Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Structural Engineering

Jimmy Ngo Luong

Game-Based Learning in Structural Engineering Education

Game Title: Designer's Den

Master's thesis in Civil and Environmental Engineering
Supervisor: Marcin Luczkowski
June 2023

NTNU
Norwegian University of
Science and Technology

Jimmy Ngo Luong

Game-Based Learning in Structural Engineering Education

Game Title: Designer's Den

Master’s thesis in Civil and Environmental Engineering
Supervisor: Marcin Luczkowski
June 2023

Norwegian University of Science and Technology
Faculty of Engineering
Department of Structural Engineering

NTNU
Norwegian University of
Science and Technology

ABSTRACT

This thesis explores the design, development, and evaluation of a game-based learning tool, "Designer's Den", tailored specifically for structural engineering education. The principal aim of the research is to address the challenges often faced by students when grappling with abstract and complex engineering concepts through traditional pedagogical methods.

Game-based learning (GBL) has been employed as a promising approach in this context, harnessing the motivational and engaging aspects of games to enhance the learning experience. "Designer's Den" integrates key elements of structural mechanics within an interactive, immersive gaming environment.

The game was developed based on the principles of modularity, scalability, and maintainability, using Angular's component-based architecture. An iterative design process was used, incorporating user feedback at each stage to ensure the game was responsive to student's learning needs.

The game's effectiveness was evaluated using a mixed-method approach, incorporating quantitative data from in-game metrics and qualitative data from student surveys and interviews. The results demonstrated high levels of engagement and positive learning outcomes, indicating that the game was successful in fostering understanding of complex engineering concepts.

The study contributes to the field of engineering education by providing empirical evidence supporting the efficacy of game-based learning tools. It also highlights the potential of such tools to bridge the gap between abstract theories and real-world applications. The insights gathered from the development and evaluation process can inform future initiatives in the area of game-based learning in engineering education.

The research concludes with reflections on the game development and evaluation process, recommendations for future improvements in the game, and suggestions for further research.

The complete source code is available at: `https://github.com/JiLuong/Thesis`

SAMMENDRAG

Denne avhandlingen utforsker design, utvikling og evaluering av et spillbasert læringssystem, "Designer's Den", skreddersydd spesielt for utdanning innen konstruksjonsteknikk. Hovedmålet med forskningen er å håndtere utfordringene studenter ofte står overfor når de møter abstrakte og komplekse konsepter innen ingeniørvitenskap gjennom tradisjonelle pedagogiske metoder.

Spillbasert læring har blitt brukt som en lovende tilnærming i denne sammenhengen, og utnytter de motiverende og engasjerende aspektene ved spill for å forbedre læringsopplevelsen. "Designer's Den" integrerer nøkkellementer av konstruksjonsteknikk i et interaktivt og engasjerende spillmiljø.

Spillet ble utviklet basert på prinsippene om modularitet, skalerbarhet og vedlikehold, ved bruk av Angulars komponentbaserte arkitektur. En iterativ designprosess ble brukt. Dette innfører brukertilbakemeldinger på hvert trinn for å sikre at spillet dekker studentenes læringsbehov.

Effektiviteten til spillet ble evaluert ved hjelp av flere blandede metoder, både kvantitative data fra målinger under bruk av spillet og kvalitative data fra studentundersøkelser og intervjuer. Resultatene viste høye nivåer av engasjement og positive læringsresultater, noe som indikerer at spillet var vellykket i å fremme forståelse for komplekse konsepter innen konstruksjonsteknikk.

Studien bidrar til feltet for ingeniørutdanning ved å gi empirisk bevis som støtter effektiviteten til spillbaserte læringsverktøy. Den fremhever også potensialet til slike verktøy for å bygge bro mellom abstrakte teorier og virkelige applikasjoner. Innsikt samlet fra utviklings- og evalueringsprosessen kan danne grunnlaget for fremtidige initiativer innen området spillbasert læring i ingeniørutdanning.

Forskningen avsluttes med refleksjoner over spillutviklings- og evalueringsprosessen, anbefalinger for fremtidige forbedringer i spillet, og forslag til videre forskning.

Den komplette kildekoden er tilgjengelig på: `https://github.com/JiLuong/Thesis`

PREFACE

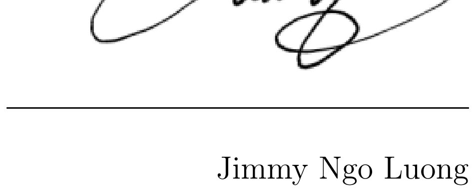
This thesis stands as a testament to many months of research, development, and learning. It has been a journey filled with many challenges, growth, and rewarding accomplishments. The experiences I have gathered during this time have broadened my knowledge and shaped my perspective in many ways.

I want to thank my supervisor, Marcin Luczkowski, for his support and guidance throughout this process. His knowledge and enthusiasm have been invaluable, and his willingness to provide assistance whenever needed has made a significant impact on my work.

To my family, I want to express my deepest gratitude. Their constant belief in my capabilities and unconditional support during difficult periods have enabled me to persevere and conquer the challenges.

A special word of thanks to my friends and colleagues whose support and valuable insights greatly enriched my academic journey. Their suggestions and feedback were invaluable in refining my thoughts and arguments.

In closing, this thesis would not have reached its fruition without the support and guidance of everyone mentioned. I am truly grateful.



Jimmy Ngo Luong

CONTENTS

LIST OF FIGURES

CHAPTER

ONE

INTRODUCTION

The purpose of this chapter is to set the context for the thesis by introducing the motivation behind the project, the problems it aims to address, and the primary research questions that drive the investigation. The chapter begins by presenting the motivation, elucidating why the integration of game-based learning into structural engineering education is crucial and timely. It then outlines the problem statement, articulating the current challenges faced in teaching and learning structural engineering, and the potential benefits of incorporating game-based learning. Subsequently, the research questions that serve as the foundation for this study are presented. The project description follows, providing a brief overview of the game-based learning tool developed for structural engineering education. Lastly, the chapter concludes with a summary of the structure and content of the rest of the thesis.

1.1 Motivation

In an era marked by technological advancement and the continuous evolution of infrastructures, structural engineering finds itself at the heart of modern civilization. From the construction of skyscrapers to the design of bridges that span vast distances, the role of a structural engineer is as challenging as it is integral to the advancement of society.

Given this context, the education provided to aspiring structural engineers is of utmost importance. Traditionally, structural engineering education has relied on textbook learning and theoretical problem-solving sessions. These methods have been effective and continue to be critical in building foundational knowledge. However, the dawn of the digital age has unveiled new styles of learning and created an opportunity to diversify and innovate the traditional methods of teaching, especially in higher education.

Game-based learning emerges as a promising approach in this context, harnessing the engagement and motivation provided by games to enhance the learning experience. Particularly in fields like structural engineering, where students often grapple with abstract concepts, the potential benefits of game-based learning are substantial (Kiili 2005).

However, despite the growing recognition of game-based learning's value in education, its implementation in structural engineering education is still in budding stages. This gap presents an opportunity to explore this concept, potentially paving the way for innovative pedagogical tools to better equip the structural engineers of tomorrow.

1.2 Problem Statement

The discipline of structural engineering is marked by the complexity of mathematical and scientific principles it encompasses. Despite the critical nature of this field, educators often face challenges in effectively conveying these intricate concepts, resulting in suboptimal learning outcomes.

While traditional educational practices are fundamental, they can struggle to engage students fully, particularly when dealing with theoretical content. This lack of engagement may lead to a surface-level understanding of the principles involved and impact the students' abilities to apply these principles in practical contexts.

The concept of game-based learning presents itself as a promising avenue to address this issue. However, while this approach has been recognized and utilized in various fields of education, its potential in the context of structural engineering education is yet to be fully realized.

1.3 Research Questions

In line with the stated objectives, this research seeks to answer the following main research questions (RQ):

RQ 1: How can game-based learning be effectively implemented in structural engineering education, specifically in teaching the courses within structural mechanics and statics? This question involves exploring the most effective strategies for designing and developing a game that can teach structural engineering concepts. It also includes investigating of how such a game can be integrated into an existing course structure.

RQ 2: Does the use of a game-based learning tool enhance students' understanding and application of the concepts taught in the courses within structural mechanics and statics? This question seeks to evaluate the effectiveness of the developed game in improving students' learning outcomes. This includes assessing their understanding of key course concepts and their ability to apply these concepts in practical scenarios.

RQ 3: How do students perceive the use of a game-based learning tool in their structural engineering coursework? Beyond the objective measurements of learning outcomes, it's important to understand how students perceive the use of the game in their learning process. This includes their level of engagement with the game, their perceived learning from the game, and their overall satisfaction with the game-based learning experience.

These research questions will guide the design, implementation, and evaluation phases of this research. The aim is not only to develop a functional, engaging game for structural engineering education, but also to gain a deeper understanding of how game-based learning can be used to improve educational outcomes and student engagement in this field. Ultimately, the goal is to provide insights that can contribute to the enhancement of teaching and learning in structural engineering education.

1.4 Research Objective

The primary objective of this research is to explore the effectiveness of game-based learning in structural engineering education, particularly in the mechanics courses related to structural statics. This will be achieved through the development and evaluation of a web-based educational game, designed to enhance the understanding and application of course concepts.

The specific objectives of this research are as follows:

Design and Development: To create a web-based game, using Angular and TypeScript, that presents key concepts from the course in an engaging, interactive format. The game design will emphasize educational effectiveness, user engagement, and usability.

Implementation: To integrate the game into a real-world educational setting, allowing students to interact with the game as part of their coursework.

Evaluation: To evaluate the effectiveness of the game as a teaching tool. This will be accomplished through testing and feedback from students and educators.

The scope of this research is confined to the use of game-based learning in the context of structural engineering education, specifically within the course "TKT4116 Mechanics 1" for the first level of the game. While the findings may have broader implications for engineering education or game-based learning in general, these wider contexts will not be the focus of the study.

It's important to note that the primary focus of this research is not to compare the effectiveness of game-based learning with other teaching methodologies, but rather to explore how game-based learning can be used as a complementary tool to enhance the learning experience in structural engineering education. This research acknowledges the importance of traditional teaching methodologies and seeks to provide an additional resource that can be used in conjunction with existing pedagogical approaches.

1.5 Outline

The remainder of this thesis is organized as follows:

Chapter 2 provides a background to the study, discussing the current course structure, challenges in higher education, limitations of existing digital resources, and requirements and limitations for an educational game in structural engineering.

Chapter 3 outlines the research methodology, including the literature review, gamification elements, and integration with coursework.

Chapter 4 details the game concept, including the framework for game design and the initial game design.

Chapter 5 presents a detailed description of the "Designer's Den" game design and its features.

Chapter 6 provides a technical description of the game, discussing the system architecture, design patterns, technology, and development methodology.

Chapter 7 reports the evaluation of the game, discussing the purpose of the evaluation, participant selection, the evaluation process, and the results.

Chapter 8 concludes the thesis, summarizing the findings, discussing their implications, acknowledging the limitations of the study, and suggesting future work.

This thesis aims to contribute to the field of structural engineering education by exploring the potential of game-based learning in enhancing student learning outcomes and engagement.

CHAPTER

TWO

BACKGROUND

The purpose of this chapter is to provide a detailed background to the study, focusing on the context of the course in question and the challenges that currently exist in higher education and structural engineering education in particular. The chapter begins by describing the traditional learning methodologies and resources used in the course, setting the stage for understanding the current learning environment. It then discusses the general challenges of learning in higher education, followed by a more specific examination of the difficulties students face when learning mechanics. The chapter also evaluates the limitations of existing digital learning resources and elucidates the specific requirements for an educational game in structural engineering. Finally, the chapter wraps up by discussing the potential limitations that such an educational game might encounter.

2.1 Course Description

The courses in structural statics form the foundation of the structural engineering curriculum. These courses are typically general mechanics courses that focus on teaching the principles of mechanics, force systems, equilibrium conditions, and structural analysis. The aim of these courses is to provide students with a strong conceptual grasp of these principles and equip them with the ability to apply them in the analysis of static beams, trusses, frames, and machines.

The curriculum covers various aspects, including statically determinate structures such as beams, plane trusses, and frames. Students learn about axial force, shear force, and bending moment distribution in structures. Additionally, the courses introduce the fundamentals of mechanics of materials, including concepts like stress, strain, and elasticity. Linear theory for beams is also covered, encompassing topics such as bending stresses, the differential equation for deformation of beams, and other related concepts.

By gaining knowledge and proficiency in these areas, students develop the necessary skills to analyze and understand the behavior of structures under different loading conditions. This knowledge lays a solid groundwork for further studies in structural engineering and serves as a crucial tool for designing safe and efficient structures.

2.1.1 Learning Resources

Learning resources are essential tools that support and enhance the learning process in higher education. In the traditional context, these resources often include textbooks, academic articles, and lecture notes.

Textbooks play a vital role in most courses, offering comprehensive coverage of course material. They often provide detailed explanations, examples, and exercises, making them a valuable resource for learning and reviewing material.

Academic articles and research papers provide students with exposure to current research and developments in their field of study. This exposure is crucial for disciplines like structural engineering that are continually evolving and innovating. Reading and analyzing academic articles also helps students develop critical thinking and analytical skills.

Lecture notes, whether provided by the instructor or taken by the students themselves, are another key learning resource. These notes serve as a record of the material covered in class and can be an effective tool when reviewing contents.

Other common learning resources include problem sets and solutions, lab manuals, educational software, and online resources. Each of these resources can play a role in supporting student learning and aiding in the comprehension of course material.

In the digital age, the range of learning resources has expanded dramatically. Online platforms offer a wealth of resources, including video lectures, online tutorials, discussion forums, and interactive simulations. These digital resources can offer increased accessibility, interactivity, and flexibility, complementing traditional resources and enriching the learning experience.

While traditional learning resources remain fundamental to education, the incorporation of innovative tools like game-based learning platforms can add a new dimension to the learning process. As we will explore in this thesis, these tools can enhance engagement, facilitate understanding of complex concepts, and provide a novel approach to learning in the field of structural engineering.

2.1.2 Traditional Learning Methodology

Traditional learning methodologies have been the foundation of higher education for centuries. These methodologies typically rely on the transmission of knowledge from educator to student, often through a combination of lectures and exercises. The cornerstone of traditional learning is the lecture, where an instructor presents material to students, often supplementing the lecture with visual aids.

During these lectures, the instructor typically follows a pre-established curriculum, presenting concepts in a sequential manner that builds upon previous material. This teaching style is often referred to as "teacher-centered" because the teacher directs the learning process, controls the flow of information, and evaluates student performance, usually through exams and assignments.

Homework and problem-solving exercises are another key component of traditional learning methodologies. These assignments give students the opportunity to apply the knowledge they've acquired in lectures. In engineering courses, these assignments often take the form of problem sets, where students are given a series of technical problems that require the application of course concepts.

Traditional learning methodologies also emphasize independent learning. Students are expected to review lecture material, complete readings, and work on assignments outside of class. This aspect of traditional learning develops important skills such as self-discipline, time management, and independent problem solving.

However, while traditional learning methodologies have proven effective in many instances, they also have limitations. They often lack interactivity, fail to accommodate diverse learning styles, and struggle to maintain student engagement, particularly when dealing with abstract or complex concepts.

2.2 Challenges of Learning in Higher Education

Higher education, especially in complex technical fields such as engineering, often faces significant challenges associated with teaching and learning processes. These challenges are multifaceted, covering a broad range of issues from individual student learning styles and motivations to broader systemic factors within educational institutions (Felder and Brent 2005). Addressing these challenges is critical to improving educational outcomes and equipping students with the skills they need to thrive in their professional lives.

One of the central challenges lies in accommodating the diverse range of learning styles and academic backgrounds that students bring to the classroom. Higher education is characterized by a heterogeneous student population. Some students may have a strong foundation in the prerequisite material, while others may be encountering these topics for the first time. Similarly, some students may prefer to learn through visual or hands-on methods, while others may thrive in lecture-based or reading-intensive environments. This diversity necessitates flexible teaching methods that can accommodate a wide range of student needs.

Engagement is another key issue in higher education. Maintaining student interest and motivation is a constant challenge, especially in courses with abstract or complex material. Traditional teaching methods, while effective for conveying large amounts of information, can sometimes lead to student disengagement, especially when the connection between the material and its real-world applications is not clear. This lack of engagement can result in a superficial understanding of the material and lower academic performance.

Another challenge in higher education is the high student-to-teacher ratio, especially in large universities. This often makes it difficult for educators to give personalized attention to each student, resulting in less feedback and a diminished ability to tailor instruction to individual student needs. Furthermore, these large classes can often inhibit active learning, as students may feel less comfortable participating in discussions or asking questions.

In fields such as structural engineering, these challenges can become even more pronounced. The complex and often abstract nature of the material can pose significant difficulties for students, especially those who are used to more concrete or hands-on learning experiences. Traditional problem-solving exercises, while crucial for developing technical skills, may not fully capture the complexity and creativity involved in real-world engineering projects.

Coursework in these fields also tends to be heavily skewed towards individual assignments, with less emphasis on collaborative problem-solving exercises that mimic real-world engineering teams. This can lead to a gap between the skills students acquire during their education and the skills they need in their professional lives.

Finally, the rapid pace of technological change presents an ongoing challenge for higher education institutions. Curricula must be continually updated to reflect current industry practices and technologies, requiring significant resources and placing additional demands on educators and students alike.

Addressing these challenges requires innovative approaches to teaching and learning. Game-based learning, with its ability to engage students, cater to diverse learning styles, and simulate real-world scenarios, presents a promising solution. By integrating game-based learning into structural engineering education, we may be able to enhance student learning outcomes, increase engagement, and better prepare students for their future careers.

2.2.1 Challenges in Learning Mechanics

Mechanics, as a branch of physics and essential component of structural engineering, introduces a host of challenges for students at the undergraduate level. These challenges can stem from the intrinsic complexity of the course contents, the pedagogical methods used, or the learning environment itself.

Conceptual Complexity: Mechanics is a field grounded in abstract concepts and mathematical models. Understanding these concepts and using them to solve problems requires a high degree of mathematical competence and spatial reasoning. For instance, comprehending forces, moments, equilibrium, and kinematics often requires a sophisticated understanding of vectors, calculus, and differential equations. Such abstract thinking can be challenging for many students, especially for those in the early stages of their academic careers. The transition from high school to university level physics often requires a leap in abstract reasoning skills, which can be a significant hurdle to many students.

Mathematical Rigor: Even when students understand the underlying principles, the mathematical rigor required in mechanics can be daunting. Problems often involve complex calculations, algebraic manipulation, and solving differential equations. This level of mathematical sophistication can be a significant obstacle for students, especially for those who face difficulties with mathematics.

Problem Solving: Mechanics problems often involve multi-step solutions that require a systematic approach. This can be difficult for students who are used to more straightforward, formulaic problems. Additionally, real-world mechanics problems rarely fit neatly into the types of problems presented in textbooks, requiring students to adapt their problem-solving strategies in creative ways.

Application and Transfer of Knowledge: One of the challenges in learning mechanics is the application of theoretical concepts to real-world scenarios. Students often struggle to see the connection between the abstract principles they learn in class and the practical applications of these principles in structural engineering. This can lead to a superficial understanding of the material and difficulties in transferring knowledge to new contexts.

Instructional Methods: The traditional lecture-based approach to teaching mechanics, while effective for some students, may not cater to all learning styles. Some students may find it hard to remain engaged or grasp complex concepts when instruction is primarily one-way communication. Additionally, the rapid pace of introducing new topics can hinder some students from keeping up.

Assessment Pressure: Mechanics courses often rely heavily on high-stakes exams to assess student performance. This can create a high-pressure environment that may hinder learning and discourage a deep understanding of the material. Students may end up focusing more on achieving high grades than on truly understanding and applying the concepts.

Overcoming these challenges requires innovative approaches to teaching and learning mechanics. The use of game-based learning, as explored in this thesis, is one such approach that holds the potential to address some of these issues and enhance student learning in mechanics.

2.3 Limitations in Digital Learning Resources

Digital learning resources have revolutionized education by offering learners the flexibility to learn at their own pace and making a wide range of learning materials available at their fingertips. Despite the many advantages, several limitations exist in the current state of digital learning resources, particularly in the context of higher education and more specifically, in structural engineering.

