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Building under Extreme Conditions

Construire dans des conditions extrêmes

Bauen unter extremen Bedingungen

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Building under Extreme Conditions and Development of Appropriate Construction Technologies

Construire dans des conditions extrêmes et évolution d'une technologie de construction appropriée

Bauen unter extremen Bedingungen und Entwicklung passender Bauverfahren

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It is interesting to look at the City of Bath which, with its complex of Georgian buildings, respresents one of the most perfect expressions in Europe of a single approach to architecture. It was designed by men who, in many cases, had never left the city and who based their designs on books about classical buildings. The root of their building style goes back to the Doric temple of 600 BC so it is perhaps not surprising that with 2300 years of study the architectural achievement was spatially superb. Yet these buildings are certainly not functionally perfect, and are often structurally weak, have few services and are damp, cold and ill built.

Compare the City with the new University at the top of the hill. The University is unusual among the new universities in Britain in that it is one single building. It is planned not only to achieve a unity but also to be adaptable for an ever evolving academic society. The cars are parked at ground level where the heavy duty laboratories are also sited. Above is a pedestrian concourse, the offices of the Schools, the library, social elements and main lecture theatres. Above these are the lighter laboratories and staff rooms while at either end of the main concourse are tower blocks providing student accommodation. The site is very exposed and the grouping considers this. The change from an individual craft based society to an industrial one is recognised economically by building with a series of standardised component parts. The realisation has entailed a whole range of clients, planners, architects, structural and environmental engineers, contractors and fabricators. Group interaction has produced it and it represents a much broader and more recent view of what is required. A view which started with the Bauhaus in the 1920's.

Modern design in civil engineering has become no different. The problems of a road are not only those of excavation, alignment and pavement design but also respond to the social and economic reasons for the road, the use of the road and its impact on the adjacent environment. The biggest volume of work lies with the civil engineer but the important decisions lie equally with the economic planners, landscape architects and environmental engineers.

Due to our density of populations, increased aspirations and new possibilities we need broader solutions which satisfy wider needs. Many professions are engaged in making design decisions and determining our built environment. These professions bring to the design and construction process different areas of knowledge and sensibility. We need these differences to achieve quality. But our biggest problem is how to work well together, how to understand what we each do best, how to have a common language and values. In other words how to evolve better methods of design and construction.

The congress in Vienna in 1980 gives an opportunity for this, perhaps more so because looking at the extreme conditions of a total construction problem exaggerates certain aspects and requires a very conscious approach. Case study papers on method and approach are needed in this area.

In a sense all civil engineering is the design of structure and has a very long history. Yet structural engineering really started about 200 years ago when the development of iron started a profession designing structures in man made materials which considers current fabrication and erection processes (for example the Central London stations, the Crystal Palace etc). This is the core of what we do, we apply rather than explain because we aim at producing a useful product. The knowledge we use need not be objective or complete as long as the product works. We redirect nature.

But in all we do we must have an aim and that aim is usually value; the cheapest appropriate structure combined with serviceability. Success in designing a structure which is cheap to build, cheap to run and cheap to maintain must depend on economic factors which are themselves dependent on geographical and other influences. No mathematical model can be evolved to optimise such a design as it would have too many variables. So we usually take a strong central 'belief' (or even two or three) as the thread to pin our design on. But to do that we need a very broad knowledge of a country's resources, materials and construction industry, climatology and other factors. For example there is no doubt that in Arabia a conditioned environment in most buildings is required for people to be able to work. Yet the indigenous population is relatively small and there is a lack of maintenance skills. So while recognising the need to air condition many buildings the minimising of electrical and mechanical servicing is essential. It has been predicted that by the year 2000 one third of the building industry in Britain will be engaged in maintenance, how much worse the problem could be in Arabia. So when we were working on the infrastructure design of the University of Riyadh we decided no building, except for symbolic ones, should be over three storeys high to reduce the need for elevators and went on to a whole series of built form studies to determine the fenestration, insulation, orientation and spacing of the buildings in order to reduce the servicing load. Climate, effective determination of land use and so on are the patterns which define the planning. While Arabia is a monetarily rich country the 'cost' of foreign skilled labour is high and the efficiency of their use of prime importance. Prefabrication in building is essential. The choice of structural materials and the choice of type and sizes of members taking into account labour skills and availability, problems of importation and the varying needs of the buildings is a complex one. Papers on projects in the context of a country's industrial abilities, its economic situation, its climate and location are needed.

