3 ROLE OF STRUCTURAL ENGINEER IN THE 21st CENTURY

1.0 INTRODUCTION

The term Engineer is derived from the Latin word ***ingerere***, i.e. to create. In essence, Engineers are creators of artefacts, using their ingenuity and capacity for original thinking within the constraints of affordability and practicability. Modern society expects the Engineer to understand the role of financing, project management and information technology in improving the quality of his designs. Thus, close collaboration with other specialised disciplines is vital. Full and on-going interaction between other members of the design team is essential in order to maintain effective communication across professional boundaries. Besides his principal role as an innovator**,** the designer of a constructed facility has the responsibility to ensure that ***his plan is***

- ***fit for its purpose***
- ***economical and durable***
- ***safe, both for the users and for the environment***
- ***buildable, without inconveniencing the community and***
- ***aesthetically pleasing.***

The world we left behind at the end of the 20th century was very different from what it was at the beginning of that century [1]. Dramatic changes to the scientific and engineering world have - undoubtedly - brought enhanced wealth and living standards to a small proportion of the world's population but it has also been accompanied by unpredictable upheavals in the economy of every part of the world, uncompromising social attitudes and unacceptable pollution and damage to the environment. Societal transformations and upheavals have occurred due to the insatiable consumption of the world's natural resources, uncontrolled pollution of our environment, creation of unacceptable quantities of waste, unacceptable disparity in the standards of living, unprecedented population growth and worldwide urbanisation. This complex scenario has also resulted in unbelievable damage, deterioration and destruction of our infrastructure.

India's per capita income remains very low; its per capita GNP (Gross National Product) is $436, which is even less than that of Pakistan ($492). Nevertheless the purchasing power of the country as a whole has increased. The wealth has not spread out among all the citizens, but is confined to a fifth of the population. A little more than 200 million Indians are going up the ladder. This distorted economic scenario has encouraged overcrowding in the cities, caused by people looking for work and the consequent growth of slums coexisting with affluent neighbourhoods has already caused significant environmental deterioration in major cities. Durable, eco-friendly and sustainable development alone can prevent this unredeemable environmental degradation and enable the maintenance and enhancement of good quality of life. Engineers have to develop sensitivity to these deeply felt concerns for the natural and man-made environment and face increasingly complex challenges in their everyday work for ensuring environmental sustainability. We begin by describing the challenges facing the Indian Engineer in the 21st century and proceed to discuss the various factors and impediments affecting the creation of sustainable and durable environment.

2.0 THE CHALLENGE FACING THE DESIGNER

Design problems are seldom amenable to solution by exact mathematical formulae. There is a considerable scope for exercising engineering judgement. Hence, there is no "***correct solution***" to a design problem, as there could be several so-called "correct solutions" to the same problem. This is because

- the designs are invariably subject to individual interpretation of Standards and Codes,
- the solutions are also subject to differing ideas about what is or what is NOT required from an engineering and environmental stand point, and
- the individual designers have ingrained ideas from ***their past experience***, ***which may be valid to-day only to a limited extent, or may not be valid at all.***

Thus the design problems are referred to as " open ended" problems. Nevertheless the Designer has the responsibility for ensuring that the goal of the project is achieved (i) safely, without taking any undue risks to lives and materials and without causing a liability, (ii) within time and (iii) within the (budgeted) cost. Hence, "***Engineering Design***" may be defined as a creative activity of building a new artefact which provides an optimum solution to satisfy a defined requirement or need, ***without endangering the environment.***

Herbert Hoover, a former President of the United States of America - (the massive arch dam called "Hoover Dam" in the U.S.A. is named after him), described the Engineering profession as follows (*1961*):

> ***"It is a great profession. There is the fascination of watching the figment of the imagination emerge through the aid of Science to a plan on paper. Then it moves to realisation in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the Engineer's high privilege. The great liability of the engineer compared to men of other professions is that his works are out on the open, where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like physicians. He cannot argue them into thin air or blame the judge like the lawyers. He cannot, like the architects, cover his failures with trees and vines. He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope that the people will forget. The engineer simply cannot deny that he did it. If his works do not work, he is damned forever….***
>
> ***"On the other hand, unlike the doctor, his is not a life among the weak. Unlike the soldier, destruction is not his purpose. Unlike the lawyer, quarrels are not his daily bread. To the engineer falls the job of clothing the bare bones of science with life comfort and hope. No doubt, as the years go by, the people forget which engineer did it, even if they ever knew. Or some politician puts his name on it. Or they credit***

> ***it to some promoter, who used other people's money… But the engineer himself looks back at the unending stream of goodness which flows from his success with satisfaction that few other professions may know. And the verdict of his fellow professionals is all the accolade he wants."***

Thus, Hoover described the professional role and responsibilities of the Engineer succinctly. But what is meant by the "***professional***" role? The word "***profess***" has religious connotations and probably has its origin in *17th* century England [2]. Monks *professed* their vows and were generally well educated. It is from this group of religious men, erudite University educators were drawn. ("*Professors*" were those who *professed*.) Hence the term "***professional" was associated with a high degree of education and societal responsibility***.
In today's context, all professions require

- extensive specialised education of significant intellectual content
- the practitioner to provide a recognisable service to the community
- a certification (usually by government or by a chartered body).

Professions are organised into professional societies, which police themselves. People engaged in these professions are independent of external influences and cannot be coerced by their clients, employers or governments to carry out unethical instructions. Controlling governments yield power to the professionals or their Societies. (For example, in many western countries, only a physician can write prescriptions; only a registered engineer/architect can approve the plans of a structure/building). In return, the professions take on a very responsible position, vis-à-vis the public. Generally, the professional should not hurt anyone unless it is required, (e.g. a dentist!).

To eliminate conflicts developing between the roles of the professional and of the citizen, every profession has a Code of Ethics developed by the professionals themselves. For example, the Code Of Ethics, developed by the American Society of Civil Engineers, is based on three fundamental principles requiring Engineers to (i) use their skills to benefit mankind (ii) be honest and fair, and faithfully serve others; and (iii) improve the competence and prestige of the profession.

3.0 DURABILITY AND LIFE CYCLE COST ISSUES

Traditionally the professional Structural Engineer had invariably played a vital role in the design of constructed facilities, often, in close association with other professionals like Architects and others in related disciplines. As a designer, he is responsible for the complete process from the conceptual stages to the finished structure. Increasingly, the Society expects him to assume ***responsibility for the durability*** of the product. In other words, the responsibility of a professional Structural Engineer in the 21st century will not be confined merely to the immediate economic and environmental impact of his design decisions; society expects him to make rational and responsible choices by ***considering the life cycle costs and the long-term environmental effects on the community*** In the following pages, we will highlight the enhanced role of the Professional Engineer in the 21st century and explore how the two design criteria are interlinked.

3.1 The Infrastructure Crisis

The Construction Industry, with all its imperfections and limitations, is rightly perceived as the provider of the Nation's infrastructure. Clearly, it is of paramount importance to train and educate those who create and manage it, in order to ensure the economic and environmental survival of the world. While the world has witnessed some fantastic advances in Science and Technology in recent years, many of these achievements have been made at an outrageous price, plunging the world into a number of crises, which have impacted directly on the construction industry. The global effect of these dramatic changes in the world in the last 50 years can be collectively termed the "**infrastructure crisis**", which has to be encountered and managed by the construction industry.

Three-fourths of the world's population live in the (non-industrialised) developing world like India. Uncontrolled population growth, (particularly in the developing world), and evolutionary industrialisation have resulted in global urbanisation. The world population has grown from 5 bn in the late 1980's to 6 bn in 2000 and is now estimated to grow to 8 bn by 2036 and to over 9 bn. by 2050. (The population of India is now just over 1 bn). More than 95% of this increase will take place in the developing parts of the world, India included. For the first time in history, more than half the world population will live around the cities. It is estimated that there are more than 120 cities with over a million people, the majority in the developing world, thus accelerating urban decay in cities which can least afford repeated remedial action.

