentals: P = 0.0339, Tool 2 Quiz Analysis: P = 0.0095, Tool 2 Survey Fundamentals: P = 0.0115) yielded a statistically significant p-value ($P < 0.05$), while the rest had higher p-values. As for the Spearman's rank correlation coefficient, all the pairings showed some correlation ranging from weak to very strong correlation (per Table 5-2). All survey pairings showed very strong correlation except for Tool 2 Design, which showed strong correlation. For quiz data, Traditional Fundamentals showed very strong correlation, while Tool 2 Fundamentals and Tool 2 Analysis showed strong correlation. Tool 1 Analysis showed moderate correlation, and Tool 1 Fundamentals, Tool 1 Design, and Tool 2 Desing showed weak correlation.

Table 5-28: Wind & Seismic Pairs Comparison p-values and Spearman's ρ

Category		Nemenyi/t-tests			Spearman's R		
		Traditional	Tool 1	Tool 2	Traditional	Tool 1	Tool 2
Quiz	Fundamentals	**0.1444** Nemenyi	0.0339 Nemenyi	**0.6480** Nemenyi	0.8123	0.2110	0.4422
	Design	-	**0.2386** Nemenyi	**0.1573** Nemenyi	-	0.2990	0.2051
	Analysis	-	**0.9000** Nemenyi	0.0095 Nemenyi	-	0.3755	0.5958
Survey	Fundamentals	**0.2801** t-test	**0.7194** t-test	0.0115 t-test	0.7139	0.9073	0.8806
	Design	**0.1643** t-test	**0.1904** Nemenyi	**0.4237** Nemenyi	0.8067	0.7801	0.5531
	Analysis	**0.1906** t-test	**0.0982** t-test	**0.4154** t-test	0.8419	0.8205	0.8831

"-" signals that the data set in that slot does not exist.

Chapter 6 – Discussion & Conclusions

One of the goals of this thesis was to explore the use of a tool that dynamically calculates and visualizes lateral loading on a building in an educational setting. The other goals were to test whether different input methods are better suited for different applications and how they impact student performance and perceptions. The chapter summarizes these results in order to answer the research questions identified in Chapter 3.

6.1 Dynamic Visualization & Learning

This section seeks to answer the first research questions: *Does a dynamic visualization tool increase learning gains as compared to a traditional education teaching for lateral loading and to what extent?* The answer to this question is based on data analyzed in Sections 5.3, 5.4, and 5.7. Comparing data sets from the Traditional learning method to both Tool 1 and Tool 2 iteration through observing means and statistical significance in student performance forms the foundation to the answer. This was done for both quiz and survey data.

Figure 6-1 shows the quiz means between all three teaching methods compared in pairs, and which pairings yielded statistical significance. Fundamental understanding was the only category available in Quiz 0, which occurred after the Traditional teaching method. Comparing the Fundamentals category scores between all three groups, the Traditional teaching method showed the lowest mean ($\bar{X}_0$ = 56.88) of all three groups, with both Tool 1 ($\bar{X}_1$ = 78.70) and Tool 2 ($\bar{X}_2$ = 82.87) having statistically significant higher means than the Traditional method. At the same time, Fundamentals category between tools had no statistically significant difference. For other learning categories (Design and Analysis) only Tool 1 and Tool 2 had existed, both improved from Tool 1 to Tool 2 (Design; $\bar{X}_1$ = 66.56 and $\bar{X}_2$ = 80.47, Analysis; $\bar{X}_1$ = 50.91 and $\bar{X}_2$ = 64.58), but with no statistical significance. This shifted the Aggregated data score down for Tool 1, making the statistical significance between means for Aggregated data only between Traditional ($\bar{X}_0$ = 56.88) and Tool 2 ($\bar{X}_2$ = 71.46). The lower score on Tool 1 for Design and Analysis could be due to the students first interaction with full analysis questions in an evaluation setting (quiz vs. class example), and that is the same for design questions. It is also noteworthy that the performance in the Analysis category was worse than Design, which will be explored more in Section 6.2.

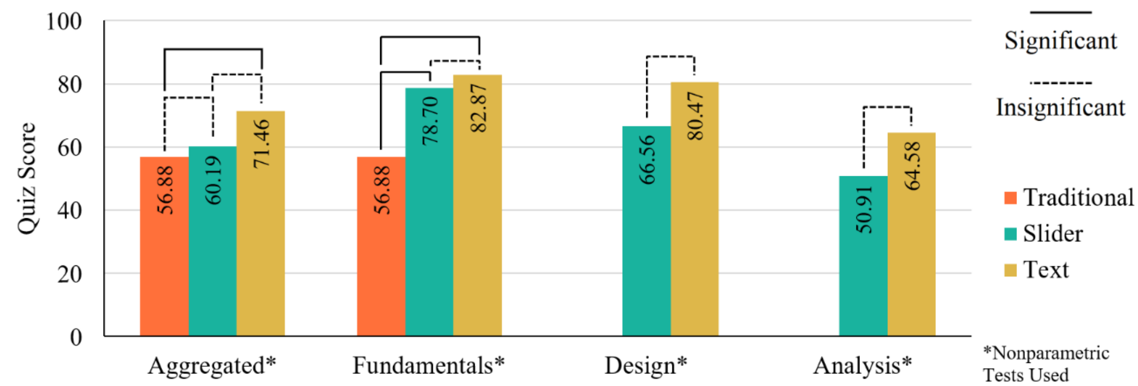

Figure 6-1: Quiz Data Means Comparison with Statistical Significance (Learning)

Similar to the survey results, Figure 6-2 shows how the survey means between all three teaching methods compared in pairs, and which pairings yielded statistical significance. The Fundamental and Design categories did not yield any statistical significance among all three groups despite the steady increase (Fundamentals; $\bar{X}_0$ = 2.900, $\bar{X}_1$ = 3.020, and $\bar{X}_2$ = 3.180, Design; $\bar{X}_0$ = 2.778, $\bar{X}_1$ = 3.056, and $\bar{X}_2$ = 3.133). As for the Analysis category, Tool 2 had a mean for Tool 2 ($\bar{X}_2$ = 3.448) that was higher than both Traditional ($\bar{X}_0$ = 2.947) and Tool 1 ($\bar{X}_1$ = 3.143) means with statistical significance. While the increase and its significance do not align with the findings from quiz data (specifically the poor performance on analysis questions), the explanation could be that after having performed wind and seismic data for three iterations, the students felt more confident in their ability to perform calculation on fixed structures, as opposed to designable changing conditions. The students would also not be biased as they took the surveys before receiving their grades back on the respective quizzes. The Aggregated data showed similar results to the quiz data, where the Traditional ($\bar{X}_0$ = 2.864) to Tool 2 ($\bar{X}_2$ = 3.344) pairing was the only one with statistical significance in the difference between them.