The process of analysis of structural behaviour is quite developed. What the engineer is often less skilled in is the process of erection in extreme environments. The limitations of working conditions in extreme environments has been experienced by few. It may be that the giving of knowledge will lead to better proposals. We have strong social obligations to the countries we work for, our children will live in the world we leave them. Working in extreme conditions accentuates the problems which occur in all situations and should provide a learning tool at both the general and detailed levels which should enable us to be better at our professions.

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Building under Extreme Climatic Conditions

Construire dans des conditions climatiques extrêmes

Bauen unter extremen klimatischen Bedingungen

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SUMMARY
This introductory report summarises the climatic conditions to be found in five different environmentally classified areas of the world. In each area it outlines briefly the effect of these conditions on design philosophy, use of materials and execution of the construction activity. The paper concludes that future engineering for extreme conditions would benefit from quantifying the experience already gained and by publishing appropriate engineering standards.

RESUME
Ce rapport introductif résume les conditions climatiques présentes dans cinq régions du monde — classées selon leur environnement. Ces conditions ont des effets divers sur la conception du projet, l'emploi des matériaux et l'exécution de la construction. Il est nécessaire que les activités futures du génie civil dans des conditions extrêmes bénéficient des expériences déjà acquises ainsi que de la publication des normes dans ce domaine.

ZUSAMMENFASSUNG
Dieser Bericht fasst die klimatischen Verhältnisse zusammen, die in 5 verschiedenen Gegenden der Welt herrschen. Für jede Gegend wird aufgezeigt, welche Einwirkungen diese Verhältnisse auf Entwurfskonzept, Anwendung verschiedener Baumaterialien und Bauausführung haben. Der Vorschlag, dass eine qualitative Bestimmung der bis jetzt gewonnenen Erfahrung und die Veröffentlichung von zweckmässigen Normen dem Ingenieur beim Bauen unter extremen Bedingungen zugute kommen würden, beschliesst den Bericht.

Introduction

The motivation for undertaking construction projects in inhospitable areas of the world is frequently related to the exploitation of valuable natural resources such as minerals or hydrocarbons. Alternately such projects are required to provide essential communications or services to existing inhabited areas. Under these conditions the development of unusual and therefore expensive solutions are justified by either the economic return or social benefits that result. In recent years an increasing awareness has developed worldwide on two subjects directly related to the theme of this paper. One is the finite and in some cases quickly decreasing known reserves of essential natural resources and the need to conserve such materials by recycling or by eliminating unnecessary wastage whilst substitute materials are developed and additional sources are found by exploration. The second is the increasing world population and their expectations which eventually can only be accommodated inhabiting parts of the world which hitherto have remained underdevloped due to difficult environmental conditions. Unfortunately, the solutions to these two problems are frequently incompatible as to sustain life under extreme climatic conditions requires a greater input of materials and energy than would be involved in temperate climates.

The design or construction engineer who has been brought up and educated in a temperate climate has little experience of how to adapt to extreme climatic conditions. The engineering textbooks and codes of practice he is familiar with have been derived from many years of construction experience in his own or similar climate. He therefore needs to understand the philosophy upon which familiar rules and standard practices are based so that when faced with totally different climatic conditions he can modify his design premise, choice of materials and construction methods to provide a comparable optimum structural solution.

Historically engineers have proved that this adaption to totally different constraints can be successfully achieved. The evidence for this success can be witnessed in all parts of the world where engineering teams from every country with a well established engineering profession have assisted local inhabitants to undertake construction projects to the highest standards. The skills displayed on such projects also assist the country of origin in improving both trade and relations between the participating countries. The contribution that our profession makes to home economies and to the raising of living standards in client countries is rarely given appropriate recognition.

Extreme environmental conditions can be divided into five distinct types where special designs, materials or construction techniques are required to produce a structure which compares with what is achievable in temperate zones.