Lack of Engagement: Many digital learning resources primarily provide passive learning experiences. They often involve reading text or watching video lectures with limited interactivity. This lack of engagement can lead to reduced motivation and learning effectiveness (Mayer 2008).

Lack of Practical Application: Digital resources often focus on theory without providing enough opportunities for practical application. In structural engineering, where understanding the practical implications of theoretical concepts is essential, this lack of application-based learning can limit the depth of understanding.

Absence of Personalization: Many digital resources follow a one-size-fits-all approach. They fail to adapt to the individual learner's pace, prior knowledge, or learning style. This can be particularly challenging in diverse classrooms where students' backgrounds and learning needs vary widely.

Limited Feedback: While digital resources can provide immediate feedback on certain types of tasks (like quizzes), they often lack the capacity to give detailed, personalized feedback that students may need to understand their mistakes, rectify them, and grow from the experience.

Technical Difficulties: Technological issues, including software glitches, internet connectivity problems, and compatibility issues, can disrupt the learning process and create barriers for students.

Overreliance on Self-Directed Learning: While fostering independent learning skills is important, completely self-directed learning can be challenging for some students. They might lack the discipline or metacognitive skills required to plan, monitor, and evaluate their learning effectively.

Cognitive Overload: The sheer volume of available digital learning resources can lead to cognitive overload. Students may struggle to determine which resources are most relevant and reliable, or they might waste valuable time navigating through an overabundance of information.

These limitations present challenges to the effectiveness of digital learning resources, particularly in a complex field like structural engineering. However, they also open opportunities for improvement and innovation. Game-based learning, the central focus of this thesis, offers one potential approach to address some of these limitations and enhance the learning experience.

2.4 Requirements for an Educational Game in Engineering

The development of an educational game for structural engineering should be designed considering specific requirements to ensure its effectiveness and engagement.

Educational Effectiveness: First and foremost, the game must serve its primary purpose - to facilitate learning in higher education. It should align with the learning objectives of the course and aid in the comprehension of complex structural engineering concepts.

Engagement: The game needs to be enjoyable and engaging. This not only improves the user's experience but also encourages repeated use, which can lead to better knowledge retention and understanding.

Practical Relevance: The game should incorporate real-world scenarios and problems that engineers might encounter in practice. This helps learners to see the relevance of their learning and how it applies in a practical context.

Usability: The game should have a user-friendly design that students can easily navigate. Unnecessary complexity in game controls or design can be a barrier to learning.

Adaptive Difficulty: The game should adapt to the individual's learning progress, increasing in difficulty as the student masters each level. This keeps the game challenging and ensures students continue to learn and grow.

Immediate Feedback: Providing immediate feedback within the game helps students understand their mistakes and learn from them. It also reinforces correct understanding and application of concepts.

Scalability: The game should be designed in a manner that allows for further development and expansion as required. This includes adding new topics, levels, or challenges as the curriculum evolves.

2.5 Limitations for an Educational Game in Engineering

While game-based learning in structural engineering offers many opportunities, it also comes with its own set of limitations.

Development Cost and Time: Developing a high-quality educational game requires significant time and financial resources. It involves a team of experts, including educators, game designers, and developers, working closely together over an extended period.

Learning Curve: While a well-designed game can facilitate learning, there's also a learning curve associated with the game mechanics itself. Students might take time to understand how to navigate and interact with the game, which can potentially detract from their learning time.

Technological Barriers: Not all students may have access to the required technology or possess the necessary digital skills to play the game. This could create accessibility issues.

Gamification vs Education Balance: Identifying the correct balance between making the game fun and engaging while ensuring it is educationally sound can be a challenge. Too much emphasis on gamification could overshadow the educational objectives.

Assessment Integration: Incorporating the game-based learning into the traditional assessment system could be challenging. How can a student's performance in a game be graded? How does it translate into their overall academic performance?

Potential Distraction: Games are generally designed to be fun and engaging. However, there's a risk that students may get overly engrossed in the gaming aspect, distracting them from the primary educational objective.

While these limitations present challenges, they do not diminish the potential benefits of game-based learning. With careful planning, good design, and effective implementation, it is possible to overcome these limitations and create a successful educational game for structural engineering.

CHAPTER

THREE

METHODOLOGY

The purpose of this chapter is to outline the research methodology used in this thesis, specifically focusing on the investigation and implementation of game-based learning in structural engineering education. The chapter commences with a comprehensive literature review that explores the current state of game-based learning and structural engineering education, providing a theoretical basis for the study. Following this, the chapter delves into the various gamification elements that were considered and incorporated into the game design, detailing their significance and potential impacts on learning. Finally, the chapter discusses the integration of the game with the existing coursework, elucidating the synergy between traditional teaching methods and this innovative educational game. Overall, this chapter provides a detailed explanation of the processes followed and considerations made during the research and development of the educational game.

3.1 Literature Review

In this chapter, a comprehensive literature review is conducted to explore the existing research and knowledge related to Game-Based Learning (GBL) and Structural Engineering Education. The review aims to provide a theoretical foundation and contextual understanding for the development and integration of a game-based learning solution in the field of structural mechanics and statics.

3.1.1 Game-Based Learning

Game-based learning (GBL) is an innovative and interactive pedagogical strategy that utilizes the captivating and engaging attributes of games to facilitate more effective learning. Over the years, it has progressively gained significant recognition and appreciation as a potential and highly effective tool for enhancing traditional education methods, actively promoting experiential learning, and fostering the development of critical thinking skills among learners.

Research has shown that GBL, when designed and implemented effectively, can enhance learner engagement and improve learning outcomes (Connolly et al. 2012). The immersive nature of games provides a rich context for learning, prompting learners to apply theoretical knowledge to practical scenarios. Moreover, games typically incorporate elements of challenge, competition, and rewards, which are known to stimulate intrinsic motivation (Kapp 2012).

Despite its potential, GBL implementation in higher education, particularly in structural engineering, is still limited. Furthermore, research dedicated to exploring its effectiveness and best practices within this discipline is sparse.

3.1.2 Structural Engineering Education

Structural engineering education forms a cornerstone of civil engineering curricula across the globe. It is essential for building a foundation for the design and analysis of structures like buildings, bridges, tunnels, and most major infrastructures.

Traditionally, structural engineering education has primarily been delivered through lectures, textbook learning, problem-solving exercises, and to some degree laboratory activities. These teaching methods focus on helping students acquire theoretical knowledge and develop analytical skills. While these approaches are fundamental, they can struggle with imparting complex, abstract concepts, often leading to a gap between theory and practice (Magin and Kanapathipillai 2000).

This disconnect is particularly evident in mechanics, a fundamental subject in structural engineering. Despite its importance, students often struggle with understanding mechanics concepts due to their abstract nature and the mathematical rigour involved. Consequently, several pedagogical strategies have been explored to improve mechanics education, such as problem-based learning, active learning, and more recently, game-based learning.

In summary, while traditional methods continue to be the backbone of structural engineering education, there is a need to explore innovative pedagogical strategies like GBL to enhance teaching and learning in this field. Further research is required to determine how GBL can be effectively designed and implemented in the context of structural engineering education.

3.2 Gamification Elements

Gamification refers to the application of game elements to enhance motivation, engagement, and the overall learning experience. In the context of educational games designed for subjects like structural engineering, the integration of gamification elements can provide a more immersive and interactive learning environment. This section will discuss the key gamification elements that hold significant potential for enriching learning outcomes when incorporated within educational games.

3.2.1 Game Mechanics

Game mechanics are the rules and procedures that govern player actions and the corresponding responses within the game. In the context of educational games for structural engineering, several game mechanics can be utilized to motivate and facilitate learning. Challenges, for example, present students with specific goals to strive for, fostering perseverance, strategic thinking, and problem-solving skills. These challenges can mirror real-world engineering scenarios, allowing students to apply their knowledge and skills in practical contexts.

Levels serve as a structured progression system, enabling students to advance through increasingly complex tasks and concepts. Each level builds upon the previous one, offering a sense of achievement and guiding students through the learning content.

Points and rewards provide a measure of accomplishment and serve as motivational factors. By earning points through successful completion of tasks, students can unlock rewards such as additional features or customization options within the game. This element incentivizes active participation and mastery of learning objectives.

Feedback is a crucial component of game-based learning. Immediate feedback informs students about their performance, helping them understand the value of their actions and adjust their strategies accordingly. Constructive feedback promotes self-reflection and supports the development of critical thinking skills.

3.2.2 Game Dynamics

Game dynamics refer to the patterns of play that emerge from the interaction between game mechanics and player actions. In the educational context of structural engineering, specific game dynamics can shape student engagement with the learning material.

Competition, for instance, can motivate learners to outperform their peers and achieve higher scores. Healthy competition fosters a sense of challenge and encourages active participation and continuous improvement.

Cooperation promotes collaboration and teamwork. By incorporating cooperative elements into the game, such as group challenges or multiplayer modes, students can work together to solve problems and enhance their communication and problem-solving skills.

Exploration allows students to navigate the game world, discover new knowledge, and autonomously engage with the learning content. Through exploration, learners can develop a sense of curiosity and a self-driven approach to learning.

Narrative provides context and meaning to the learning experience. By incorporating a compelling storyline that aligns with the structural engineering domain, students can relate to the content more effectively and develop a deeper understanding of its real-world applications.

3.2.3 Game Aesthetics

Game aesthetics involve the visual and auditory elements that enhance the appeal and immersion of the game. In the context of educational games for structural engineering, aesthetics play a crucial role in attracting and maintaining student interest.

Visual design helps illustrate abstract concepts and complex structures, making them more tangible and easier to comprehend. Engaging visuals can enhance the overall learning experience and facilitate conceptual understanding.

Sound design, including crafty sound effects and captivating background music, adds another layer of immersion to the game. Well-chosen audio elements can create an immersive atmosphere and enhance the engagement and enjoyment of the learning process.

Story and character design can bring the learning content to life and make it relatable to students. By incorporating real-life scenarios and allowing students to assume the role of engineers solving practical problems, the game's narrative and characters create a meaningful context for learning.

By strategically integrating these gamification elements into the game-based learning solution for structural engineering education, educators can create an engaging and effective learning experience. The interplay between game mechanics, dynamics, and aesthetics enhances student motivation, critical thinking, problem-solving skills, and conceptual understanding. The subsequent chapters will delve into the practical implementation and integration of these gamification elements, providing insights into their effectiveness and practical application.

3.3 Integration with Coursework

The integration of game-based learning within the curriculum is a critical factor in the success of this pedagogical approach. Careful planning and consideration need to be exercised to ensure that the game is not perceived as an added burden or a distracting element, but instead as a valuable complement to traditional teaching methods.

3.3.1 Alignment with Learning Objectives

The first and foremost consideration in integrating a game into coursework is the alignment of the game's content with the course's learning objectives. The game must be designed to help students meet these objectives, providing them with an opportunity to apply and deepen their understanding of the concepts taught in class. This requires a thorough understanding of the course content and a careful design of game tasks and challenges that reflect this content.

3.3.2 Timing and Sequence of Game Sessions

Deciding when and how often students should interact with the game is another crucial aspect of integration. The game sessions should ideally be scheduled at a time when they can reinforce what's been taught in class. For instance, after a lecture on a particular topic, a game session focusing on that topic can help consolidate students' understanding. Another example is before an exam so the game session works as a summary of the curriculum.

3.3.3 Assessment and Feedback

In a well-integrated educational game, student progress in the game should be linked with their academic assessment. The performance in the game can be used to assess the students' understanding of the course material. Furthermore, the game can provide instant feedback, helping students identify their mistakes and improve.

3.3.4 Student Support and Guidance

The introduction of a game into coursework will require some level of support and guidance for students. This might involve an initial introduction to the game and its mechanics, as well as ongoing support in case students face any issues while playing the game.

In summary, the integration of the game with coursework should be a carefully designed process, with the game acting as a supplementary tool that enhances traditional teaching methods and enriches the learning experience. The game should serve as a medium that provides students with an engaging and interactive way to apply and reinforce their knowledge.

CHAPTER

FOUR

GAME CONCEPT

The purpose of this chapter is to elaborate on the game concept that establish the design and development of the educational game. It begins by outlining the framework that guides the game design, shedding light on the core principles that derive the process. The chapter then delves into the initial game design, exploring the learning objectives it aims to achieve, the motivation behind its creation, and the game elements incorporated to foster learning and engagement. Subsequently, the chapter discusses the game concepts in detail, tracing the design process, exploring the variations considered, and culminating in the elected concept that forms the basis for the final game.

4.1 Framework for Game Design

The design and development of the game are rooted in a structured framework that considers both pedagogical and technical requirements. The game "Designer's Den" incorporates concepts from the courses within structural mechanics, transforming them into interactive tasks within the game. This chapter describes the framework used to design the game, including the considerations made to ensure alignment with the course content and the choice of technologies used in the game's development.

4.1.1 Learning Framework

The learning framework of the game is directly tied to the curriculum of the courses within structural mechanics provided at NTNU. It identifies the core learning objectives of the courses and maps them to specific game elements. The game mechanics are designed in a way that allows students to interact with and apply these principles in a simulated environment. The learning framework ensures that playing the game is not just an entertaining activity, but also a means of reinforcing course content and fostering a deeper understanding of the course contents.

4.1.2 Pedagogical Considerations

The game design takes into account key pedagogical principles to ensure that it effectively facilitates learning. These include:

Constructive alignment: The learning objectives, the game tasks, and the assessment tasks are all aligned to ensure that students' engagement with the game helps them achieve the course outcomes.

Active learning: The game encourages students to actively participate in their learning process, rather than being passive recipients of information.

Feedback: The game provides immediate feedback, helping students to identify their mistakes and correct their understanding.

4.1.3 Technical Framework

"Designer's Den" was developed using Angular, a popular web development framework, and TypeScript, a statically typed superset of JavaScript that adds optional types to the language. Angular's robustness and TypeScript's ability to catch errors during development make them an excellent choice for a complex application like an educational game.

KaboomJS was also used as the primary game development library. KaboomJS is a powerful and flexible JavaScript game programming library that simplifies the process of creating games. It offers an assortment of tools and functionalities that make it easier to implement the various game mechanics required in "Designer's Den".

4.1.4 Design Principles

Several key design principles guided the development of the game:

Usability: The game is designed to be user-friendly and intuitive, reducing the learning curve and allowing students to focus on the educational content.

Engagement: The game employs various techniques to engage the students, including a compelling storyline, challenging tasks, and an interactive game environment.

Accessibility: The game is designed to be accessible to all students, regardless of their gaming experience or technical skills.

In summary, the design of "Designer's Den" is guided by a comprehensive framework that integrates pedagogical considerations and technical requirements. The aim is to create a game that not only engages students, but also facilitates their learning of concepts within structural mechanics and statics in an interactive and engaging way.

4.2 Initial game design

The initial game design for "Designer's Den" is a significant step in this project. It lays the foundation on which the rest of the game is built. The design process began with a clear identification of learning objectives and proceeded with the development of a compelling motivation for players to engage with the game. Key game elements were also defined in this initial design phase, determining the structure and interactivity of the game.

4.2.1 Learning Objective

In line with the course TKT4116 Mechanics 1, the following learning objectives were identified for the first level of "Designer's Den":

- Understand fundamental principles of structural mechanics, including forces, moments, and equilibrium.
- Apply the principles of structural mechanics to solve problems involving simple structures.
- Analyze beam structures to determine forces in individual members.
- Design simple structures for specific strength and stability requirements.

These learning objectives form the basis of the game's content. Each challenge has been designed to reinforce these objectives and provide students with an opportunity to apply their knowledge in a practical, albeit simulated, scenario.

4.2.2 Motivation

The motivating factor for students to engage with "Designer's Den" is twofold: the intrinsic motivation to understand and excel in the course material and the extrinsic motivation provided by the game's mechanics and narrative.

Intrinsic motivation is fostered by designing a game that aligns closely with the course content, making it a valuable learning tool (Ryan and Deci 2000). Furthermore, the ability to directly apply learned concepts within the game environment reinforces their relevance, contributing to a deeper understanding. Moreover, the game's structure allows students to see their progress and gain a sense of accomplishment when they master a concept.

The game enhances extrinsic motivation by incorporating a compelling storyline (Ryan, Rigby, and Przybylski 2006). In "Designer's Den," players take on the role of a novice engineer tasked with creating structurally sound designs. Each completed design is a step toward becoming a master engineer, providing an engaging context for the application of the course content. This narrative aspect not only adds an entertaining element, but also instills a sense of purpose and progression, further driving the player's motivation to learn and succeed.

4.2.3 Game Elements

"Designer's Den" consists of various game elements designed to facilitate learning and keep players engaged:

Levels: The structure of the game is organized into several distinct levels. Each level corresponds to a specific course within structural mechanics, featuring a unique set of tasks that require the application of relevant course concepts. The structure of the levels is as follows:

- Level 1: TKT4116 Mechanics 1
- Level 2: TKT4122 Mechanics 2
- Level 3: TKT4132 Mechanics 3
- Level 4: TKT4134 Mechanics 4

Players advance through these levels as they demonstrate their comprehension and ability to apply the concepts associated with each course.

Tasks: Each level comprises a series of tasks that the player is required to complete. The tasks are designed to encourage players to apply the principles of structural mechanics and statics in problem-solving scenarios and the creation of designs.

Feedback: Upon submission of each task, players are presented with feedback that details the quality of their responses. This feedback not only provides an indication of whether the player's answer is within an acceptable range, but also gives access to a proposed solution for correct task submissions, allowing them to explore and understand alternative problem-solving methods.

Theories: The game includes comprehensive theoretical material and example supplements relevant to each task. This educational resource equips players, even those with no prior knowledge in structural mechanics, with the theoretical understanding necessary to progress in the game.

Score: Players earn scores based on their performance in each level. High scores not only represent successful completion, but also demonstrate a thorough understanding of the content. Player performance is evaluated based on the amount of time remaining upon the completion of a level.

Penalty System: To maintain a sense of challenge and encourage accuracy, "Designer's Den" incorporates a soft penalty system. When a player submits an incorrect response to a task, a penalty of 10 seconds is deducted from the total time countdown. This penalty serves as a motivator for players to carefully consider their answers before submission. In addition, it reinforces the importance of accuracy in applying the principles of structural mechanics and statics. It adds an element of pressure and urgency, simulating real-world scenarios where precision and attention to detail are vital.

Reward System: As players successfully complete tasks in "Designer's Den," they are awarded cosmetic points. These points serve as a form of virtual currency that can be accumulated and later exchanged for different cosmetic options. This reward system provides an additional incentive for players to strive for accuracy and completion in their task submissions. It allows players to personalize and customize their in-game experience, fostering a sense of ownership and satisfaction.

Progress Tracker: A progress tracker is included in the game interface, enabling players to visualize their advancement and identify remaining challenges. This feature fosters a sense of achievement and provides clarity on the learning journey ahead.

The initial design of "Designer's Den" blends the pedagogical objectives of the courses within structural mechanics with the appealing features of a game format. By uniting rigorous educational goals with captivating game elements, it forms a conducive learning environment that inspires students to immerse themselves in, and comprehend, the course content.

4.3 Game Concepts

This section elaborates on the game's design process, the variations of concepts considered, and the final concept chosen for the "Designer's Den" game.

4.3.1 Design Process

The design process for "Designer's Den" followed an iterative approach based on agile principles. It commenced by identifying the core learning objectives and aligning them with potential game mechanisms suitable for an educational gaming format. These mechanisms were then visualized through initial sketches and flow diagrams to outline the gameplay structure.

User personas were developed, encompassing students with diverse proficiencies in structural mechanics. This enabled the game to cater to a wide range of players effectively. Wireframes of the game interface were created, and basic prototypes were developed for user testing.

The design process embraced iterative cycles of feedback from potential users and domain experts. This feedback was of great importance in refining the game mechanics, improving the user interface design, and ensuring the alignment of game elements with the intended learning outcomes.

4.3.2 Concept Variations

During the design process, multiple concepts were explored for "Designer's Den." The initial concept revolved around a simulation-based game, allowing players to virtually construct and test their own structures. Another concept emphasized problem-solving, presenting players with mechanics problems framed as real-life scenarios to encourage practical application of their knowledge.

A third concept incorporated a competitive element, inspiring a sense of achievement and providing additional motivation for players. Lastly, a sandbox concept aimed to offer players an open environment for exploration and experimentation with various aspects of structural mechanics.

Each concept brought unique strengths to the educational gaming experience, adding value in different ways.

