

Structural Engineering

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Intended Learning Outcomes (ILO)

Upon completion of this topic, the students should be able to:

- Familiarize themselves with the history of structural engineering and its notable events.
- Determine the different specialized areas covered in structural engineering.
- Familiarize themselves with the necessary skills, roles, and responsibilities a structural engineer should uphold.
- Explore the diverse range of potential career opportunities within the dynamic field of structural engineering.
- Understand the path to becoming a qualified structural engineer in the Philippines.
- Identify the notable structural engineers throughout history and their renowned works.
- Identify the commonly used software in structural engineering and its respective purposes.

Introduction

Envision a world lacking sturdy buildings, bridges, and secure living spaces – this is where the significance of structural engineering becomes evident. It functions as a concealed hero, ensuring the strength and safety of our structures. Just like a superhero operating in the background, applying the concepts of structural engineering guarantees the safety and security of buildings and constructions.

This concealed heroism is indispensable to society, as it guarantees the stability, safety, and overall functionality of structures. Drawing upon the principles entrenched in physics and mathematics, structural engineers craft designs that imbue structures capable of withstanding an extensive spectrum of forces and environmental variables. In this capacity, they undertake a critical role in not only preserving lives but also propelling societal progress forward.

Moreover, structural engineering, a specialized field of civil engineering, concentrates on the design, assessment, and assurance of balance and safety for various structures. These structures encompass everything from buildings and bridges to dams and towers. This discipline is instrumental in shaping our constructed surroundings and converting architectural concepts into tangible, efficient, and secure outcomes.

The realm of structural engineering encompasses an expansive scope, leaving its mark on every facet of our constructed surroundings. At its core, the employment of structural engineering assumes a pivotal function in shaping secure, versatile, and visually pleasing edifices that amplify

the welfare and advancement of individuals, communities, and entire societies. This impact resonates throughout the landscape, from the buildings providing shelter and labor to the pathways and spans facilitating our movements.

It is in the hands of structural engineers to enable the birth of structures that stand as bastions of safety and reliability. With these wide-ranging applications come profound responsibilities. Tasked with abiding by strict building codes, structural engineers engage in the meticulous formulation of designs that can brave numerous trials. Their vigilance extends to the construction phase, safeguarding the integrity of their creations. As committed to security and ingenuity, structural engineers are ceaselessly devoted to refining designs, amalgamating principles of sustainability, and embracing nascent technologies. This tenacity extends to the sphere of resource management, where the judicious utilization of materials and equipment stands paramount. For instance, they gauge the optimal material grade, harmonizing fortification, utility, and financial considerations. This field strikes a harmonious equilibrium between architectural elegance, utilitarian requisites, and fiscal prudence, emerging as a pivotal nexus where functionality and artistry converge to fulfill pragmatic and imaginative imperatives.

History

The impact that structural engineering has had on our society is crucial, and it warrants a look back at its history. Understanding how structural engineering has developed continuously from ancient times to the present is important because it serves as a blueprint for further developments.

I. Pre-Scientific Revolution (27th Century BC – 18th Century A.D.)

- 27th Century BC: *Imhotep*, the first-named engineer and architect in history, built the step pyramid for Pharaoh Djoser.
- 26th Century BC: The *Great Pyramid of Giza*, the largest man-made structure before, was built.
- 3rd Century BC: *Archimedes* invented the sciences of mechanics and hydrostatics. It was also when Archimedes published his work.
- 1st Century: *Vitruvius* recorded the methods, materials, and machines in his *De Architectura*.

- 1638: *Galileo Galilei* published *Dialogues Relating to Two New Sciences*, where he outlined the sciences of strength of materials and motion of objects.
- 1676: *Robert Hooke* provides a scientific understanding of the elasticity of materials and their behavior under load.
- 1687: *Sir Isaac Newton* published *Philosophiae Naturalis Principia Mathematica*. *Newton* and *Gottfried Leibniz* both independently developed the *Fundamental Theory of Calculus*.
- 1750: *Leonhard Euler* and *David Bernoulli* developed the *Euler–Bernoulli Beam Equation*, the fundamental theory underlying most structural engineering design. *Daniel Bernoulli* and *Jean Bernoulli* also developed the *Theory of Virtual Work*.
- 1797: The *Ditherington Flax Mill* in Shrewsbury, England, was built.

