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DESIGN INNOVATION IN STRUCTURAL ENGINEERING: AN OVERVIEW

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Abstract: This work examines how innovations could be factored into design of structural engineering systems to provide a deviation from the codified design approaches that grossly under-utilized engineering materials and lack of optimization and reliability considerations. The paper highlights some of the innovative approaches in design and innovative construction materials. The context in which innovation as a process or concept can be used effectively is dealt with in the paper. The use of innovative materials such as Fibre Reinforced Self Compacting Concrete could be beneficial for dry joint construction which provides solution to the construction in confined places such as congested city centers. In addition, the use of numerical analytical tools interfacing with optimization and reliability analysis such as Monte Carlo simulation is highlighted. This clearly leads to design optimization that leads to efficient system and reduction of construction cost.
Keywords: structural engineering, innovation, Fibre Reinforced Self Compacting Concrete

INTRODUCTION

It is important to understand the meaning of innovation before interpolating to the realm of structural engineering. Innovation is an improved way of doing old things such as processes and services with added values for the benefit of the consumers. It is clearly understood that traditional design is very conservative with the use of high safety measure with material usage in the elastic region. This leads to high construction cost and inefficient use of materials. In this respect, the present work examines some best practices that could be argued as new means of structural engineering with value addition of some sort for the benefit of the consumers.

The innovation is examined on the premises of new materials that provide better performance at reduced weight and cost. Also, the new construction methodologies such as dry joint that provides more span with reduced depth leading reduced cost. Application of Finite Element Method of analysis provides platform for the complex interaction of structural members. This could be coupled with the reliability analysis of the engineered structures using Monte Carlos simulation or any other stochastic approach linked with structural optimisation using Genetic Algorithm or Evolutionary Genetic Algorithm for multi objective functionalities. This definitely defines the failure probability of such structures using the optimal structures.

TRADITIONAL PRACTICE

The traditional codified design approach has been the practice of most engineers across the world and most especially in Nigeria. This approach is inherent with lack of intuition of experimenting with novel approach that can be beneficial to the consumers. Although the ultimate limit state design tends to lean on reliability approach for the determination of partial factors of safety and in most cases the stress resultants from the elastic analysis using factored loads are used in design. The reason is not far-fetched because at the planning stage project cost analysis are not the priorities of planning of the project and the life cycle cost is never in the mind of the designers. It is understood that resolution of constraints, code specifications and the client's need are usually the overriding considerations. The need for innovation is seldom considered at this stage. This leaves the gap for improvement unfilled and most times opportunities are missed to have a process for value addition for the design under consideration. Although, in certain cases, nonlinearity of material and geometry are taken into consideration in stability analysis but the ultimate design is based on the use elastic stress resultants. Even, the elastic perfectly plastic material idealisation is not an ultimate realisation of material capabilities in steel for example, the material ductility that takes the response of structural members to the strain hardening realm of stress-strain relationship is never exploited by the current codified design approach. This may be argued as charting the extreme utilisation of material but the factor of safety has discounted any excessive usage of material strength. This leaves a substantive material strength unused and on top of this is the huge factor of safety on both the materials and loadings. It is very evident that such a system of design based on codes is uneconomical despite the facts much is known of the capabilities of modern material. Although certain codes such Euro Codes provide for stability analysis that accounts for the material and geometric nonlinearities. In many countries in the world, particularly developing and underdeveloped worlds such as Nigeria, British Standards are adopted without customising the codes provision to the situation on ground. For example, blank adoption of foreign codes without adjustment for local materials available on ground can be a dangerous proposition.

Most of the research outputs from the country are of substandard and with little or no effort to explore numerical simulation that can assist greatly in coming up with innovative design concepts. Apart from the lack of adequate facilities, it is a strange concept to many practising engineers in the countries the use of numerical modelling to solving engineering problems. The engineering bodies are virtually doing little or nothing to advance the agenda of innovative design. This is evident in the research papers published in many of the conferences organised in the country. This could be said of many developing countries. In situations where researchers are interested in the pursuant of competitive research using state of the art computing facilities, hardly can you find adequate resources such as high powered computer software such as ANSYS [1] and ABAQUS [2] to mention but few. The laboratories in most Nigerian universities are scantly resourced with obsolete and nonfunctioning equipment. Where modern equipment are available, they are either not put into use because of lack of knowledge of calibration or some components are missing. In an instance, a full tri-axial machine is lying fallow in a laboratory because the engineers could not operate it. These are just some of the inherent problems facing researchers in Nigeria today and thus innovation in structural design is not explored rigorously.

Strictly speaking, innovative design can be summarised as follows according to Yamakazi [3]:

- innovative material-based structural components and elements, that is reusable and recyclable as social infrastructure stocks.
- multi-functional, flexible, and long-life building systems that support to maintain and to improve urban functions.
- maintenance and revitalization technologies for urban functions that create a new urban building industry.