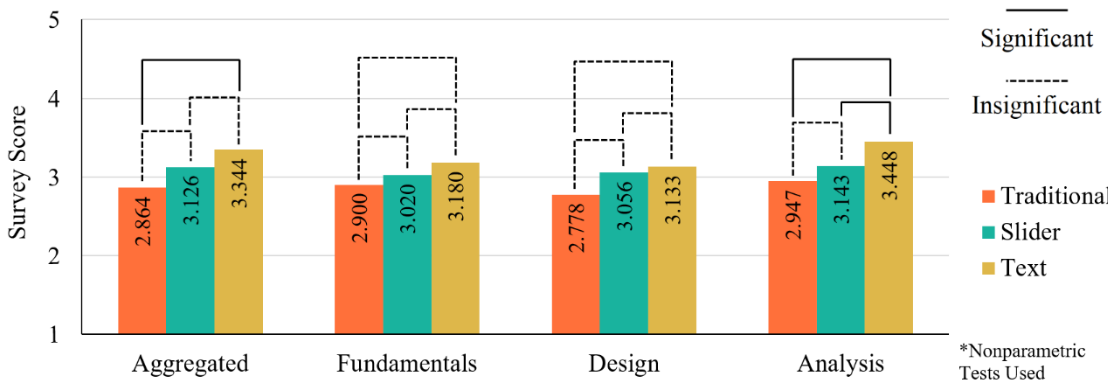

Figure 6-2: Survey Data Means Comparison with Statistical Significance (Learning)

While the Aggregated quiz and survey data gave matching results, the separation of learning categories showed less alignment between the results. Further investigation of the correlation between the individual students' quiz and survey scores (Table 5-10) showed most of the survey-quiz pairings to have negligible correlation statistics (8 of 10 pairings including Aggregated and all categories), and weak to moderate at best for the remainder of the pairings. This lack of correlation can explain the difference in results between survey and quiz data, which may not necessarily disprove the quiz or the survey, but rather shows that the students have more confidence in finding a solution when all conditions are fixed. Examining the responses to the open-ended question regarding preference of the tool (Figure 5-5), 15/25 students preferred either of the tools (5 for Tool 1 and 10 for Tool 2) to the one student who preferred hand calculations. Nine students either did not respond to the question or had more complex answers. This might be due to the majority having this be their first introduction to a dynamic tool (89% of responses in Figure 5-3) or structural software (35% of responses in Figure 5-4).

Final Response: Yes, the tools help with statistical significance evidence with lateral loads according to the quiz. However, this is not supported by the survey, which uncovers different results that will be discussed in Section 6.2. Students' direct responses on the other hand showed preference towards the tool.

6.2 Input Methods & Applications

This section seeks to answer the second of the research questions: *For a dynamic visualization tool, did the input and interaction approach reflect in learning differences for different applications and to what extent?* The answer to this question is based on data analyzed in Sections 5.4, 5.6 and 5.7. Comparing the two data sets of both Tool 1 and Tool 2 and observing means and statistical significance in performance to helps find an answer to the question. This was done for both quiz and survey data.

Figure 6-3 focuses on the quiz scores for two different methods of input for the tool and compares the means of the performance between each application for the same input. For the Slider input tool (Tool 1), the mean score was the highest for the Fundamentals category ($\bar{X}_F$ = 78.70), followed by Design ($\bar{X}_D$ = 66.56) then Analysis ($\bar{X}_A$ = 50.91), with the only statistical significance being between Analysis and Fundamentals. The Text input tool (Tool 2) followed the same trend of Fundamentals ($\bar{X}_F$ = 82.87), followed by Design ($\bar{X}_D$ = 80.47) then Analysis ($\bar{X}_A$ = 54.58); however, the statistical significance was present for two categories: between Analysis and Fundamentals as well as between Analysis and Design. Comparing both tools, the Slider input method had a lower score than the Text input method in all learning categories but there was no statistical significance (Figure 6-1). The behavior of the quiz scores generally follows the same pattern with Fundamentals and Design showing no statistical significance in the difference of their means, but Analysis having a lower mean with statistically significance to one or both other groups. Observing the comparison for Design and Analysis specifically (the two practical applications), the data shows that the Slider input may have been indifferent for both applications, but the Text input helped in Design more than Analysis. An explanation could be due to a combination of the grading and the accuracy of sliders. Furthermore, the efficiency of the design (how close is the answer to the limit set in problems) was used in grading design questions, and the text boxes provide the ability to enter precise numbers that can get closer to the limits while the sliders lack that precision.

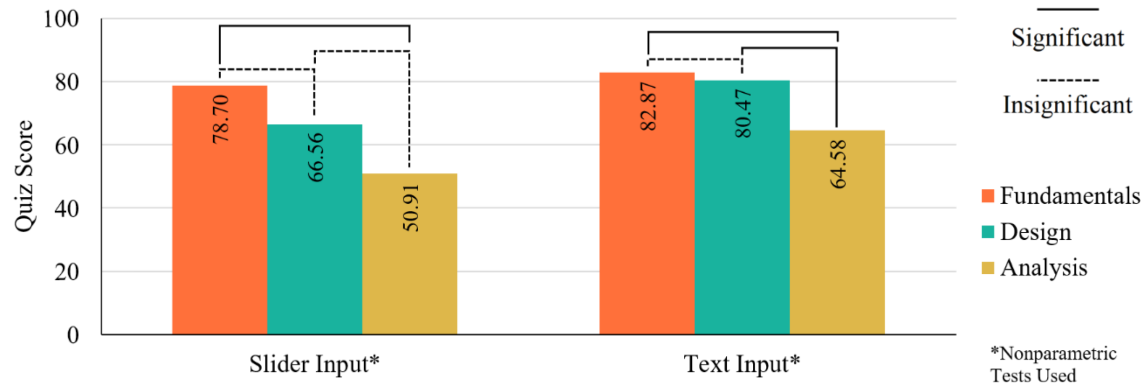

Figure 6-3: Quiz Data Means Comparison with Statistical Significance (Input)

Figure 6-4 shows survey mean scores for two different methods of input for the tool. Like the quiz data, the Text input tool had higher scores across all categories with the Analysis pair having statistical significance (Figure 6-2). For the Slider input tool, the Analysis category had the highest mean ($\bar{X}_A = 3.143$), followed by Design ($\bar{X}_D = 3.056$) then Fundamentals ($\bar{X}_F = 3.020$). For the Text input tool, the Analysis category also had the highest mean ($\bar{X}_A = 3.448$), followed by Fundamentals ($\bar{X}_F = 3.180$) then Design ($\bar{X}_D = 3.133$). However, all comparisons in Figure 6-4 showed no statistical significance, except for the Analysis and Fundamentals pairing in the Text input tool (Tool 2). This contrasts with the quiz data results discussed in 6.1. This difference could infer that the students feel more comfortable when statements imply fixed conditions, meaning they are comfortable in performing calculations, but not their design ability or Fundamental understanding of the loads. Even with this confidence, the students appear to fail on solution precision and yet they are consistent enough to respond with a higher score on Analysis survey statements.