1. OFFSHORE ENVIRONMENT

Undeveloped mineral resources on, or beneath, the continental shelf and beyond have been identified for some time. The only industry so far to seriously venture offshore has been the oil industry in its search for new supplies of oil and gas. Initially, offshore development took place in shallow i.e., up to 50 m water depth and relatively sheltered locations such as the Persian Gulf, Gulf of Mexico, Lake Maracaibo and South East Asia. In the last 10 years development has moved into water depths up to 300 m in the U.S.A. and up to 200 m in the North Sea where environmental conditions are the most extreme encountered to date.

Design parameters in the North Sea are dominated by the effect of 100 year storm waves which can reach 30 m in height. The associated current speed is 1.5 m/sec and wind speed is 50 m/sec. In addition an offshore platform typically has to support a 20,000 tonnes pay load of drilling and production equipment. These storm conditions control the size of structural members of both jacket and deck structures even though allowable material stresses are increased by one third for extreme load cases. The joints of such structures however require careful fatigue investigation for during a single year 5 million waves varying from 1 m to 30 m wave height will pass through the structure. Stiffening or thickening of members at joints subjected to large wave action force components is often necessary.

The majority of offshore structures are built of steel and as offshore development has moved into colder climates such as the North Sea the selection of steel properties for these conditions has required careful investigation and judgement. Grade 50 steel is universally used as greater stress capacity would be ineffective due to fatigue considerations. Primary steel work is generally grade 50D (BS 4360) with improved properties for low temperature impact. For parts of the structure subject to tension normal to the steel plate such as a brace connection on a node then additional through thickness properties are required to prevent laminar tearing. As the structure has a potential life of up to 25 years it has to be adequately protected against corrosion. Sacrificial anodes sometimes with epoxy coal tar coatings are the most common solution.

The construction and installation of offshore structures is based on the philosophy of doing as much work on land as possible and in the North Sea to restrict offshore construction to the summer weather window from May to September. The size of land built components is only limited by the capacity of the offshore construction equipment available for the installation. Jackets have been traditionally transported to the offshore location by barge but with the early deep water platforms the capacity of existing barges was insufficient and self floating designs were evolved or as on the Forties field temporary floatation rafts were used. More recently larger launch barges have become available and designs up to 25,000 tonnes can now be accomodated. The deck structure is constructed in segments which are lifted by crane barges and set on top of the jacket after it has been piled to the seabed. The equipment is then installed in modular pieces on top of the deck structure. The current lifting capacity of offshore cranes is 3000 tonnes and the sea state conditions for such operations have been extended significantly by the new semi-submersible crane barges. A recent development to further reduce the installation and commissioning of the deck structure and modules is the concept of installing offshore a complete deck including equipment directly onto the jacket substructure. Part of this concept has already been used by many of the concrete offshore platforms where the buoyancy of the storage caissons of the structure allow a major percentage of the deck pay load to be installed inshore in deep sheltered water.

2. HIGH RAINFALL AND HIGH TEMPERATURES

In the tropics and semi-tropics temperatures vary from 20^{o} to $45^{o}C$ and the annual rainfall varies from 200 to 400 cm per year with rainy season peaks of 75 cm per month and 7 cm per hour. The average humidity is 80 percent and although wind speeds are generally low speeds of 65 m/sec can occur during typhoons.

A major design problem is accomodating material temperature changes of $60^{o}C$ by allowing sufficient movement at expansion joints. Differential temperatures are equally important as the resulting curvature will produce complex support reactions in an indeterminate structure. The rapidity of temperature changes as the sun sets or a tropical storm approaches can produce visible and audible motion as observed at the supports of a major steel box girder bridge in South America. Adequate drainage is essential to avoid foundation undermining and slope erosion during peak run offs.

On concrete structures reinforcement cover of 5 cm is required to avoid spalling due to corrosion of the reinforcement. Exposed steelwork requires regular painting and partly embedded steel should be galvanized. All materials are subjected to biological attack which quickly disfigure their surface although the structural properties may not be affected. Frequently local materials in particular hard woods have excellent durability. For example, in South America all temporary supporting members during building construction are timber due to the scarcity of steel scaffold.

Construction under these conditions can be extremely difficult due to simple problems like materials too hot to physically handle or more serious the presence of disease organisms. The availability of local construction plant may be limited and specialised skills such as welding among the local labour force may be non-existent.

