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Are our structural engineers geared up for the challenges of the profession?

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Huge infrastructure projects in countries like China and India are creating a shortage of qualified engineers (The Indian Government has allocated USD 36.16 billion for the year 2020-11 for the infrastructure sector alone). In addition, infrastructure in countries like USA is in desperate need of an overhaul. Money magazine just named civil engineering as one of the top 10 "Best Jobs in America" and U.S. News & World Report just named civil engineering one of the 50 best careers. Moreover the climate change and the resulting necessity to provide environmental friendly housing, requires that today's engineers should be good and quick learners. Also, to stay current and relevant in this competitive economy, and to provide efficient service to clients, civil or structural engineers have to re-learn some skills and develop new ones through continuing education and other training programs and opportunities. To this end, this article discusses some of the ailments facing structural engineers in our country and offers some remedial measures.

In a recent article, Buch discussed about the possible reasons of why fresh engineers are not able to handle even simple design problems.[1] Also, the failure of a pedestrian over-bridge at the Common Wealth Games collapsed near Jawaharlal Nehru Stadium, and the simple detailing problem which resulted in the failure of Metro Over-bridge at New Delhi, outline the importance of training our structural engineers. This important topic was discussed under various heads in the Structural Engineering Forum of India (SEFI)-which has about 10,000 members discussing about day-to-day structural engineering problems over the Internet. The points suggested by various engineers, along with the author's own points, based on his 35 years of experience, are discussed in this paper.[2-5]

Undue reliance on computers

The present day students are computer literate, in the sense that they are confident of analysing any type of structure using commercial software. But, some of the problems of today may be due to the same computer literacy. In fact, many civil engineers, who passed out recently, may not know how to write software, but know how to use standard, ready to use software packages like STAAD Pro, SAP 2000, ETABS, and STRUDS. (Of course many of them do know how to write spreadsheets programs, which are much better to understand the process of design). They think that they can analyze and design any type of structure, just because they have access to these software. One should realize that such software should be regarded as mere tools in the hand of a structural engineer. While using these programs, the designer should be aware of any assumptions used and limitations of these programs.[6-8] This is because any amount of mathematical precision can not make up for the use of an analytical method that is not applicable to the structure being designed. Moreover the present day engineers tend to blindly accept the results given by the computers, forgetting that the results are based on the input, as per the old saying "Garbage in Garbage out". Any inadvertent error in the input, or even assumption made in the modeling, boundary conditions, joint rigidity, etc may produce either erroneous results or results that may not match with the actual behaviour of the structure. Many of these engineers also lack the appreciation of the behaviour of the structure.

In the words of Dr Emkin, Founder and Co-Director, Computer Aided Structural Engineering Center and Professor, School of Civil and Environmental Engineering Georgia Institute of Technology, "Large numbers of structural engineers actually believe that they are "engineering" by simply using computers, rather than realizing that quality engineering can only be the outcome of extensive knowledge of engineering principles, extensive and relevant experience, and very hard human brain effort.[6] Strictly speaking, *Real* structural engineers do not need application software. In other words, real structural engineers can create simplified models of complex structural systems, perform appropriate analyses on such simplified models, and create designs based on such simplified models that can be constructed with high degrees of confidence that they are safe, reasonably economical, and functional. Any structural engineer who cannot do this without a computer is not a real structural engineer, and must not be permitted to perform structural engineering analysis and design with a computer.[6] Fresh engineers should realize that repeatedly doing hand calculations enable them to gain invaluable knowledge about how a design is progressing and help develop that ever-elusive skill: sound engineering judgment.