INNOVATIVE MATERIALS AND DRY JOINT CONSTRUCTION

It is imperative to exploit the huge capacities in the modern materials to reduce cost and add values in term of space and aesthetics for the benefits of mankind. Some innovative materials have been found to be of great asset. Such composite material is Fibre Reinforced Self Compacting Concrete. There are other composite concretes that are of great values in term of strength and improved shear resistance. Even, the use of ceramic wastes has proven to be of great benefit to the industry with the material strength improvement in excess of 30%.

Fibre Reinforced Polymer (FRP) is another innovative material for the repair of damaged concrete. This may be seen as post design and construction phases of engineering system but it requires innovative approach to accomplish the set goals. In the third world, engineering systems never perform to the end of designed life span before being degraded leading to sudden collapse. Using a product like FRP will rectify the anomalies built into the systems during design and construction phases with enhanced reliability. Ede [4] demonstrated the improved performance of strengthened cracked concrete beam using FRP that is externally bonded to the concrete surface.

The objectives of innovative structural design could be summarised into the followings:

- reduction of the structural weight by a sizeable proportion that is beneficial to founding medium and cost
- cost reduction of complex fabrication
- reduction of the design, engineering, build, test & qualification time cycle by a sizeable proportion.

These objectives could be realisable through system optimisation, efficient analytical tools, statistical reliability analysis, new material developments, construction methodologies and reduction of time cycle to a nominal window. In the current situation of climate change, new materials are currently being experimented using agricultural and industrial waste products. For example, composite concrete developed from coconut fibres and lathe steel wastes are proving to be of high strength and their potential use in the blast resistant construction is looking good. Although more work needs to be done to fully characterise these materials for blast resistance design and construction but reports already published are positive indicators. Galvanized steel also is of great values in the construction industry in the developed world today. In the Asian countries, bamboo stems have been used successfully to construct fascinating and aesthetically pleasing structures.

The use of many stabilising materials for soils has proven to be of great value adding approach. In Nigeria, Nigeria Building and Road Research Institute has developed a methodology of constructing stabilised roads in the rural country sides without the use of any fossil materials such as asphalt [5]. These roads are proving to be durable but statistics on their long time performance are non-existent. The innovative concept of design and construction is yet to be standardised. The institute has developed pozzolanic material that can be used as cement replacement for low cost building construction [5]. This material could also be of great benefit in stabilising weak founding medium for structures. Standardising the design and construction methods for such materials is necessary in order to permit the engineers to take advantage of these innovative materials.

The utilisation of new materials is linked to the innovative structural designs. Such materials are high performance steel and advanced complex functional materials that render the attainment of wider span and higher vertical dimension beyond what could be attained some years back a reality. This is made possible because of their light weight and high strength. These materials have excellent service performance, durability and low cost maintenance. The combination of these characteristics enables few connections for rapid assembly and disassembly of buildings which reduce wastes of structural materials and components.

The concept of dry joint construction is a fascinating one more so in a restricted city centre enclaves where multi storey buildings are needed for commercial purposes. The large operational space for in-situ construction can be a constraint to such an extent that surrounding buildings encroachment is a hindrance to the required haulage manoeuvring space for heavy duty cranes. The only solution is dry joint precast structural elements that could be assembled on site. This may not be limited to only beam and column framing but the entire building including the slab system. The use of post tensioning technology like Mac Alloy bars to hold the beam slabs together and the jointing of the beam and columns that can be an hybrid of post tensioning and in-situ construction. Although, traditional precast building construction is the moment resisting column base with a hinged connection between the beam and column.

The provision of the hybrid in-situ and post tensioning mechanism using un-bonded tendon can produce a ductile connection of significant moment capacity that is quite useful in a seismic event. A particular special beam-column joint was investigated by Meteli and Riva [6] whereby the joint is characterized by the use of high strength steel bars and of a fibre reinforced grout pad in the "Z" shaped beam-column interface, increasing the shear resistance of the connection.

The experimental results show a good performance of the joint, in term of resistance, ductility and energy dissipation, with little damage observed in the connected members. A pictorial view of such a joint is shown in figure 1.

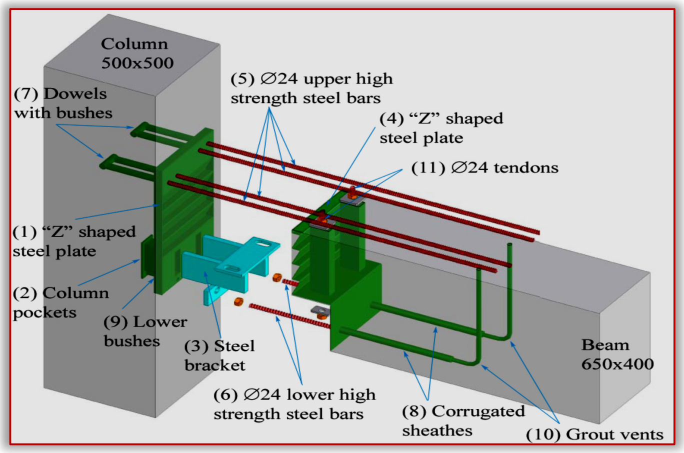

Figure 1: Details of the dry beam-column joint without rebar linkage

It is clear that the three encapsulating philosophies of innovative design can be developed to accommodate the break downs of each of the main captions. Some of these sub themes have been highlighted earlier but it is important to expatiate to broaden the scope of the current discourse. Innovative materials have been correctly identified for an innovative design. In the current culture of prevailing climate change and environmental degradation, researchers have embarked on the research programs with the emphasis on turning waste to wealth. Among such laudable investigation are the composite concrete made from lathe waste, coco nut fibre and so many as discussed earlier. These composite concretes are highly improved that their shear resistance is so high that fibre are suspected of providing more of the shear resistance. A self-compacting concrete used with these materials can lead to high strength and durable concrete that can improve dry joint capacity with great ductility.