Additionally, using the open-ended responses regarding the preference (Section 5.7), there were several articulate responses (Table 6-1). These responses are mixed as to why and which tool they prefer for different applications. This can explain the indifference for both quizzes and

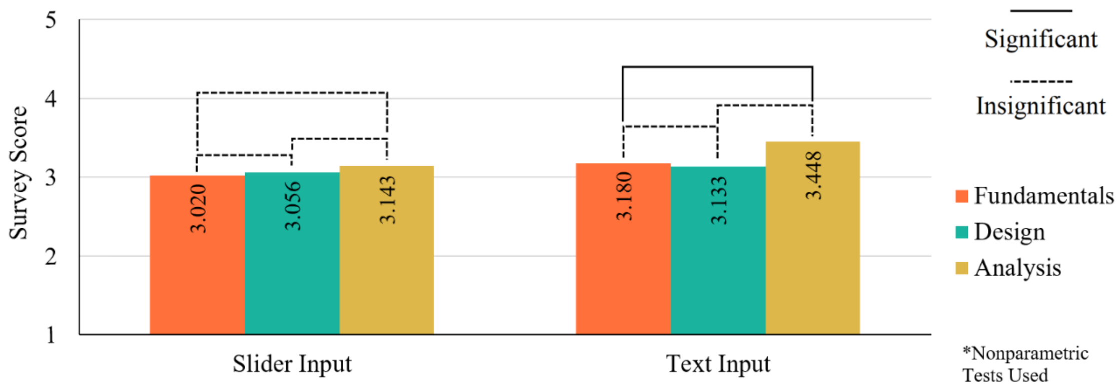

Figure 6-4: Survey Data Means Comparison with Statistical Significance (Input)

surveys. Some responses chose the Text input (Tool 2) over Slider input (Tool 1) for Design, which aligns with the precision explanation speculated earlier. The fact that Text input (Tool 2) was presented and used last may affect the preference responses or the understanding of the interface.

Final Response: No, there was not a difference in the tools besides the Text input performing marginally better. There was no difference in behavior of one tool for one application or learning category.

Table 6-1: Articulate Preference Responses

"The first tool because it was simple to enter in the information."
"I prefer the [First]* tool because I like being able to use the slider to adjust the building in real time and watching the changes."
"First, it was easier to see changes by moving sliders"
"For design, I am not sure I have enough experience to judge. Probably the second. For analysis either of the tools if very convenient although I like hand calcs as well."
"I liked both tools for just seeing how if i change one variable it affects the rest of the design. Probably would do it by hand if I wanted to make sure all of the right numbers get used."
"Second tool. It simplifies the whole process and reduces potential for math errors."
"The first tool was nice to use, if i had better direction prior in class on how to do these load calculations i would've understood how to use the tool better."

*The actual response was "Second", but the rest clearly indicates the first tool is mean

6.3 Wind & Seismic Dynamic Visualization & Learning

This section seeks to answer the third of the research questions: *Was there, and to what extent were the impacts on the relationship between Fundamentals, Analysis and Design across wind and seismic loading on how students learned?* The answer to this question is based on data analyzed in Sections 5.4 and 5.5, by comparing data sets of the Traditional learning method to both Tool 1 and Tool 2 and observing means and statistical significance in performance, but further categorizing the data into Wind and Seismic loads. This was done for both quiz and survey data.

Figure 6-5 shows the comparison between the quiz means for all three learning categories for Wind and Seismic isolated along with their combined performance, along with statistical significance. Observing Figure 6-5 reveals that the mean scores for Wind were higher than that of Seismic for every category for every method, except for the Fundamentals category data at the Traditional stage where Seismic had a higher score ($\bar{X}_S$ = 60.87) than wind ($\bar{X}_W$ = 52.90). For the rest of the Fundamental category, both Tools had a higher Wind score than Seismic with Tool 1 having a larger difference (Tool 1; $\bar{X}_W$ = 84.26, $\bar{X}_S$ = 73.15) than Tool 2 (Tool 2; $\bar{X}_W$ = 84.26, $\bar{X}_S$ = 52.90). Comparing the statistical significance behavior for Fundamentals, both loads had the same behavior except for the Traditional and Tool 1 pairing for Seismic loading. This can be due to the Traditional method having a higher score for Seismic, implying that the understanding of seismic loading was better than wind before the tool was used, and did not benefit as much wind from Tool 1. Observing Design and Analysis categories (only existing for the two tool stages), they followed the same trends of improvent for Tool 2 over Tool 1 as well as the same statical significance behavior. However, it is important to note the difference in the magnitude of improvement between Design and Analysis. For the Design category, the improvement was similar for Wind ($\bar{X}_{W1}$ = 70.15, $\bar{X}_{W2}$ = 82.56, $\bar{X}_{\Delta W}$= 12.41) and Seismic ($\bar{X}_{S1}$ = 62.96, $\bar{X}_{S2}$ = 78.38, $\bar{X}_{\Delta S}$ = 15.42) with Seismic slightly better. For the Analysis category the improvement for Wind ($\bar{X}_{W1}$ = 53.73, $\bar{X}_{W2}$ = 72.68, $\bar{X}_{\Delta W}$ =18.95) was bigger than that of Seismic ($\bar{X}_{S1}$ = 48.10, $\bar{X}_{S2}$ = 56.47, $\bar{X}_{\Delta S}$ =8.37).

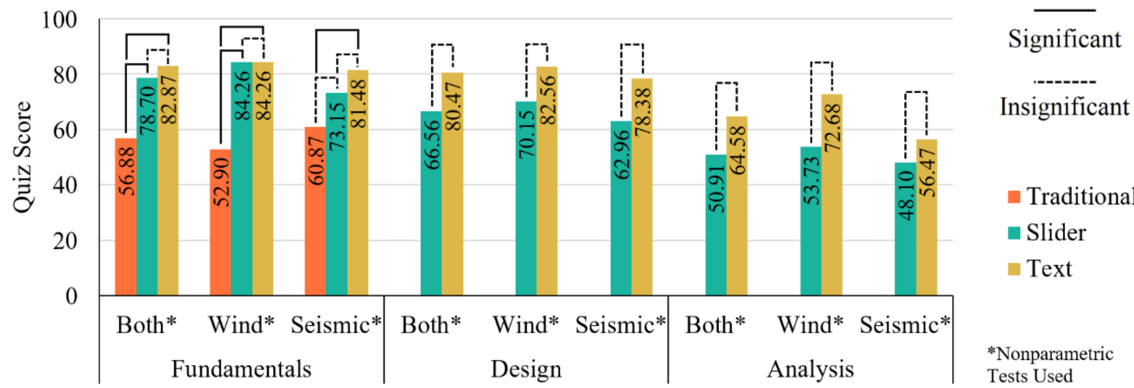

Figure 6-5: Quiz Data Means Comparison with Statistical Significance (Learning-Loads)

Figure 6-6 is similar to Figure 6-5, showing the means of the survey data with statistical significance noted. Both Fundamentals and Design categories showed no statistical significance between means, and the separated Wind and Seismic data did not behave differently. By visually observing Figure 6-6 for the Fundamentals category and Tables 5-13 and 5-17, Seismic scores were higher for Traditional and Tool 2 methods and Wind score was higher for Tool 1, while Design had Wind have higher scores for all categories. For the Analysis category, Tool 2 had higher scores for both Wind ($\bar{X}_{W2}$ = 3.480) and Seismic ($\bar{X}_{S2}$ = 3.416) in comparison to the other two methods (Traditional; $\bar{X}_{W0}$ = 3.013, $\bar{X}_{S0}$ = 2.880 & Tool 1; $\bar{X}_{W1}$ = 3.229, $\bar{X}_{S1}$ = 3.057). The Tool 1 and Tool 2 pairing for Wind Analysis was statistically insignificant, unlike the overall Analysis result. The Traditional and Tool 2 pairing showed no statistical significance for both Wind and Seismic despite Analysis overall showing statistical significance. All data sets in question are normally distributed (Table 5-19), so this behavior cannot be explained by skewness. The Wind and Seismic pairings showed insignificance because of the applied Bonferroni correction, so an explanation could be that the results were over-corrected. Observing most of the data, Survey data behavior was arbitrary in comparison to quiz data, and this may be another example of that.