4.3.3 Elected Concept

The chosen concept for "Designer's Den" integrates elements from the various considered concepts, resulting in a comprehensive and impactful learning experience. The game incorporates a free environment that allows players to personally prioritize within the given boundaries, while also providing access to additional resources for deepening their understanding of key concepts in structural mechanics.

Problem-solving elements are seamlessly woven into the gameplay, presenting players with realistic scenarios that require the practical application of course concepts. This approach not only enhances students' comprehension of the course contents, but also cultivates their problem-solving skills in real-world contexts.

The competitive element is introduced through a scoring system that fosters a healthy level of competition among players, motivating them to improve their understanding and performance. Lastly, the game provides a controlled sandbox experience, granting players the freedom to explore and experiment within the parameters of each level and task.

By integrating these elements, the elected concept ensures that "Designer's Den" delivers an engaging and enjoyable gaming experience while effectively addressing the learning objectives of the courses within structural mechanics.

CHAPTER

FIVE

DESIGNER'S DEN GAME DESIGN

The purpose of this chapter is to provide a comprehensive description of the final design of "Designer's Den," the educational game developed for this study. The chapter begins by giving a detailed description of the game, explaining the game loop, the process of starting a game session, and the experience of playing the game. It also specifies the target audience for the game, which provides a context for its design features and objectives. Subsequently, the chapter discusses the continuation of the game development process, highlighting how the initial design evolved into the final product.

5.1 Game Description

"Designer's Den" is an educational game designed to reinforce the learning of key concepts in the courses within structural mechanics. It offers an interactive environment where players solve tasks related to different levels of structural mechanics, earning scores based on their performance. The game seeks to enhance the learning experience by blending education with an engaging game format, facilitating a deep understanding of the course content.

5.1.1 Game Loop

The game loop of "Designer's Den" is designed to be intuitive and engaging. It starts with the player selecting a level corresponding to the specific mechanics course they wish to tackle. Upon entering the level, the player is presented with a series of tasks related to the chosen course content.

The player is required to solve these tasks using the principles of structural mechanics, gaining points for correct answers. Upon completion of each task, the player receives immediate feedback and can access the correct solutions for further understanding.

After successfully completing all tasks in a level, the player earns a score based on their performance, with high scores indicating a thorough understanding of the content. The player can then choose to move on to the next level or replay the current level to improve their score.

5.1.2 Playing the Game

Playing "Designer's Den" involves progressing through levels by solving a series of tasks. The tasks require the application of structural mechanics principles and may involve calculating unknown parameters or validating designs.

Each task has a description, and players earn points based on their overall speed and accuracy. After each task submission, players receive immediate feedback on their solutions, allowing them to learn and improve continuously.

Players can access theory materials and examples within the game, assisting them in understanding and solving the tasks. They can also access a solution proposal for solved tasks, promoting retrospective learning (Siegler et al. 2002).

5.1.3 Target Audience

The target audience for "Designer's Den" is primarily students enrolled in structural mechanics courses at the university level. The game caters to students of varying proficiencies, from those new to the subject to those seeking to consolidate and extend their knowledge.

However, the game's intuitive design and engaging format also make it suitable for anyone interested in structural mechanics. Whether they are high school students considering a future in structural engineering or professionals seeking a fun way to refresh their knowledge, "Designer's Den" offers an engaging learning experience for all.

5.2 Typical Gameplay and Sequence of Events

This section provides a visual walk through of the "Designer's Den" gameplay, and descriptions of key events and interactions. The figures presented below showcase different stages and features of the game, highlighting its mechanics and flow of gameplay.

The game lobby interface, as shown in Figure 5.2.1, serves as the starting point for players to access different levels and track their progress. Here, players can select the desired level and begin their gaming session.

Figure 5.2.1: Game Lobby Interface

Additionally players can track the performances of all successful game completions through the high score feature shown in Figure 5.2.2. This screenshot showcases the highscore leader board for all of the levels, providing motivation and a sense of achievement for players.

Figure 5.2.2: Game Highscore Interface

When starting the game players are spawned in the starting area. From this point they can move around and explore interactable entities within the game. The elements in the game that are interactable is indicated with a darkened color of the specific element when the position of the avatar is sufficiently close to the element as shown in Figure 5.2.3. This visual cue helps players identify and interact with the relevant elements within the game. This feature adds clarity and intuitiveness to the gameplay, allowing players to seamlessly engage with the interactive aspects of the game world.

Figure 5.2.3: Visual Cue for Interactable Entities

The player is also met with a series of graphical user interfaces such as buttons and displays around the perimeter of the game screen. In the top left corner is a button that navigates the player back to the lobby as seen in Figure 5.2.4. By incorporating the Back button, "Designer's Den" offers players the freedom to manage their gameplay session according to their preferences. It ensures a seamless and user-friendly experience, allowing players to easily navigate between different levels, tasks, and game features.

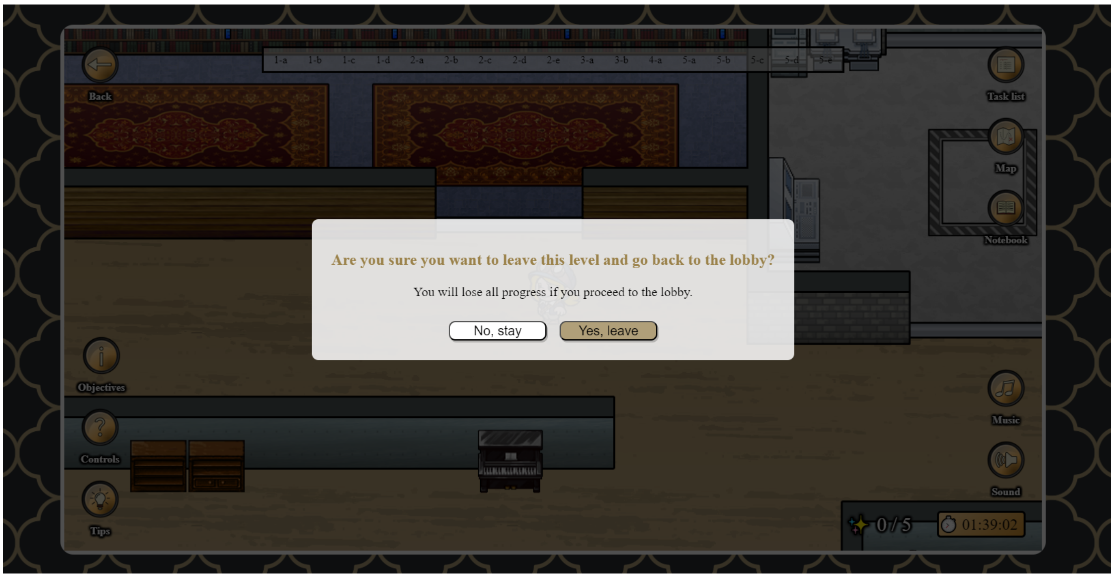
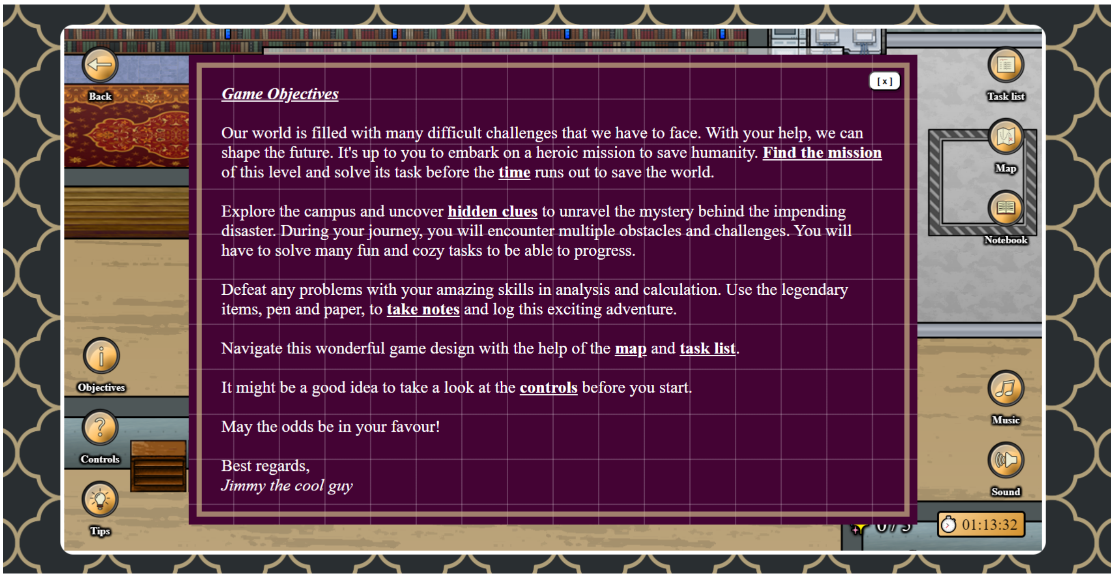
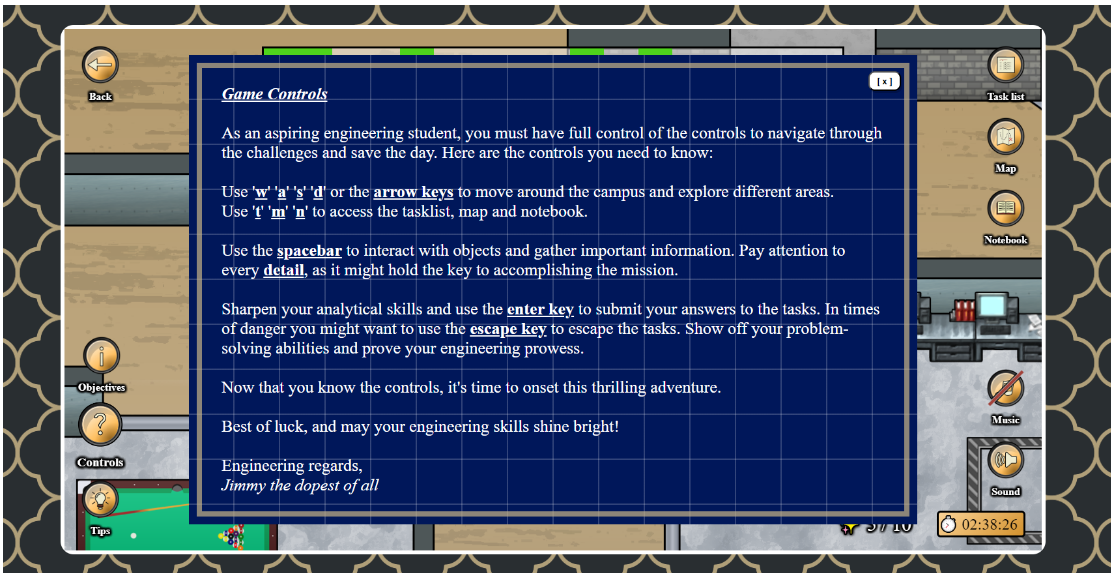


Figure 5.2.4: Back Navigation Interface

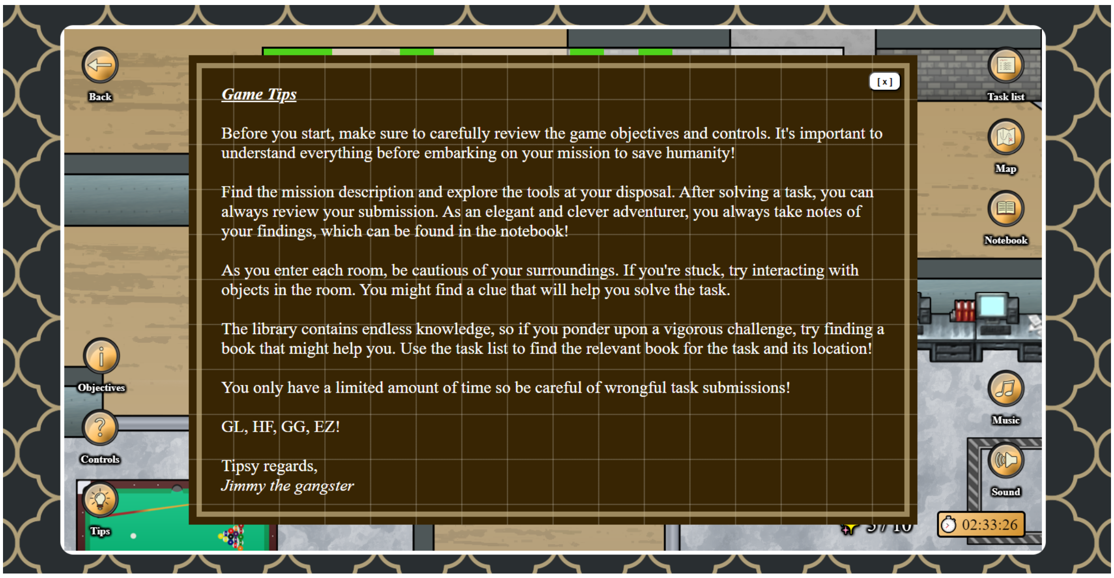
In the bottom left corner are a series of interfaces that helps the player understand the objective and controls of the game as well as providing some tips and hints as seen in Figure 5.2.5.



(a) Game Objectives Interface



(b) Game Controls Interface



(c) Game Tips Interface

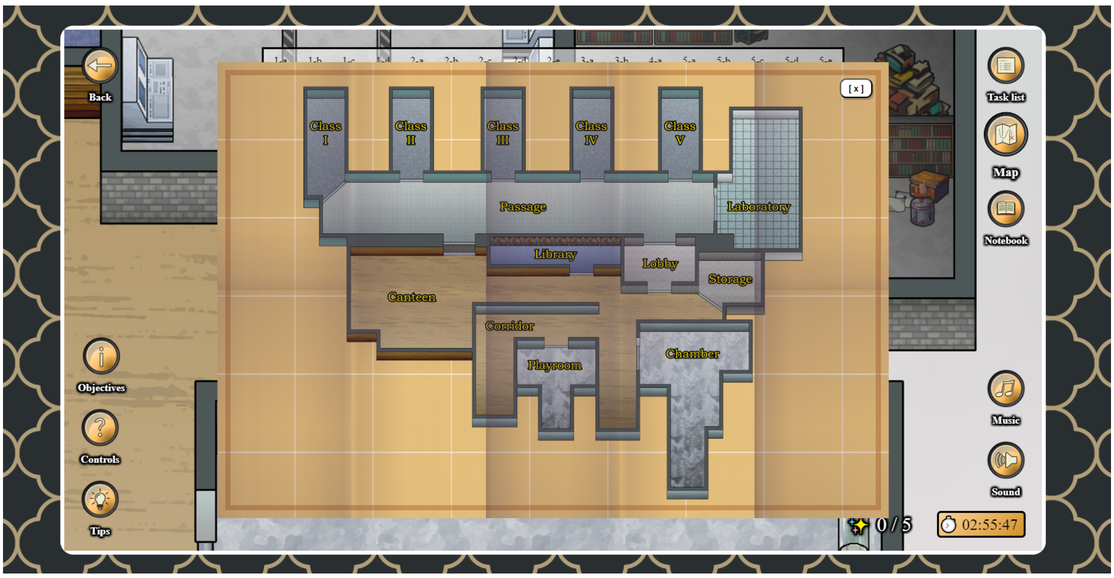
Figure 5.2.5: Support Interfaces

In the bottom right are audio interfaces. The music and sound elements of the game can preferably be muted. In addition the player will see a timer countdown. The performance of the player is measured by how much time is remaining when the game is completed. The player will also see a collection of cosmetic points that can be spent when the number requirement is met.

In the top middle of the game screen is a progressbar where players can see their current progression, solved tasks, and the remaining tasks to conquer.

In the top right corner is a list of the tasks. This list is used to identify available tasks as well as which theory documents to review that are relevant course material to solve this specific task. In addition players will see a map feature that provides an overview of all the locations in the game. These tools are seen in Figure 5.2.6.

(a) Game Objectives Interface



(b) Game Tips Interface

Figure 5.2.6: Game Tools

When playing the game players will use these tools to identify and locate the tasks of a level. Each task comes with a concise description like shown in Figure 5.2.7, providing players with instructions and objectives they need to accomplish. This example showcases a task related to bending deformation of a beam.

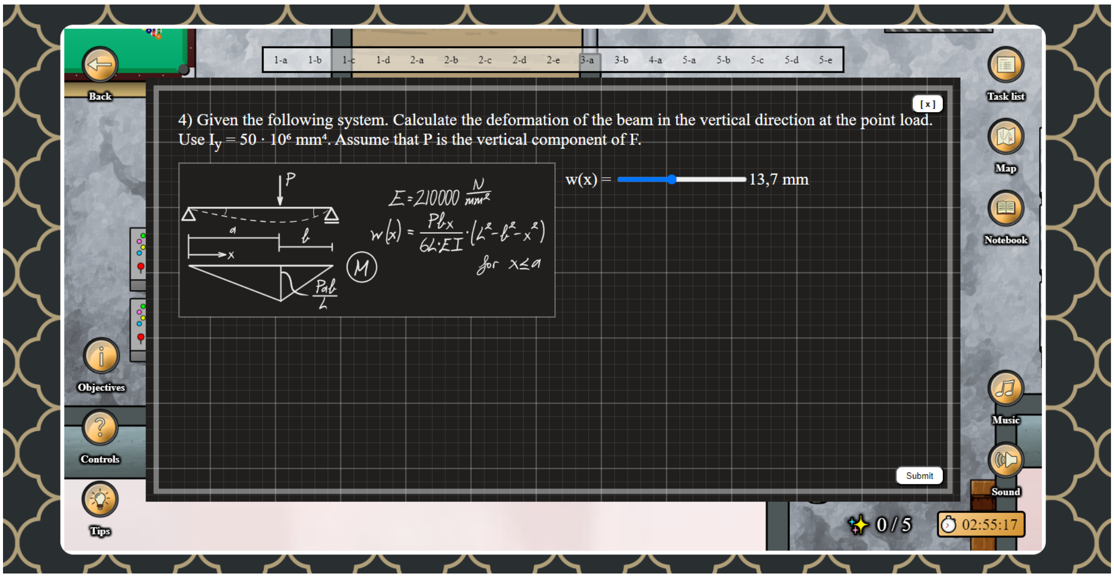


Figure 5.2.7: Task Description

Using the map tool the players can navigate to the correct location and find the hidden task within a room. The task list provides information on the location of the tasks. The task list not only displays the available tasks but also provides information on the corresponding theory documents that are relevant to solving each task. By referencing the theory documents associated with a particular task, players can review the relevant course materials and strengthen their understanding of the underlying concepts necessary to successfully complete the task. An example of a theory document is shown in Figure 5.2.8.