The magnitude of the problem in the Indian context is illustrated next by considering the "housing sector". Over the next 40 years, India is set to overtake China as the most populous country in the world. The present urban population is estimated to be 330 million, equalling the total population of the country 50 years ago. The urban population that was merely 14% of the total number of citizens 50 years ago now amounts to 33% and is set to grow to 50% by 2025. With economic liberalisation and expected enhanced growth, the rate of urbanisation in India in coming decades is likely to increase. Despite the best of efforts of well-intentioned people in Government and aid agencies, the Nation has not been unable to cope up with the ever-increasing need for shelter for every citizen. India needs some 200 million houses to accommodate all its citizens, whereas we have only167 million houses, of various types [3]. Half of these houses had mud, grass and straw walls and more than a third had grass, straw and thatch roofs. The need for upgrading the housing stock and the magnitude of the task are obvious, particularly in the context of expected urban growth.

It has been estimated that over 50% of the land in urban areas is second-hand. Much land is adversely affected by foundations from demolished buildings, which previously stored harmful chemicals, petroleum products etc. Old foundations must be viewed as contaminants and it is important to prevent land contamination by sub-structures.

Another major source of concern is water pollution. Many rivers and streams in India are not in their natural state, mainly because of industrial pollution and irresponsible drainage of sewage into them. The adverse effects of high pollution levels in our water resources are already painfully evident in India.

It is now widely recognised that much of the recent economic progress in the Western world has been at the expense of the environment and the effects of this environmental degradation are being felt globally, for instance in the form of climate change, ozone depletion, deforestation and acid rain. It is necessary therefore to assess and improve the environmental performance in all economic sectors including construction. Global warming caused by the emission of Greenhouse Gases (i.e. CO_2) into the atmosphere puts increased energy into the climate system, resulting in increases in the number and intensity of storms, rapid climatic changes, and larger, more damaging and extreme weather events. As the effects of greenhouse gases in the atmosphere take 30 years to show, the current changes in the world weather (rise in sea levels, global warming, larger deserts, severe draughts and storms) relate to emissions up to the year 1970. The effect of current pollution levels will not be evident until 2030; the present century will, therefore, be a century of disaster management. Besides the large-scale deaths and devastation of the environment that follow from these disasters, the greatest effect will be the destruction of the infrastructure and therefore its impact on the Construction Industry [1].

3.2 The "Durability Crisis"

Issues of durability have always been subjects of debates among Engineers. Is it better to spend (say) 40% more initially, in order that the life of a structure could be doubled? What is better value to the client? Spend less initially or opt for a longer life? Total neglect of durability considerations in all the infrastructure projects undertaken so far combined with primitive construction practices still prevailing in India have resulted in what can only be termed a "**durability crisis".** It is now well established that degradation of all structures has become very common in almost all the cities in India and this is particularly true of buildings and structures made of reinforced/prestressed concrete. **The great tragedy is that there have been no efforts to address this issue by the present generation of Developers, Engineers, Architects and other design professionals. As a consequence, major problems have been allowed to accumulate for future generations of owners and taxpayers to face.**

This is not to say that other parts of the world are free from this "***durability crisis*".** For example, the present total construction expenditure in the UK is 56 million British Pounds, of which 50% is spent in repairs and rehabilitation of recently completed structures. As an example, the Midlands Link Motorway around the city of Birmingham cost around 28 million British Pounds to construct; this motorway needed repairs and rehabilitation within 20 years of its completion. Between 1972 and 1989, a further 45 million British Pounds were spent in repairs. It is now estimated that another 125 million Pounds will be required in the next 15years. In Europe, the annual repair cost is estimated as 1.4 billion ECU; in the U.S. the cost of rehabilitating half a million bridges (mostly concrete) is estimated to be $100 billion. It must be noted that in many countries in the West, life cycle costing is now a mandatory requirement in the planning process. For example, International Surface Transport Efficiency Act of the US (1991) mandates that state wide and metropolitan planning processes consider Life-Cycle Costs (LCC) in the design and engineering of bridges, terminals and pavements, rather than basing decision solely **on initial costs alone** as until then.

There is no particular merit in Indian Engineers making the same mistakes and blunders as their Western counterparts did and then rectifying them. In any case, India cannot afford the luxury of these blunders. Sustainability of the Environment is NOT an Option; it is vital for the economic and environmental survival. We do not inherit the world from our ancestors - we borrow it from our children [1].

3.3 Time wasted is money wasted and opportunities lost

When a constructed facility - be it a private home or a public highway - is completed, it will be put to use immediately and this results in a return on the capital employed. Delays in the completion of a project would therefore represent a delay in the return on capital invested, besides the loss of interest, which that sum would have earned otherwise. This essential relationship between time and money is well understood in the Western world but unfortunately this is not the case in India.

The recent liberalisation and globalisation of the Indian Economy has brought with it a potential (and an opportunity) for significant growth of the construction activity particularly in the infrastructure industry. Design and construction of buildings and bridges have been major growth areas, supposedly to facilitate the expected economic upturn. In the following paragraphs, we shall discuss the factors affecting the lifetime costs and durability of a structure, in some detail. In a later section, we highlight the fallacies and errors frequently committed by professionals in India that militate against arriving at an optimum overall design.

3.4 Cost competitiveness by using Alternative Materials

Unfortunately for the Indian client, many architects and designers seldom consider the use of alternative materials of construction and the designs are invariably limited to “concrete-intensive” structures. Often the best optimal design solution is obtained by a sensible combination of reinforced and/or prestressed concrete elements with structural steel elements. Even when a “steel-intensive” solution is selected; it is very rare for limiting the selection of materials of construction to steel only.

Although India has an installed capacity to produce 35 million tonnes of steel/year, we manage to produce only 24 million tonnes/year of which the use in the construction sector accounts for around 25% - 30%. By way of comparison, China produced 120 million tonnes of steel during 1999 - 2000 and Japan, 95 million tonnes. The total per capita consumption of steel in all its forms in India is one of the lowest in the world, being 24 kg/annum, compared with 500 kg/annum in the USA and 700 kg/annum in Japan. According to the recent research by the Steel Construction Institute [4], there is a direct link between the gross national product per capita and the per capita consumption of steel.

Indeed, structural steel has inherently superior characteristics to a very significant extent, when compared with competing materials. For example, to replace one unit area of steel in tension, (with a yield stress of 450 MPa), we would need to use an equivalent plain concrete area of about 200 units. For concrete to be able to compete with Structural Steel in construction, we need to put Reinforcing Steel into it! Even then, there is no way to prevent the cracking of concrete in tension, which often encourages corrosion of reinforcement. In compression (or squash loading), one unit area of steel is the equivalent of 15-20 units of M20 concrete. A comparison of strength/weight ratio will reveal that steel is at least 3.5 times more efficient than concrete. For a given compressive loading, concrete would have 8 times the shortening of steel. Again we need reinforcing steel to prop up the plain concrete.

In structures built of Structural Steel, occasional human errors (like accidental overloading) do not usually cause any great havoc, as there is a considerable reserve strength and ductility. Steel may thus be regarded as ***a forgiving material*** whereas concrete structures under accidental overload may well suffer catastrophic collapse of the whole structure. Repair and retrofit of steel members and their strengthening at a future date (for example, to take account of enhanced loading) is a lot simpler than that of reinforced concrete members. The quality of steel-intensive construction is invariably superior, when compared with all other competing systems (including concrete structures) thus ensuring enhanced durability. This is especially true in India, where quality control in construction at site is poor.