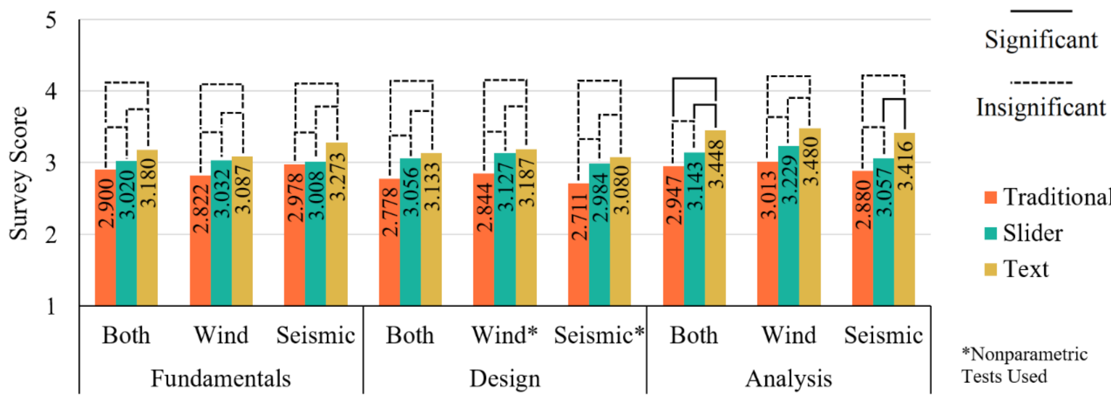

Figure 6-6: Survey Data Means Comparison with Statistical Significance (Learning-Loads)

Final Response: Yes, there was an impact on the learning for the categories, with some variation for Wind and Seismic in comparison to the sum of both. This is based on quiz data, as Survey data was inconclusive. Further analysis may be needed to determine whether separation is important in future studies.

6.4 Wind & Seismic Input Methods & Applications

This section seeks to answer the fourth and last of the research questions: *Was there, and to what extent were the impacts on the different input across wind and seismic loading on how students applied the tool for design and analysis?* The answer to this question is based on data analyzed in Sections 5.5 and 5.6, by comparing the two data sets of both Tool 1 and Tool 2, then observing means and statistical significance in performance for Wind and Seismic loads. This was done for both quiz and survey data.

Figure 6-7 shows the quiz data for both Slider and Text input tools and the performance of Wind and Seismic loads and their statistical significance. Visual observations show that the performance of Wind was overall better than Seismic in both tools for all categories, and the same general behavior of the means can be observed for Wind and Seismic with Fundamentals being the highest scoring category, followed by Design, then Analysis. Statistical significance change was limited to Fundamentals and Analysis pair for the Seismic loads in Slider input tool (now insignificant in comparison to overall), and Fundamentals and Analysis pair for the Wind loads in Text input tool (now insignificant in comparison to overall).

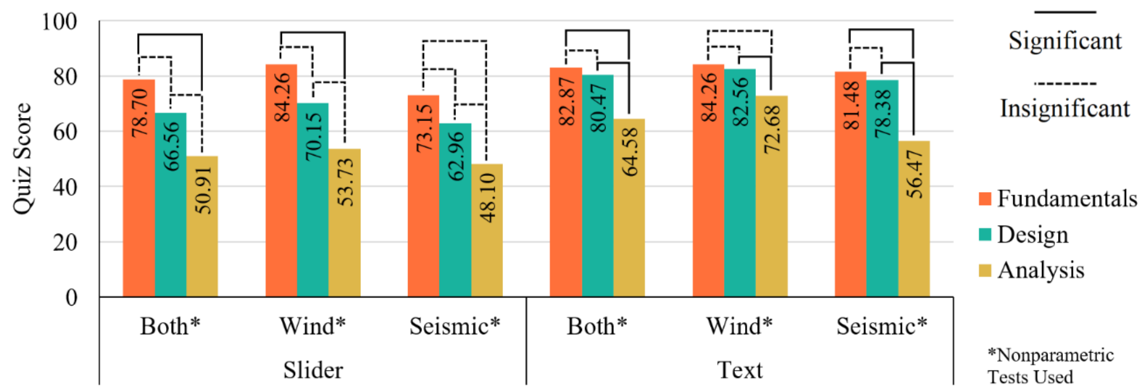

Figure 6-7: Quiz Data Means Comparison with Statistical Significance (Input-Loads)

Figure 6-8 shows the survey data for both Slider and Text input tools and the performance of Wind and Seismic loads and their statistical significance. For the Slider input tool (Tool 1), the survey data showed lower scores for Seismic than Wind across all learning categories, but the ranking of the means did not change. Slider input survey data still showed no statistical significance for all pairings. For the Text input tool, the behavior of means and statistical significance varies more. Seismic loads still had lower scores for Design ($\bar{X}_W = 3.187$, $\bar{X}_S = 3.080$) and Analysis ($\bar{X}_W = 3.480$, $\bar{X}_S = 3.416$) categories, but higher for Fundamentals ($\bar{X}_W = 3.087$, $\bar{X}_S = 3.273$). This may be the reason statistical significance for the Fundamentals and Analysis pairing became insignificant for Seismic in comparison to Wind and both. Additionally, the difference between Design and Analysis pairing for Seismic became bigger and therefore statistically significant.

Final Response: Yes, there was an impact on the application of both wind and seismic, but that did not vary from the results of the combination of both. More difference in behavior was observed between Fundamentals and the other two categories. Survey data behavior was arbitrary.