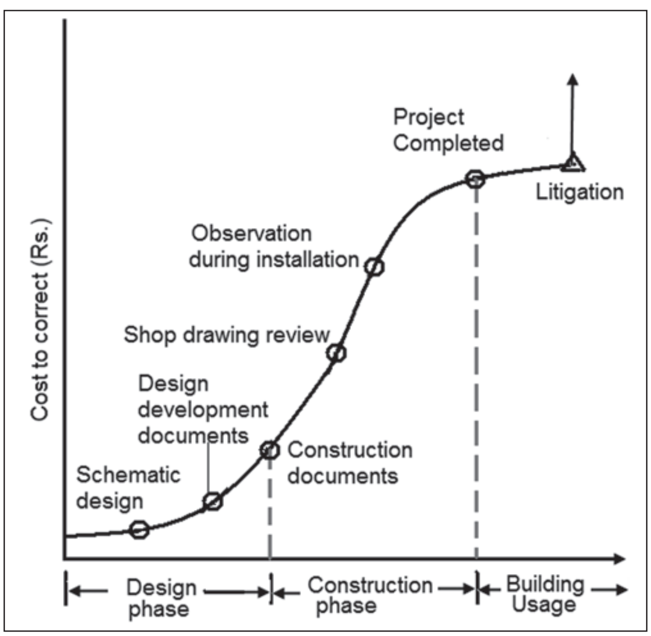


Figure 1. Cost at different phases of a construction project

The applicability of the above statements may be appreciated by considering the example of the Hartford Civil Centre coliseum, Connecticut, USA, which was built in 1973. Its cutting edge, space-frame roof design required the engineers to use computer programs, extensively. Unfortunately, many assumptions were made during the computer analysis, which, in reality, were not correct. The assumed dead load was 20% too low, the true unbraced lengths of some members were double than that considered by the computer program, and many brace connections had a true eccentricity that was not assumed in the computer analysis. In addition, the Hartford Civil Centre coliseum roof design was extremely susceptible to torsional buckling of compression members which, as a mode of failure, was not considered by the computer analysis used by the designers. These errors, along with a lack of proper oversight during construction, resulted in the collapse of the roof in 1978, due to a large snow storm.[9,10]

A thorough hand check of the computer assumptions and calculations of the Hartford coliseum roof could have revealed some of the errors that were made in the design. It is because, the step-by-step hand analysis will allow the engineer to have a feel of the behaviour of the structure and at the same time allow the designer to check the assumptions at each stage of design. On many occasions, the author has seen that costly reinforcement or modifications had to be done during the construction phase, because the computer's output was not thoroughly checked by engineers. It has to be noted that modifications during the construction stage are very expensive than doing modification during the design phase, as shown in Figure 1.

Conversely, sometimes the use of computers may result in overly conservative designs, because the software may not incorporate certain helpful design provisions. For example, some computer programs ignore compression steel when calculating the maximum allowable reinforcement in a concrete beam. This may result in adopting a larger section, instead of simply adding compression steel to achieve the desired result.

