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Modern Developments in Structural Engineering

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ABSTRACT :*Due to the innovations and developments of new topics like fracture mechanics, earthquake engineering and, composite materials, temperature effects on materials, dynamics and vibration control, fatigue, creep and others, structural engineering now provide basis for great future developments and new techniques for different structures with increasing complexity. This paper discusses state of art developments in the fields of Structural Engineering and also focuses on new challenges and future developments.*

Keywords:*complexity, creep, fatigue, structures, vibration etc.*

INTRODUCTION

Modern developmentsand innovations in structural engineering started with the publication of three great scientific works in the seventeenth century by Galileo, Robert Hook and Isaac Newton. Tremendous developments occurred in 19^{th} and 20^{th} century in the fields of material science and structural analysis.

The development of computational methods and increasing use of computers allowed great advances in structural engineering design and architecture. Many modern structures could not be understood and designed without the use of computational analysis. In the latter part of the 20th century detailed understanding of topics such as fracture mechanics, earthquake engineering, composite materials, temperature effects on materials, dynamics and vibration control, fatigue, creep and others were developed. The depth and breadth of knowledge is now available in structural engineering, and the increasing range of different structures and the increasing complexity of those structures has led to increasing specialization of structural engineers.

An old trend of learning from failures has vanished due to innovations in computational methods and 3D modeling of structures. Development of new materials and techniques have changed this world.This paper discusses the modern developments in the field of structural engineering.

1. Review Of Literature

In 19th and early 20th centuries, materials science and structural analysis were developing very fast. Claude-Louis Navier formulated the general theory of elasticity in a mathematically usable form. In his "*leçons* of 1826", he explored a great range of different structural theory, and was the first to highlight that the role of a structural engineer is not to understand the final, failed state of a structure, but to prevent that failure in the first place. In 1826 he also established the elastic modulus as a property of materials independent of the second moment of area, allowing engineers for the first time to both understand structural behaviour and structural materials. Towards the end of the 19th century, in 1873, Carlo Alberto Castigliano presented his dissertation "Intornoaisistemielastici", which contains his theorem for computing displacement as partial derivative of the strain energy.

In 1824, Portland cement was patented by the engineer Joseph Aspdin as *"a superior cement resembling Portland Stone"*, British Patent no. 5022. Although different forms of cement already existed (Pozzolanic cement was used by the Romans as early as 100 B.C. and even earlier by the ancient Greek and Chinese civilizations) and were in common usage in Europe from the 1750s, the discovery made by Aspdin used commonly available, cheap materials, making concrete construction an economical possibility.

Developments in concrete continued with the construction in 1848 of a rowing boat built of ferrocement - the forerunner of modern reinforced concrete - by Joseph-Louis Lambot. He patented his system of mesh reinforcement and concrete in 1855, one year after W.B. Wilkinson also patented a similar system.[18] This was followed in 1867 when a reinforced concrete planting tub was patented by Joseph Monier in Paris, using steel mesh reinforcement similar to that used by Lambot and Wilkinson. Monier took the idea forward, filing several patents for tubs, slabs and beams, leading eventually to the Monier system of reinforced structures, the first use of steel reinforcement bars located in areas of tension in the structure.

Steel construction was first made possible in the 1850s when Henry Bessemer developed the Bessemer process to produce steel. He gained patents for the process in 1855 and 1856 and successfully completed the conversion of cast iron into cast steel in 1858. Eventually mild steel would replace both wrought iron and cast iron as the preferred metal for construction.

During the late 19th century, great advancements were made in the use of cast iron, gradually replacing wrought iron as a material of choice. Ditherington Flax Mill in Shrewsbury, designed by Charles Bage, was the first building in the world with an interior iron frame. It was built in 1797. In 1792 William Strutt had attempted to build a fireproof mill at Belper in Derby (Belper West Mill), using cast iron columns and timber beams within the depths of brick arches that formed the floors. The exposed beam soffits were protected against fire by plaster. This mill at Belper was the world's first attempt to construct fireproof buildings, and is the first example of fire engineering. This was later improved upon with the construction of Belper North Mill, a collaboration between Strutt and Bage, which by using a full cast iron frame represented the world's first "fire proofed" building. The Forth Bridge was built by Benjamin Baker, Sir John Fowler and William Arrol in 1889, using steel, after the original design for the bridge by Thomas Bouch was rejected following the collapse of his Tay Rail Bridge. The Forth Bridge was one of the first major uses of steel, and a landmark in bridge design. Also in 1889, the wrought-iron Eiffel Tower was built by Gustave Eiffel and Maurice Koechlin, demonstrating the potential of construction using iron, despite the fact that steel construction was already being used elsewhere.

During the late 19th century, Russian structural engineer Vladimir Shukhov developed analysis methods for tensile structures, thin-shell structures, lattice shell structures and new structural geometries such as hyperboloid structures. Pipeline transport was pioneered by Vladimir Shukhov and the Branobel company in the late 19th century.