II. 19th and 20th Century

- 1804: The *Belper North Mill*, a fire-proof building, was built.
- 1824: *Portland Cement* was patented by *Engineer Joseph Aspdin*.
- 1826: *Claude-Louis Navier* published the *Elastic Theory of Beams*. He also established the elastic modulus, a known property of a material. Navier's work deemed him the Founder of Modern Structural Analysis.
- 1858: *Henry Bessemer* completed the conversion of cast iron into cast steel.
- 1867: *Joseph Monier* filed several patents for tubs, slabs, and beams that use his steel mesh reinforcement and concrete system.
- 1885: *William Le Baron Jenney* built the *Home Insurance Building* in Chicago.
- 1889: The wrought iron *Eiffel Tower* was built by *Gustave Eiffel* and *Maurice Koechlin* to demonstrate the potential of building structures using iron.
- 1928: *Eugène Freyssinet* pioneered and patented *Prestressed Concrete*, a method still used to overcome the inherent weakness of concrete structures in tension.
- 1930: *Professor Hardy Cross* developed the *Moment Distribution Method*, a tool used to approximate the real stresses or complex 1930 structures quickly and accurately.
- 1953: The *Soviet Union* successfully built seven massive skyscrapers, dubbed the "*Seven Sisters of Moscow*."

- 1955: Fazlur Khan was involved in some of the most innovative structural designs for 1955's *Skyscrapers*, including the Tube Structural Systems, Framed Tube, Trussed Tube and X-Bracing, Bundle Tube, Tube in Tube, and Shear Wall Frame Interaction System.
- 1956: *Stiffness and Deflection of Complex Structures* was published. It introduced the name "*finite-element method*," which is still regarded as the first comprehensive treatment of the method today.

III. Information Age

- 1965: NASTRAN (NASA Structural Analysis) was developed as a structural analysis solver tool.
- 1969: The *MacNeal-Schwendler Corporation* initiated the first commercially available version of NASTRAN and dubbed it *MSC/NASTRAN*, which would be known as the first generation of FEA software.
- 1973: The *Sydney Opera House* was built. It is where structural engineers used computational analysis software for the first time.
- 1982: *Autodesk Co.* introduced *AutoCAD*, which is still among the most widely used CAD programs used by structural engineers to this day.
- 2002: The terms "*Building Information Model*" and "*Building Information Modeling*," including the acronym "*BIM*," were popularized after Autodesk released a White Paper entitled "*Building Information Modeling*."

Specialized Areas in Structural Engineering

Have you ever wondered about the expansive opportunities within a career in structural engineering? While the common perception might be one of overseeing building construction, the reality is far more intriguing. Many professionals in this field are indeed involved in the construction process. Structural engineers can end up working in a range of varied and exciting disciplines. Here are just a handful of the wide-ranging professional fields a structural engineering career can bring:

1. Buildings

Structural engineers play a crucial role in ensuring the stability and safety of various structures. They meticulously examine the array of forces and loads building encounters over its

operational life, encompassing factors such as gravity, wind, seismic disturbances, and more. By leveraging their expertise, they formulate the blueprint for the building's framework, foundation, and structural components. This design process is essential not only for guaranteeing the security of occupants but also for enhancing the structure's overall durability. Whether it is a modest dwelling or an imposing skyscraper, an architectural house, or a sprawling sports stadium, the insights of structural engineers are indispensable in creating edifices that stand the test of time while prioritizing safety and resilience.

2. Aeronautical

Aeronautical structural engineering encompasses the design, development, and maintenance of runways, airport facilities, and hangars. Their primary duty revolves around the construction, inspection, maintenance, and repair of the structures associated with the transportation and housing of aircraft. Structural engineers play a vital role in guaranteeing the integrity and safety of aircraft-related buildings in the aeronautical sector.