3. HIGH RAINFALL AND LOW TEMPERATURES

These conditions occur in areas where continual wet snow occurs in the artic and subartic. Temperatures can vary between extremes of -70° to +40°C and remain below -45°C for 8 weeks at a time. Wind speeds reach a maximum of 45 m/s in the subartic and only 18 m/s in the artic. In spring and autumn fog and poor visibility are prevalent and during November, December and January there is no sunlight and minimal twilight.

Permafrost can extend up to 600 m below the surface and of course presents an excellent foundation providing the structure is thoroughly insulated from the ground to avoid disturbing the natural thermal equilibrium. Continuous foundations should be avoided and all loads should be carried on footings or piles extending down at least twice the summer thawing depth. The use of separated foundations also assists the structure in accomodating the large temperature movements which occur.

Construction materials have to withstand the continuous presence of moisture and the seasonal freezing thawing cycles. Concrete can be successfully used provided freezing is avoided during setting by using a combination of rapid hardening cement and heated aggregates and/or water and leaving formwork in place until a strength of 10 N/mm^2 is achieved. Steam heating during curing is beneficial as strength only develops slowly at low temperatures. The supply of water is a major problem as to melt snow requires large quantities of energy. The most dependable sources are deep lakes and rivers with water below the maximum freezing depth.

All the construction materials apart from aggregates have to be imported to the construction site. In Alaska for example material can only be brought in by sea during August and September and for the rest of the year air transport is the most reliable although overland freighting using tractors and sledges is possible. The output of construction workers lowers once the temperature falls below -30°C and construction equipment has to be modified to operate below -50°C.

4. LOW RAINFALL AND HIGH TEMPERATURES

Desert conditions exist in the western areas of North and South America, the Sahara, Arabia, Iran, South Central U.S.S.R., Mongolia, North Central China and Central Australia. They are characterised by temperatures varying daily from 15°C to 50°C and surface temperatures reaching 80°C. Rainfall is less than 25 cm per year which occurs in less than 30 days producing extremely low humidity. Dust storms frequently occur at speeds up to 10 m/sec.

Design considerations are mainly concerned with minimising the effects of heat particularly for buildings where thick walls and insulation with minimum window areas can utilise the relatively cool nights to reduce artificial cooling during the day. Foundations are generally simple due to well compacted sand layers but attention must be given to protecting them from undermining during wind storms by placing them deeper than usual. Large scale expansion of materials should be considered in detailing joints to avoid penetration of airborn dust.

Materials are subject to heat-aging resulting in premature loss of properties. Sand erosion can damage glass and plastic components and can remove protective coatings which is further aggravated by ultraviolet radiation. Steel lasts well provided it is coated with highly reflective paint as little corrosion takes place. Concrete of high quality can be produced by making sure the water and aggregate sources are uncontaminated and cool. Water curing should be used for a minimum of 24 hours to avoid surface cracking or plastic shrinkage cracks. Water supply is a major problem with sources being limited to wells, diversions from nearby streams or rivers on higher ground or from underground tunnels. Locally produced stone or bricks may sometimes be available and reduce the quantity of imported materials.

Construction in this climate has its difficulties for example, mechanical equipment requires carefully sealed high temperature lubrication systems. Personal discomfort may result from insects and night and early morning shifts should be used to minimise loss of worker efficiency. Western clothing and local clothing styles will help acclimation of personnel by increasing the loss of excess body heat.

5. LOW RAINFALL AND LOW TEMPERATURES

These conditions are found in the summerless polar ice caps of the Artic and Antartic and in Greenland. Compacted ice thickness in these regions can vary from a few metres up to 3000 m with dry powdery snow constantly present. Wind speeds can reach 90 m/sec and visibility can drop to 3 m particularly with fog in coastal areas. Temperatures can fall as low -90°C and may average -70°C with almost no rainfall.

Building design requires imaginative solutions and it is essential that all structures should be interconnected. Surface construction can be achieved using prefabricated components but requires extensive insulation and will continually attract snow drifts. Under surface construction within the ice cap has found to be more efficient as the temperature remains constant at -8°C and the ice is structurally sound for tunnelling without supports. Snow and ice can be used as a construction material for after mechanical compaction it can replace concrete in no-thaw areas. The disposal of waste material and polluted air from buildings requires careful consideration to avoid contaminating the area of inhabitation. Water supply is only available by melting the ice or by distillation of salt water.