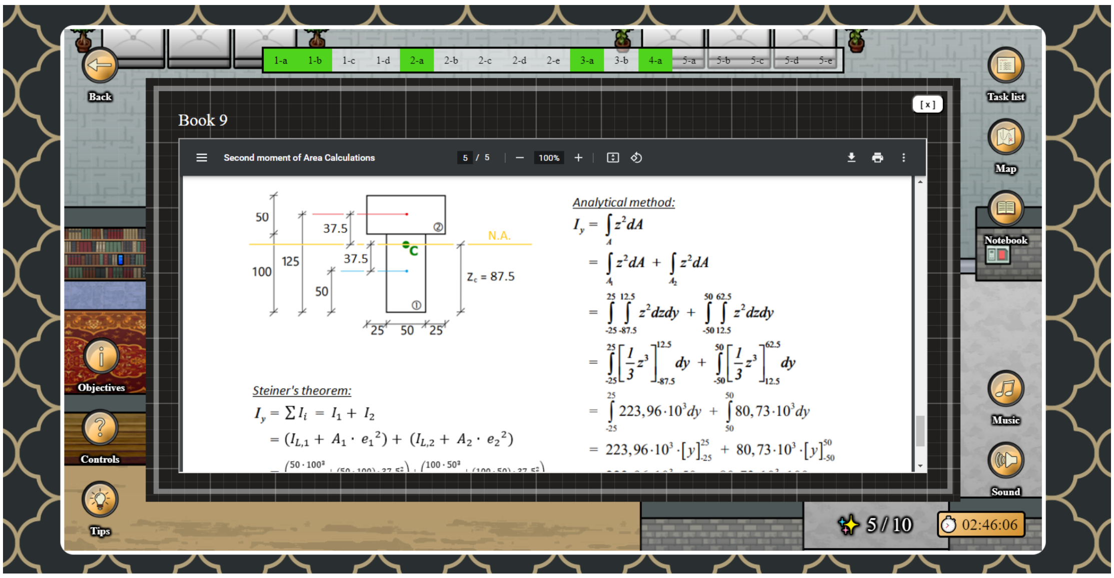
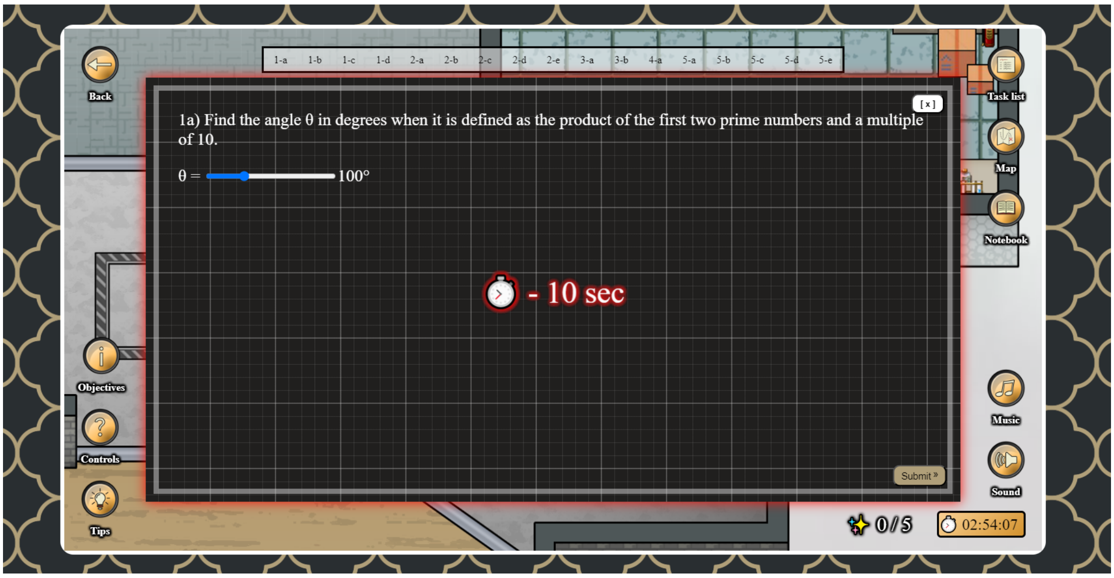


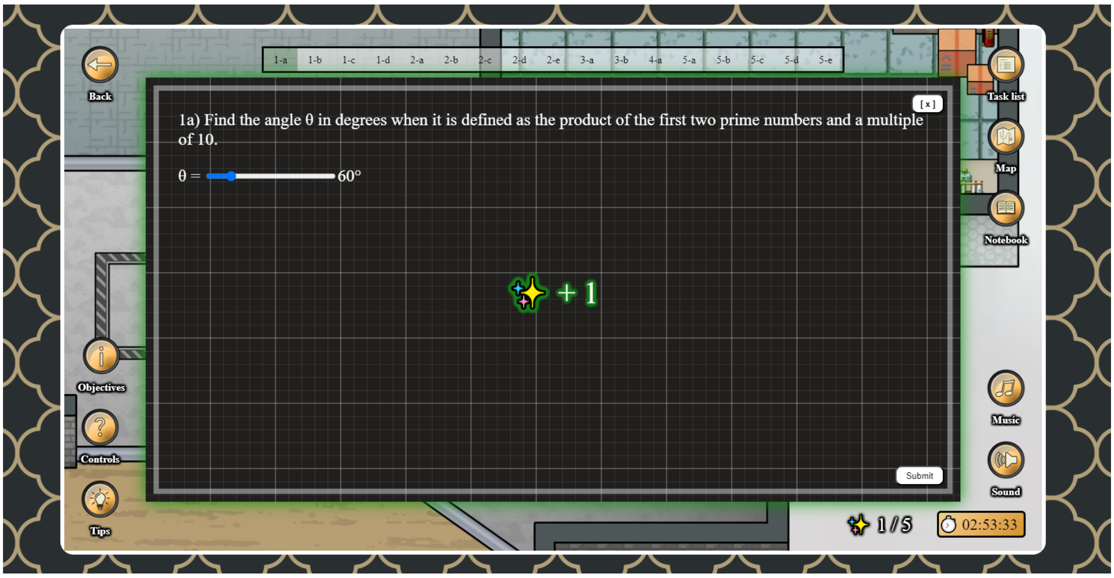
Figure 5.2.8: Book Theories

The game incorporates distinct visual and audio cues to provide immediate feedback to players when they submit an incorrect answer. Upon an incorrect submission, the game responds by deducting 10 seconds from the countdown timer. The countdown timer serves as a means of evaluating player performance and adds an element of challenge and time management to the gameplay experience. This deduction visually reinforces the player's error and emphasizes the importance of accurate task completion within the given timeframe.

When a player submits a correct answer, the game responds with positive visual and audio cues to reinforce their success. In "Designer's Den," a correct submission results in the addition of 1 cosmetic point to the player's account. These cosmetic points allow players to customize their avatar with various cosmetic elements. This system is showcased in Figure 5.2.9.



(a) Incorrect Submission

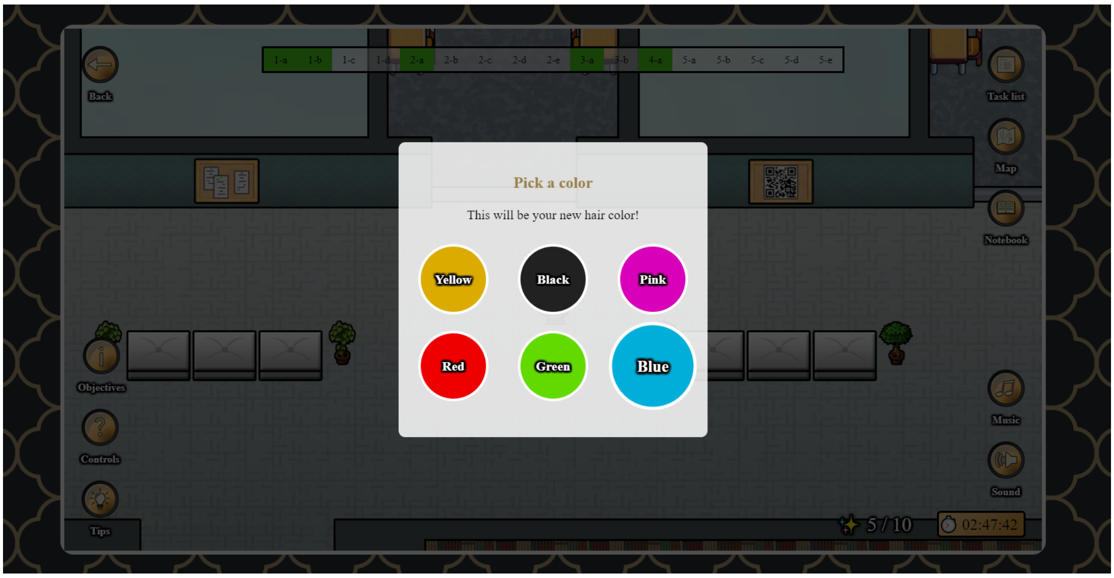


(b) Correct Submission

Figure 5.2.9: Answer Submission Responses

Players have the opportunity to personalize their in-game character through a cosmetic customization system. By accumulating sufficient cosmetic points, players can unlock and choose new cosmetics to enhance the appearance of their character.

The personalization effect of character customization offers players a sense of ownership and individuality within the game. By allowing them to select from a variety of cosmetic options, such as different outfits, accessories, or visual effects, players can tailor their character's appearance to reflect their preferences and personality. This customization aspect adds a layer of personalization and immersion, enabling players to feel more connected to their in-game avatar. The accumulation of cosmetic points as a currency for unlocking new cosmetics creates a sense of progression and achievement. Character customization not only provides a visual appeal but also fosters a sense of self-expression and creativity.



(a) Hair Color Picker Interface

(b) New Cosmetic Avatar

Figure 5.2.10: Cosmetic Options

After a correct task submission, players are not only provided with feedback on the quality of their responses but also gain access to a solution proposal as shown in Figure 5.2.11. This solution proposal can be found in the notebook interface situated in the top right corner and serves as a valuable resource, allowing players to explore and understand alternative problem-solving methods or validate their own approach.

The solution proposal offers players a detailed explanation and step-by-step guide on how to correctly solve the task. It presents alternative approaches and problem-solving strategies, showcasing different paths that can lead to the desired solution. By examining the proposed solution, players can deepen their understanding of the concepts and techniques involved in the task, expanding their knowledge beyond their initial approach.

They have the opportunity to compare their own solution with the proposed solution, identify any gaps in their understanding, and learn from alternative problem-solving approaches. The availability of a solution proposal after a correct submission promotes a supportive and constructive learning environment. It empowers players to independently explore different problem-solving methods, encouraging them to become active learners and enabling them to refine their approach to future tasks.

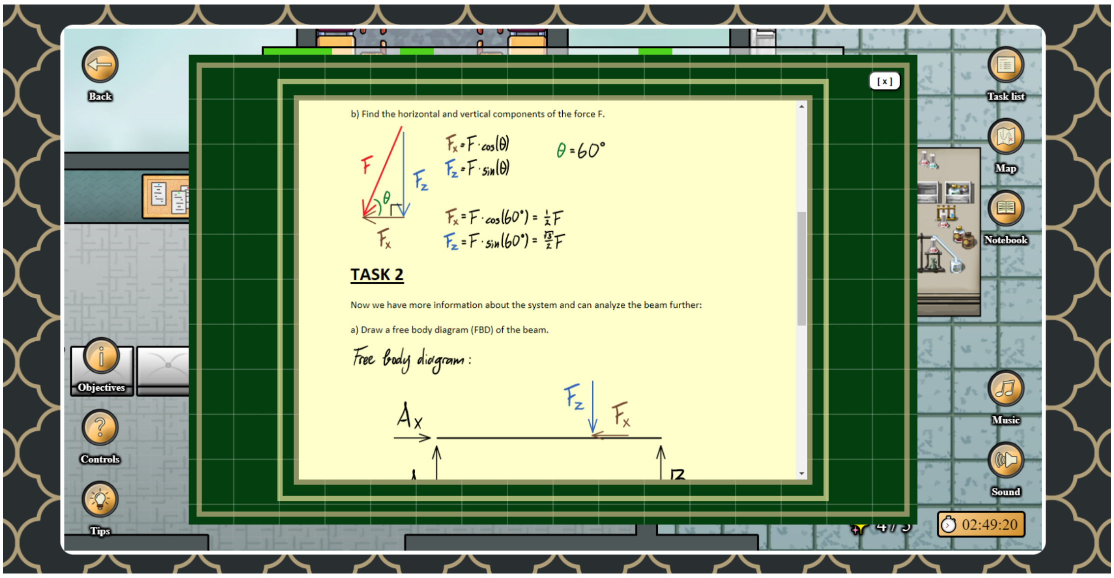


Figure 5.2.11: Solution Proposal Interface

5.3 Continuation of the Game Development

Building upon the initial development progress, this section discusses the plans for continuing the game development of "Designer's Den" beyond Level 1, with the intention of expanding the game to encompass all four levels of the courses within structural mechanics and statics. Additionally, considerations for future scalability and customization of the game's content to accommodate other teachers and professors are addressed.

5.3.1 Level Progression and Content Expansion

The next phase of development for "Designer's Den" focuses on expanding the game to include Levels 2, 3, and 4, corresponding to the TKT4122 Mechanics 2, TKT4132 Mechanics 3, and TKT4134 Mechanics 4 courses, respectively. Each level will introduce new concepts, challenges, and tasks that align with the curriculum of the respective courses.

The content expansion involves designing and implementing a range of engaging tasks and scenarios that provide students with opportunities to apply advanced structural mechanics principles and problem-solving techniques. These tasks will be carefully crafted to ensure progression in difficulty and to reinforce the learning objectives of each course. Feedback mechanisms and solutions will be developed for these new tasks to facilitate self-assessment and further learning.

To maintain consistency in gameplay mechanics and user experience, the design principles and gamification elements established in Level 1 will be carried forward and refined in the subsequent levels. This will ensure a seamless and cohesive learning journey for players as they progress through the game.

5.3.2 Scalability and Customization for Additional Content

One of the primary goals for the continued development of "Designer's Den" is to create a framework that allows for easy scalability and customization of the game's content. This will enable other teachers and professors to integrate their own course materials and create tailored educational experiences within the game.

To achieve this, the game's architecture and codebase will be designed with modularity and extensibility in mind. The use of Angular and Typescript provides a solid foundation for creating modular components and reusable code. By following best practices in software development, such as separating game logic from content-specific data, the application can be easily extended and customized without the need for extensive code modifications.

Additionally, a user-friendly interface will be developed to allow educators to input their own tasks, questions, and solutions into the game. This interface will provide clear guidelines and templates for structuring the content, ensuring that the newly added materials seamlessly integrate with the existing game framework.

By prioritizing scalability and customization, "Designer's Den" aims to empower educators to adapt the game to their specific teaching objectives and incorporate their own course content. This flexibility will enhance the game's long-term sustainability and enable a wider range of educators to leverage the benefits of game-based learning in the field of structural engineering education.

In summary, the continuation of "Designer's Den" involves expanding the game to include Levels 2, 3, and 4 while maintaining consistency in gameplay mechanics. Furthermore, the development process will prioritize scalability and customization, allowing for easy integration of additional content by other teachers and professors.

CHAPTER

SIX

TECHNICAL DESCRIPTION

The purpose of this chapter is to give a technical overview of the game, delving into the system architecture, design patterns, and technologies used in its development. The chapter commences by explaining the system architecture that underpins the game, providing a high-level view of the game's structure and functionality. It then discusses the design patterns utilized, elucidating the strategic decisions made during the game's development. The chapter then delves into the technologies used, splitting the discussion between the client-side and server-side technologies to provide a comprehensive understanding. The development process and implementation are also covered, including the methodology followed and the key stages in implementing the game.

6.1 System Architecture

The system architecture of "Designer's Den" is designed as a single-page application with a server less architecture, meaning all game functionality is processed on the client-side.

Given that the game does not rely on server-side data processing, the application is highly responsive as it reduces the time taken for server communication. This will minimize the potential effects of delay or latency lag tied to a player's action and the server's reaction time. This server less architecture also reduces operational costs and complexity as it eliminates the need for server management and scaling.

The game's structure follows a component-based architecture typical of Angular applications. The game application is divided into distinct functional units, or components, each encapsulating a part of the game's functionality. Each component is self-contained, managing its own view (HTML) and styling (SCSS) and having a corresponding Typescript class handling its behavior.

A significant part of the game's logic is handled by the task service. This service is responsible for retrieving the data for each level (levelOne, levelTwo, etc.), which are separate data structures containing the respective level's tasks. Each game start triggers the task service to fetch the relevant level's data, which is then used to populate the game components, thereby determining the tasks the player faces.

The game also incorporates a highscore functionality, which interfaces with the Google Sheets API. All highscores are stored in a public Google Sheet, which is updated through the API whenever a player achieves a new highscore. This approach allows for a simple and accessible highscore tracking system without the need for a dedicated database.

6.2 Design Patterns

In the development of "Designer's Den", several design patterns were employed to promote code reuse, maintainability, and clarity. Design patterns are typical solutions to common problems in software design, and utilizing them can streamline the development process and facilitate communication among developers.

One prominent design pattern used in "Designer's Den" is the Service pattern. In Angular, services are typically used to share data or functionalities that are required by multiple components. The task service in "Designer's Den", for example, fetches the data for each level and makes it accessible to the various components. By abstracting this functionality into a service, the logic of fetching and sharing level data is centralized, reducing code duplication and enhancing maintainability.

The Singleton pattern is also applied in the case of the task service. The task service is instantiated only once throughout the application, ensuring that all components interact with the same service instance. This singleton property is essential for maintaining consistent level data across all game components.

The Model-View-Controller (MVC) pattern is implicitly used in Angular's architecture which is component-based. Each component in "Designer's Den" has an associated view (HTML), style (SCSS), and class (Typescript). The class acts as the controller, manipulating the model data and updating the view accordingly. The view is separated from the model, only reflecting the current state of the model and allowing for a clear separation of concerns.

By adhering to these design patterns, "Designer's Den" achieves a well-structured and maintainable codebase, paving the way for potential future enhancements and modifications.

6.3 Technology

The development of "Designer's Den" required an array of modern technologies to ensure a responsive, engaging, and accessible web-based game. The chosen technologies aimed to ensure high performance, easy maintainability, and scalability of the game.

6.3.1 Client

The client-side technology stack of "Designer's Den" was carefully selected to ensure a responsive and dynamic user interface, high performance, and maintainability of the game application. The client-side development was centered around Angular, TypeScript, HTML, SCSS, and KaboomJS, each playing a pivotal role in shaping the game experience.

Angular is a powerful JavaScript-based open-source front-end web application framework developed and maintained by Google. Chosen for its component-based architecture, Angular provided the underlying structure for the game, enabling us to build a modular, organized, and scalable application. With Angular, each part of the game interface was developed as an independent, reusable component, promoting code reusability and maintainability. Angular's two-way data binding was an added benefit, keeping the Model and the View in sync at all times, thus providing a seamless user experience.

TypeScript, a statically typed superset of JavaScript, was used for implementing the game's logic. TypeScript was primarily selected for its static typing feature which allows for type checking at compile time rather than at runtime. This not only enhances the robustness of the application but also makes the code easier to understand and debug, given that TypeScript code is generally more predictable and less prone to runtime errors. TypeScript's support for object-oriented programming principles such as classes and interfaces further added to the structural organization of the code.

HTML (HyperText Markup Language) was used to structure the game's content and form the skeletal structure of the game's web pages. It defined the various elements of the game interface and their positioning relative to each other. Given its universal acceptance and support across all web browsers, HTML was the natural choice for building the game's structure.

Styling the game interface and making it visually appealing and responsive was achieved using SCSS (Sassy CSS), a preprocessor scripting language that is compiled into CSS. SCSS extends the capabilities of CSS by introducing features like variables, nesting, mixins, and inheritance, which are otherwise absent in CSS. This dramatically enhances the maintainability and reusability of the styling code, leading to more organized and DRY (Don't Repeat Yourself) CSS.

Lastly, KaboomJS, a JavaScript game programming library, was employed to handle the game-specific elements of "Designer's Den". KaboomJS provides a suite of essential features required for game development such as sprite rendering, a game loop, user input handling, and physics mechanics. Its easy-to-use and intuitive API allowed for the creation of complex game interactions and movements with relative ease.

In conclusion, the client-side technology stack was a carefully curated mix of general-purpose web development technologies and game-specific libraries. This blend allowed us to develop an engaging, performant, and highly interactive game that remains maintainable and scalable.

6.3.2 Server

Since "Designer's Den" is a server-less game, all computations are performed on the client-side, simplifying the game's architecture and reducing potential points of failure. The lack of a traditional server-side does not imply the absence of data storage. Highscores are stored in a public Google Sheet, and this data is interacted with using Google Sheets API. This way, a server-side database is substituted by a more approachable and less resource-intensive solution that seamlessly fits into the game's architecture.

In conclusion, the combination of these technologies allowed for a dynamic, interactive, and responsive game interface, while reducing the complexity associated with a traditional client-server architecture.

6.4 Development

The development of "Designer's Den" was a diligent process, involving careful planning and a rigorous methodology. Both the architecture and the flow of the game were systematically laid out before the development process began, with a clear understanding of the game's objectives and the player's journey.

6.4.1 Methodology

The development methodology employed for "Designer's Den" was an agile-based approach, with iterative development cycles and regular feedback loops. This allowed for continuous improvement and adaptation throughout the development process, ensuring that the final product was in line with the project's goals and user expectations.

Initially, a comprehensive development plan was laid out, detailing the tasks to be accomplished in each development cycle. These tasks were prioritized based on their impact on the game's functionality and user experience. Each development cycle, or sprint, typically lasted two to three weeks and ended with a thorough testing and review phase. This allowed for quick identification and rectification of any issues, thereby ensuring a high-quality product.

In addition, regular meetings were held to discuss the progress of the project, any challenges faced, and potential improvements. This collaborative approach fostered a dynamic and flexible development environment, facilitating quick decision-making and problem-solving.