3. Oil and Gas

A structural engineer is needed in the oil and gas sector since they have to construct oil fields, gas fields, pipelines, bases, oil refineries, fuel stations, and shelters for a wide array of machinery, storage facilities, and more. Their primary role is to design, plan, execute, and manage civil works for a particular building or facility.

4. Nautical

Nautical structural engineering encompasses the planning, creating, and maintaining ports, piers, and sea-based platforms. Its primary responsibility involves establishing and overseeing marine systems and facilities for maritime vessels. Structural engineers are crucial in furnishing subaquatic life support systems and wind turbines to generate energy.

5. Bridges

Structural engineering plays a crucial role in bridge design, construction, and maintenance. Structural engineers design bridges by considering location, budget, and usage. They analyze various loads, select appropriate materials, and use software for modeling and analysis. Dynamic behavior and foundations are vital considerations. In earthquake-prone areas, seismic design is crucial. Engineers collaborate with construction teams and focus on maintenance. Ongoing

innovations drive bridge engineering towards sustainability and resilience, involving multiple disciplines for safe and functional bridge infrastructure. Given these circumstances, structural engineers are responsible for verifying that the structure can support the loads to ensure everyone's safety.

Skills of an Effective Structural Engineer

To be an ideal structural engineer takes time and dedication for their career, and they must undergo professional growth and develop the necessary skills. Undoubtedly, an effective structural engineer is not just an expert in technical aspects but also a critical problem solver and a sociable communicator. Aside from having a thorough understanding of fundamental engineering principles, structural engineers should also consider proper communication among architects, builders, and clients to ensure terms and safety are met. Their capability to adapt to different scenarios enables them to resolve unexpected obstacles during construction while maintaining their work ethic. Essentially, an ideal structural engineer always utilizes fundamental mastery and interpersonal skills. Thus, aspiring structural engineers must have the technical and soft skills discussed in the succeeding sections to become seasoned and successful engineers.

A. Technical Skills

Alternatively known as hard skills, technical skills are particular abilities aligned explicitly to one's profession, expertise, field, or discipline, making them a significant factor for rapidly evolving modern jobs. These attributes are commonly taught and developed through learning, training, and experience in school or the real world. As such, structural engineers must be equipped with such skills to be more effective and globally competitive. In structural engineering, these skills enable an engineer to be fully efficient in analyzing, designing, and overseeing the construction of various structural components and systems within built environments. With this, the following are some of the essential technical skills that should be observed within a structural engineer:

- 1. Structural Analysis Software Proficiency** – Structural engineers must be proficient in utilizing advanced computer software, such as STAAD Pro, SAP2000, ETABS, or other tools to perform complex structural analyses. These software packages assist in simulating and predicting the behavior of structures under various conditions, ensuring design safety and efficiency.

- 2. Foundation Design Skills** – Since the foundation is the base of any structure, structural engineers must be skilled in designing foundations that can safely distribute loads from the system to the ground, accounting for soil properties and site conditions.
- 3. Proficiency in AutoCAD and BIM Software** – AutoCAD and Building Information Modeling (BIM) software are vital tools for developing detailed and accurate design drawings and models, allowing engineers to effectively collaborate with architects, contractors, and other professionals throughout the design and construction processes.
- 4. Construction Materials Testing and Quality Control Skills** – Being highly capable of conducting and interpreting material testing, such as concrete strength tests, among many others, is crucial for ensuring that the materials used for construction meet the design specifications while still following necessary building codes and standards.
- 5. Finite Element Analysis (FEA) Knowledge** – FEA is a numerical method used to simulate the behavior of complex structures and systems. Thus, being proficient in applying FEA allows structural engineers to analyze intricate structural components and systems, helping to optimize designs and identify potential failure points.