Structural Steel is recyclable and environment-friendly. Over 400 million tonnes of steel are recycled annually worldwide, which represents 50% of all steel produced. The infrastructure and technology for the recycling of steel is very well established. Steel is the world's most versatile material to recycle. But once recycled, steel can hop from one product to another without losing its quality. Steel from cans, for instance, can as easily turn up in precision blades for turbines or super strong suspension cables. Recycling of steel saves energy and primary resources and reduces waste. A characteristic of steel buildings is that they can readily be designed to facilitate disassembly or deconstruction at the end of their useful lives. This has many environmental and economic advantages; it can mean that steel components can be re-used in future buildings without the need for recycling, and the consequent avoidance of the energy used and CO_2 emitted from the steel production processes**.**

Steel-intensive construction causes the least disturbance to the community in which the structure is located. Fast-track construction techniques developed in recent years using steel-intensive solutions, have been demonstrated to cause the least disruption to traffic and minimise financial losses to the community and business.

Even though “the initial cost” of a concrete intensive structure may sometimes appear to be cheaper, compared to the equivalent steel-intensive structure, it has been proved time and again that its total lifetime cost is significantly higher [5]. Thus the popular perception of the concrete-intensive structure being cheaper is NOT based on verifiable facts! There is therefore no real cost advantage either.

Except in a few special structures like tower cranes and transmission towers, it is rare to build a structure entirely in steel. Frequently the optimal solution is obtained by employing concrete elements compositely with structural steel, especially in multi-storeyed buildings and bridges. These methods ensure significant cost benefits to the developers (or owners of property) as well as to the community. Composite structural forms have been extensively developed in the western world to maximise the respective benefits of using structural steel and concrete in combination, but **this technology is largely ignored in India, despite its obvious benefits**. The sizes of composite beams and columns will be appreciably smaller and lighter than that of the corresponding reinforced or prestressed sections for resisting the same load. A direct economy in the tonnage of steel and indirect economies due to a decrease in construction depths of the floors and reduced foundation costs will, therefore, be achieved. Generally, improvements in strengths of the order of 30% can be expected by mobilising the composite action. An independent study carried out by the Central Building Research Institute (CBRI) Roorkee demonstrated that there are substantial cost savings to be achieved by the use of Composite Construction [6].

3.5 Life Cycle Costs

ASTM E917-83 (1983) describes the standard practices for evaluating LCC of buildings and building systems. The motivation for the LCC is that on any investment decision, all costs arising from the decision, both immediate and in future are potentially important. The recent development of ***fast track methods in construction*** in the western industrialised world triggered the wide spread implementation of Life Cycle Cost study, which would ensure enhanced productivity and efficient utilisation of the capital. Construction projects completed on the basis of lower initial cost alone have often proved to be far more expensive in the long run, besides causing damage to the environment and bringing poorer return on the investment. Thus the durability of structure and its life cycle cost are closely inter-linked. Enhanced durability invariably reduces or eliminates the construction-related adverse environmental impact on the community.

As pointed out already, Indian Engineers seldom give any serious consideration to vital factors like durability and lifetime costs. Environmental safety and inconvenience to the community do not seem to be given even a cursory thought. As a result, the owners (and taxpayers) do not get the most rational choice arrived at by taking into account all aspects of the design challenge. The result is that - both in the short term as well as on a long-term basis -. the construction costs in India are among the highest in the world, (despite the labour costs being very low, compared to the West) while the Construction Industry continues to pollute the environment and cause long-term damage to it.

At this stage it is appropriate to define the Life Cycle Cost of a Structure, made up of several components listed below **[7].**

1. Initial Cost

- Actual "Cash" Cost of the project

- Cost of the Investment locked-up without Returns ("The Time Cost")
- Cost penalty to the community by traffic delays and detours; Losses suffered by local Business ("Hidden Penalty Cost")
- Cost of damage to the Environment due to Pollution ("The Environment Cost")

2. Periodic Maintenance Cost, including energy cost

3. Cost of dismantling the structure, at the end of its life

***4. Less the salvage value of the construction products*.**

All these values are evaluated in life cycles, present value terms or Annual Value terms. A more comprehensive LCC analysis may include adjustment for taxes, adjustment of financing cost etc. The basic aspects of lifetime costs are discussed in some detail in the following paragraphs:

3.5.1 Initial Cost

(a) ***Actual "Cash" Cost***: Many government departments report the "cash cost" as the **Cost of the project**. This is both wrong and misleading. Frequently, many reputed Designers also report that the **cash costs** of Reinforced or Prestressed concrete alternatives are cheaper than Steel Options. This is because the Steel Intensive Options considered by them are based on outdated design and construction practices. For example, they do NOT employ the relatively new "Steel-concrete composite" construction, or Limit State methods of Design, possibly because Indian Codes have not kept pace with developments in technology! A recently published CBRI study has demonstrated that likely cash savings by using Steel-Intensive Designs, compared with concrete-intensive option for multi-storey buildings will be at least 3% - 16%. The experience in Europe, particularly in the United Kingdom, bears this out. (Over 90% of the new buildings in the London area are built of Steel-Concrete Composite Construction; over 60% of all bridges throughout Great Britain are built of Steel-concrete composite construction.) It is difficult to believe that the necessary expertise is unavailable in India, as the technology is not complex.

(b) ***Cost of the Investment Lock-Up without Returns ("The Time Cost")*****:** Ignoring the "time cost" has been a cultural weakness in India and needs to be overcome if we are to take our place in the community of Nations. It must be recognised that ***time does cost money***. The time taken for concrete-intensive construction would be 2-3 times it takes for steel-intensive alternative. Locking up the capital – without any return – by choosing the former results in a loss to the owner of at least 12% - 15% per year of delay. A recent study reported that even for a modest project like a flyover costing Rs. 10 crores, [See Fig. 1] the loss under this head amounts to Rs. 1.00 crore of taxpayer's money, i.e. 10% of the total cost.

(c) ***Cost penalty to the Community due to inappropriate construction planning*** **(**e.g. Traffic Delays and Detours; Losses suffered by local Businesses etc. collectively termed -

"Hidden Penalty Cost"): A prestressed concrete fly-over built in Chennai was chosen as a case study. This construction, which lasted 15 months, had resulted in all local road users and residents having to take a detour of 2 km for each trip resulting in a needless extra expenditure by the community of one crore of rupees in a project costing approximately Rs. 10 crores! This was spent in burning petrol bought by using the valuable foreign exchange. Is this a wise use of foreign exchange?