Construction is limited to a period of 60 to 120 days i.e., November to January in Antartica and June to September in Greenland. During these periods a 24 hour working day is possible provided material delivery is correspondingly scheduled. Outside these periods the combination of darkness, wind and blown snow make outside work highly inefficient. Land equipment for these regions has only been partly successful with four track vehicles superior to two track vehicles where the crossing of crevasses is a problem. Power generation from imported fuel is expensive with up to 80% of the cost required for transportation. Nuclear power plants have been operating successfully in Alaska, Greenland and the Antartic but the waste products have to be returned in containers for disposal.

CONCLUSIONS

Construction problems in areas of adverse climatic conditions are now being overcome through the development of environmental engineering. This is achieving acceptable living and working conditions despite the extreme weather or terrain naturally present. Experience of designing for and building in these remote areas is now considerable and will help in finding improved solutions for the future.

The conditions outlined previously can occur temporarily in temperate zones and when they do normal construction has to be suspended or revised construction methods adopted subject to satisfying the original design criteria. In temperate areas of the world low temperature weather conditions occur in mountainous regions resulting in limited construction periods and compliance with extreme climatic design and material constraints. Occasionally it is necessary to develop design codes for specialised structures subject to unique environmental forces as those previously described for offshore structures. An example is the recent work in the U.K. to produce a new code of loading for the design of tower structures up to 300 m tall. The code is intended to be applicable worldwide although specific meteorological data is only given for the U.K.

As development in extreme climatic regions becomes more commonplace then rationalisation of design and construction methods will occur and appropriate engineering standards will be published. The engineering development for the Alaskan oil fields and pipeline should enable detailed design codes for this region to be produced from the experience of the oil companies, their designers and their contractors. It is to be hoped that the detailed case studies to be written for this congress will also assist in promoting a wider knowledge of the solutions which have already been achieved.

REFERENCE

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Building under Extreme Environmental and Infrastructural Restrictions

Construire dans des conditions extrêmes d'environnement et d'infrastructure

Bauen unter extremen Infrastruktur- und Umweltbedingungen

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SUMMARY
This report outlines the extreme environmental and infrastructural restrictions and discusses their influence on building design and construction. The restrictions may include shortage of materials, limited equipment and transport facilities, limited availability of skilled personnel, socio-economic and time factors. Development of appropriate construction technologies depends on adequately identifying these restrictions and taking them into account at all stages of a building project.

RESUME
Ce rapport esquisse les restrictions extrêmes d'environnement et d'infrastructure et présente leur influence sur le projet et l'exécution de constructions. Les restrictions peuvent avoir trait à un manque de matériaux, à un équipement et une infrastructure de transport de faible qualité, à une offre limitée de personnel qualifié, ainsi qu'à des facteurs socio-économiques et de temps. Le développement d'une technologie de construction appropriée dépend de la connaissance et de l'appréciation de ces restrictions ainsi que de leur prise en considération à chaque étape du projet.

ZUSAMMENFASSUNG
Dieser Bericht zeigt diejenigen Randbedingungen auf, die durch die Infrastruktur und extreme Umweltverhältnisse verursacht werden, und erörtert deren Einfluss auf den Entwurf und die Ausführung von Bauten. Unter Einschränkungen zählt man Mangel an Baumaterialien, Ausrüstungs- und Verkehrsanlagen, beschränkte Anzahl von Fachleuten und sozio-ökonomische sowie zeitliche Umstände. Die Entwicklung passender Bauverfahren hängt von einer genauen Kenntnis dieser Einschränkungen und deren Beachtung während aller Entwurfs- und Bauphasen ab.

1. INTRODUCTION

Building design and construction are influenced by a number of factors including local physical, environmental and infrastructural conditions. The success of a building project, therefore, depends on understanding these conditions and adopting suitable methods of design and construction. This is particularly important for building activity in a developing region where environmental and infrastructural restrictions may not allow the use of conventional methods of construction.

The environmental and infrastructural restrictions may include shortage of materials, limited equipment, limited availability of skilled personnel, transportation and communication problems, socio-economic and time factors. Overestimation of resources and facilities or underestimation of difficulties in the design of a building project may lead to lengthy delays during construction, overrun costs, legal complications, substrandard end product or even structural collapse. It becomes, therefore, imperative to develop suitable designs and advance appropriate construction technologies in keeping with the extreme local conditions and restrictions. The specifications for works should also be consistant with local conditions, materials and equipment.