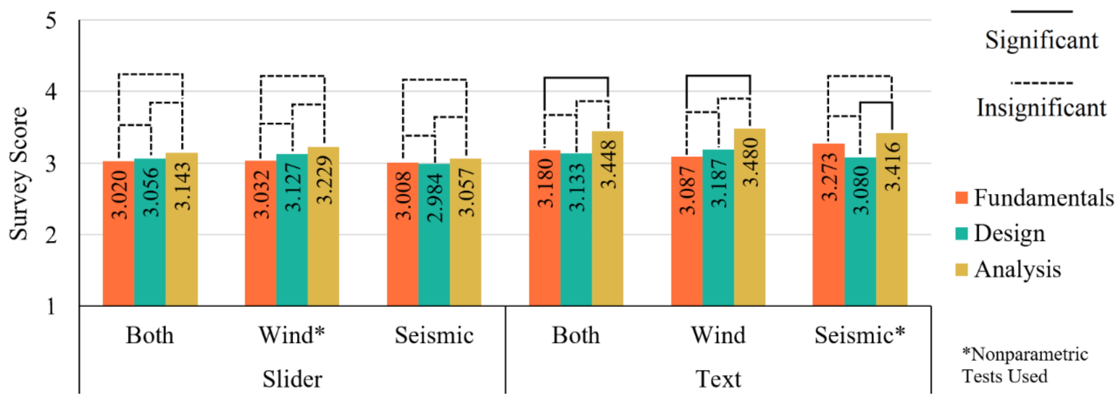

Figure 6-8: Survey Data Means Comparison with Statistical Significance (Input-Loads)

6.5 Wind & Seismic Comparison

This section seeks to answer the fifth and last of the research questions: *Was there, and to what extent was the difference in performance between wind and seismic across the study dimensions?* The answer to this question is based on data analyzed in Sections 5.5 and 5.8, by comparing the pairs of wind and seismic data for all of the categories at the lowest level using a post hoc test (Nemenyi/t-test), as well as Spearman's rank correlation coefficient.

Quiz and survey data comparison across the study stages and the learning categories is shown in Figures 6-9 and 6-10 quiz and survey, respectively. The general trends observed in Sections 6.3 and 6.4 were that Wind had higher scores than seismic for most of the data sets, the exceptions were Traditional Quiz Fundamentals, Traditional Survey Fundamentals, and Tool 2 Survey Fundamentals. Of all the pairings, only three had statistically significant difference in the means (Tool 1 Quiz Fundamentals, Tool 2 Quiz Analysis, and Tool 2 Survey Fundamentals). This shows that there is not a big difference between the results of the wind and seismic data, particularly that the same trends of the means were followed. Additionally, Table 6-2 shows the observed correlation between the sets. All data sets showed varying degrees of correlation. Most of the survey data showed strong correlation between wind and seismic, while the quiz data showed a range of correlation (1 very strong, 2 strong, 1 moderate, and 3 weak). For the survey, this provides some validations that the data was not entirely arbitrary despite the lack of correlation with the quiz data. For the quiz data, this showed that the behavior is similar for both loads.

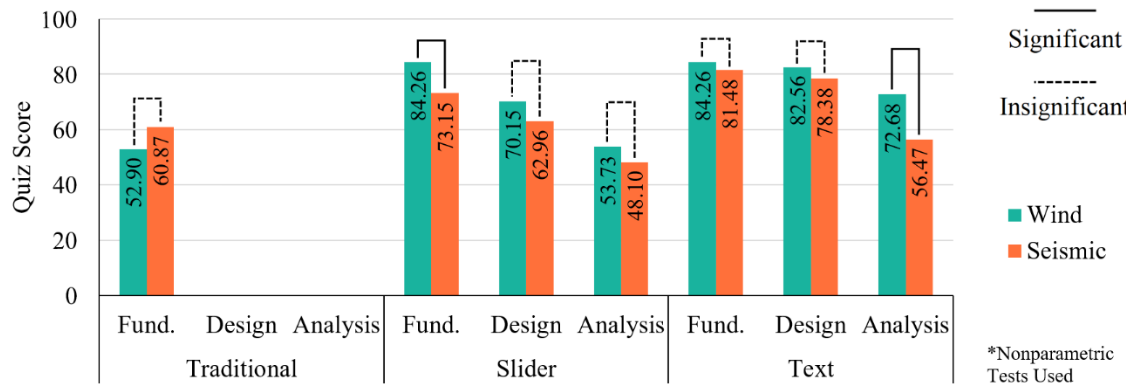

Figure 6-9: Quiz Data Means Comparison with Statistical Significance (Loads Direct)

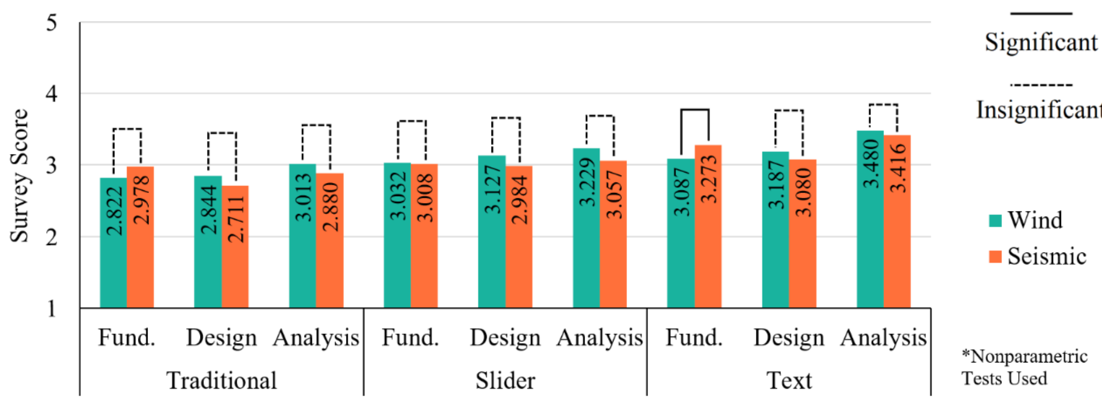

Figure 6-10: Survey Data Means Comparison with Statistical Significance (Loads Direct)

Table 6-2: Wind & Seismic Pairs Correlation Comparison

Category		Spearman's R		
		Traditional	Tool 1	Tool 2
Quiz	Fundamentals	Very Strong	Weak	Strong
	Design	-	Weak	Weak
	Analysis	-	Moderate	Strong
Survey	Fundamentals	Very Strong	Very Strong	Very Strong
	Design	Very Strong	Very Strong	Strong
	Analysis	Very Strong	Very Strong	Very Strong

"-" signals that the data set in that slot does not exist.

Final Response: No, there was not enough difference between the wind and seismic behavior. The small number of pairings that had statistically significant differences was low and may be affected by the sample size. The correlation shown between the data sets also showed that the behavior of the sets aligned. There is enough evidence to not need to separate the study into wind and seismic in the future.

Chapter 7 – Limitations, Future Work, & Conclusion

The conclusions presented in Chapter 6 raise questions regarding the next steps, as well as a hindsight reflection given the results. This chapter discusses both study limitations, along with recommended changes if the study was to be run again. Lastly, several suggestions on the next steps in this area of research are proposed.

7.1 Study Limitations

This section refers to uncontrolled factors that may have affected the results or their accuracy.