6.4.2 Implementation

The implementation of "Designer's Den" was centered around the principles of modularity, scalability, and maintainability. As mentioned earlier, the game was built using Angular's component-based architecture, where each part of the game interface was developed as an independent, reusable component. This not only allowed for a high degree of code reuse but also made the application easier to maintain and extend (de Boer and van Vliet 2009).

TypeScript was used to implement the game's logic, with its static typing feature contributing to the robustness and predictability of the code. The game elements were rendered using KaboomJS, allowing for complex game interactions and movements.

The task service was responsible for fetching the correct level data for each game session. All game data, including the tasks and levels, were stored in separate JSON files. The task service would load the relevant data based on the current game level, ensuring a smooth and dynamic game experience.

The highscore functionality was implemented through integration with the Google Sheets API. All the high scores were stored in a public Google sheet, allowing for easy access and update of the data.

In summary, the implementation of "Designer's Den" was a well-orchestrated process, involving a range of technologies and a flexible development methodology. This careful and systematic approach ensured that the game was not only engaging and enjoyable but also robust and maintainable.

CHAPTER

SEVEN

EVALUATION OF THE GAME

The purpose of this chapter is to provide a detailed analysis of the evaluation results from the game testing sessions and follow-up interviews. This compromises a summary of participant feedback, the usability, challenge, and engagement of the game, and suggestions for future development. We will discuss the observations made during the gaming sessions and analyze the participants' feedback, aiming to identify the game's strengths and potential areas for improvement.

7.1 Purpose

The primary purpose of the evaluation was to assess the effectiveness and appeal of the game 'Designer's Den' as an instructional tool for teaching structural mechanics. Based on the experiences and input from a broad set of users, the evaluation was created to gauge the game's usability, task difficulty level, engagement factor, and customization options.

In more specific terms, we aimed to understand:

- How intuitive and user-friendly the game interface and mechanics are.
- Whether the tasks posed in the game are appropriate in terms of difficulty and relevance to the content.
- The level of engagement the game fosters, and if the customization options add value to the gaming experience.
- The extent to which the game could enhance learning and comprehension of structural mechanics.
- Any potential improvements or modifications that could be implemented to improve the game, based on user feedbacks and suggestions.

The evaluation procedure and subsequent feedback from the participants are vital in guiding the future development and refinement of 'Designer's Den'. Through this procedure, we aspire to create a game that is not only entertaining to play, but also serves as an effective learning aid for structural mechanics.

7.2 Participants

In the evaluation of the game, a diverse group of participants within engineering disciplines was selected to ensure a wide range of experiences and perspectives.

The participants have the following profiles:

- Associate Professor within Conceptual Structural Design
- Associate Professor within Structural Dynamics
- Master Graduate within Energy and Environmental Engineering
- 5th year Student within Fire Safety Engineering
- 4th year Student within Geotechnical Engineering
- Bachelor Graduate within Chemical Engineering
- 3rd year Student within Structural Engineering
- 2nd year Student within Civil and Environmental Engineering
- 1st year Student within Mechanical Engineering

We ensured that all participants had a basic understanding of general mathematics and physics, so they could meaningfully engage with the game's tasks and challenges. Each participant volunteered their time to engage in the gaming session and follow-up interview. Their input provided valuable insights into the effectiveness of 'Designer's Den' and the potential improvements that could be implemented in future iterations of the game.

7.3 Evaluation Procedure

The evaluation procedure was conducted in two main parts: a gaming session and a post-game interview session. This dual-phase approach was designed to provide a comprehensive understanding of the participants' experiences and perceptions of the game. Furthermore, the gaming session and the follow-up interview were designed to be complementary, with the practical gameplay influencing the thoughtful observations provided during the interview. Participants were able to provide specific instances and in-depth insights during the interview by actively participating in the game, which improved the evaluation results. The order of the game and interview sessions also made it possible for direct, honest criticism to be given while the participants' memories of the experience were still recent.

7.3.1 Gaming Session

In the gaming session, each participant was given access to the 'Designer's Den' game and requested to play it for a duration of three hours. This duration was chosen to give participants sufficient time to familiarize themselves with the game mechanics, navigate the game environment, and explore the contents.

The three-hour gaming session was intended to simulate the realistic scenario of a student using the game as a self-paced study tool to summarize and test their knowledge within the course. This timeframe was also appropriate for capturing any initial difficulties or hurdles a player might face, as well as for observing how they overcome such challenges and adapt to the game environment under time pressure.

7.3.2 Interview Session

Participants were asked to conduct a post-game interview after the gaming session. The interview, which was carried out through a survey, was created to collect thorough and unique feedback about the participants' experiences with the game "Designer's Den".

The survey contained a mix of multiple-choice and open-ended questions, focusing on various aspects such as the game's usability, task difficulty, level of engagement, character customization, and overall enjoyment. It also sought participants' views and suggestions for improving the game.

Combining the gaming session with the post-game interview allowed for a comprehensive evaluation, enabling us to gain insight into the participants' individual reflections, perceptions, and suggestions for the game.

7.4 Results

This section outlines the key findings from the evaluation process, which included both observations made during the gaming session and feedback received from the post-game interview.

7.4.1 Gaming Session Observations

Several observations were made about how players interacted with "Designer's Den" during the gaming session. Most participants were able to grasp the game's controls and mechanics after initial exploration and experimentation. The notebook tool and the task list as well as the map were frequently used by the participants, indicating their importance in the gameplay.

During the gaming session, several observations were made about how participants interacted with 'Designer's Den'. Most participants were able to grasp the game's controls and mechanics after initial exploration and experimentation. The notebook tool and the task list were frequently used by the participants, indicating their importance in the gameplay.

The difficulty of tasks was varied, with some tasks being completed quickly while others proving more challenging. The game's timer mechanism was effective in driving urgency and promoting efficiency among players, as well as adding a competitive element to the gaming experience. The participants demonstrated creativity and critical thinking in their task approaches and solutions, and used the notebook actively to study alternative ways to solve a task.

7.4.2 Interview Feedback

The feedback from the post-game interviews provided valuable insights into the players' experiences and perceptions of the game. Generally, the response towards 'Designer's Den' was positive, with participants appreciating the integration of sound effects and the exploratory elements of the game. They also expressed enjoyment in the game's comedic and creative aspects.

Participants agreed that the game was a fun and engaging way to learn about structural mechanics. The tasks were viewed as effective tools for self-assessment, and the educational content provided in the game's library was deemed helpful. Participants appreciated the high-score system and the competitive edge it added to the game.

However, some areas for improvement were identified. The ability to have the notebook and task open simultaneously was a frequent suggestion, as participants found it inconvenient to switch between these two features during tasks. Another frequent suggestion was to show the players' location relative to the map as an active pointer to further enhance the experience of orientation and navigation within the environment of the game. Also, further customization options for avatars were suggested.

Overall, the evaluation results provided constructive feedback and important insights for improving and refining 'Designer's Den'.

7.5 Discussion

The following discussion reflects on the findings of the evaluation process, addressing several aspects of the game's design, execution, and overall experience. These observations provide insights into the game's effectiveness as a learning tool and its impact on participants' engagement with the course subject. Furthermore, these insights contribute to the broader discussion on the integration of gaming elements in educational contexts, particularly in the field of structural engineering.

7.5.1 Usability

Overall, the usability of 'Designer's Den' was well-received by the participants. After initial exploration, the game mechanics and objectives were understood, and participants were able to navigate the game environment effectively. However, feedback suggests that the player position relative to the map tool could be added to cater for even smoother gameplay.

7.5.2 Difficulty

The range in task difficulty was appropriate, challenging participants while keeping the game engaging. Participants noted that certain tasks were more difficult than others, which could be beneficial in promoting learning and encouraging players to utilize available resources. However, the theory materials provided within the game helped bridge the potential knowledge gaps to ensure solvability of the tasks. While accessing these materials, the participants were highly likely to encounter and learn about other relevant concepts while looking for knowledge to solve a specific task. The game's difficulty, however, should be continuously calibrated to ensure it aligns with the target demographic's skill level.

7.5.3 Engagement and Customization

The game's competitive aspects, dynamic setting, and sound effects were successful in keeping participants engaged. Participants considered the learning experience refreshing compared to traditional educational settings because of the charming and creative components in the game that helped make it distinctive and fun. More character customization possibilities were requested, which might increase player connection and involvement with the game.

7.5.4 Proposed Changes

Participants' suggestions for improvement have provided valuable insights for future updates and enhancements of 'Designer's Den'. Implementing a reactive visualization of the player position relative to the map could optimize for a better navigation experience within the game. Other suggestions, such as increased avatar customization and a short game tutorial to help players quickly understand the game elements and get started, can enhance the overall player experience.

Overall, the feedback and observations gathered from the evaluation process indicate that 'Designer's Den' has been successful in delivering an engaging and educational experience. However, there are several areas where the game can be refined and further improved, ensuring it continues to meet the needs and preferences of its players while maintaining its educational objectives.

7.5.5 Technical Requirements and Compatibility

In light of the evaluation process, it became apparent that some technical aspects of the game had an impact on the participant's experience. The diversity of devices used by participants, each with varying processing power and graphics capabilities, introduced a layer of complexity to the game's performance and overall playability. Some participants reported experiencing dropped frame rates during movements and prolonged loading times when interacting with certain elements of the game. These instances have made it evident that device specifications significantly influenced the gaming experience. This varied experience underscores the importance of optimizing the game to cater to a broader range of system specifications, thus ensuring a seamless experience for every player (M. Claypool and K. Claypool 2006).

Further considerations need to be taken into account to improve the game's compatibility across various devices and operating systems, thus enhancing its accessibility to a broader audience. This includes factors such as device screen size, resolution, frame rates, and operating system compatibility. It is important to note that the technical requirements should not become a barrier for the player to engage with the game, which is meant to serve as a learning tool. As a result, future developments could consider incorporating scalable graphics or different gameplay modes suitable for varying system capabilities.

Evidently, the technical requirements and compatibility of the game play a crucial role in its overall effectiveness as an educational tool. A thoughtful approach to these considerations not only contributes to a smoother gameplay experience, but also broadens the game's reach, ultimately enhancing its potential impact on structural engineering education.

CHAPTER

EIGHT

CONCLUSION

The purpose of this chapter is to encapsulate the entirety of the research, presenting a comprehensive summary of the findings and their implications, and offer reflections on the study as a whole. The chapter begins by summarizing the key insights drawn from the development process and evaluation of the educational game. It then discusses how the game addresses the initial problem statement and the research questions posed at the outset of the study. Finally, the chapter considers potential future directions for this work, including potential improvements and new avenues for exploration based on the results obtained.

8.1 Revisiting the Research Questions

In this section, the three primary research questions posed at the beginning of the study are revisited. Through the development, implementation, and evaluation of "Designer's Den", these questions are addressed.

8.1.1 RQ 1: Implementation of Game-Based Learning in Structural Engineering Education

The first research question explored how game-based learning could be effectively implemented in the domain of structural engineering education. In response, the study saw the design and development of "Designer's Den", an application that integrated key elements of structural mechancis within a game-based environment.

This game was developed with a clear objective: to supplement traditional teaching methods and improve the understanding of complex concepts by delivering them in an engaging, interactive manner. Throughout the game, players were engaged with tasks that required them to apply structural engineering principles, allowing for a contextualized learning experience that was both educational and enjoyable.

Each game element, from the mechanics to the storyline, was thoughtfully designed to serve a pedagogical purpose. For instance, the challenges within the game required the player to understand and apply knowledge of forces, moments, equilibrium, fostering a deeper comprehension of these concepts than might be achieved through traditional teaching methods alone.

Furthermore, the game employed a component-based architecture, ensuring modularity, scalability, and maintainability. This approach allowed each part of the game interface to function as an independent, reusable component, facilitating a high degree of code reuse and making the game easier to maintain and extend.

Through the successful development and deployment of "Designer's Den," the study has effectively demonstrated a viable strategy for integrating game-based learning within the realm of structural engineering education. The game has provided a model of how engaging gameplay and serious educational content can coexist to create a valuable learning tool that both teaches and captivates students.

8.1.2 RQ 2: Effectiveness of Game-Based Learning Tool

The second research question was concerned with assessing the effectiveness of the game-based learning tool in fostering understanding and retention of structural engineering concepts. To address this, a comprehensive evaluation was carried out using multiple assessment methods, including player feedback and engagement metrics.

Player feedbacks were highly encouraging. Students reported that the game-based learning experience was enjoyable and beneficial, noting that the application of theory in a practical, game-based context provided a greater understanding of structural engineering concepts. They particularly appreciated the ability to learn at their own pace and the immediate feedback provided by the game, which facilitated self-assessment and iterative learning. In addition, they appreciated the theory materials within the game, noting it contributed to a comprehensive understanding of relevant topics.

The engagement metrics, captured during the gameplay sessions, also painted a positive picture. High rates of game completion and repeated attempts at solving in-game challenges suggested a high level of student engagement and commitment. These findings are in line with the premise that the game-based learning environment, by virtue of its interactivity and immediate feedback, is conducive to sustained engagement.

Collectively, the results from these assessments provide a strong validation of the game-based learning tool's effectiveness. They demonstrate that the game "Designer's Den" was not only successful in engaging students but also successful in improving their understanding and retention of complex structural engineering concepts.

8.1.3 RQ 3: Student Perceptions of Game-Based Learning Tool

The third research question aimed to understand student perceptions towards the game-based learning tool and its integration into the structural engineering curriculum. To answer this question, feedback was collected through post-gameplay surveys and interviews.

Overwhelmingly, the student response towards the game was positive. Many participants reported that the interactive, engaging nature of the game enhanced their learning experience. They valued the innovative approach to learning, noting that the game clarified abstract concepts and made learning more enjoyable.

In addition to recognizing the educational benefits, students also appreciated the game's design and user experience. They praised the intuitive interface, engaging storyline, and the inclusion of real-world engineering problems. These features, they indicated, made the game not only a valuable learning tool but also a compelling gaming experience. Furthermore, students consistently expressed that this innovative approach to learning provided a refreshing and stimulating shift from conventional educational environments

However, it wasn't all without criticism. Students provided constructive feedback, offering suggestions for further improving the game. Some students expressed a desire for more complex challenges and an expanded storyline. Others recommended the incorporation of collaborative elements to promote teamwork and cooperative problem-solving. These comments indicate that while the game was well-received, there are opportunities for enhancement to further enrich the learning experience.

Overall, student perceptions towards the game-based learning tool were positive, reinforcing the potential value of such tools in education. The feedback provides insights into students' preferences and expectations, which are invaluable for the ongoing improvement and evolution of the game.

8.2 Contributions and Implications

The development and successful implementation of "Designer's Den" serve as a significant contribution to the field of structural engineering education. The game-based learning tool presented in this research offers a novel and effective approach to facilitate understanding of complex engineering concepts, bridging the gap between abstract theories and real-world applications. It lays a foundation for educators and researchers to further explore and improve upon the use of such interactive tools in their educational strategies.

8.2.1 Contribution to Structural Engineering Education

The game "Designer's Den" introduces a new dimension to the pedagogical methods used in structural engineering education. The game's ability to make abstract concepts tangible, to promote active engagement, and to encourage self-paced, iterative learning make it a valuable addition to the array of educational resources.

Furthermore, the game's success in enhancing student comprehension and retention of structural engineering concepts signifies its potential as a complementary tool to traditional teaching methods. The overwhelmingly positive reception by students, along with their performance improvements, supports the assertion that this approach could reshape how complex concepts are taught in this field. It paves the way for further adoption and development of game-based learning tools in structural engineering and, potentially, other areas of engineering education in general.

8.2.2 Implications for Game-Based Learning

This project reinforces the potential of game-based learning (GBL) as an effective pedagogical approach in higher education, particularly in domains characterized by complex, abstract concepts such as structural engineering. The success of "Designer's Den" serves as evidence of the practicality and effectiveness of GBL, suggesting that this approach can indeed facilitate learning, increase student engagement, and improve educational outcomes.

The research also illustrates that GBL can offer a high degree of versatility. The game's success across a diverse student body suggests that it can cater to a variety of learning styles and paces, a key advantage of GBL. This versatility, combined with the inherent engagement and interactivity of games, highlights the potential of GBL to address some of the common challenges in education, such as maintaining student motivation and facilitating student understanding of complex concepts.

8.2.3 Potential Impact on Teaching Practices

The project's findings could potentially have a transformative impact on teaching practices in structural engineering and other similar disciplines. The demonstrated effectiveness of "Designer's Den" provides educators with a compelling case for integrating GBL tools into their teaching strategies.

The game not only serves as a valuable resource for independent learning but could also be used as an adjunct tool in classrooms to complement lectures and traditional problem-solving exercises. This could enhance classroom interactivity and engagement, making learning a more dynamic, immersive, and enjoyable experience.

In addition, the project underscores the importance of continuous feedback in learning. The instant, detailed feedback offered by the game was highly appreciated by the students, indicating a clear demand for such features in educational tools. This points towards the need for a shift from one-size-fits-all feedback mechanisms towards more personalized, immediate, and iterative feedback systems in education.

8.3 Reflections on the Game Development and Evaluation Process

The process of creating and assessing "Designer's Den" has been an enriching and informative journey. This section encapsulates the experiences and lessons accumulated from the development and evaluation phases, providing an overview of the challenges encountered, the achievements realized, and the insights gained throughout this project.

8.3.1 Design and Development Phase

The design and development of "Designer's Den" was an engaging and insightful process, providing a deeper understanding of the intersection between pedagogy and technology. One of the key challenges faced during this phase was translating abstract engineering concepts into game mechanics that would be both educational and engaging. Addressing this required a careful balance between maintaining the academic rigour of the content and creating a gaming experience that would hold students' interest.

Incorporating user-friendly design and intuitive navigation also emerged as crucial considerations. Ensuring that the game was easily accessible to students of all backgrounds and levels of gaming experience was a central goal during its development. The implementation of a component-based architecture using Angular greatly facilitated this, allowing for a highly modular and scalable design.

Ultimately, the design and development phase served as a testament to the iterative nature of game creation. It underlined the importance of continuous refinement and testing in creating a game that was both functional and enjoyable.

8.3.2 Evaluation Phase

The evaluation phase provided a wealth of valuable insights into the game's performance and effectiveness as a learning tool. Utilizing a combination of questionnaires and user feedback proved to be a successful approach, allowing for both quantitative and qualitative assessment of the game.

Perhaps the most rewarding part of the evaluation phase was witnessing the enthusiasm and engagement of the students during gameplay. The high degree of interaction and the overall positive feedback provided validation for the game's design principles and the pedagogical approach adopted.

However, the evaluation phase also shed light on areas for improvement, such as optimizing game performance across different device specifications and enhancing certain aspects of the user interface. This feedback is invaluable for the future refinement of the game.

8.3.3 Lessons Learned

The development and evaluation of "Designer's Den" offered several important lessons. The first is the centrality of user-centered design in the development of an effective learning tool. Taking into account the needs, preferences, and feedback of the end users, who in this case are the students, is crucial for creating a tool that not only educates but also engages.

The second key lesson is the importance of balancing education and engagement in a game-based learning tool. While the primary aim is to facilitate learning, maintaining an engaging and enjoyable gaming experience is equally vital to ensure continued usage and motivation.

Finally, this project reiterated the importance of iteration in the development of such tools. Continuous refinement, based on regular testing and feedback, is key to developing a product that successfully meets its educational goals and provides an enjoyable user experience.

8.4 Future Work

Having embarked on the journey of creating and evaluating "Designer's Den", the potential for further expansion and refinement in this field becomes evident. This section outlines potential future directions for the improvement and optimization of the game and for broader research within the context of game-based learning in structural engineering education.

8.4.1 Game Improvement and Optimization

While "Designer's Den" has proven to be effective and engaging, there is always room for improvement and optimization. One of the key areas of focus could be enhancing the game's performance across different device specifications to ensure a seamless and smooth gaming experience for all players. Additionally, the game could aim to be more inclusive by catering to a wider range of learning styles, thereby bolstering its role as a universally accessible educational tool.

Further work could be undertaken to augment the user interface based on user feedback, making it even more intuitive and user-friendly. Additionally, the scope of the game could be expanded to encompass more complex or diverse engineering problems, thereby extending the range of concepts that students can engage and interact with.