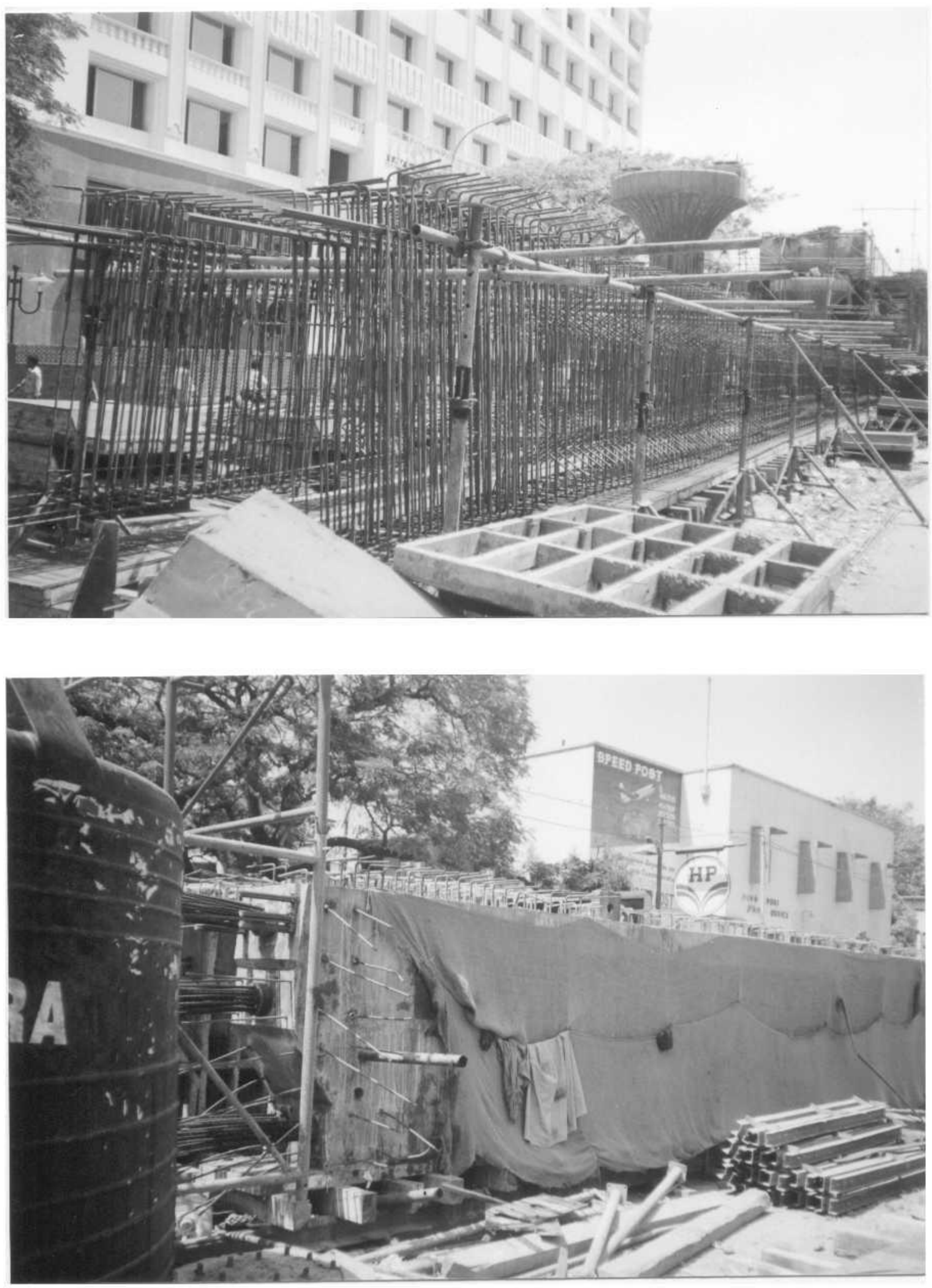


Fig. 1 Flyover construction – The Indian way

Fig. 2 Do the business need roads?

Fig. 3 Where else do we store junk?

Secondly, many businesses had lost huge sums of money because of road closures during construction and some smaller businesses had closed down, probably forever. [See Fig. 2] The study referred above estimated the total loss to the business community due to this one fly-over, to be around Rs 40,00,000, to Rs. 75,00,000. (There are 15 fly-overs currently being built in Chennai!!) A third "penalty" is the time spent by busy executives in the traffic jams and hold-ups, caused by this construction work.

There is no evidence to suggest that the Community had given its informed consent for the colossal sums being spent on their behalf. Hiding "the hidden penalty cost" (particularly in metropolitan cities) would cause long-term damage to the attractiveness of the city as a place to invest. As the public become aware that technologies do exist to create infrastructure with minimum negative impact or inconvenience to public they will increasingly demand utilisation of such technologies.

(d) *Cost Of Damage to The Environment Due To Pollution* ("The Environment Cost"): As a direct result of pollution by particulate material (construction dust, movement of heavy construction equipment etc), the penalties paid by the hundreds of residents in the locality, by way of health-care costs must be adding to staggering sums. It is, of course, impossible even to guess this figure unless a detailed study is undertaken. Many road users are horrified to observe that the highway is closed up for prolonged periods merely for storing construction materials and junk, contributing to substantial dirtying of the environment. [See Fig. 3] Traffic hold-ups due to the construction cause added air pollution in the neighbourhood. It is clear that Professional Engineers are unlikely to be admired for irresponsibly causing pollution in the neighbouring environment for prolonged periods.

(e) ***Total Initial Cost:*** From the foregoing it is clear that the total likely savings by adopting steel-concrete composite construction to the taxpayer when a building, fly-over or bridge is completed, (compared with concrete-intensive construction) will be at least 30% - and more. Substantial reduction in pollution levels, environmental damage and traffic hold-ups will be added bonuses.

3.5.2 Periodic Maintenance Cost

Periodic and preventive maintenance undoubtedly contributes to the longevity of the structure. Unfortunately this is the most neglected activity in India. Economising on periodic maintenance will invariably result in much enhanced expenditure at a later date. The problem is compounded by several myths that seem to prevail among Engineers and Architects. Some of these that affect the periodic and timely maintenance of structures are discussed below:

(a) Myth No. 1: Concrete lasts forever without maintenance: ***The reality is*** that there ***is no <u>magical ingredient</u> in concrete to do it***! Concrete is subject to deterioration by the same environmental factors as steel (viz. Chloride contamination, alkali silicate reactions, sulphate attack etc.) In addition, we have problems due to poor site control, insufficient concrete cover, ineffective drainage, insufficient cement content, shrinkage, creep etc.

(b) **Myth No. 2: Concrete bridges outlast steel bridges:** ***The reality is that there is no credible statistical evidence that concrete bridges outlast steel bridges.*** Many steel bridges with over 100 years of service life are still performing well. In contrast, the first major prestressed concrete bridge in the USA (Walnut Lane Bridge in Philadelphia) had to be replaced by a steel bridge after a service life of about 40 years. The deterioration rates of 57000 bridges listed in Federal Highway Administration analysed by Lehigh University showed no correlation with the material of construction. The only factors they could identify are (1) age, (irrespective of the material of construction) and (2) the intensity of daily traffic.

Studies by the OECD (Organisation for Economic Co-operation and Development) reveal that steel bridges are expected to last much longer than prestressed concrete bridges. Indeed in Belgium and Japan they found that steel bridges outlast prestressed concrete bridges by 15 – 26 years.

(c) Myth No. 3: Concrete bridges last forever without maintenance: ***Some people believe that once in place, reinforced and prestressed concrete bridges last forever and that steel bridges are slowly corroding away.*** The perception is that concrete is an inert material, less vulnerable to the environment than structural steel. ***The fact is that Concrete deterioration is a subject, which is widely researched but not so widely discussed. Appearances can be deceiving – at least in the case of Concrete Bridges; according to US Govt. Strategic Highway Program, a bridge deck or sub-structure that appears sound, may actually be deteriorating from inside out.***

Steel is easily repairable at almost any stage of corrosion and over the years has shown a remarkable tolerance to lack of maintenance.

(d) Myth No. 4: Structural steel can not be adequately protected from corrosion: ***The reality is that there are high performance coatings available to day, which provide long term protection for EXPOSED Structural Steel at an economic price.*** Frequently, interior Steelwork does NOT require any paint or other protective coatings.

For Steelwork to corrode we need the presence of both water and air SIMULTANEOUSLY, or exposure to aggressive conditions. These conditions do NOT exist in most buildings and in many inland structures and bridges. There is certainly no evidence to suggest that many landmark structures like the London Bridge, Eiffel Tower, Empire State Building, Sears tower and many other Steel intensive structures are corroding away!

(e) Myth No. 5: A steel structure is less safe in a fire than other types of structures: ***The reality is that Steel Structures are no less safe than other structures***. The properties of **all** materials are degraded when exposed to fire. The modulus of elasticity of concrete is permanently reduced; the cross section of timber is consumed. The modulus of elasticity of steel is however, not permanently reduced and recovers once the member cools down. Steel structures can be economically fire protected to meet all building code requirements. Steel structures can be rehabilitated after a fire at a modest cost.