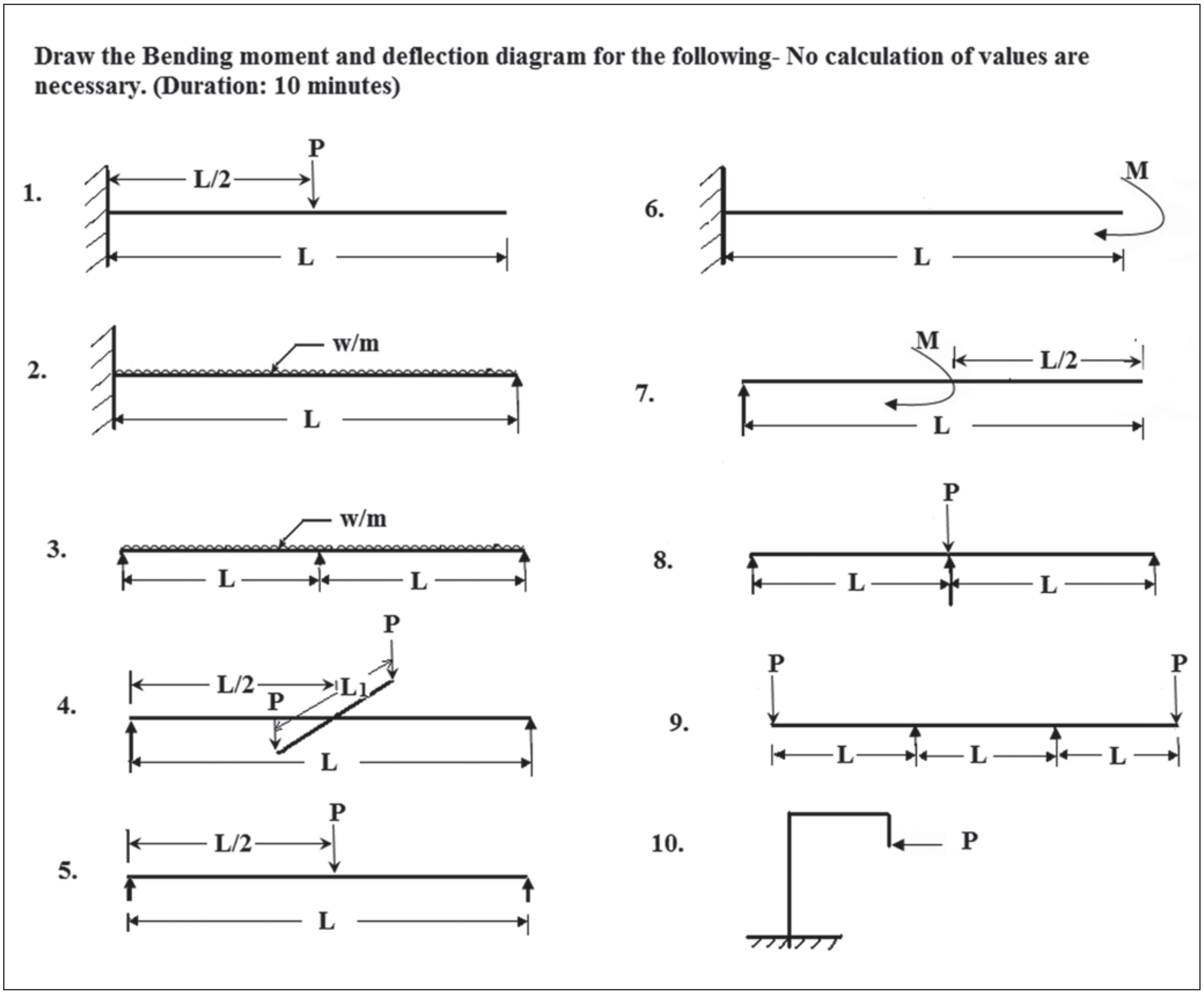


Figure 2. Test to check the understanding of behaviour

Understanding the behaviour of structures and structural elements

From the above discussions it is clear that structural engineers should have clear understanding of the behaviour of structures and structural elements. They should be in a position to check the accurate results produced by the computer by using some approximate, "back of the envelope" calculations. Even lateral load analysis of multi-storey buildings can be checked by using portal or cantilever method of frame analysis. The author had on many occasions conducted a small test to design aspirants, to check their understanding on the behaviour of structures. This test is reproduced in Figure 2.

Unfortunately many engineers (irrespective of their degree), were not able to solve most of the problems. The students who faired well were from IITs or Regional Engineering colleges. Many aspirants were not able to draw the deflection diagram properly, which is very important in reinforced concrete structures, as we have to reinforce the locations, which are under tension. Many of them did not have proper understanding of stability or constructability.

Engineering curriculum

The present system of engineering curriculum gives more importance to theory; the professors hardly take the students to construction sites / testing Laboratories / Fabrication Shops / Crushing Plants / Landmark Structures / Failure Sites, etc. The students do not have opportunity to prepare 'models' of structures. Probably no college has any plans to impart such live-Education to make a 'Complete-Structural Engineer'.[1] Structural engineers should also have knowledge about the Professional practice, Professional Ethics, symbols followed in profession, rules & regulations, and marketing& finance. Very few colleges have courses on professional practice, which include the above issues. Many colleges do not even train students on available software such as STAAD or AutoCAD, which are essential for their work in design offices. In fact, detailing, which is as important as design, is found to be lacking in college curriculum.

Moreover, practical training is a very important aspect of the curriculum and students should take it seriously. More site visits and interaction with professionals will enable a better concept of the construction process and will familiarize students with the latest practices.[11] Seminars and project work in advanced and interdisciplinary areas will broaden the students' knowledge about the civil engineering field. The involvement of students in on-site training strengthens their understanding of various construction activities.[11] Students should learn about various types of disasters and about the behaviour of various structures during earthquakes, tsunamis and cyclones. Students should also be aware about the blast-resistant features of structures.[11]

As per the recent earthquake code, more than 65% of the country is covered by Seismic zone 3 or above. Still, the subject of Earthquake Engineering is not offered in many colleges at the B. Tech. level. Most of the Master's level courses in structural engineering do have some coverage of structural dynamics but hardly any coverage on earthquake engineering.[12] It is disheartening to note that a few private colleges offering Master's level courses, eliminated subjects such as stability, dynamics, and plates and shells, as they involve mathematics and they do not have teachers to teach them. Most of the colleges do not even have the subject of concrete technology in their syllabus at the bachelor's level, even though most of the construction in India is involved with concrete and reinforced concrete.