8.4.2 Further Research

The development of "Designer's Den" and the positive results from its implementation open up several ares for further research. There is potential for a more detailed analysis of the impact of specific game elements on learning outcomes and engagement. For example, future research could focus on identifying and determining which elements of gamification most effectively facilitate learning in this context.

There is also the potential for exploring how game-based learning tools like "Designer's Den" could be adapted or expanded for other areas of engineering education, or even other disciplines entirely. Such research could contribute to a more comprehensive understanding of the strengths and limitations of game-based learning, paving the way for more widespread and effective use of this educational strategy.

By building upon the foundations laid by this project, future work has the potential to further advance the field of game-based learning in education and contribute to innovative pedagogical practices.

8.5 Final Remarks

As we conclude this journey, it is important to reflect on the potential of game-based learning in structural engineering education. The success of "Designer's Den" demonstrates the ability of this innovative educational approach to bridge the gap between abstract theoretical concepts and tangible real-world applications. It provides a testament to the capacity of games to create a more engaging, interactive, and effective learning experience.

The feedback from students and the results obtained from the study affirm the potential of game-based learning not only to complement traditional educational methods, but also to introduce a new dimension to how complex subjects can be taught and learned. The game has shown that it can enhance learners' understanding, foster active engagement, and facilitate self-paced and iterative learning.

Despite the accomplishments of this research, it is important to remember that game-based learning, like any educational tool, is not an independent elixir that should be used isolated. It should be used in conjunction with other teaching methods, considering the unique needs and learning styles of students. Moreover, while "Designer's Den" is a step forward, there is always room for improvement and evolution in its design and implementation.

In the future, it is hoped that more research will be conducted in this area, with a focus on improving the game's accessibility, its performance on different devices, and adding more complex scenarios or topics. It would also be interesting to explore the long-term impact of using such a tool on students' performance and interest in the field of structural engineering.

In conclusion, this project has made strides in highlighting the potential benefits of game-based learning in structural engineering education. It is hoped that "Designer's Den" serves as a stepping stone for further innovations in this field, fostering a more engaging, effective, and enjoyable learning experience for students worldwide.

REFERENCES

[1] Claypool, Mark and Claypool, Kajal. "Latency and Player Actions in Online Games". In: *Commun. ACM* 49.11 (2006), pp. 40–45. ISSN: 0001-0782. DOI: 10.1145/1167838.1167860. URL: https://doi.org/10.1145/1167838.1167860.

[2] Connolly, Thomas M. et al. "A systematic literature review of empirical evidence on computer games and serious games". In: *Computers & Education* 59.2 (2012), pp. 661–686. ISSN: 0360-1315. DOI: https://doi.org/10.1016/j.compedu.2012.03.004. URL: https://www.sciencedirect.com/science/article/pii/S0360131512000619.

[3] de Boer, Remco C. and van Vliet, Hans. "On the similarity between requirements and architecture". In: *Journal of Systems and Software* 82.3 (2009), pp. 544–550. ISSN: 0164-1212. DOI: https://doi.org/10.1016/j.jss.2008.11.185. URL: https://www.sciencedirect.com/science/article/pii/S0164121208002574.

[4] Felder, Richard and Brent, Rebecca. "Understanding Student Differences". In: *Journal of Engineering Education* 94 (Jan. 2005). DOI: 10.1002/j.2168-9830.2005.tb00829.x.

[5] Kapp, Karl M. *The gamification of learning and instruction: Game-based methods and strategies for training and education.* John Wiley & Sons, Jan. 2012. ISBN: 9781118096345.

[6] Kiili, Kristian. "Digital game-based learning: Towards an experiential gaming model". In: *The Internet and Higher Education* 8.1 (2005), pp. 13–24. ISSN: 1096-7516. DOI: https://doi.org/10.1016/j.iheduc.2004.12.001. URL: https://www.sciencedirect.com/science/article/pii/S1096751604000776.

[7] Magin, D. and Kanapathipillai, S. "Engineering Students' Understanding of the Role of Experimentation". In: *European Journal of Engineering Education* 25 (Dec. 2000), pp. 351–358. DOI: 10.1080/03043790050200395.

[8] Mayer, Richard. "Applying the Science of Learning: Evidence-Based Principles for the Design of Multimedia Instruction". In: *The American psychologist* 63 (Dec. 2008), pp. 760–9. DOI: 10.1037/0003-066X.63.8.760.

[9] Ryan, Richard M. and Deci, Edward L. "Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions". In: *Contemporary Educational Psychology* 25.1 (2000), pp. 54–67. ISSN: 0361-476X. DOI: https://doi.org/10.1006/ceps.1999.1020. URL: https://www.sciencedirect.com/science/article/pii/S0361476X99910202.

[10] Ryan, Richard M., Rigby, C. Scott, and Przybylski, Andrew. "The Motivational Pull of Video Games: A Self-Determination Theory Approach". In: *Motivation and Emotion* 30.4 (2006), pp. 347–363. ISSN: 0146-7239. DOI: 10.1007/s11031-006-9051-8. URL: https://link.springer.com/article/10.1007/s11031-006-9051-8.

[11] Siegler, Robert S et al. "Microgenetic studies of self-explanation". In: *Microdevelopment: Transition processes in development and learning* (2002), pp. 31–58.

APPENDICES

A - GITHUB REPOSITORY

The codebase for "Designer's Den" is included in the Github repository linked below. Further explanations are given in the Readme-file within the repository.

Github Repository Link

- `https://github.com/JiLuong/Thesis`

B - THEORY DOCUMENTS

GENERAL MATHEMATICS

Book 1

Designer's Den

Contents

Numbers

- Whole Numbers: These include all the natural numbers along with the number 0: 0, 1, 2, 3, 4, 5, ...
- Integers: Integers include both positive and negative whole numbers along with zero: ..., -3, -2, -1, 0, 1, 2, 3, ...
- Rational Numbers: Rational numbers are numbers that can be expressed as fractions, where the numerator and denominator are integers. Examples include 1/2, -3/4, 5/6, etc.
- Irrational Numbers: Irrational numbers cannot be expressed as fractions and have non-repeating, non-terminating decimal representations. Examples include √2 (square root of 2), π (pi), and e (Euler's number).
- Even Numbers: These are the numbers that are divisible by 2, resulting in no remainder when divided by 2. Examples include -4, -2, 0, 2, 4, ...
- Odd Numbers: These are the numbers that are not divisible by 2, resulting in a remainder of 1 when divided by 2. Examples include -3, -1, 1, 3, 5, ...
- Prime Numbers: Prime numbers are positive integers greater than 1 that have no divisors other than 1 and itself. Examples include 2, 3, 5, 7, 11, ...

Digital mathematical functions

Common practices:

Decimal separator: Dot

Angles: Degrees

Sine of an angle: sin(angle)

Cosine of an angle: cos(angle)

Tangent of an angle: tan(angle)

Square root of a number: sqrt(num)

Absolute value of a number: abs(num)

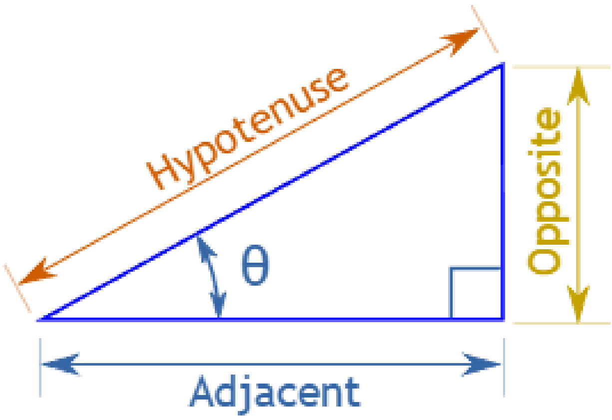
Trigonometry

For right-angled triangles:

$$\sin\theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\cos\theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$\tan\theta = \frac{\text{Opposite}}{\text{Adjacent}}$$



Derivation

Common formulas:

$$\frac{d}{dx}(x)=1$$
$$\frac{d}{dx}(\sin x)=\cos x$$
$$\frac{d}{dx}(\cos x)=-\sin x$$
$$\frac{d}{dx}(\tan x)=\sec^2 x$$
$$\frac{d}{dx}(\sec x)=\sec x\tan x$$

$$\frac{d}{dx}(\csc x)=-\csc x\cot x$$
$$\frac{d}{dx}(\cot x)=-\csc^2 x$$
$$\frac{d}{dx}(\sin^{-1} x)=\frac{1}{\sqrt{1-x^2}}$$
$$\frac{d}{dx}(\cos^{-1} x)=-\frac{1}{\sqrt{1-x^2}}$$
$$\frac{d}{dx}(\tan^{-1} x)=\frac{1}{1+x^2}$$

$$\frac{d}{dx}(a^x)=a^x\ln(a)$$
$$\frac{d}{dx}(\mathbf{e}^x)=\mathbf{e}^x$$
$$\frac{d}{dx}(\ln(x))=\frac{1}{x},\quad x>0$$
$$\frac{d}{dx}(\ln|x|)=\frac{1}{x},\quad x\neq 0$$
$$\frac{d}{dx}(\log_a(x))=\frac{1}{x\ln a},\quad x>0$$

Integration

Common formulas:

$$\int k\,dx = k\,x + c$$
$$\int x^n\,dx = \frac{1}{n+1}x^{n+1} + c, n \neq -1$$
$$\int x^{-1}\,dx = \int \frac{1}{x}dx = \ln|x| + c$$
$$\int \frac{1}{ax+b}dx = \frac{1}{a}\ln|ax+b| + c$$
$$\int \ln u\,du = u\ln(u) - u + c$$
$$\int \mathbf{e}^u\,du = \mathbf{e}^u + c$$

$$\int \cos u\,du = \sin u + c$$
$$\int \sin u\,du = -\cos u + c$$
$$\int \sec^2 u\,du = \tan u + c$$
$$\int \sec u \tan u\,du = \sec u + c$$
$$\int \csc u \cot u du = -\csc u + c$$
$$\int \csc^2 u\,du = -\cot u + c$$

$$\int \tan u\,du = \ln|\sec u| + c$$
$$\int \sec u\,du = \ln|\sec u + \tan u| + c$$
$$\int \frac{1}{a^2+u^2}du = \frac{1}{a}\tan^{-1}\left(\frac{u}{a}\right) + c$$
$$\int \frac{1}{\sqrt{a^2-u^2}}du = \sin^{-1}\left(\frac{u}{a}\right) + c$$

MATERIAL PROPERTIES

Book 2

Designer's Den

Contents

- Yield stress
  - Concrete
  - Steel
  - Timber

- Material factor
  - Concrete
  - Steel
  - Timber

Yield stress

Definition: Yielding stress, often denoted f_y, refers to the amount of stress that a material can withstand before it starts to deform permanently or exhibit plastic behavior. It is the stress at which a material undergoes a transition from elastic deformation (where it can return to its original shape when the load is removed) to plastic deformation (where permanent deformation occurs even after the load is removed).

Elastic vs. Plastic Deformation: In the elastic range, a material experiences temporary deformation in response to an applied stress but can recover its original shape when the stress is removed. However, once the yield stress is exceeded, the material enters the plastic range, and permanent deformation occurs.

Yield Point vs. Yield Strength: Some materials, particularly metals, exhibit a distinct yield point on their stress-strain curve, indicating the onset of plastic deformation. For these materials, the stress at the yield point is referred to as the yield strength. However, not all materials have a well-defined yield point, and in such cases, the yield stress is determined based on a specific criterion, such as a certain amount of strain or deviation from linearity in the stress-strain curve.

Importance in Design: Design engineers ensure that stresses on structural elements remain below yielding stress to sustain expected loads without undergoing excessive plastic deformation.

Steel

Steel is widely used in construction due to its high strength and durability. In Norway, steel used in structural applications typically adheres to the Eurocode design standards. The yielding stress of structural steel depends on its grade or strength class. Common steel grades include S235, S275, and S355, which correspond to minimum yield strengths of 235 MPa, 275 MPa, and 355 MPa, respectively. These values indicate the stress at which steel will begin to deform permanently.

Concrete

Concrete is a composite material composed of cement, aggregates, and water. Its strength and behavior depend on various factors, including the mix design, curing conditions, and reinforcement. In Norway, concrete design follows the Norwegian Standard NS-EN 1992-1-1 (Eurocode 2). The yielding stress of concrete is not as well-defined as in steel since it exhibits a gradual and nonlinear stress-strain behavior. However, the characteristic compressive strength of concrete is often used as a reference. Common characteristic compressive strengths range from 20 MPa to 60 MPa, depending on the concrete mix.

Timber

Timber, or wood, is a natural material used in construction, particularly in residential and low-rise buildings. The yielding stress of timber varies depending on the species, grade, and moisture content. In Norway, the most commonly used timber species include pine, spruce, and birch. The yielding stress of timber is determined through mechanical tests, such as bending or compression tests. As an example, structural softwood species like pine and spruce typically have yielding stresses ranging from 20 MPa to 50 MPa.

Material factors

Definition: Material factors, also known as safety factors or partial safety factors, are used in structural design to account for uncertainties and variations in material properties, loads, and other factors. These factors ensure that the designed structures have an appropriate level of safety and reliability.

Purpose: The primary purpose of material factors is to provide a safety margin by reducing the nominal or characteristic strength of a material to obtain a lower design strength. This accounts for uncertainties in material properties, manufacturing processes, environmental conditions, and other factors that can affect the performance and reliability of a structure.

Material-Specific Factors: Material factors can differ based on the type of material being used. For example, steel, concrete, timber, and other materials may have their own specific material factors determined through research, testing, and empirical data.

Design yielding stress: Design yielding stress refers to the maximum stress or load that a structural element or material is designed to safely withstand taken into account material factors.

Steel

In steel design, the material factor is denoted as γ (gamma). It is a dimensionless factor that is applied to the yield stress (f_y) of the steel to obtain the design yield stress (f_d). The design yield stress represents the maximum stress that the steel is allowed to experience under the design loads. The material factor accounts for uncertainties and variability in material properties, such as strength, manufacturing processes, and environmental factors.

For steel grade SXXX, which has a yielding stress (f_y) of XXX MPa, the material factor γ is commonly used to determine the design yield stress (f_d) as follows:

$$f_d = f_y / \gamma$$

The value of γ depends on the design standards and the specific application. In Eurocode design standards, such as Eurocode 3 (EN 1993-1-1) for steel structures, different material factors are assigned to different limit states (e.g., ultimate limit state, serviceability limit state). A common material factor γ is taken as 1.05

So for example steel grade S235 which corresponds to a steel type that have a minimum yielding stress of 235 MPa would have the following design yielding stress:

$$f_d = f_y / \gamma = 235 / 1.05$$

In steel design engineers would want to assure that the stresses in an element is less than f_d

Concrete
In concrete design, the material factor γ is also used to account for uncertainties and variations. It is used to determine the design characteristic strength of concrete (f_{cd}) from the characteristic compressive strength (f_{ck}) of concrete. The design characteristic strength represents the maximum stress that the concrete is allowed to experience under the design loads.

The design characteristic strength (f_{cd}) is calculated as:

$$f_{cd} = f_{ck} / \gamma$$

The value of γ depends on the specific limit states and the level of reliability required. In Norway, the material factor γ is typically taken as 1.5 for the ultimate limit state design (ULS) and 1.0 for the serviceability limit state design (SLS). These values ensure an appropriate level of safety for the intended design life of the structure.

It's important to note that these values are general guidelines, and the specific material factors for concrete design in Norway may vary based on the applicable design standards, regulations, and specific project requirements. Consulting the Norwegian design standards, such as NS-EN 1992-1-1 series for concrete, will provide the accurate values and recommendations for material factors in concrete design.

In concrete design engineers would want to assure that the stresses in an element is less than f_{cd}

Timber

In timber design, material factors are used to account for the variability in timber properties and load effects. It is applied to the characteristic strength of timber (f_{mk}) to determine the design strength (f_d) of timber.

The design strength (f_d) is calculated as:

$$f_d = f_{mk} / \gamma$$

The value of γ depends on the timber species, grade, and specific application. In Norway, different values of γ are provided based on the reliability level and intended service class of the structure. For example, γ values of 1.2 or 1.3 are commonly used for normal reliability levels and service classes.

It's important to note that these values are general guidelines, and the specific material factors for timber design in Norway may vary based on the applicable design standards, regulations, and specific project requirements. Consulting the Norwegian design standards, such as NS-EN 1995 series for timber, will provide the accurate values and recommendations for material factors in timber design.

In timber design engineers would want to assure that the stresses in an element is less than f_d

FORCES IN GENERAL STATICS

Book 3

Designer's Den

Contents

- SI Units
- Forces and moments
- Boundary conditions
- Free Body Diagram (FBD)

SI Units

SI: Système International d'Unités (defined since 1960)

Important Base:

- Length	m (meter)
- Time	s (second)
- Mass	kg (kilogram)
- Temperature	K (Kelvin)

Important Derivations:

- Force	N	$= kg \cdot m/s^2$	(Newton)
- Moment	Nm	$= N \cdot m$	(Newton-meter)
- Stress, pressure	Pa	$= N/m^2$	(Pascal) *

** In structural mechanics it is common to use Mega Pascals (MPa = N/mm²) instead of Pascals due to the scale of stresses encountered in engineering applications.*

Forces and moments

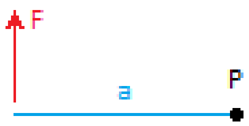
Force

In mechanics, force refers to a physical quantity that can cause an object to accelerate, deform, or change its motion. It is a vector quantity, which means it has both magnitude and direction. Force is commonly denoted by the symbol "F" and is measured in newtons (N) in the International System of Units (SI).

Moment

In mechanics, a moment is a rotational force or turning effect produced by a force acting on an object. It is also known as torque. Unlike force, which primarily causes linear motion, a moment causes angular or rotational motion. Similar to force, the moment is a vector quantity and has both magnitude and direction. The moment of a force about a particular point or axis depends on the magnitude of the force, its distance from the point or axis, and the angle between the force and a line perpendicular to the point or axis. The unit of moment is newton-meter (Nm).

Example:



In the figure to the left: The force (F) is acting perpendicular to the point (P) from a distance (a). In this system the moment at point P is defined as $M_{Point,P} = F \cdot a$

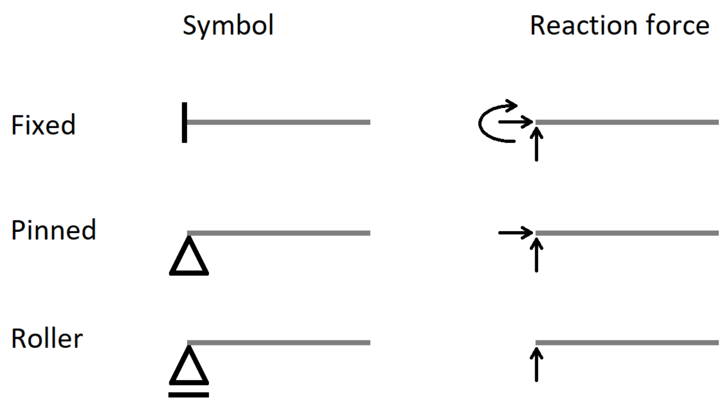
Boundary conditions

In statics, boundary conditions refer to the constraints or limitations imposed on a system or structure at its boundaries or supports. These conditions help define how the system interacts with its environment and play a critical role in analyzing the equilibrium and behavior of the system. Here are some common types of boundary conditions in statics:

Fixed Support: A fixed support, also known as a built-in or immovable support, completely restrains the translational and rotational motion of a structure or object at a specific location. It prevents both vertical and horizontal displacements as well as any rotation.

Pinned Support: A pinned support, also called a hinge support, allows rotation but prevents translation at the point of support. It allows the structure or object to pivot or rotate about the support, but it does not permit any horizontal or vertical movements.

Roller Support: A roller support allows only one translational degree of freedom, typically in the horizontal direction. It prevents vertical and rotational motions but allows the structure to move or roll horizontally along the support.



Free Body Diagram (FBD)

A free body diagram (FBD) is a graphical representation that depicts an isolated object or body and all the forces acting on it. It is a fundamental tool used in physics and engineering to analyze the forces and their effects on a system. The purpose of a free body diagram is to simplify the analysis of forces acting on an object by isolating it from its surroundings and focusing solely on the forces acting on that object.