(f) Myth No. 6: Maintenance of Concrete intensive structures is significantly cheaper than that of Steel intensive Structures: Concrete–intensive construction is not as simple as is usually imagined**. Nor are concrete-intensive structures cheap, to maintain (contrary to popular myth).** Structural steel forgives human errors or lapses in maintenance, but not concrete! It is vital that Engineers pay attention to vital maintenance issues and not be carried away by myths.

The incidence of major concrete repairs to bridges is significantly greater than many realise and time cost of such repairs, when all costs including traffic delay costs are taken into account is very significant. It has been shown in published literature that the probability of significant repair work to be carried out within each 20 year life of concrete bridges is as high as 0.185. The direct cost of such repairs is insignificant (around 0.1 to 0.5% of the initial cost in present value) whereas the indirect cost due to the traffic delay during such longer repairs in concrete structures has been estimated to be at least 25%. Further, it is well known that repair and retrofit of steel members is a lot simpler than reinforced concrete members.

3.5.3 Cost of Dismantling the Structure at the End of its Life

Many structures in the urban environment are being demolished due to deterioration beyond repair, due to land values escalating very high, rendering the building economically unviable, or due to their inability to meet the modern functional requirements. At this stage a cost is incurred to dismantle or demolish the structure. It is well known that the cost of dismantling the steel structure is well below that of reinforced concrete structures.

3.5.4 Salvage Value of the Construction Products

Some of the products salvaged from the structure dismantled are of some economic value. This value is subtracted from the total cost after adjusting for the time of salvage. It is well known the cost of material recovered from steel intensive construction is almost equal to the original cost of the structure, although this value is to be reckoned at a later time in the life cycle, whereas in concrete intensive construction, substantial additional cost is incurred in disposing off the material. The recycling of demolished material from urban construction has become a major problem in urban areas, leading to intensive research on the subject.

3.5.5 Uncertainties in Life Cycle Costing

The effort to evaluate the life cycle cost is fraught with many difficulties listed below.

- Non-availability of reliable and consistent cost data

- Non-availability of reliable historical information on costs associated with construction, maintenance, repair, rehabilitation, and demolition (structure management system).
- Data on and experience with some of the recent technologies being only subjective and not rational and impartial (e.g. Prestressed concrete versus Steel bridge.).
- Changes in design criteria and techniques with time and location, construction materials and methods, patterns of use including magnitude and frequency of loads, maintenance methods etc.

As a direct consequence, many decision-makers experience uncertainties in arriving at reasonable estimates for LCC evaluations. Analytical techniques such as sensitivity analysis and probability analysis are sometimes used to make decisions about investments whose economic consequences are uncertain. It should, however, be noted that the LCC decisions are more influenced by life and discount; both these factors favour steel structures, since steel structures generally exhibit longer life and shorter construction and repair/rehabilitation time duration.

There is no doubt that a massive research effort is needed to assess the life cycle cost reliably and the durability aspects and environmental impact of any design decision. A sustained educational effort is also needed to persuade engineers to take a holistic approach to structural design, rather than merely confining themselves to myths and dogmas not based on rational analysis.

4.0 THE EVERYDAY LIFE OF STRUCTURAL ENGINEER

A structural engineer's responsibility is to design the ***structural systems*** of buildings, bridges, dams, offshore platforms etc [8,9,10]. A ***system*** is an assemblage of components with specific objectives and goals and subject to certain constraints or restrictions. System components are required to co-exist and function in harmony, with each component meeting a specific performance. ***Systems design*** is the application of a scientific method to the selection and assembly of components to form the optimum system, to achieve the specified goals and objectives, while satisfying the given constraints or restrictions.

In practice, any constructed facility can be considered as a "System". The Structural System is one of its major subsystems and is indeed its backbone. Some of the other coexisting subsystems are those connected with the mechanical, electrical, plumbing and lighting facilities.

Structural components have to meet the design requirements of adequate strength under extreme loads and required stiffness under day-today service loads, while satisfying the criteria of economy, buildability and durability.

Examples of civil engineering systems include buildings, bridges, airports, railroads, tunnels, water supply network etc. For example, a building system is an assemblage constructed to provide shelter for human activities or enclosure for stored materials. It is

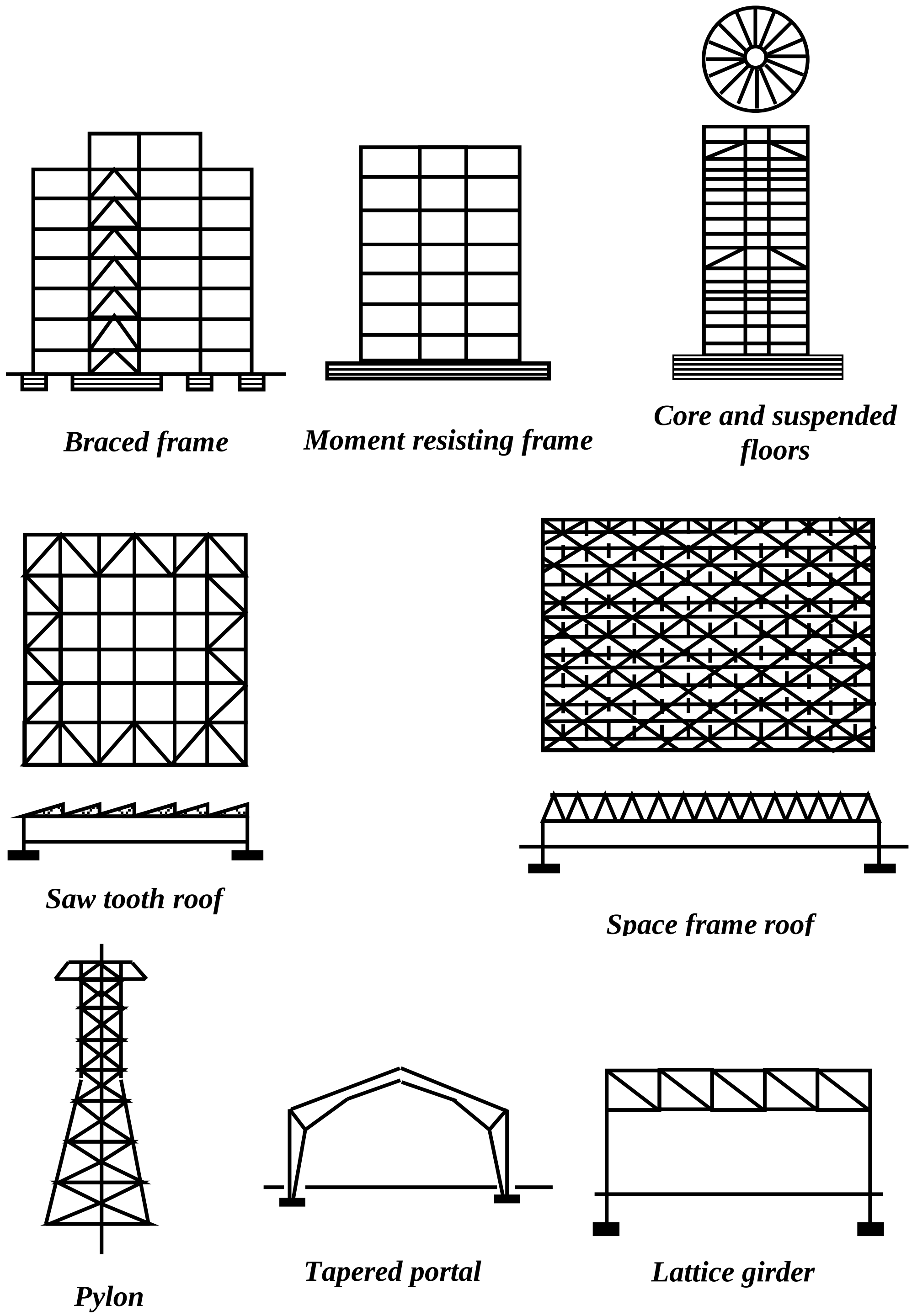


Fig. 4 Examples of steel-framed structures

subject to restrictions by building specifications on height, floor area etc. Constraints include ability to withstand loads from human activities and from natural forces like wind and earthquakes.