- **Sample size:** With the constraint being students currently enrolled in AE 430 and learning wind and seismic loading, the potential sample size was limited to 29 students. Out of the 29, even less participated due to the surveys being optional and the quizzes being the last three of fourteen total where four are dropped.
- **Group dependence:** the tools were tested in one class to ensure justice in research of (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979), therefore the methods were given to student in sequence. This caused the data to be dependent which can affect the statistical evaluation, but it also meant that some results may have been affected by the repeated exposure.
- **Learning sequence:** Related to the group dependence, the sequencing of the different methods of teaching could have played a part in the results of each method.
- **Grading control & scales:** the grading of the quizzes was done by the course instructor. The Fundamentals category had a clear grading process without partial credit. The Design and Analysis categories included partial credit that was evaluated by the course instructor, who was

given a brief description on recommended grading practices. Design questions were graded based on accuracy and effort (efficiency in designs), while Analysis questions were graded based on the accuracy of the reported answers. This meant the grading was consistent but was unverified. In addition to that, the methods of grading impose limitations due to the variation of the assessment techniques and scales used. This is because the questions vary in meaning and therefore grading. Fundamentals is Correct/Incorrect, Design is scaled based on design efficiency, and Analysis is scaled based on accuracy. This causes the comparison to be less direct.

- **Tool design:** the tool was created in Google Colab for ease of accessibility, which does not allow for permanent hiding of the code for the users. By default, this made the tool feel more inconvenient given certain necessary procedures had to be taken to get working results which may have led to more susceptible to errors.

7.2 Future work

This section refers to recommended changes to incorporate in different parts of the study moving forward:

- **The tool:** One of the more recurring comments on the interface was to better incorporate the story data with the rest of the input on the main interface rather than being separated at the beginning. The python library used, ipywidgets has the capability to make a separate tab within the same interface. This eliminates the need for scrolling and once activated, all of the input can be available in one window. The results from the two tools also show lack of statistical significance between the two, with Tool 2 (Text Input) having slightly better results and preferences. The improvements in Tool 2 could have been due to the length of exposure to the material (third time), hence the use of one tool could be sufficient.

- **Data categorization:** The small variation in the means of wind and seismic and the statistical insignificance shows that future studies, wind and seismic loading can be studied together (for these procedures) until a bigger sample proves otherwise. However, the decision to have separated learning categories and loads is still recommended.
- **Data collection techniques:** For the quiz, familiarity with the project/question often plays a factor in performance. Combining the wind and seismic design and analysis questions into one design and one analysis question can be beneficial. Additionally, equally weight the three categories on the quizzes may help students value them equally. The survey data not aligning with quizzes can either infer that the behaviors do not align or signal issues with the survey. Performing an exploratory factored analysis on the quiz and survey questions can evaluate the accuracy and the effects of individual questions.

The next steps in this research should be to incorporate some of the above changes and collect more data over multiple years using different samples and different schools. The benefit of performing this over multiple years and universities helps eliminate the effect of factors such the university program itself and helps separate the data sources into independent groups. This also gives the ability to test different variations of the survey, which comes at the disadvantage of collecting data that is not fully consistent and partially usable. Additionally, wind was taught first in the Traditional teaching method then followed by seismic. Switching their order around in may cause some change in the scores of wind and seismic.

7.3 Conclusion

The use of Computer-Aided Learning has potential in the field of structural engineering, as this thesis used it in the teaching of lateral loadings on building structures with some successful results showing. There is more to be explored in the use of software in teaching of these loads and how to design data collection methods to measure more specific aspects of the learning of such loads. While the different input methods did not help learning categories differently, the same study may yield different results if the users of the tool were professional engineers.

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Appendix A – Full Quizzes

Quiz 0

1. For the following situations, please select all the statements that are true:

- ☐ Wind loads increase
- ☐ Wind loads do not change
- ☐ Wind loads decrease
- ☐ Seismic loads increase
- ☐ Seismic loads do not change
- ☐ Seismic loads decrease
- ☐ Other/Explanation: Elaborate in the textbox below

1a. A neighborhood community building was built on a flat surface with no ground features nearby before any houses are built. The building is planned to be on the edge of the neighborhood, and a small but significant hill is planned to be created around the neighborhood. Consider two cases, before and after the hill was made.
Which of the two cases is more conservative, and which load (seismic vs wind) is the one affected?
Ignore potential Exposure Category change.

1b. You proposed a steel braced frame for a 80' structure and calculated wind and seismic loads. According to that proposal footing sizes were estimated. The architect wanted a flexible floor plan, so a concrete moment frame was proposed instead. Consider the two cases to be before and after the proposed change in the framing system.
Do you need to recalculate your loads?

1c. A 10-story building is being retrofitted. Part of the project is moving the mechanical floor from the top floor to the 4th floor because the view on the top floor is quite valuable. The building occupancy, use, and relative finishes are relatively the same. Consider two cases, before and after the retrofitting job is started and is complete.
Assuming gravity members are adequate, is there any concerns from a lateral load perspective?

1d. A structure was constructed as an outpatient public health center. The city is proposing new plans, and want to evaluate if the building can be designated as an essential facility. Consider the two cases to be the facility designated as non-essential vs essential.
What lateral loads get affected?

1e. A building is currently in the schematic design phase. A preliminary load estimate and a lateral system has already been proposed based on the design the architect provided. The architect is now proposing a change to the façade by decreasing the brick and increasing the curtain wall percentage of the total façade on the individual floors. Consider two cases, before and after the proposed façade change.
Which loads (if any) need to be reconsidered?

1f. Early in design, a building was changed from 8 stories to 9 stories, with the total effective weight and height staying the same. Consider the What change does that have on what loads?

Quiz 1

1. For the following situations, please select all the statements that are true:

- ☐ Wind loads increase
- ☐ Wind loads do not change
- ☐ Wind loads decrease
- ☐ Seismic loads increase
- ☐ Seismic loads do not change
- ☐ Seismic loads decrease
- ☐ Other/Explanation: Elaborate in the textbox below

1a. A neighborhood community building was built on a flat surface with no ground features nearby before any houses are built. The building is planned to be on the edge of the neighborhood, and a small but significant hill is planned to be created around the neighborhood. Consider two cases, before and after the hill was made.
Which of the two cases is more conservative, and which load (seismic vs wind) is the one affected?
Ignore potential Exposure Category change.

1b. You proposed a steel braced frame for a 80' structure and calculated wind and seismic loads. According to that proposal footing sizes were estimated. The architect wanted a flexible floor plan, so a concrete moment frame was proposed instead. Consider the two cases to be before and after the proposed change in the framing system.
Do you need to recalculate your loads?

1c. A 10-story building is being retrofitted. Part of the project is moving the mechanical floor from the top floor to the 4th floor because the view on the top floor is quite valuable. The building occupancy, use, and relative finishes are relatively the same. Consider two cases, before and after the retrofitting job is started and is complete.
Assuming gravity members are adequate, is there any concerns from a lateral load perspective?

1d. A structure was constructed as an outpatient public health center. The city is proposing new plans, and want to evaluate if the building can be designated as an essential facility. Consider the two cases to be the facility designated as non-essential vs essential.
What lateral loads get affected?

1e. A building is currently in the schematic design phase. A preliminary load estimate and a lateral system has already been proposed based on the design the architect provided. The architect is now proposing a change to the façade by decreasing the brick and increasing the curtain wall percentage of the total façade on the individual floors. Consider two cases, before and after the proposed façade change.
Which loads (if any) need to be reconsidered?