B. Soft Skills

Also known as people skills, soft skills are characteristics an individual possesses that enable them to interact and collaborate with others personally and professionally, which is truly important for a structural engineer. Structural engineering requires an innovative individual. This profession is responsible for its actions as they influence economic properties and environmental structures. Being defined as an innovative person, various soft skills are drawn:

- 1. Analytical Thinking & Problem Solving** – The specialty of structural engineering focuses on analyzing structural frameworks and systems. The main factor responsible for safety and durability is the result of the evaluation conducted by a structural engineer.
- 2. Communication & Presentation** – The transaction of information and details is vital for structural engineering. They should comprehend the content and engage with feedback to enhance their understanding of project tasks and assessments.
- 3. Leadership & Collaboration** – Commitment to work is crucial in structural engineering. Additionally, a sharp intellect that can make decisions under pressure, effectively communicate orders, and assign duties is required.

- 4. Creativity & Originality** – Solving problems with creativity is a significant factor in structural engineering to work faster without neglecting the fundamentals and regulations. When coming up with fresh and original ideas, it is crucial to understand how to investigate, be inspired by, absorb, and reflect on others.
- 5. Adaptability** – Since structural engineering aims to find answers to unforeseen issues to adapt to new circumstances or surroundings, flexibility is necessary.

Roles and Responsibilities of Structural Engineers

A structural engineer is a professional responsible for designing and supervising the construction of various structures, ensuring their safety and longevity. They employ computer-aided design tools, analyze loads and pressures, collaborate with contractors, and oversee on-site construction. The core duties of structural engineers include the following:

- 1. Designing Structures:** Structural engineers create building plans and designs based on technical specifications to ensure structural integrity and safety. This process includes calculating the forces and pressures the construction must endure due to environmental conditions.
- 2. Investigation:** Before the commencement of activities, structural engineers examine and assess construction sites to determine their appropriateness for the requirements of upcoming projects.
- 3. Collaboration:** Structural engineers liaise with architects and other professionals to effectively coordinate design and construction efforts.
- 4. Project Management:** Structural engineers oversee projects, coordinating activities among various stakeholders and managing resources efficiently. They commonly have the responsibility of coordinating and ensuring the provision of appropriate construction materials and equipment essential for the durability and long-term stability of the structures.
- 5. On-Site Inspection:** Structural engineers inspect construction work carried out by contractors to ensure adherence to design specifications and safety protocols. They monitor construction progress and provide regular reports on project advancement and outcomes.

- 6. Regulatory Compliance:** Structural engineers obtain necessary planning and building regulations approvals and ensure projects adhere to legal standards. They manage contracts and project timelines, ensuring smooth project execution.
- 7. Safety and Durability:** Ensuring the safety and durability of structures is a central responsibility, intending to withstand external forces and environmental conditions.

Structural engineers work in office and construction site settings, often with long hours and multidisciplinary teams. They need a solid understanding of physics, strong 3D conceptual skills, and creative problem-solving abilities to succeed in their role. Whether designing new structures or enhancing existing ones, structural engineers play a vital role in the construction process, contributing to the physical integrity and safety of buildings, tunnels, bridges, and other large structures.

Potential Careers or Jobs in the Structural Engineering Industry

Structural engineers are engaged in various sectors, spanning from construction to manufacturing. Buildings, bridges, and other significant infrastructure projects are designed and constructed under their supervision. This profession requires a combination of analytical thinking and creative perspectives to turn innovative ideas into reality. After completing a degree in structural engineering, graduates have a surfeit of career paths available to them. Here are some potential options:

1. Structural Engineer

Structural Engineering represents a specialized field within the realm of Civil Engineering. Professionals in this discipline create plans and specifications, carry out calculations, examine the work of other engineers, write reports and evaluations, and monitor construction sites. Structural engineering showcases a wide range of applications. Planning for structures -- such as buildings, bridges, tunnels, and other constructions makes up a large portion of structural engineers' work. Most structural engineers primarily serve as consultants for designers or design-build firms.

2. Construction Design Engineer

A construction design engineer plays a crucial role in creating detailed and compliant structural designs for buildings and infrastructure projects within the realm of structural

engineering. They collaborate with architects and multidisciplinary teams in translating concepts into practical plans, considering aesthetics, functionality, and safety. These professionals bridge the gap between architectural vision and structural integrity, ensuring that designs not only meet regulatory standards but also visually represent the intended project while addressing challenges that arise during construction.