Though the field of civil engineering is vast and new innovations are taking place rapidly, the 5 year course was reduced to a four year course, even though the Architecture course is still in the 5 year format. It is high time a one year practical training is introduced at the Bachelor's level. Fresh students do not have communication skills (preparation of well written reports or effective presentation of the job done is very important for the success of engineers in their professional life). Many institutions do not stock important reference books, as they are expensive.

Making courses interesting

John B. Fenn, who shared the 2002 Nobel Prize in chemistry, believed that college courses ought to be fun. He said that the purpose of education is to develop young peoples' minds. He stressed the importance of teaching them to think instead of filling them up with a lot of facts. It is true to our civil engineering courses also. Once the fundamentals are taught properly, the students will be in a position to tackle difficult problems easily.

For example, the Concordia University in Montreal, Canada conducts the Troitsky Bridge Building Competition, annually from the year 1960, during the National Engineering Week. Participating teams of engineering students come from universities across Canada with some from the United States and Europe. They design and build model bridges out of Popsicle sticks, toothpicks, white glue and dental floss. The strength of each bridge is tested by using a hydraulic press. The winner is chosen based on the highest overall score in terms of capacity, aesthetic value, and originality. Such competitions give confidence to students in designing bridges, even though the bridges may be miniature models. See Figure 3.

Similarly, the American Society of Civil Engineers (ASCE) jointly with the American Institute of Steel Construction (AISC) conducts an annual steel bridge

Figure 3. Miniature bridge building competition being held in the University of Concordia, Canada-A model built by a group of students
(source: www.bcee.concordia.ca)

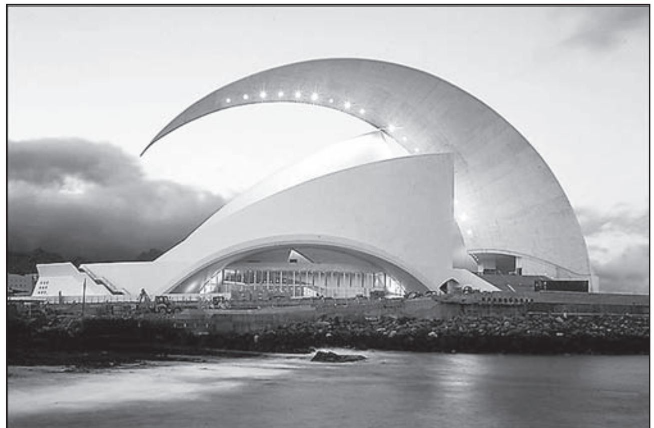
design competition. This competition involves real calculations, design, fabrication, and testing in a smaller scale than the real bridge. However, it gives an opportunity for the students to execute their own design into practice. Each bridge is ultimately judged by a panel of professors and consulting engineers on the following design requirements: display, construction speed, constructability, lightness (lowest total weight), stiffness (lowest aggregate deflection), construction economy (lowest construction cost), and structural efficiency.[13]

In addition, ASCE also conducts National Concrete Canoe Competition, every year. The competition is both academic and athletic, with each team's score being based on engineering design and construction principles used in the creation of the canoe, as well as results from men's, women's and co-ed race events. The scores are divided into four components that are each worth 25 percent of the final score: a design paper, an oral presentation, the final product and the results of five different races.[14] Such activities can open the young minds for free thinking and may introduce the principles of engineering in a more interesting and creative way. It is also important to study the earlier failures and learn from them; this will also prevent similar future mistakes. Unfortunately in India, the reports of the causes of failures are not made public.