1f. Early in design, a building was changed from 8 stories to 9 stories, with the total effective weight and height staying the same. Consider the What change does that have on what loads?

2. You have a steel residential building in Seattle, WA. Due to various limitations on the first floor, you want to limit your building base shear due to wind to no more than 150 kips, but maximize the size of the building. Provide 3 different building shapes (L, B, &h) that satisfy that requirement. Ignore seismic loads

   Please screen capture your window for every configuration and submit the 3 captures as a response.

   Do not change the variables below:

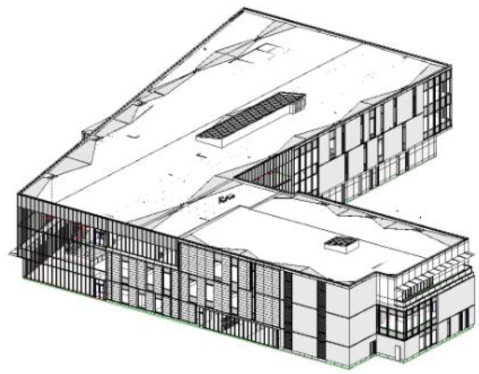
   Exposure B
   K_e = K_zt = 1.0
   K_d = 0.85

3. A 3-story hospital (designated as an essential facility) is currently being designed, in Indianapolis, IN. Concrete elevator shaft walls act as its lateral system. It is 60' tall with equal floor-to-floor heights. Each story has significantly different finishes. Provide 3 different iterations for the story weight that limit each story to less than 150 kip story force and the base shear to less than 300 kips. Site Class C. Ignore wind loads

   Please screen capture your window for every configuration and submit the 3 captures as a response.

4. Calculate the seismic base shear for the university classroom building shown in the figure, which is located in Houston, TX Ignore possible torsional effects and structural irregularities.

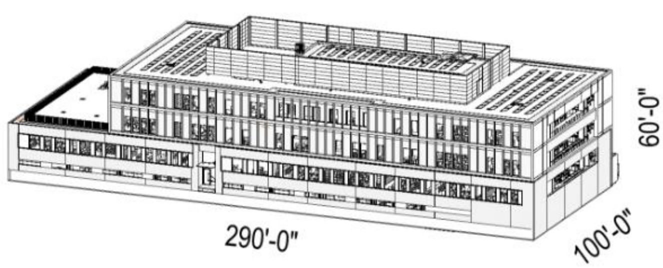
   Site Class E
   Non-seismically detailed moment frames



Floor	Weight (kips)	Height
Roof	2000	14'
Floor 2	3750	14'
Floor 1	3700	16'

5. Calculate the wind story force of the research lab shown in the figure. The building houses toxic materials. It is in Los Angeles, CA.

   Assume a bounding box, and ignore the mechanical screen wall.
   Story height is 15'
   Steel intermediate moment frames
   K_e = K_zt = 1.0
   K_d = 0.85



Quiz 2

1. For the following situations, please select all the statements that are true:

- ☐ Wind loads increase
- ☐ Wind loads do not change
- ☐ Wind loads decrease
- ☐ Seismic loads increase
- ☐ Seismic loads do not change
- ☐ Seismic loads decrease
- ☐ Other/Explanation: Elaborate in the textbox below

1a. A 10-story concrete building was designed to a height limit of 110', with equal floor-to-floor height. Later in design development, a number of design incentives were applied and the height limit was increased to 140'. The decision was made to use the extra height as plenum space and high ceilings with nothing else changing. Ignore extra weight added from the façade. Consider two cases, the two designs with the different heights.
How does this change affect base shears?

1b-
1c. A recent client of yours, a residential developer, whom you designed a building for in Buffalo, NY recently, wants to use the identical floor plans for a different site in San Francisco, CA, as well as Tampa, FL. Hint: Use ATC Hazards by Location
What affect could this have on lateral loads?
(1b is Buffalo to San Francisco)
(1c is Buffalo to Tampa)

1d. A government office building was designated as an essential facility when it was first constructed. It was recently sold to a private developer who plans on leasing floors as office space to regular companies.
What effects does this have on the lateral loads?

1e. An office building project in New York, NY was originally assumed to have a Site Class A, since an adjacent building to the site had that. When the Geotech report came it, the Site Class was specified as C. What effect can this have in the lateral loads?

1f. You are working on a retrofitting and expansion project. The expansion will be attached to the existing structure enough to be considered a single structure. The existing structure has ordinary concrete shear walls. In the expansion, moment frames were added. How does this affect the lateral loads?

2. You are performing a study on an office building in Detroit, MI. The façade that the owner wants to use can only handle a maximum of 30 psf wind pressure. Provide 3 different building shapes that maximize the building size while allowing this façade to be used. Ignore seismic loads

   Please screen capture your window for every configuration and submit the 3 captures as a response.

   Do not change the variables below:

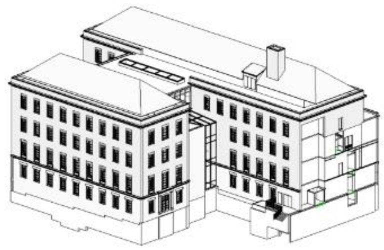
   Always assume a 10' floor-to-floor height
   Exposure C
   $K_e = K_{zt} = 1.0$
   $K_d = 0.85$
   Internal Pressure is positive
   SDC C

3. A 15-story concrete mixed use building in Philadelphia, PA that was built in the late 2000s was sold to a new owner. The building is 180' tall. The new owner is proposing adding four stories and a rooftop bar to be added on top of that, as a wood podium. The foundations and the concrete structure was extremely overdesigned, so it is not a limitation. The podium floor however, can only transfer 400 kips worth of story shear. Provide 3 different floor weight configurations and total heights that satisfy the base shear requirement. Ignore wind loads.

   Please screen capture your window for every configuration and submit the 3 captures as a response.

   Exposure B
   $K_e = K_{zt} = 1.0$
   $K_d = 0.85$
   Internal Pressure is positive
   SDC B

4. Calculate the seismic story force for the hospital building shown in the figure in Arlington, VA. Ignore possible torsional effects and structural irregularities.