As pointed above, a system consists of many subsystems, i.e. components of the system. For example, in a building, major subsystems are structural framing, foundations, cladding, non-structural walls and plumbing. Each of these subsystems consists of several interrelated components. In the case of structural framing, the components include columns, beams, bracing, connections etc.

The richness and variety of structural systems can be appreciated by the available building structural types that range from massive building blocks to shell structures, from structures above or below ground or in water, to structures in outer space. Examples of a few steel-framed structures are shown in Fig. 4.

4.1 Goals

Before starting the design of a system, the designer should establish the goals for the system. These specify what the system is to accomplish and how it will affect the environment and other systems or vice versa. Goals are generally made in statements of specific design objectives such as purpose, time and cost limitation, environmental constraints etc., which would enable the generation of initial and alternative designs.

The goals for a system design applied to a subsystem serve the same purpose as for a system. They indicate the required function of the subsystem and how it affects and is affected by other subsystems.

4.2 Objectives

Having set down the goals, the designer defines the system objectives. These objectives are similar to goals but explain in detail the requirements that the system must satisfy to attain the goals. Some of the essential objectives of any project relate to health, safety and welfare requirements of the occupants, which are generally defined in local building codes or building regulations. Other special objectives include minimisation of initial costs, life-cycle costs, construction time etc.

At least one criterion (e.g. Fire resistance) must be associated with each objective. A criterion is a range of values within which the performance of the system must lie (e.g. Two hours fire rating is needed). The criterion serves as a guide in the evaluation of alternative systems to the project.

4.3 Constraints and standards

Constraints are restrictions on the values of design variables, which may or may not be under the control of the designer. For example, an I-beam section of *200 mm* depth may be desirable, but not available. There are also various legal and building code requirements. A minimum of one ***standard*** must be associated with each constraint.

4.4 Codes and Specifications

A structural engineer is guided in his design efforts by the relevant codes and specifications. Although the word '***codes***' and '***specification***' are normally used interchangeably, there is a distinction between them. A detailed set of rules and suggestions prepared by an interested party is called an ***engineering specification***.

On the other hand, ***Codes*** are frequently formulated by a group of professionals with a view to their adoption by the profession as a whole. These are revised at regular intervals based on new developments in materials, research, construction techniques etc.

Though codes offer general guidance to a certain extent, they do not provide answers to all the problems that arise in practice. Mere adherence to codes and specifications will curb all initiatives and innovative designs.

4.5 Construction and other costs

Construction cost and time are usually dominant design concerns. If the construction cost exceeds the budget, the completion of the project may be in jeopardy. Minimisation of the life cycle cost of a system would result in the most desirable solution.

5.0 DESIGN REQUIREMENTS

The principal design requirements of a structure are set out already under ***Introduction***. The primary structural safety requirement is met by ensuring that the structure has an acceptably low risk of failure during its design life. Another important requirement is that the structure must be sufficiently stiff to ensure that excessive deflection and vibrations do not affect the in-service performance of the structure.

The requirement of harmony within the structure is affected by the relationships between the different subsystems of the main system, the architectural subsystem, the mechanical and electrical subsystems, and the functional subsystems required by the use of the structure. Finally, the system should be in harmony with its environment, and should not react unfavourably with either the community or its physical surroundings.

Conceptual design refers to the task of choosing a suitable system. (As an example architect is generally concerned with the building layout, limits and parameters). In modern construction practices, a multidisciplinary team of architect, structural designer and service engineer together evolve the conceptual design. A typical organisational chart for a multidiscipline design team is seen in Fig. 5, which shows the inter-relationship between the various design professionals.

The structural engineer is charged with the task of ensuring that the structure will resist and transfer the forces and loads acting on it with adequate safety, while supporting other subsystems and making due allowance for the requirements of serviceability, economy, harmony and constructibility. The iterative process of achieving such a design is shown in Fig. 6.

Since several simplifying approximations are made in the preliminary design, it is necessary to re-check the design. The loads are recalculated more precisely and the structure is reanalysed. The performance of the structure is then re-evaluated with respect to the structural requirements, and any changes in the member and joint sizes are made [See Fig. 7].