When creating a free body diagram, certain guidelines are followed:

1. Isolate the Object: The first step is to identify the specific object or body for which you want to analyze the forces. Mentally separate it from its surroundings and consider it as an individual entity.
2. Represent the Object: Draw a simple and clear sketch of the object as a single point or as a solid body, depending on the context and level of detail required for analysis.
3. Identify and Label Forces: Identify all the external forces acting on the object and label them using arrows. The arrows indicate the magnitude, direction, and sense of the forces. Common forces include applied forces, weight (due to gravity), normal forces, frictional forces, and any other relevant forces.
4. Position and Orientation: Position the forces correctly with respect to the object's geometry. Consider the direction and line of action of each force accurately.
5. Omit Irrelevant Forces: Include only the forces that are directly acting on the object of interest. Disregard forces internal to the object or forces that are not relevant to the analysis.

EQUATIONS OF EQUILIBRIUM

Book 4

Designer's Den

Contents

- Definition
- Examples

Definition

In statics, the equations of equilibrium are mathematical expressions that describe the conditions for an object to be in a state of equilibrium. These equations relate the forces and moments acting on an object to ensure that it remains at rest or in a state of constant motion with no acceleration. The equations of equilibrium are derived from Newton's laws of motion and are essential for analyzing the forces and moments in a static system.

Translational Equilibrium

$\sum F_x = 0$: The sum of all the horizontal (x-direction) forces acting on the object is zero.

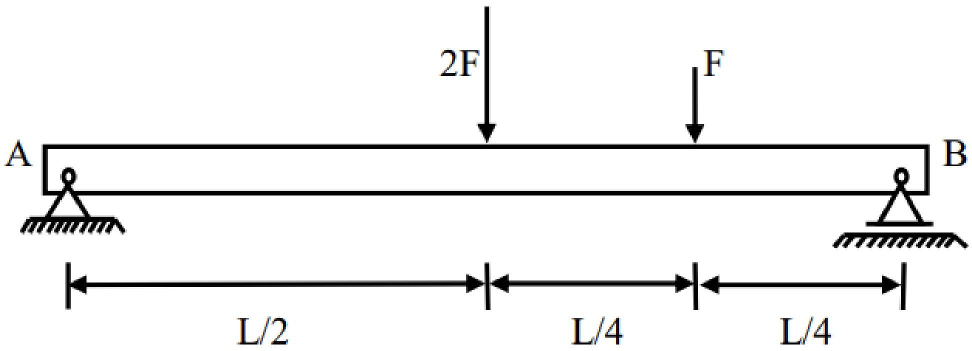
$\sum F_z = 0$: The sum of all the vertical (z-direction) forces acting on the object is zero.

Rotational Equilibrium

$\sum M = 0$: The sum of all the moments about a reference point or axis is zero. The moments are calculated by multiplying the force magnitude by the perpendicular distance from the reference point or axis.

Examples

Example 1: Calculate the reaction forces of the beam using the equations of equilibrium



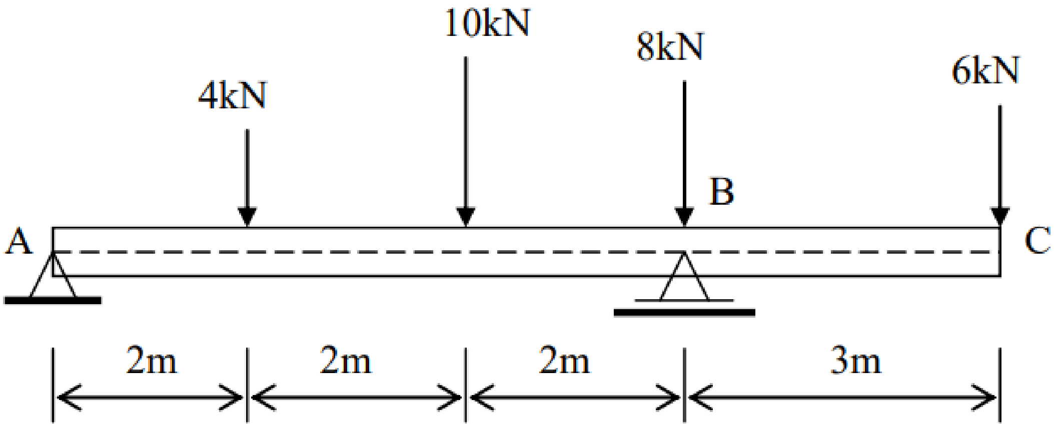
Solution:

$$\sum F_x = 0 \Rightarrow A_x = 0$$

$$\sum M_A = 0 = 2F \cdot \frac{L}{2} + F \cdot \frac{3L}{4} - B_y \cdot L \Rightarrow B_y = \frac{7F}{4}$$

$$\sum F_y = 0 = A_y + B_y - 2F - F \Rightarrow A_y = \frac{5F}{4}$$

Example 2: Calculate the reaction forces of the beam using the equations of equilibrium



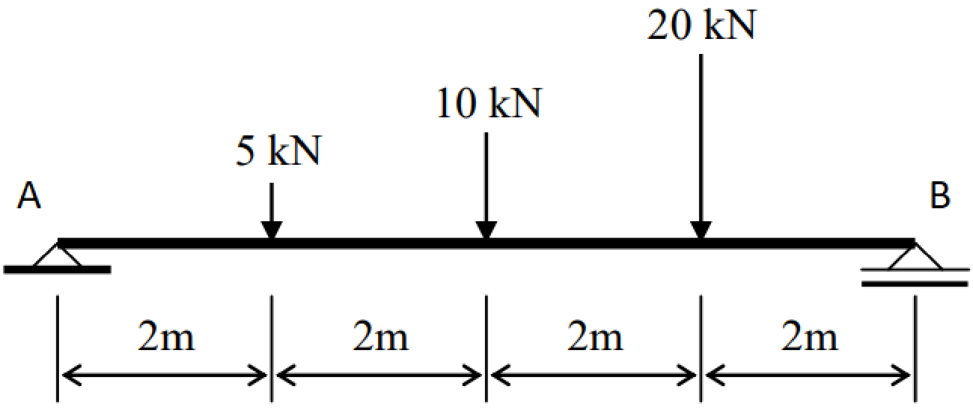
Solution:

$\Sigma F_x = 0 :\quad A_x = 0$

$\Sigma M_A=0 :\quad B_y \cdot 6 - 4 \cdot 2 - 10 \cdot 4 - 8 \cdot 6 - 6 \cdot 9 = 0 \Rightarrow B_y = (8 + 40 + 48 + 54)/6 = 25 \text{ kN}$

$\Sigma F_y = 0 :\quad A_y + B_y - 4 - 10 - 8 - 6 = 0 \Rightarrow \quad A_y = 4 + 10 + 8 + 6 - 25 = 3 \text{ kN}$

Example 3: Calculate the reaction forces of the beam using the equations of equilibrium



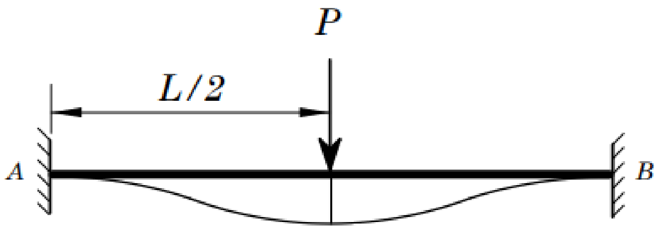
Solution:

$\Sigma M_A = 0: \quad B_y \cdot 8 - 5 \cdot 2 - 10 \cdot 4 - 20 \cdot 6 = 0 \quad \Rightarrow B_y = 21{,}25 \text{ kN}$

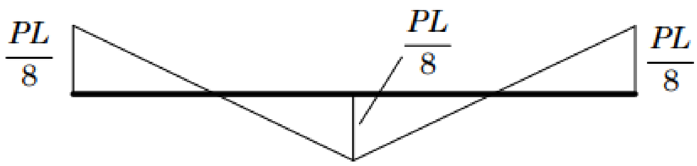
$\Sigma F_y = 0: \quad A_y = 5 + 10 + 20 - 21{,}25 = 13{,}75 \text{ kN}$

$\Sigma F_x = 0: \quad A_x = 0$

Example 4: Calculate the reaction forces of the beam using the equations of equilibrium given that the moments at the fixed supports A and B are $M_A = M_B = \frac{PL}{8}$



Moment diagram:



Solution:

$$\Sigma F_x = 0: \quad A_x = B_x = 0$$

$$\Sigma F_y = 0: \quad A_y + B_y = P \Rightarrow A_y = B_y = \tfrac{P}{2}$$

Alternatively:

$$\Sigma M_A = 0: -M_A + M_B + P \cdot \tfrac{L}{2} - B_y \cdot L = 0$$

$$-\tfrac{PL}{8} + \tfrac{PL}{8} + P \cdot \tfrac{L}{2} - B_y \cdot L = 0 \Rightarrow B_y = \tfrac{P}{2}$$

(*Same process from point B for* A_y)

INTERNAL FORCES

Book 5

Designer's Den

Contents

- Definition
- N – Diagram
- V – Diagram
- M – Diagram
- Calculation procedure
- Examples

Definition

Internal forces refer to the forces that act within a structure or object, rather than on its external surfaces. These forces develop as a result of the external loads applied to the structure or object and are distributed throughout its interior. Understanding internal forces is crucial for analyzing the structural behavior and integrity of various engineering systems. These forces are denoted N, V and M and are usually represented in diagrams to help visualize the distribution and magnitude of internal forces within a structural member. Engineers use these diagrams to analyze and design structural elements.

N – Diagram

N (Axial Force): "N" represents the axial force, also known as the normal force or axial load, acting along the longitudinal axis of a structural member. It is a force that causes the member to either be in compression (contracting) or tension (stretching). The positive sign convention is typically used, where "N" is positive for tension and negative for compression. The axial force is represented by a straight arrow pointing along the axis of the member.

V – Diagram

V (Shear Force): "V" represents the shear force acting parallel to the cross-section of a structural member. It induces a sliding or shearing effect within the material. Shear forces arise due to unequal distribution of external loads across the cross-section of the member. The shear force is represented by an arrow perpendicular to the longitudinal axis of the member, indicating the direction and magnitude of the force.

M – Diagram

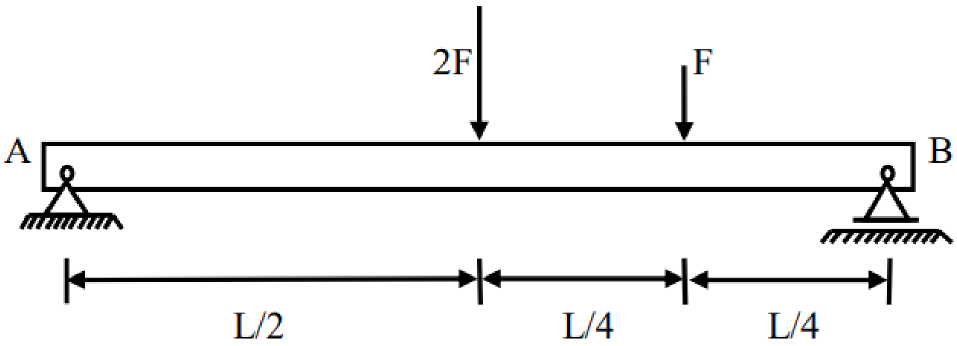
M (Bending Moment): "M" represents the bending moment, which is a measure of the internal bending action within a structural member. Bending moments occur due to the application of external forces that cause the member to bend. The bending moment is represented by curved arrows, with the direction of the arrows indicating the rotational effect on the member. The magnitude of the bending moment is typically represented by the length of the arrows.

Calculation procedure

1. Identify the Member and Supports: Determine the structural member for which you want to create the internal force diagrams. Identify the type of member (e.g., beam, column) and the supports or connections at its ends.
2. Draw the Member: Sketch a clear and accurate representation of the member, including its length and any applied loads or moments. Label the relevant dimensions.
3. Calculate External Forces: Determine all the external loads acting on the member, such as point loads, distributed loads, and moments. Analyze the structure to find the magnitudes and positions of these loads.
4. Determine Reactions: Calculate the reactions at the supports or connections based on the applied loads and the equilibrium conditions of the member.
5. Intersect the Member: Start from one end of the member and move along its length, section by section. At each section, calculate the axial force (N), shear force (V) and bending moment (M) by considering the applied loads and reactions.
6. Plot: Create a plot of each diagram with reaction symbols to mark the direction of the internal forces. The moment diagram is drawn on the tension side of the section.

Examples

Example: Calculate the internal forces for this system and draw their diagrams

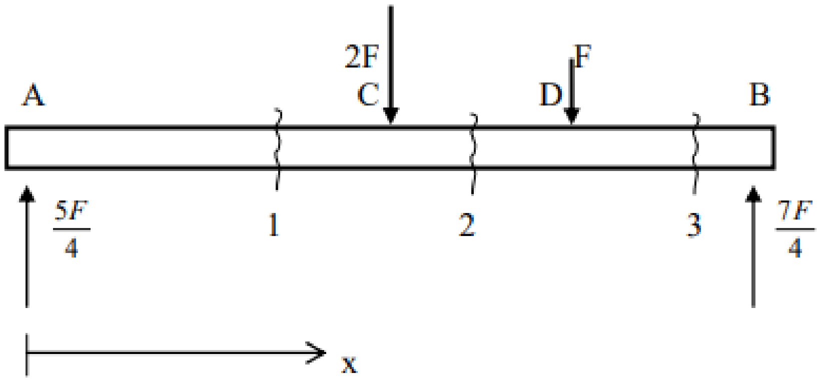


Solution:

$$\sum F_x = 0 \Rightarrow A_x = 0$$

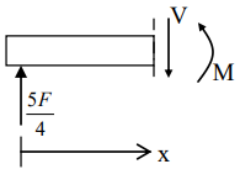
$$\sum M_A = 0 = 2F \cdot \frac{L}{2} + F \cdot \frac{3L}{4} - B_y \cdot L \Rightarrow B_y = \frac{7F}{4}$$

$$\sum F_y = 0 = A_y + B_y - 2F - F \Rightarrow A_y = \frac{5F}{4}$$



Section 1:

$0 \le x \le \frac{L}{2}$

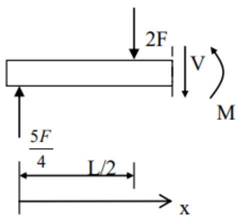


$$\sum F_y = 0 = \frac{5F}{4} - V \Rightarrow V = \frac{5F}{4}$$

$$\sum M = 0 = -M + \frac{5F}{4} \cdot x \Rightarrow M = \frac{5F}{4} \cdot x$$

Section 2:

$\frac{L}{2} \le x \le \frac{3L}{4}$

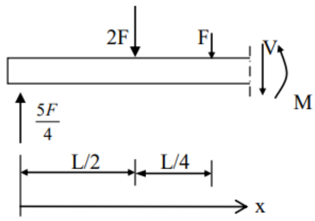


$$\sum F_y = 0 = \frac{5F}{4} - 2F - V \Rightarrow V = -\frac{3F}{4}$$

$$\sum M = 0 = -M - 2F \cdot (x - \frac{L}{2}) + \frac{5F}{4} \cdot x \Rightarrow M = FL - \frac{3F}{4} \cdot x$$

Section 3:

$\frac{3L}{4} \le x \le L$



$$\sum F_y = 0 = V - \frac{5F}{4} + 2F + F \Rightarrow V = -\frac{7F}{4}$$

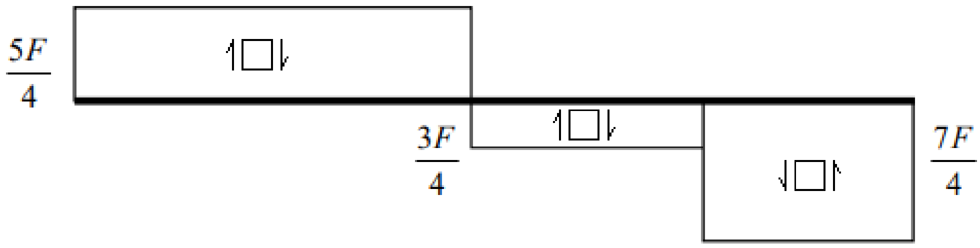
$$\sum M = 0 = -M + \frac{5F}{4} \cdot x - 2F \cdot (x - \frac{L}{2}) - F \cdot (x - \frac{3L}{4})$$

$$\Rightarrow M = \frac{7FL}{4} - \frac{7F}{4} \cdot x$$

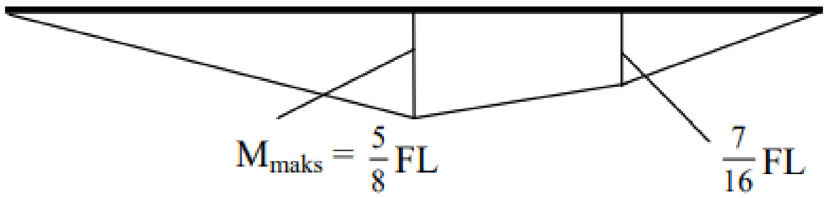
N – Diagram:

There are no axial forces in this system

V – Diagram:



M – Diagram:



BEAM DEFORMATION

Book 6

Designer's Den

Contents

- Definition
- Criterion
- Examples

Definition

In structural mechanics, beam deformation refers to the bending and deflection of a beam under the action of applied loads. When a beam is subjected to external forces, it undergoes elastic deformation, causing it to bend and change shape. Understanding and analyzing beam deformation is essential for designing structures that can withstand the anticipated loads without excessive deflection or failure.

Beam deformation occurs due to the internal stresses induced by external loads. When a load is applied to a beam, it causes bending moments and shear forces within the beam. The beam's material properties, cross-sectional shape, and support conditions influence the magnitude and distribution of these internal forces, resulting in beam deformation.

The beam's material properties are described by the elastic modulus (E). This modulus, also known as Young's modulus, measures the material's ability to deform elastically when subjected to stress. The beam's cross-sectional shape affects its second moment of area (I) which is a geometrical property of an area which reflects how its points are distributed about an arbitrary axis. These two concepts together determine a beam's stiffness. Stiffness refers to the resistance of a material or a structure to deformation.

Criterion

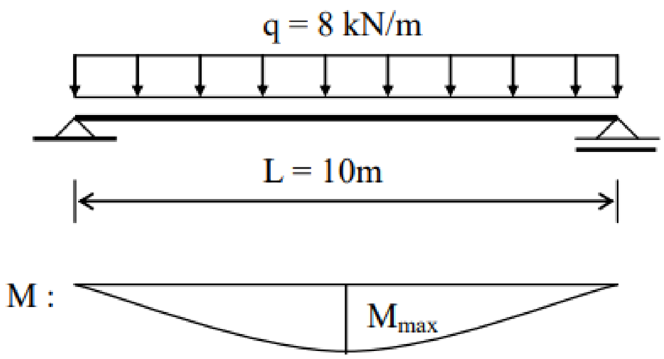
The criterion of L/200 is a common deflection limit used in structural design for beams. It specifies that the maximum deflection of a beam should not exceed L/200, where L represents the span length of the beam. This criterion is based on the assumption that smaller deflections generally result in more visually acceptable and structurally sound designs.

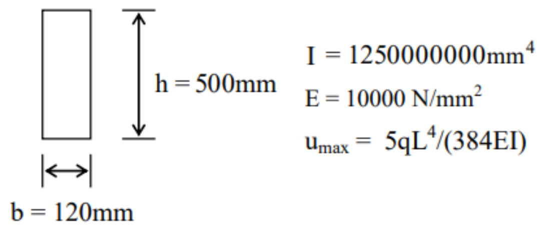
The L/200 deflection criterion is typically applied to beams in order to ensure adequate serviceability and user comfort. By limiting the deflection to a fraction of the beam's span, it helps maintain the appearance, functionality, and stability of the structure. Excessive deflection can lead to aesthetic concerns, cracking of finishes, discomfort to occupants, and potential damage to nonstructural elements.

It's important to note that the L/200 criterion is not a strict requirement in all cases and can vary based on the specific design requirements, codes, standards, and engineering practices. Different applications and building codes may specify different deflection limits, such as L/240 or L/360. Specialized structures or unique cases may have their own specific deflection criteria based on specific considerations.

Examples

Example: Calculate the beam's deformation and ensure it is within the deflection criterion





Solution:

$$u_{max} = \frac{5 \cdot 8 \cdot 10\,000^4}{384 \cdot 10\,000 \cdot 1\,250\,000\,000} = \frac{250}{3} \approx 83$$

L/200 = 10000/200 = 50

$\Rightarrow u_{max} > L/200$

Since the deformation u_{max} is greater than the criterion this beam needs to be adjusted such that it is more stiff and deflects less. A good idea is to increase the cross-section height.