3. Project Manager

Project managers in the structural engineering industry oversee the entire lifecycle of a project. They plan, coordinate, and manage various aspects of a project, such as budgeting, scheduling, resource allocation, and team coordination. Project managers ensure that projects are completed on time, within budget, and meet quality standards. They also facilitate communication among different stakeholders, including clients, engineers, contractors, and regulatory authorities.

4. Researcher or Lecturer

Those interested in research and lecturing pursue careers in academia or research institutions. They contribute to advancing the field of structural engineering by conducting research, developing new methodologies, and analyzing emerging trends. They might also teach courses related to structural engineering at universities or other educational institutions, passing on their knowledge and expertise to the next generation of engineers.

5. Consulting Engineer

Freelance consulting involves offering independent expertise to clients on a project-by-project basis. Freelance structural engineers can provide specialized services such as structural assessments, feasibility studies, and design reviews. They work directly with clients or firms, leveraging their experience to offer insights, solutions, and recommendations for various structural engineering challenges.

Becoming a Structural Engineer in the Philippines

Among all the things discussed about the field of structural engineering, particularly its specialized areas, the necessary qualities, roles, responsibilities, and potential careers, one can genuinely consider pursuing the path toward becoming a structural engineer. As such, if one aspires to be a structural engineer in the Philippines, one would have to consider the following guide:

1. Finish Educational Requirements

Obtain a Bachelor's Degree in Civil Engineering, Major in Structural Engineering from a school accredited by the Philippine Commission on Higher Education (CHED). In light of this, Batangas State University - The National Engineering University offers students the said major or specialization in the 3rd year of the program, with professional courses aligned for structural engineering. Obtaining such a degree provides the fundamental knowledge necessary for a career in structural engineering.

2. Pass the Licensure Examination

After completing and graduating from the program, one must pass the Civil Engineering Licensure Examination administered by the Professional Regulation Commission (PRC) of the Philippines. This examination assesses your knowledge and competence in various areas of civil engineering, with structural engineering being encompassed by the included subjects. In doing so, one must have an overall score of 70% or greater, with no subjects ranking below 50%.

3. Gain Work Experience

After passing the licensure examination, it is necessary to acquire hands-on practical experience while being mentored by a licensed structural engineer. The PRC mandates a minimum of 4 years of pertinent work experience prior to being eligible to seek a Professional Engineer (PE) license.

4. Apply for a Professional Engineer (PE) License

Once the necessary years of work experience are fulfilled, one is eligible to submit an application for a PE license through the PRC. This license grants an individual the legal authority to engage in professional practice and utilize the designation as a Professional Engineer.

5. Specialize in Structural Engineering

Being a professional engineer enables one to practice engineering in general. However, if one wants to specialize in structural engineering, one can pursue further education or additional training aligned with the discipline. This includes but is not limited to attending workshops, seminars, short courses, or even entering graduate studies for a Master's or a Doctoral Degree in Civil Engineering with structural engineering as the selected field of study.

6. Join Professional Organizations

After immersing in education and work experience, one can take a step further by joining professional civil and structural engineering organizations, such as the Philippine Institute of Civil Engineers and the Association of Structural Engineers of the Philippines. These organizations can provide networking opportunities, access to resources, and a platform to learn and socialize with experienced professionals.

Notable Structural Engineers

Distinguished for their exceptional contributions to the field of structural engineering, these engineers have profoundly influenced the built environment. Their groundbreaking designs and innovative solutions have transformed architectural landscapes and redefined the possibilities of engineering. These individuals have not only engineered iconic structures but have also inspired future generations to push the boundaries of structural design, making them pivotal figures in the evolution of modern construction.

1. Fazlur Rahman Khan

Fazlur Rahman Khan was the world's most important of all skyscraper engineers. He was a Bangladeshi-American architect and structural engineer. He is known as the "Father of Tubular Designs," credited with designing several skyscrapers, including the Willis Tower and the John Hancock Center. Khan is often referred to as the 20th century's greatest structural engineer and the Einstein of structural engineering due to his ingenious use of structural systems.