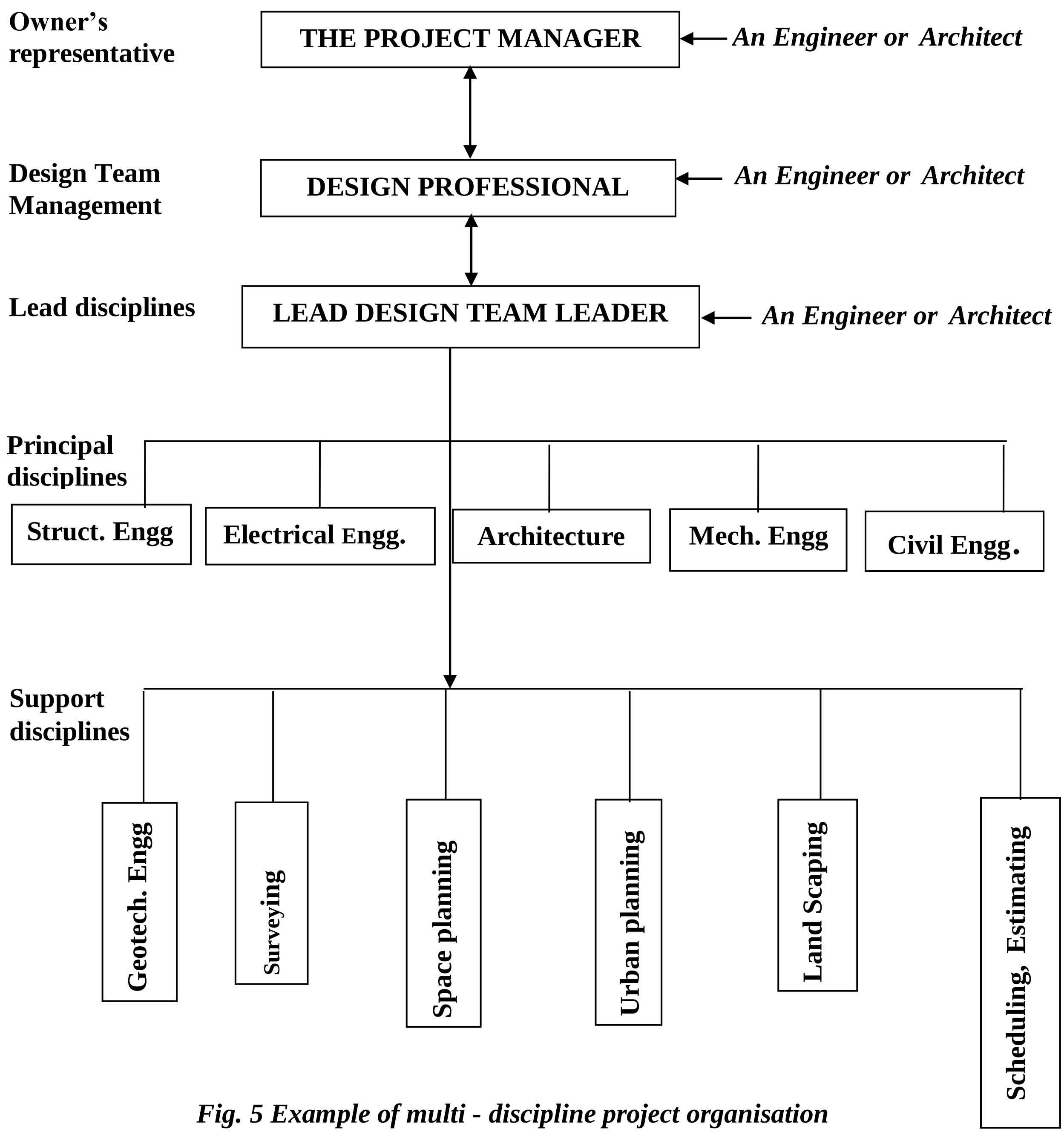


Fig. 5 Example of multi - discipline project organisation

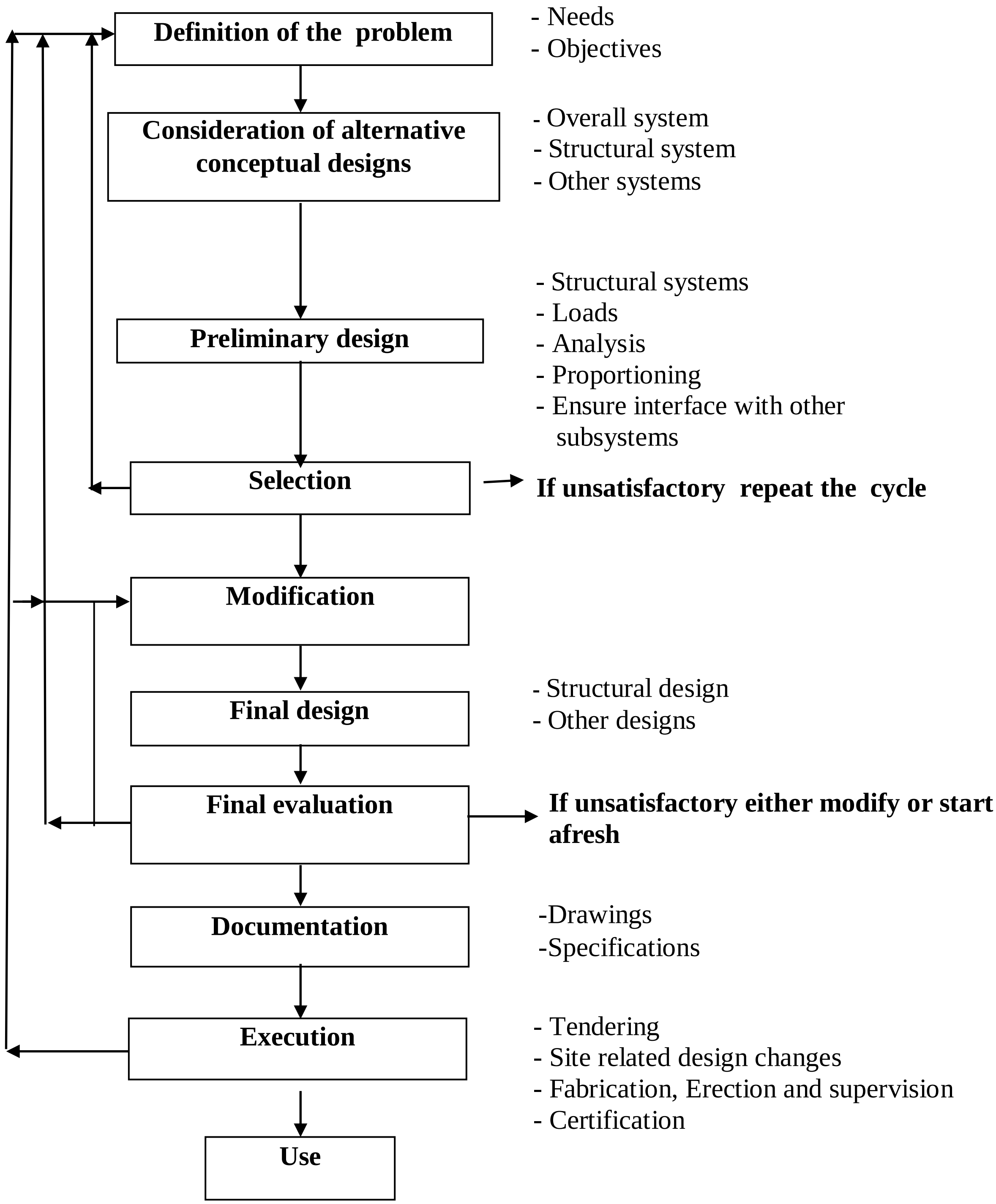


Fig: 6 The overall design process (Iterative)

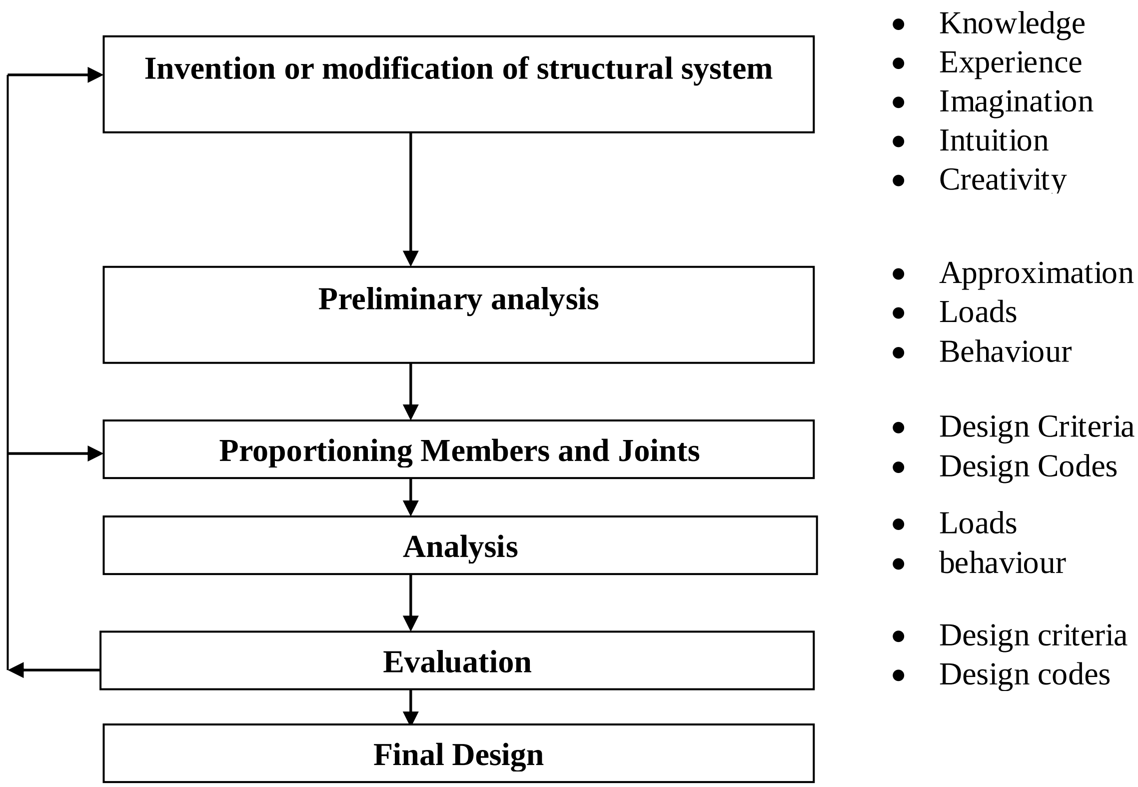


Fig. 7 The structural design process

Frequently, there is a fundamental confusion among students between a problem on Analysis and one on Design. In an analysis problem, all the parameters are known. (For example, if deflection of a loaded beam is required and the span, loading and the cross sectional properties are all known then a unique solution for the value of deflection can be arrived). The problem encountered in design (as compared to analysis) is that it involves the selection of the span, assessment of the loading, choice of the material of which the beam element is made, definition of its cross section and so on.. As a consequence, no unique solution can be offered for any design problem. It is clear that the designer has to make several decisions, each of which could affect the final result. Considerable engineering discretion of the designer is implicit in every design project.