The paper describes the extreme environmental and infrastructural restrictions and discusses their influence on building design and construction. Several innovations in the fields of design and construction have recently been made for the speedy development of various regions of the world. It is not possible to present all such innovations and detailed case histories in one paper. The scope of the present paper is therefore limited to the discussion of main aspects of environmental and infrastructural restrictions and development of appropriate construction techniques.

2. BUILDING MATERIALS

Availability of materials plays a major role in the successful completion of a building project. At present, concrete and steel are the two main materials of construction. Steel is not locally produced in many countries and therefore it may not be feasible to construct a large number of steel structures in these countries.

Production of concrete also depends on the availability of constituent materials, e.g., cement and aggregates. It is usually most economic to use locally available aggregates to avoid increase in transportation cost and large storage at construction site. Depending on geographical location and source, some aggregates may not conform to relevant specifications. These aggregates should not be rejected solely on their physical properties, but should be tested in trial mixes to assess their suitability in terms of strength and durability of the concrete produced.

Due to tremendous increase in construction activity, there is a shortage of cement in many countries. The shortage can be overcome by setting up more cement plants or by importing cement from other countries. However, setting up of a new plant cannot be regarded within the purview of a building project and may have to be decided on a national level depending on the total demand of cement in the region. Import of cement may not be an economic proposition except for construction work in border and coastal areas. Inland transportation of the imported cement may raise its delivered price substantially, thus affecting overall cost of the construction work.

Economy in the use of cement can be obtained by adopting proper methods of mixing and placing concrete and also by using good formwork to get smooth concrete surfaces which do not need plastering.

Special types of reinforcing steels and bar sizes above 1 in.(25 mm) diameter may not be readily available in certain areas. Some countries have recently changed to SI units of measurements but have not yet redesignated and produced metric reinforcing bars. Therefore, to avoid delays and gross mistakes at the site, working drawings should be prepared keeping in view the available materials and sizes.

In some regions it may be more economical to use brick or stone masonry than concrete construction for buildings up to 4 storeys. In the case of limited availability of portland cement, other cementing materials can be used for making mortars for brickwork and stonework. Gypsum, lime and pozzolanas have been used in various parts of the world for making mortars. In Pakistan, India and Egypt powdered broken tiles and pottery are also used for making mortar in minor masonry works.

Soil-cement blocks were introduced in many countries some time ago for low cost construction to replace the traditional mud or adobe dwellings. Recent studies indicate that due to increase in the price of cement, soil-cement block construction cannot be regarded 'low cost'. Therefore, in order to maintain the usefulness of this appropriate construction technology of machine made adobe blocks, it is essential to find out alternate cheap stabilizing materials. Lime may be used as a stabilizing material and studies are in progress to determine the optimum values of lime and water for making lime stabilized blocks.

To overcome the shortage of building materials research is also in progress on other locally available materials, including agricultural and industrial wastes, which may prove useful for constructing various types of structures.

3. CONSTRUCTION EQUIPMENT

In order to obtain certain standards it becomes imperative to use some mechanized operations in building construction. For example, large quantities of concrete cannot be produced without a concrete mixer. Development of an appropriate construction technology may, therefore, necessitate the introduction of simple and readily available equipment for achieving the desired standards. Cinvaram, the hand operated block making machine, can be an example of this type of equipment. Cinvaram is now locally manufactured in many countries. Two skilled labourers can use one Cinvaram for making about 300 blocks of stabilized soil in one day.

Most of the heavy construction equipment is not locally manufactured in developing countries, and therefore, limited equipment and machinery may be available at a building project. Efficient use of the available equipment can be made by analysing the operation of each machine and carefully planning the construction work. For example, at most construction sites a crane (mobile or tower) may be the only equipment available for handling formwork and steel reinforcement and also for placing concrete above ground level. Building work can be successfully accomplished with the crane if all the operations are preplanned and a balanced cycle between different operations is maintained.

In some countries the energy crisis may also limit the use of mechanized means of construction. Maximum use of the available labour should be made in such cases. For example, unskilled labour can be used for excavation of building foundations and earthwork in road construction. However, it will be mandatory to employ compaction equipment for getting desired results.