The modern innovation of buildings must be anchored on reusability of structural members among other important factors. This calls for limited connections that would permit rapid disassembly and reassembly that ensures limited generation of waste materials. The second of its kind is the development of high strength light structural materials that will be capable of wide span members in ultimate limit state and the same time satisfying the serviceability limit state. Such materials must have high energy dissipation characteristics such that even in the event of seismic activities limited damage will be experienced and the building will be reusable with little retrofitting. It is important to note the current demand as a result of terrorism. The colossal loss of life and properties as a result of terrorist attacks across the globe calls for development of blast resisting materials.

In Africa where technological advancement is at slow pace, the double whamming consequence of terrorist attack is very visible. The effort has to be doubled with the help of international agencies to pay more attention to the development of blast resisting materials that will improve the performance index of buildings. Although, many researchers are very much keen to search for such materials but lack of adequate equipment and computing resources has plagued their initiatives. Some of the composite concretes investigated recently have shown promising signs of their blast resisting capabilities. However, more exhaustive works need must be done to fully characterize these products. It is unfortunate to note that despite the incessant terrorist attacks in Nigeria, the government has not come to the realization of employing engineering to fight terrorism. The effort is on humongous spending to acquire ammunitions. The emphasis on the development of high caliber materials is very elusive. The regulatory bodies for engineering in the country are in a deep slumber into the foreseeable future. They are the extensions of the political institutions in various shapes or forms. We hope they will heed the clarion calls to rise up to their original responsibilities.

APPLICATION OF NUMERICAL SIMULATION

It is important to focus on the use of technology to develop innovative design in structures and other engineering systems. The application of Finite Element Methods (FEM) is paramount to full realisation of the potential of innovative design. In fact, it is absolutely impossible to discount FEM out the equation of innovation in engineering. Ranging from inelastic analysis to the reliability analysis of engineering systems, FEM is positioned to help drive this agenda. There is no way we can rely on elastic analysis only in the drive to establish innovative design. The inelastic static and dynamic analysis (material and geometrical) could only be carried out with FEM and other versatile numerical computational approaches. For example, to effectively simulate the reliability of new design method using Monte Carlo approach, it may be required that the system has to be analyzed to its collapsed capacity for various configurations and sizes of members.

These physical analyses could only be achieved through the employment of powerful analytical tools like FEM. The outputs are fed into Monte Carlo simulation computer system. In many African tertiary institutions today, hardly can one find well equipped computing laboratory to accomplish such tasks. One has to praise the courage of our researchers who persistently continue to bite the finger nails to get things done. The administrators in those institutions are concerned with the immediate benefits for themselves leaving the primary reasons of having a job in the first instance to suffer. The dry joint construction could not be fully realized without the application of FEM to fully understand the true behavior of tensioned and non-tensioned joints. The friction surface where elements overlap cannot be fully studied without the representation of the slip surface elements in the FEM models. Ordinary classical analysis cannot avail the researchers the opportunity to fully investigate the dry slip plane interaction.

In order to engineer systems to resist fire for a desired period before catastrophic collapse, FEM is the only available tool to study the collapse behavior of various frame configurations. The likely culprit phenomenon, local buckling, in the progressive collapse of high rise steel buildings can effectively be studied using nonlinear FEM analysis. Even the business of soil-structure interaction can only be effectively investigated using FEM without recourse to extensive soil test that is time and resources consuming. It is apparent that powerful analytical tool like FEM cannot be overlooked in the drive to establish innovative design approaches for engineering systems.

Finally, Value Engineering is a driver for innovation in design and construction. It is understood to be a means of analyzing alternatives to either drive the cost down with an improved performance or to improve performance without change in cost or performance remains unchanged but cost is driven down. Through the process of Value Engineering, innovation becomes a vital aspect of sourcing for alternative solution that is optimum without increasing cost and the performance is enhanced.

CONCLUSION

It has been demonstrated that design innovation will resort to added value for the engineering systems and thus the consumers will benefit immensely. Light is shed on the use of innovative materials, dry joint construction and numerical analysis to predict structural responses. In addition, reliability analysis is an important of design tool to predict how reliable any design is before being built or constructed. In the 21st century, innovative material-based building structures are solutions to urban rejuvenation and development of new cities that will reduce pressure on the land utilization by utilizing the vertical space. Value Engineering is shown to be important in structural systems design because of it enable performance enhancement and cost reduction through innovation.

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