The aim of the comparison of designs is to enable the designer to ascertain the most acceptable solution that meets the requirements for the given structure. All factors must be taken into consideration. Factors to be taken into account in a typical building project are given below by way of illustration:

1. Materials to be used
2. Arrangement and structural system (e.g. flooring system) to be adopted
3. Fabrication and type of jointing
4. Proposed method of erection of the framework
5. Type of construction for floor, walls, cladding and finishes

6. Installation of ventilating/ heating plant, lifts, water supply, power etc.
7. Corrosion protection required
8. Fire protection required
9. Operating and maintenance costs

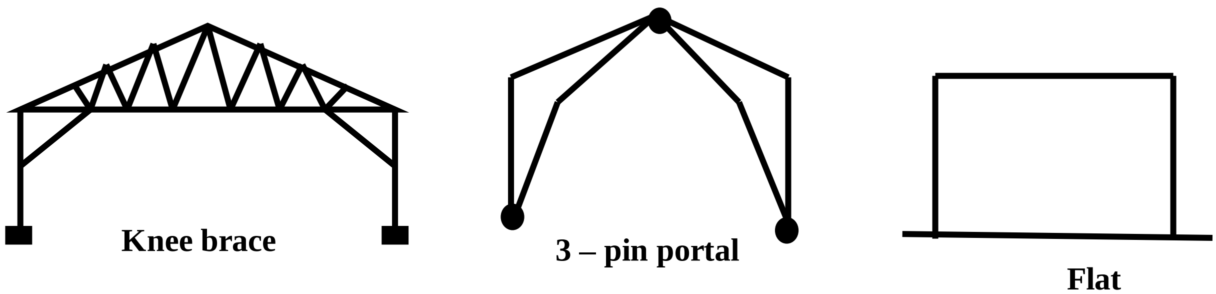


Fig: 8 Single Bay, Single-storey Structures

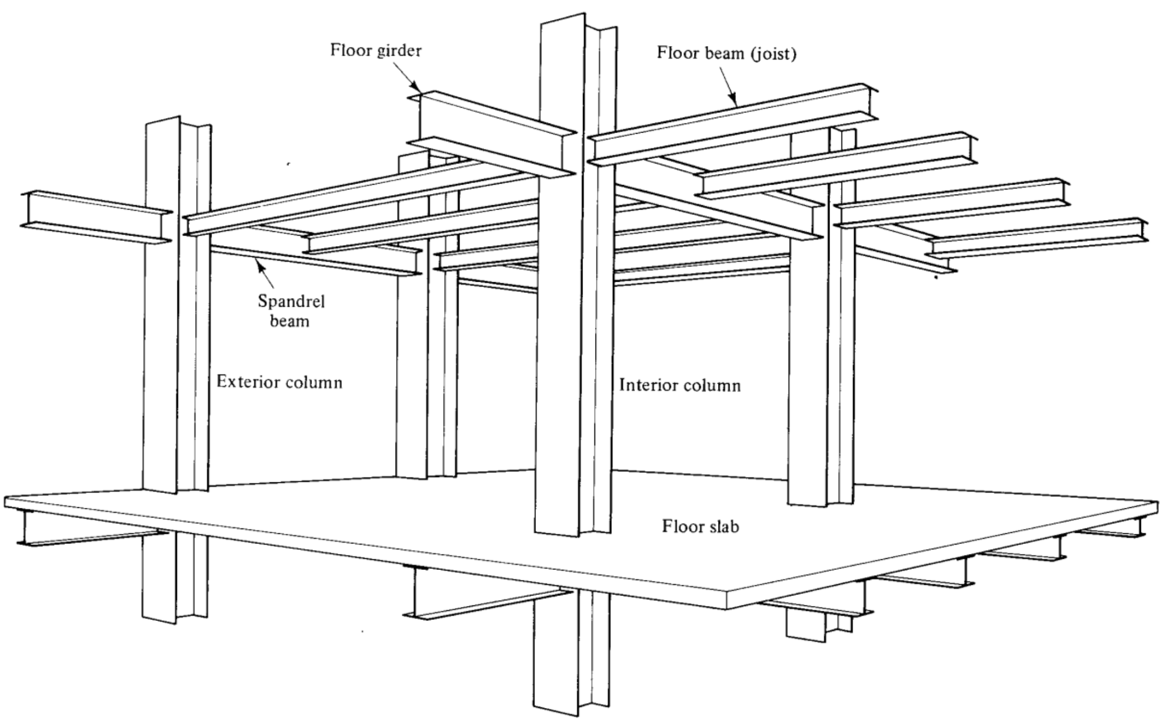
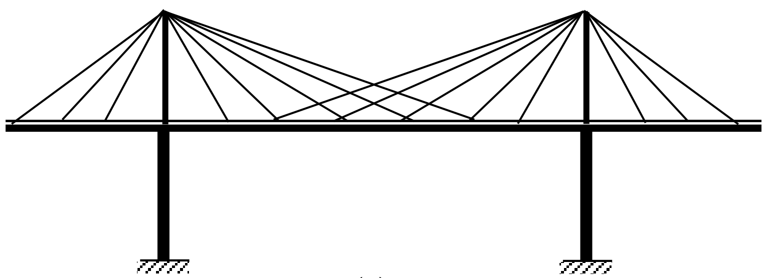
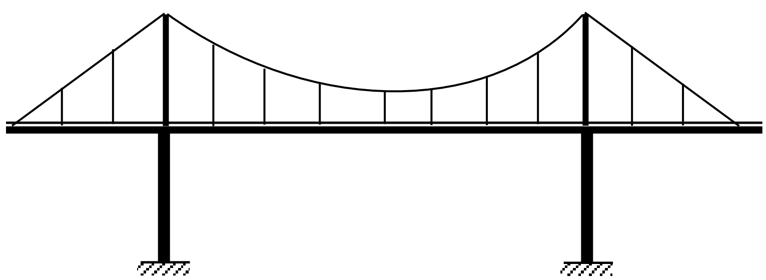


Fig.9 Beam and column construction

Aesthetic considerations are important in many cases and the choice of design may not always be based on cost alone. The weight saving may be offset by the higher cost of the stronger material or the higher cost of fabrication/construction of complicated systems. Often no one solution for a given structure is prominent or obvious to the exclusion of all other alternatives. As an example, we can illustrate several choices available to the designer for a single bay, single storey structure [See Fig. 8]. An example of beam and column system frequently used is illustrated in Fig. 9. Cable stayed structures are frequently employed in long span bridges and buildings and are shown in Fig. 10. In the following chapters, the analysis and design of steel elements are discussed in depth, followed by the analysis and design of selection of structural elements.



(a)



(b)

Fig. 10 Cable-stayed structures

6.0 CONCLUDING REMARKS

The paper discussed the role of a Structural Engineer in designing constructed facilities in the 21st century. The relevant environmental factors which affect his work, the durability and infrastructure crises, which face the Industry, are all discussed in detail. The importance of life cycle costing and the rational selection of appropriate materials for construction are discussed in depth.

A strong case is made for taking account of the durability and environmental considerations in the design process. They make a vital contribution to the life cycle cost of a structure. The paper concludes with a description of the structural design process in the everyday life of a structural engineer.

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