Proper sequence in construction work can also be helpful in overcoming equipment shortage. In low-rise buildings if staircases are completed simultaneously with other construction, the stairs can be used for transporting materials and tools to work points above ground level. Concrete and bricks can be head carried in metallic baskets to the underconstruction level by labourers.

The design of precast concrete members and steel structure components and arrangement of shop and field connections should be carried out keeping in mind the available erection and transportation methods. Capacity of handling, erection and transporting facilities will control the weight and lengths of various members.

With limited equipment at a construction site, the need for its repairs and maintenance becomes very important, because breakdown of some machinery may mean stoppage of construction work. Therefore proper facilities for regular inspection, lubrication and maintenance work should be provided to keep the available stock in a running condition.

Materials testing equipment forms an essential part of modern building industry for maintaining quality and developing new materials of construction. Quite often adequate testing facilities are not available near the construction site and it becomes difficult to employ worthwhile quality control measures. Experience has shown that in such cases non-destructive methods of testing can be effectively used for checking quality and detecting defects during construction. Inexpensive and portable equipment is now available for conducting non-destructive tests. However, limitations of non-destructive methods must be kept in mind while interpreting the test data.

4. TRANSPORTATION AND COMMUNICATION

Lack of communication and transportation facilities may hamper speedy procurement of building materials and equipment and cause delays in the completion of a project. Construction techniques should, therefore, be developed keeping in view the limited transportation and communication facilities available in a region.

Besides irregular supplies of building materials, narrow and substandard roads may affect the working of ready mixed concrete industry in a developing region. The situation may be further aggravated due to non-existance of a communication system, say, a two-way radio, as most developing countries do not allow private use of a radio or wireless set. In such cases, it may be more appropriate to install small or medium sized ready mixed concrete plants in various parts of a city than a big plant. Telephone connections at the plant and the construction site may provide the necessary communication link.

The selection of a definite method of industrialized construction also depends, to a great extent, on the transportation system. For example, the use of heavy panels and box modules may not be feasible at present due to nonavailability of special trailers and good roads (1). However, precast beams of usual spans and slab units have been transported by medium sized trucks, even over long distances, for the construction of houses, schools and hospitals in many developing countries. In the absence of proper roads and trucks, horse and ox drawn carts have also been used to transport simple precast elements in remote areas without appreciable breakage.

Precasting and prestressing at site can be used to overcome shortage of transportation facilities. This method has been successfully used for the corstruction of major highway bridges in many developing countries. Precasting at site can also be used for large building projects. This method of construction will be particularly useful when sufficient space is available near the site to set up precasting plants.

Besides roads and railways the use of other types of transportation system should also be explored. In some cases waterways can provide excellent means of transporting materials and equipment.

5. SKILLED MANPOWER

Architects, engineers, managers, technicians and labourers form a part of the manpower needed for designing and executing building programmes. In many countries labour is available but engineers and other qualified supervisory personnel are not available. In some other countries there is a shortage of expertise and skilled labour. An analysis of the failures of four bridges in Bangladesh (2) indicates that the lack of supervision during construction due to the shortage of experienced engineers was the main cause of the bridge failures. In most cases the reinforcement had not been placed according to the detailed drawings of various bridges.

The oil-rich developing states which are deficient in construction materials, equipment and labour imported almost every thing from other countries for their building projects. In such cases the approach is to develop structural systems and construction technologies which require a minimum of manpower and a short construction period. This objective is achieved by using sophisticated materials and advanced construction equipment.

Export of labour to oil-rich developing countries has caused a shortage of skilled labour in other developing countries. Labour in these countries is now not cheap when considered in terms of skills and output.

The success of labour intensive methods of construction also depends on the effective control over the labourers by experienced supervisory staff. Therefore, there is a need to develop improved construction management techniques taking in to account the local socio-economic and political conditions.

The shortage of skilled personnel cannot be solved in an overnight. Appropriate steps should be taken to establish technical institutions and training centres for producing qualified engineers, managers and other skilled personnel. The objectives of these institutions should be to teach the modern know-how of building design and construction and practical ways of adapting this know-how to suit local materials, tools and methods. Opportunities of continuing education should also be provided to the technical personnel working in developing countries to improve their knowledge.