Again taking reinforced concrete design forwards, from 1892 onwards François Hennebique's firm used his patented reinforced concrete system to build thousands of structures throughout Europe. Thaddeus Hyatt in the US and Wayss&Freitag in Germany also patented systems. The firm *AG fürMonierbauten* constructed 200 reinforced concrete bridges in Germany between 1890 and 1897 The great pioneering uses of reinforced concrete however came during the first third of the 20th century, with Robert Maillart and others furthering of the understanding of its behaviour. Maillart noticed that many concrete bridge structures were significantly cracked, and as a result left the cracked areas out of his next bridge design - correctly believing that if the concrete was cracked, it was not contributing to the strength. This resulted in the revolutionary Salginatobel Bridge design. Wilhelm Ritter formulated the truss theory for the shear design of reinforced concrete beams in 1899, and Emil Mörsch improved this in 1902. He went on to demonstrate that treating concrete in compression as a linear-elastic material was a conservative approximation of its behaviour.[24] Concrete design and analysis has been progressing ever since, with the development of analysis methods such as yield line theory, based on plastic analysis of concrete (as opposed to linear-elastic), and many different variations on the model for stress distributions in concrete in compression.

Prestressed concrete, pioneered by EugèneFreyssinet with a patent in 1928, gave a novel approach in overcoming the weakness of concrete structures in tension. Freyssinet constructed an experimental prestressed arch in 1908 and later used the technology in a limited form in the Plougastel Bridge in France in 1930. He went on to build six prestressed concrete bridges across the Marne River, firmly establishing the technology.

Structural engineering theory was again advanced in 1930 when Professor Hardy Cross developed his Moment distribution method, allowing the real stresses of many complex structures to be approximated quickly and accurately.

In the mid 20th century John Fleetwood Baker went on to develop the plasticity theory of structures, providing a powerful tool for the safe design of steel structures. High-rise construction, though possible from the late 19th century onwards, was greatly advanced during the second half of the 20th century. Fazlur Khan designed structural systems that remain fundamental to many modern high rise constructions and which he employed in his structural designs for the John Hancock Center in 1969 and Sears Tower in 1973. Khan's central innovation in skyscraper design and construction was the idea of the "tube" and "bundled tube" structural systems for tall buildings. He defined the framed tube structure as "a three dimensional space structure composed of three, four, or possibly more frames, braced frames, or shear walls, joined at or near their edges to form a vertical tube-like structural system capable of resisting lateral forces in any direction by cantilevering from the foundation."[33] Closely spaced interconnected exterior columns form the tube. Horizontal loads, for example wind, are supported by the structure as a whole. About half the exterior surface is available for windows. Framed tubes allow fewer interior columns, and so create more usable floor space. Where larger openings like garage doors are required, the tube frame must be interrupted, with transfer girders used to maintain structural integrity. The first building to apply the tube-frame construction was in the DeWitt-Chestnut Apartment Building which Khan designed in Chicago. This laid the foundations for the tube structures used in most later skyscraper constructions, including the construction of the World Trade Center.

Another innovation that Fazlur Khan developed was the concept of X-bracing, which reduced the lateral load on the building by transferring the load into the exterior columns. This allowed for a reduced need for interior columns thus creating more floor space, and can be seen in the John Hancock Center. The first sky lobby was also designed by Khan for the John Hancock Center in 1969. Later buildings with sky lobbies include the World Trade Center, Petronas Twin Towers and Taipei 101.

In 1987 JörgSchlaich and Kurt Schafer published the culmination of almost ten years of work on the strut and tie method for concrete analysis - a tool to design structures with discontinuities such as corners and joints, providing another powerful tool for the analysis of complex concrete geometries.

In the late 20th and early 21st centuries the development of powerful computers has allowed finite element analysis to become a significant tool for structural analysis and design. The development of finite element programs has led to the ability to accurately predict the stresses in complex structures, and allowed great advances in structural engineering design and architecture. In the 1960s and 70s computational analysis was used in a significant way for the first time on the design of the Sydney Opera House roof. Many modern structures could not be understood and designed without the use of computational analysis. Developments in the understanding of materials and structural behaviour in the latter part of the 20th century have been significant, with detailed understanding being developed of topics such as fracture mechanics, earthquake engineering, composite materials, temperature effects on materials, dynamics and vibration control, fatigue, creep and others. The depth and breadth of knowledge now available in structural engineering, and the increasing range of different structures and the increasing complexity of those structures has led to increasing specialisation of structural engineers[1]

2. Modern Developments in Structural Engineering

Due to the innovations and developments of new topics like fracture mechanics, earthquake engineering and, composite materials, temperature effects on materials, dynamics and vibration control, fatigue, creep and others, structural engineering now provide basis for great future developments and new techniques for different structures with increasing complexity.

Modern developments in structural engineering should be in view of problems due to global warming and sustainability in order to minimize carbon footprint of buildings. Structural engineers will therefore need to development an understanding of sustainability in general and how it affects design and construction and how to quantify the carbon content of a project balancing different aspects.

In order to avoid consequences of structural failure the approval process must be strong and must be technically in pace with new research development in this field. That will pose increasing responsibility on structural engineer. Hence structural engineer should prepare himself with the modern tools of analysis and design of structures keeping in mind globalization of construction industry.[2]

CONCLUSION

With increasing concern of global warming, climatic change and changing natural processes and phenomenon future development in structural engineering need considerations of different aspects in the analysis and design of sustainable structures considering globalization of construction industry. With the available tools (like advanced computers, 3D modeling software) and knowledge new challenges are not truly serious when they are not neglected.

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