CROSS SECTIONAL CENTER OF MASS

Book 7

Designer's Den

Contents

Definition

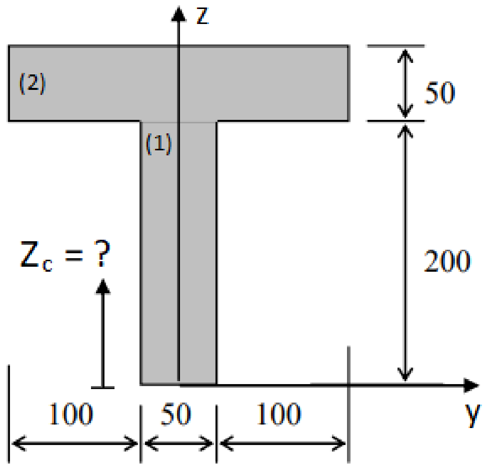
The center of mass, or centroid, is an important concept used in various fields, including physics, engineering, and mechanics. It refers to the average position of the mass distribution within an object or system. The center of mass is often used as a reference point for analyzing the motion, stability, and equilibrium of objects or systems.

For cross sections with multiple shapes, you can find the centroid by dividing the section into simpler shapes (such as rectangles, triangles, or circles), calculating the centroid of each shape, and then determining the overall centroid using the weighted average of the individual centroids.

For more complex shapes, such as irregular polygons, the centroid can be found using mathematical integration methods or by using computer-aided design software that provides centroid calculation tools.

Examples

Example 1: Find the centroid of the following cross-section:

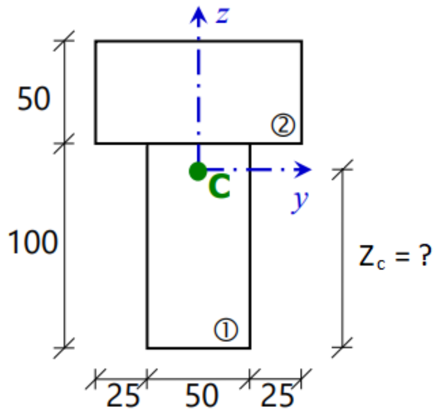


Solution:

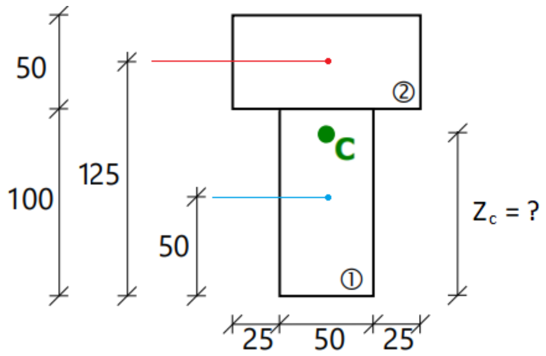
$A_1 = 50 \cdot 200 = 10000 \text{ mm}^2$; $A_2 = 50 \cdot 250 = 12500 \text{ mm}^2$; $A = 22500 \text{ mm}^2$

$Z_c = (100 \cdot 10000 + 225 \cdot 12500)/22500 = 169{,}44 \text{ mm}$

Example 2: Find the centroid of the following cross-section:



Solution:



$$Z_c = \frac{\sum A_i \cdot z_i}{A_{Total}} = \frac{A_1 \cdot z_1 + A_2 \cdot z_2}{A_1 + A_2} = \frac{(50 \cdot 100) \cdot 50 + (100 \cdot 50) \cdot 125}{(50 \cdot 100) + (100 \cdot 50)}$$

$$Z_c = 87.5$$

SECOND MOMENT OF AREA

Book 8

Designer's Den

Contents

- Definition
- Common geometrical shapes

Definition

The second moment of area, also known as the moment of inertia, is a property used in structural mechanics to quantify how a cross-sectional shape of an object is distributed around a particular axis. It provides information about the object's resistance to bending and torsional deformations.

The second moment of area is denoted by the symbol I and is specific to the axis of rotation or bending being considered. It is calculated by summing the products of infinitesimally small areas within the cross section and the square of their distances from the axis of rotation. Mathematically, the formula for calculating the second moment of area is:

$$I = \int z^2 \, dA$$

Where:

- I is the second moment of area or moment of inertia.
- z is the perpendicular distance between an infinitesimal area element (dA) and the axis of rotation.
- ∫ represents integration, summing up all the infinitesimal areas over the entire cross section.

The second moment of area provides information about the cross-sectional shape's resistance to bending. The larger the value of the second moment of area, the more resistant the object is to bending deformations. It quantifies the distribution of material around the axis of rotation and plays a crucial role in determining the deflection, stress distribution, and overall structural behavior of beams, columns, and other structural elements.

The second moment of area varies depending on the shape and geometry of the cross section. For common shapes, such as rectangles, circles, and triangles, there are specific formulas to calculate the second moment of area. These formulas take into account the dimensions and geometry of the shape.

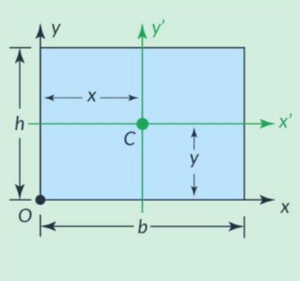
The second moment of area is an important parameter used in various engineering calculations, such as calculating bending stresses, deflections, and natural frequencies of structural elements. It is also used in beam theory equations, such as the Euler-Bernoulli beam theory and the Timoshenko beam theory, to analyze the behavior of beams under bending loads.

Understanding the second moment of area is crucial in structural design and analysis as it helps engineers optimize the shape and dimensions of structural elements to ensure they meet the required strength, stiffness, and performance criteria.

The second moment of area (moment of inertia, I) and the resistance to bending or deformation of a cross-section tend to increase when there is a greater distribution of area away from the neutral axis.

Common geometrical shapes

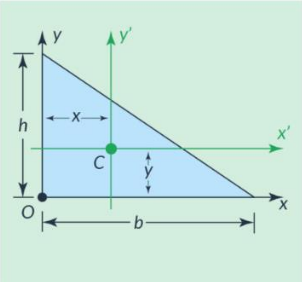
Rectangle



$$I_{x'} = \frac{1}{12} bh^3 \qquad I_{y'} = \frac{1}{12} b^3h$$

$$I_x = \frac{1}{3} bh^3 \qquad I_y = \frac{1}{3} b^3h$$

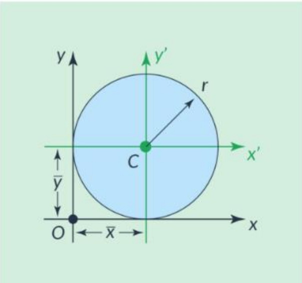
Triangle



$$I_{x'} = \frac{1}{36} bh^3 \qquad I_{y'} = \frac{1}{36} b^3h$$

$$I_x = \frac{1}{12} bh^3 \qquad I_y = \frac{1}{12} b^3h$$

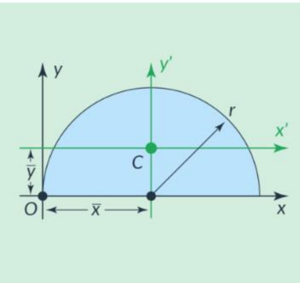
Circle



$$\bar{I}_{x'} = \bar{I}_{y'} = \frac{\pi}{4} r^4$$

$$I_{x'} = I_{y'} = \frac{5\pi}{4} r^4$$

Half Circle



$$\bar{I}_{x'} = \left(\frac{\pi}{8} - \frac{8}{9\pi}\right) r^4 \qquad \bar{I}_{y'} = \frac{\pi}{8} r^4$$

$$I_x = I_y = \frac{\pi}{8} r^4$$

SECOND MOMENT OF AREA CALCULATIONS

Book 9

Designer's Den

Contents

Steiner’s theorem

Steiner's theorem, also known as the parallel axis theorem, is a fundamental principle in mechanics that relates the moments of inertia of a body about two different axes. It provides a method to calculate the moment of inertia of a body about an axis parallel to a known axis.

According to Steiner's theorem, the moment of inertia of a body about an axis parallel to and at a distance (e) from a known axis can be determined by adding the moment of inertia about the known axis to the product of the body's mass and the square of the distance (e) between the two axes.

Mathematically, Steiner's theorem can be expressed as:

$I_{Parallel} = I_{Local} + A \cdot e^2$

Where:

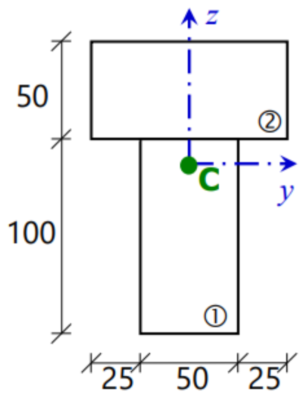
- $I_{Parallel}$ is the moment of inertia about the parallel axis.
- I_{Local} is the moment of inertia about the local axis.
- A is the area of the body.
- e is the distance between the two axes.

Steiner's theorem is particularly useful when calculating the moment of inertia of complex shapes or composite bodies. Instead of deriving the moment of inertia directly about the desired axis, it allows us to determine it based on the moment of inertia about a simpler or more convenient axis.

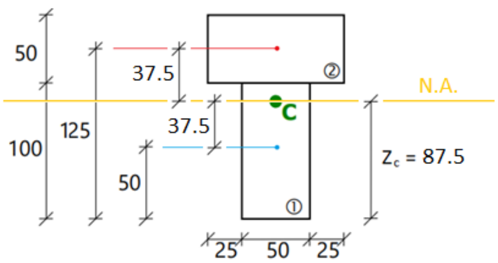
By applying Steiner's theorem, engineers and physicists can simplify calculations for objects with irregular shapes or distributed masses. It enables the determination of the moment of inertia about various parallel axes, facilitating accurate analysis of rotational motion, stability, and structural behavior.

Examples

Example: Find the second moment of area for the following cross-section:



Solution:



Steiner's theorem:

$$I_y = \sum I_i = I_1 + I_2$$

$$= (I_{L,1} + A_1 \cdot e_1{}^2) + (I_{L,2} + A_2 \cdot e_2{}^2)$$

$$= \left(\frac{50 \cdot 100^3}{12} + (50 \cdot 100) \cdot 37.5^2\right) + \left(\frac{100 \cdot 50^3}{12} + (100 \cdot 50) \cdot 37.5^2\right)$$

$$= 11{,}20 \cdot 10^6 + 8{,}073 \cdot 10^6$$

$$= \underline{19{,}27 \cdot 10^6 \text{ mm}^4}$$

Analytical method:

$$I_y = \int_A z^2 dA$$

$$= \int_{A_1} z^2 dA + \int_{A_2} z^2 dA$$

$$= \int_{-25}^{25} \int_{-87.5}^{12.5} z^2 dz dy + \int_{-50}^{50} \int_{12.5}^{62.5} z^2 dz dy$$

$$= \int_{-25}^{25} \left[\frac{1}{3} z^3\right]_{-87.5}^{12.5} dy + \int_{-50}^{50} \left[\frac{1}{3} z^3\right]_{12.5}^{62.5} dy$$

$$= \int_{-25}^{25} 223{,}96 \cdot 10^3 dy + \int_{50}^{50} 80{,}73 \cdot 10^3 dy$$

$$= 223{,}96 \cdot 10^3 \cdot [y]_{-25}^{25} + 80{,}73 \cdot 10^3 \cdot [y]_{-50}^{50}$$

$$= 223{,}96 \cdot 10^3 \cdot 50 + 80{,}73 \cdot 10^3 \cdot 100$$

$$= 11{,}20 \cdot 10^6 + 8{,}073 \cdot 10^6$$

$$= \underline{19{,}27 \cdot 10^6 \text{ mm}^4}$$

NORMAL STRESS

Book 10

Designer's Den

Contents

- Definition
- Axial stress
- Bending stress
- Combination of axial loading and bending
- Examples

Definiton

Stress refers to the internal resistance or force per unit area within a material when subjected to external loads or forces. It represents how a material reacts to applied forces and can affect its deformation, structural integrity, and failure behavior.

There are several types of stresses commonly encountered in engineering and mechanics:

1. **Normal Stress:** Normal stress acts perpendicular to the cross-sectional area of a material. Normal stress come from axial and bending forces. The axial forces cause tension or compression. Tensile stress occurs when the material is being pulled apart, while compressive stress occurs when the material is being compressed or squeezed together. Bending stress occurs in beams or structural members subjected to bending moments. It results from the distribution of forces and moments within the material, causing tension on one side (top) and compression on the other side (bottom) of the beam. *(In this course we are only dealing with normal stresses)*
2. **Shear Stress:** Shear stress arises when forces act parallel to the cross-sectional area of a material, causing adjacent layers to slide past each other. Shear stress plays a significant role in the behavior of materials under torsion or when subjected to cutting or sliding forces.
3. **Torsional Stress:** Torsional stress occurs in structures or components subjected to twisting or torsional loads. It is characterized by shear stresses acting on various planes within the material.

4. **Thermal Stress:** Thermal stress arises due to temperature variations within a material, leading to expansion or contraction. It can cause deformation and structural failure, particularly when materials with different coefficients of thermal expansion are combined.
5. **Residual Stress:** Residual stress exists within a material even in the absence of external forces or loads. It arises from manufacturing processes, such as welding, casting, or heat treatment, and can influence the material's behavior and stability.

Understanding and analyzing stresses is crucial in engineering design, structural analysis, and material selection. Engineers evaluate stress levels to ensure that they remain within acceptable limits for the material being used. By considering stresses, engineers can design structures and components that can withstand anticipated loads, maintain structural integrity, and avoid excessive deformation or failure.

Axial stress

Axial stress is a type of normal stress that acts perpendicular to the cross-sectional area of an object. It represents the force per unit area that acts within a material and can cause deformation or structural failure. There are two types of axial stresses: tensile stress and compressive stress.

Tensile Stress: Tensile stress occurs when forces act to elongate or stretch a material. It is considered positive when the material is being pulled apart. Tensile stress is calculated by dividing the applied force (F) by the cross-sectional area (A) perpendicular to the applied force. Mathematically, tensile stress (σ) is expressed as:

$$\sigma = \frac{F}{A}$$

Compressive Stress: Compressive stress occurs when forces act to compress or squeeze a material. It is considered negative when the material is being pushed together. Compressive stress is also calculated by dividing the applied force (F) by the cross-sectional area (A). Mathematically, compressive stress (σ) is expressed as:

$$\sigma = -\frac{F}{A}$$

Tensile stress is usually denoted with a positive sign (+)
while compressive stress with a negative sign (-)

Bending stress

Normal stress due to bending, also known as bending stress, occurs in a beam or structural member when it is subjected to a bending moment. Bending stress results from the internal distribution of forces and moments within the material due to the applied bending moment.

In a beam, the top portion experiences tensile bending stress, while the bottom portion experiences compressive bending stress. At the neutral axis, the bending stress is zero.

The magnitude of bending stress varies along the cross-section of the beam. It is highest at the extreme fibers, farthest from the neutral axis. The bending stress can be calculated using the bending moment (M) and the distance from the neutral axis (z) to the fiber where the stress is being calculated. Mathematically, the bending stress (σ) is given by the formula:

$$\sigma = \frac{M}{I} \cdot z$$

Where:

- M is the bending moment at that location,
- z is the distance from the neutral axis to the fiber where the stress is being calculated,
- I is the second moment of area (moment of inertia) of the cross-sectional shape.

Navier’s formula

Navier’s formula is the equation where the total stress (σ) is expressed as the sum of axial stress (σ_{Axial}) and bending stress ($\sigma_{Bending}$) is known as the Principle of Superposition.

Mathematically, the equation can be written as:

$$\sigma = \sigma_N + \sigma_M = \frac{F}{A} + \frac{M}{I} \cdot z$$

This equation is used when analyzing the combined effects of axial loading (such as tension or compression) and bending in a structural member, such as a beam or column. The axial stress accounts for the direct stress resulting from the axial force, while the bending stress represents the stress induced by the bending moment.

By considering the individual contributions of axial and bending stresses, engineers can assess the combined stress state and ensure that the total stress in the material remains within acceptable limits. This principle is commonly applied in structural analysis and design to evaluate the strength and structural integrity of components and systems subject to complex loading conditions.

Examples

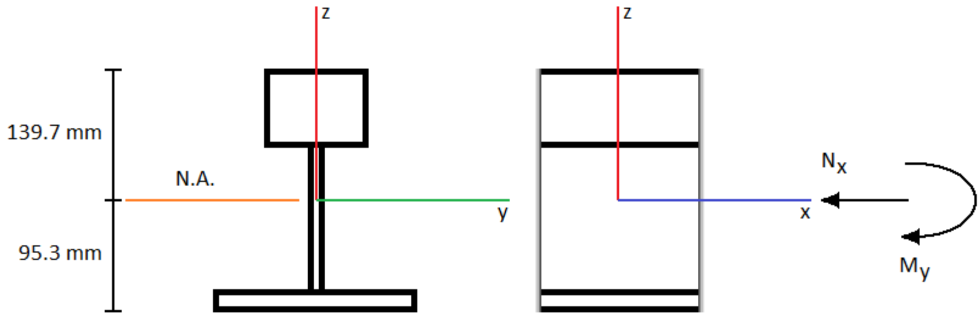
Example: An arbitrary cross-section is experiencing the following conditions. What is the maximum compressive and tensile stresses that this element is undergoing?

$N_x = 20 \text{ kN}$

$M_y = 25 \text{ kNm}$

$A = 3650 \text{ mm}^2$

$I_y = 29.5 \cdot 10^6 \text{ mm}^4$



Solution:

We recall that this element is undergoing both axial loading and bending. Therefore we will use Navier's formula which takes into account both of the stresses (axial and bending)

On top:

$\sigma_{Top} = \sigma_N + \sigma_M = -\frac{F}{A} + \frac{M}{I} \cdot z = -\frac{20 \cdot 10^3 \text{ N}}{3650 \text{ mm}^2} + \frac{25 \cdot 10^6 \text{ Nmm}}{29.5 \cdot 10^6 \text{ mm}^4} \cdot 139.7 \text{ mm} = -5.5 \text{ N/mm}^2 + 118.4 \text{ N/mm}^2$

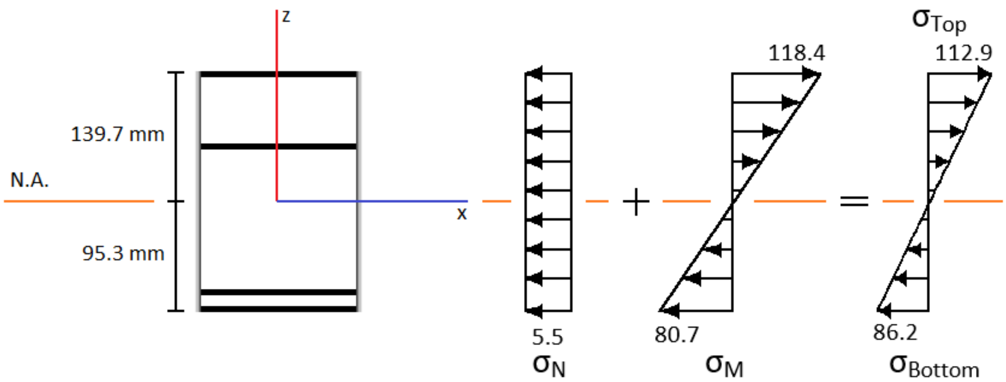
$\sigma_{Top} = 112.9 \text{ N/mm}^2$ (Tension)

On bottom:

$\sigma_{Bottom} = \sigma_N + \sigma_M = -\frac{F}{A} + \frac{M}{I} \cdot z = -\frac{20 \cdot 10^3 \text{ N}}{3650 \text{ mm}^2} + \frac{25 \cdot 10^6 \text{ Nmm}}{29.5 \cdot 10^6 \text{ mm}^4} \cdot (-95.3 \text{ mm}) = -5.5 \text{ N/mm}^2 - 80.7 \text{ N/mm}^2$

$\sigma_{Bottom} = -86.2 \text{ N/mm}^2$ (Compression)

Visualization:



NTNU
Norwegian University of
Science and Technology