2. William Frazier Baker

William Frazier Baker, aka Bill Baker, is an American structural engineer best known for his engineering work on the Burj Khalifa. This skyscraper is currently the world's tallest man-made structure and a true feat of engineering. He is widely recognized for his work on supertall buildings. His work on the Burj Khalifa required him to develop the "buttressed core" structural system. This design enabled the tower to reach its record heights while retaining the necessary strength to stay erect. This system consists of a hexagonal core reinforced by three buttresses that form a Y-shape. This setup lets the system support itself both laterally and torsionally.

3. Sir Ove Arup

Sir Ove Arup is widely considered the foremost engineer of his era. Ove became most famed for his work on the extraordinary Sydney Opera House, which remains one of the world's

most iconic structures. Ove combined a philosophical, artistic, and practical approach to business and is remembered as an eminent bridging figure between the aesthetics and the constructional aspects of building design. He believed there are no natural boundaries between architecture and engineering and that a collaborative spirit can overcome these, leading to a practice called ‘Total Architecture.’ His technical achievements include the groundbreaking use of precast concrete and structural glue.

4. Alexandre-Gustave Eiffel

Alexandre-Gustave Eiffel is a French civil engineer and architect best known for the world-famous Eiffel Tower, built for the 1889 Universal Exposition in Paris, France. He made his name with various bridges for the French railway network, most famously the Garabit viaduct. In addition, Eiffel was one of the first engineers to employ compressed-air caissons in bridge building. He designed the movable dome of the observatory at Nice and the framework of the Statue of Liberty in New York Harbor.

Widely Employed Software in Structural Engineering

Since structural engineers are tasked with conceptualizing, designing, and executing complete structures, they utilize these resources to formulate, organize, and implement their plans and designs.



1. AutoCAD

Fully known as Automated Computer-Aided Design, this is the most popular software in the world of civil engineering. Autodesk designed it, which helps create 2D and 3D designs, drafting, modeling workflows, architectural drawings, and more. It allows you to evaluate and understand project performance, respond quickly to changes, and consistently maintain data and processes. Some of its essential features include a powerful set of intuitive design and documentation tools to explore and visualize 3D concepts, a user-friendly interface that works across a range of integrated devices, including desktop, mobile, and cloud, the elimination of the need for manual drafting to boost accuracy, and providing the ability to share your work through TrustedDWG™ technology.

2. STAAD Pro

Standing for Structural Analysis and Design Pro, STAAD Pro is a structural design and analysis tool developed by Research Engineers, which was later acquired by Bentley Systems, a CAD/CAM software company based in Pennsylvania. STAAD Pro is considered the best structural analysis software and has been adopted by over a million structural engineers around the globe.



It features ease of use and an array of essential tools required for accomplishing an analytical process on different structures. STAAD Pro further integrates with several other Bentley products. The models created using STAAD Pro can be imported to OpenSTAAD to make the models transferrable to other third-party tools.

3. SAFE

This software is mainly used in designing foundation slab systems and concrete floors. SAFE is a comprehensive package that combines all the aspects of the engineering



design process, from creating a layout to detailed drawing production in a single, intuitive environment. It enables highly advanced local assessment of foundation systems within larger structures and imports files from CAD, ETABS, and SAP2000. Some other benefits it offers are wide-ranging templates to quickly initiate a model, post-tensioning, and support conditions and loadings.



4. RISA

Rapid Interactive Structural Analysis is another popular 3D analysis and design tool for creating general structures such as buildings, bridges, arenas, industrial structures, crane rails, and more. It is fast, productive, and accurate. Its intuitive interface can be integrated with other products like RISAFloor and RISA Foundation. It comes packed with the latest steel, cold-formed steel, concrete, aluminum, masonry, and timber design codes, providing the tools you need to manage multi-material projects easily.

5. Navisworks

Navisworks is a comprehensive project review solution mainly used by design, engineering, and construction management professionals to gain detailed insight into the project and enhance productivity and quality. Autodesk developed and marketed it, allowing users to open, combine, review, and share Detailed 3D Design Models in various file formats. It lets you import all file formats and merge all the files to create a model.



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