6. SOCIO-ECONOMIC CONSTRAINTS

Building projects should be constructed at a cost society can afford. It may not be within the constraints of available resources to implement very spectacular, luxurious and expensive plans. The designs should, therefore, be simple and functional. Specifications and quality of workmanship should also be in keeping with the ultimate use of the projects.

Socio-economic constraints may include settlement patterns, family size and organization, educational levels, employment, distribution of wealth, cultural and religious practices. These constraints will influence planning and design of projects as well as methods of construction. For example, it may be considered appropriate to adopt labour intensive building techniques for a large project as such techniques will also provide a means of unemployment relief for the region. In rural areas it may be possible to develop appropriate construction techniques for dwellings and farm houses on a self-help basis. In these methods rural families construct their houses on a self-help or mutual aid basis with or without technical and financial support from government. Such schemes of rural development are already in operation in many countries.

Design of houses, schools and work spaces should take into consideration the local climatic conditions and sociological needs as most people cannot afford artificial heating/cooling arrangements and other services. Inadequate identification of these needs may lead to partial or total rejection of the constructed facility by the intended occupants. Most of the low cost housing techniques developed during the years do not provide adequate thermal comforts. The saving in cost has been permitted by reducing ceiling height and thickness of walls without paying much attention to the climatic conditions. In some new type of houses constructed in rural areas of Turkey (3) the bathroom and kitchen became useless as no running water was available. These services were ultimately converted into stores for crops because no provision existed in those dwellings for storing agricultural produce.

Maintenance also forms an important part of building construction. Only such structures, finishes, paints and fittings should be used which are in complete harmony with the social and economic characteristics and require a minimum maintenance. It has been observed that some times consultants specify expensive materials and fittings which are not locally available and replacements are difficult to obtain. The building therefore presents an ugly appearance due to broken fittings and worn out paints and finishes.

7. TIME RESTRICATIONS

Time factor assumes a great importance in modern construction industry. Worldwide inflation, increase in construction volume and energy crisis are some of the factors which impose time restrictions on building projects.

Lengthy delays in the completion of a project may affect its overall cost. These delays can be avoided if causes of difficulties are adequately identified and considered in design and construction. Each operation of design and construction should be carefully analysed and scheduled. Alternate solutions should be considered to determine the most efficient, economical and time saving procedures. Material and equipment delays should be avoided by advance procurements and expediting deliveries. These steps certainly call for a team work by the planner, architect, engineer and contractor.

Considerable savings in time can be obtained if drawings are available at the start of the project. Excavations can start even before the completion of drawings, provided the general layout and certain structural dimensions are known.

As mentioned earlier, alternate materials and methods can be used to reduce construction time. For example, in precast concrete construction the duration of production cycle can be reduced (and thus output increased) by using high alumina cement in place of portland cement or by using steam curing procedures for portland cement concrete.

Construction management techniques should be applied to minimize the risk of not completing a project within estimated cost and time. The critical path method may be used to plan, analyse and control a building project. Abnormal time limitations may require a project to be completed under a crash programme of construction (4). Crash programme may be implemented by increasing the rates of providing materials, increasing the labour force and/or increasing the construction equipment. This programme may also require the available labour to work overtime at premium wage rates. Therefore, crash programme may result in an increase in the overall cost of construction. An analysis by the critical path method can be carried out, using possible alternatives, to select the schedule which requires a minimum increase in the cost.

8. CONCLUSIONS

There are a number of environmental and infrastructural constraints which influence building design and construction in a developing region. These constraints may include availability of materials, equipment, transport and manpower, energy supplies, cultural and religious practices and time limitations.

Appropriate methods of design and construction should be developed in keeping with these constraints. Building projects must be correct in concept right from the feasibility studies to the ultimate use of the constructed facilities. These facilities must be socially and economically justified.

Due to the rapidly increasing oil prices, energy consumption in building construction has assumed a great importance in recent years. Studies in developed countries (5) indicate that structures in concrete consume the lowest energy when compared with similar structures in steel or brick. Such studies should also be carried out in developing regions on locally available materials and methods to find out appropriate construction technologies which require a minimum consumption of energy.

In the development of appropriate construction technologies success can be achieved if the environmental and infrastructural constraints are properly identified and the planners, architects, engineers, contractors and other technical personnel work as a team.

Management techniques must be applied for the proper planning of construction works in developing countries in order to obtain savings in cost and time.

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