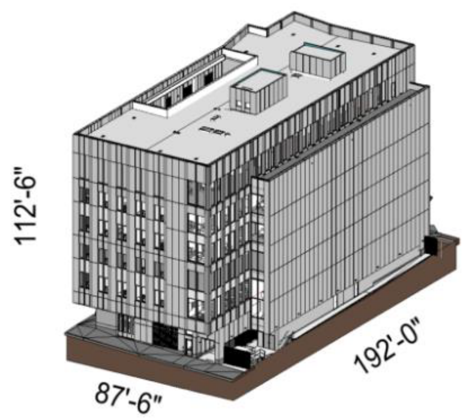


Site Class D – Stiff Soil
Ordinary concrete shear walls

Floor	Weight (kips)	Height
Roof	1200	14'
Floor 3	1800	14'
Floor 2	1800	14'
Floor 1	1800	14'
Ground	1000	N/A

5. Calculate the wind base shear of the office building shown in the figure. The building is in Omaha, NE in an urban area. The building is

Non-seismically detailed braced frames
K_zt = 1.0
K_d = 0.85



Appendix B – Survey Likert Scale Questions

Wind Evaluation:

- Please read the following statements and use the scale to answer

1 = Strongly disagree, 3 = Neither agree or disagree, 5 = Strongly agree

1.	I can perform a full wind load analysis of a building using MWFRS (directional)	1	2	3	4	5
2.	I can propose building changes to reduce wind loading on a structure	1	2	3	4	5
3.	I understand what affects vertical load distribution for wind loads	1	2	3	4	5
4.	I can easily navigate the many parameters that influence wind loads	1	2	3	4	5
5.	There are too many variables that affect wind loads	1	2	3	4	5
6.	For wind loads, I understand which variables affect windward pressure	1	2	3	4	5
7.	For wind loads, I understand which variables affect leeward pressure	1	2	3	4	5
8.	During schematic design, I can collaborate with an architect to reduce wind loads on a building.	1	2	3	4	5
9.	I am able to perform wind analysis on an existing structure	1	2	3	4	5
10.	I would rather calculate wind loads on a predetermined building than reiterate calculations based on changing parameters	1	2	3	4	5
11.	If a building shape has no room for change, I can calculate wind loads	1	2	3	4	5
12.	I can spot errors in calculations for wind loads	1	2	3	4	5

- Describe how much each of the following categories affect wind loads

1 = No effect at all, 2 = Minor change, 3 = Moderately effect on the load

4 = Significant effect on the load, 5 = Main driver of the load

1.	Location/Site effect on wind loads	1	2	3	4	5
2.	Building use effect on wind loads	1	2	3	4	5
3.	Architectural design effect on wind loads	1	2	3	4	5
4.	Structural design effect on wind loads	1	2	3	4	5

Seismic Evaluation:

- Please read the following statements and use the scale to answer

1 = Strongly disagree, 3 = Neither agree or disagree, 5 = Strongly agree

1.	I can perform a full seismic load analysis of a building using ELFP	1	2	3	4	5
2.	I can propose building changes to reduce seismic loading on a structure	1	2	3	4	5
3.	I understand what affects vertical load distribution for seismic loads	1	2	3	4	5
4.	There are too many variables that affect seismic loads	1	2	3	4	5
5.	I can easily navigate the many parameters that influence seismic loads	1	2	3	4	5
6.	For seismic loading, I understand why changing some parameters might not change the loads at all	1	2	3	4	5
7.	For seismic loading, I understand the effect of a single story weight on the overall vertical loading profile of the building.	1	2	3	4	5
8.	During schematic design, I can collaborate with an architect to reduce seismic loads on a building.	1	2	3	4	5
9.	I am able to perform seismic analysis on an existing structure	1	2	3	4	5
10.	I would rather calculate seismic loads on a predetermined building than reiterate calculations based on changing parameters	1	2	3	4	5
11.	If a building design and architectural program are not flexible, I can calculate seismic loads	1	2	3	4	5
12.	I can spot errors in calculations for seismic loads	1	2	3	4	5

- Describe how much each of the following categories affect wind loads

1 = No effect at all, 2 = Minor change, 3 = Moderately effect on the load

4 = Significant effect on the load, 5 = Main driver of the load

1.	Location/Site effect on seismic loads	1	2	3	4	5
2.	Building use effect on seismic loads	1	2	3	4	5
3.	Architectural design effect on seismic loads	1	2	3	4	5
4.	Structural design effect on seismic loads	1	2	3	4	5

Other Evaluation:

- Please read the following statements and use the scale to answer

1 = Strongly disagree, 3 = Neither agree or disagree, 5 = Strongly agree

1.	I am able to manipulate building parameters to achieve an efficient building design	1	2	3	4	5
2.	I understand which variables are relevant to which load type	1	2	3	4	5

Appendix C – Data Granulation Breakdown

Aggregated

	Traditional	Tool 1	Tool 2
Quiz	Q0	Q1	Q2
Survey	S0	S1	S2

Separate by Learning Category

Learning Categories

		Traditional	Tool 1	Tool 2
Quiz	A	N/A	AQ1	AQ2
	D	N/A	DQ1	DQ2
	F	FQ0	FQ1	FQ2
Survey	A	AS0	AS1	AS2
	D	DS0	DS1	DS2
	F	FS0	FS1	FS2

Separate by Load Types

Learning Categories for Loads

		Traditional		Tool 1		Tool 2	
		W	S	W	S	W	S
Quiz	A	N/A		WAQ1	SAQ1	WAQ2	SAQ2
	D	N/A		WDQ1	SDQ1	WDQ2	SDQ2
	F	WFQ0	SFQ0	WFQ1	SFQ1	WFQ2	SFQ2
Survey	A	WAS0	SAS0	WAS1	SAS1	WAS2	SAS2
	D	WDS0	SDS0	WDS1	SDS1	WDS2	SDS2
	F	WFS0	SFS0	WFS1	SFS1	WFS2	SFS2

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EDUCATION

The Pennsylvania State University — University Park, PA
Bachelor of Architectural Engineering — Graduation: August '23
Master of Science in Architectural Engineering
Schreyer Honors College

WORK EXPERIENCE

SmithGroup — Detroit, MI
Structural Intern — May 2022 – November 2022

- Designed a foundation system for a simple item, starting with load calculations from code, to analysis, to foundation design, and documentation.
- Drafted various structural details and modeled various structural elements in Revit
- Reviewed structural submittals that included shop drawings and calculation checks
- Performed minimal embodied carbon calculations
- Performed connection analysis for various types of connections.

AE TEAM @ Penn State — University Park, PA
Manager & Tutor — August 2021 – May 2022

- Managed a team of undergraduate tutors in the AE Department
- Scheduling and delegating tutoring to best suit team members skill sets
- Tutor for various AE 2nd & 3rd year courses including structural and mechanical

BEAM Lab @ Penn State — University Park, PA
Research Assistant for Dr. Rebecca Napolitano — May 2021 – October 2021

- Executed controlled experimental work using a Ground Penetrating Radar probe on concrete partitions and raw materials to gather scan data
- Performed Ground Penetrating Radar simulations using python libraries and compared results to experimental data with the goal of extracting more information of partition geometry and physical material properties
- Documented detailed experimental notes and processes and created weekly presentations

OTHER EXPERIENCE

Study in AE 308: Introduction to Structural Analysis — Fall 2020

- Individual Honors Work: Investigation of the Hard Rock hotel collapse in New Orleans, LA
- Read and used the permit set drawings to analyze the structure
- Performed load path analysis & followed the loads in area of the building that failed
- Presented findings to peers in class

SKILLS

- Revit
- Sketchup
- AutoCAD
- Microsoft Office
- Bluebeam Revu
- Language – Arabic
- Adobe Photoshop
- Python
- Grasshopper
- Communication
- ETABS
- SAP2000
- RAM Struct. System
- EnerCalc
- RISA