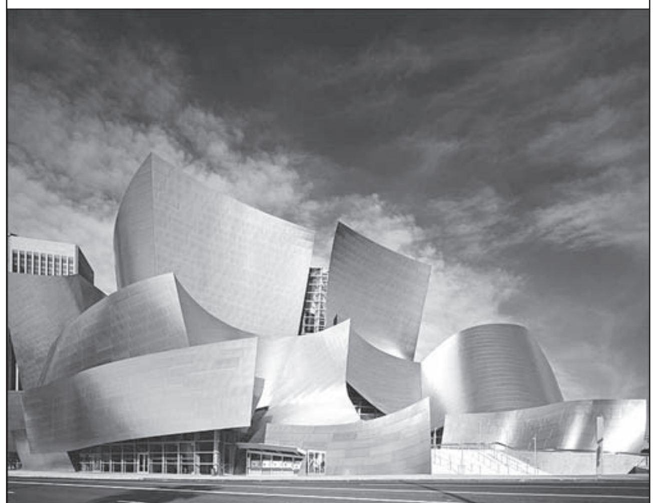
Dearth of qualified and experienced teachers

Realizing that there is a boom in construction activities, many private colleges in India have started Civil Engineering courses both at the Bachelor's and Master's level. Some of these colleges lack laboratory facilities (Unlike IT oriented courses which require only a few computers, Civil Engineering Laboratories may require huge space and costly equipment to conduct experiments), and many of them do not employ proper teachers. Though there are a few technical teachers Institutes, several teachers are not trained and do not have communication skills. Moreover only those who do not get a suitable job end up in teaching. As the salary offered by private firms has increased considerably, it is also difficult for the institutions to attract or sustain talented teachers. Many teachers also do not update their knowledge.

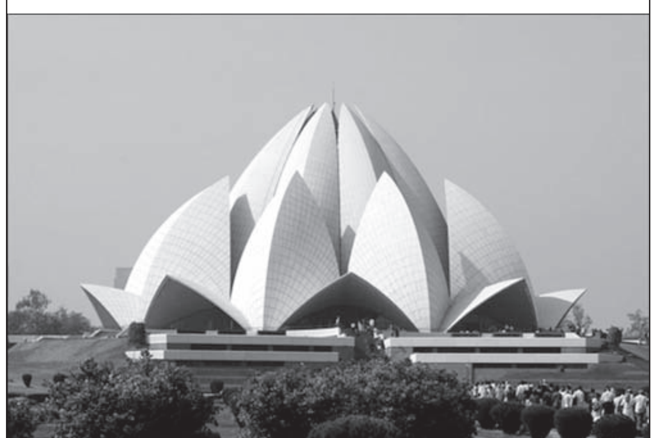
In some cases, the professors were allowed to do their own consultancy practice; in addition to teaching (this decision was taken by the policy makers to patch-up the difference in salaries at Institutes and the Industry).



(a) The Opera House at Tenerife in the Canary Islands, designed by Architect Santiago Calatrava



(b) The Walt Disney Concert Hall in Downtown Los Angeles, California, Designed by Architect Frank O. Gehry



(c)The Bahai Temple in New Delhi, designed by Architect Fariborz Sahba

Figure 4. Few examples of innovative structures designed by architects

Though this practice may help the students to get to know practical aspects, in some cases it has resulted in teachers not giving priority to teaching. In countries like Germany teachers are eligible to teach, only after having a few years of practical experience. In USA, professionals teach at universities as Adjunct professors. Such a industry-institute interaction will be beneficial both ways; students will get to know practical difficulties and professionals can solve their problems by some research studies.

Complexity of present day projects

Today's Architects are demanding. Several of them are also innovative. A few of the innovative examples are shown in Figure 4. Such structures should be designed only by structural engineers having sufficient experience and knowledge about their analysis, design, and behaviour. In order to arrive at a safe, stable, economical and environment friendly structure, the structural engineer has work as a team member in the group consisting of him, the architect, the contractor, the electrical engineer, the HVAC (Heating, Ventilating, and Air Conditioning) consultant, the quantity surveyor and the fire protection engineer.

In addition to the above 'once-in-a blue-moon' structures, there are a number of innovations that are taking place that include high performance and ultra-high performance concrete, fibre-reinforced concrete, ready mixed concrete, self compacting concrete, blended cements, High-volume Fly Ash Concrete, nano-technology, sustainable development, base-isolated tall buildings, use of dampers, Integral bridges, Structural health monitoring, Novel structures through form-finding, Novel erection techniques, Novel systems for lateral load resistance, Space frames, Tensile structures, high performance steel, steel frame Buckling restrained braces, pre-qualified steel moment connections, Steel plate shear walls, performance based specifications, etc. Moreover, structures can be made of a variety of materials, such as concrete, steel, composites, wood, or aluminum and the structures may be found in a variety of forms such as buildings, bridges, stadia, towers, chimneys, silos, foundations, space frames, shells, water retaining structures etc. It is impossible for any one to follow the developments in all these structures and fields. Considering the above facts, the ASCE proposed master's degree or equivalent education requirement for licensure beginning in 2020.

The dwindling energy resources and materials have resulted in the development of sustainable constructions, which will totally change the way in which we make our designs. For example, in high rise buildings, wind will not be just treated as an obstacle to be overcome, but as a source of energy to be harnessed. Several skyscrapers are under construction, which will integrate large wind turbines into their design.[15] Moreover, buildings have to be designed to last more than 100-120 years, in order to conserve our resources.[15] Building materials which require minimum energy to produce, locally available, and uses as much waste products as possible will be used in future buildings.[15] From the above, it is clear that the structural engineers should not only choose a particular area and specialize, but also continuously update their knowledge, by reading journals and magazines such as *The Indian Concrete Journal* and attending specialty conferences and seminars.

Quality control

Buildings like Burj Khalifa or bridges like Bandra–Worli Sea Link, which appear in newspaper articles, are designed, proof checked and executed by experienced and qualified engineers. However, the majority of constructions is ground plus three to floor floors only and may be designed by fresh engineers. In many of these structures the quality at construction sites is either not checked or inadequate. In countries like Germany, the designs are proof-checked by competent authorities. Such a practice should be introduced in India. Though this kind of checking may delay the design process, it will result in durable structures. It is also equally important to have training programmes for construction professionals, so that quality is maintained not only in designs but also in the construction.

Continuing education

In India, continuing education is not given proper importance; many engineers think that what they learnt in colleges is sufficient. However, the Professional Engineer registration by the Institution of Engineers (India) gives importance to continuing education also. Even though some seminars are being organized by engineering colleges, they are not attended by practicing engineers, may be due to the theoretical content of these seminars. In USA several organizations like American Society of Civil engineers, American Concrete Institute, American Institute of Steel Construction and Portland Cement Association conduct practice oriented seminars in different cities and give continuing education credit for the same. Since attending such seminars have become expensive, they now offer *webinars* (A key feature of a webinar is its interactive elements - the ability to give, receive and discuss information), which are becoming very popular. In addition, magazines like *Structural Engineering & Design* have developed *Professional Development Series*, which offer a unique opportunity to earn continuing education credit by reading specially focused, sponsored articles or viewing specially focused, sponsored Webcasts. Thus the engineer can fulfill a portion of their continuing education requirements at no cost. Companies like *Contech Construction Products Inc*., *Bentley* and *Tekla Inc*. sponsor offer such free webcasts. The *Indian Concrete Journal* may start such a service for the benefit of practicing civil/structural engineers.

Availability of resource material

In addition to training of teachers, it is necessary to stock the libraries of the colleges with specialized books dealing with the new developments. Such books are often published by overseas publishers and are quite expensive. Indian publishers are not interested in publishing books on special topics such as fibre reinforced concrete, formwork design, design of industrial structures, liquid retaining structures, space structures, offshore structures, concrete admixtures, etc. Also very few practicing engineers write books/papers based on their experience. In this connection it is heartening to note that engineers like Buch, Varyani, and Raina have published books on several important practical topics. The *Indian Concrete Journal* may also consider publishing books on some specialized topics, to help structural engineers to update their knowledge.

Summary and conclusions

The construction boom in China, India, and other developing countries has opened up an unprecedented opportunity for civil and structural engineers. An introspection of the current situation has been examined under the following heads: undue reliance on computers, understanding the behaviour of structures and structural elements, engineering curriculum, making courses interesting, dearth of qualified and experienced teachers, complexity of present day projects, quality control, continuing education, and availability of resource material. Based on this it may be concluded that each one of us should play a role in the preparation of structural engineers to tackle the challenges posed by the profession: the colleges, by updating the syllabus periodically; the companies, by providing proper training required for their needs; the professional organizations and journals, by providing necessary material for updating the knowledge and conducting continuing education programs, and finally the structural engineers themselves, by taking responsibility to update their knowledge, understanding the behaviour of structures and structural elements, and incorporating quality control measures in their designs and constructions.

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