Construction Technology

SUBIR K. SARKAR
Former Visiting Faculty
Department of Construction Engineering
Jadavpur University

SUBHAJIT SARASWATI
Professor
Department of Construction Engineering
Jadavpur University

OXFORD
UNIVERSITY PRESS

Contents

1
Fundamentals of Construction Technology

INTRODUCTION

Construction work at its rudimentary stage was based totally on manual efforts. The scenario is different now, and technology has changed it for the better. Construction work involves different activities carried out by diverse processes by skilled and unskilled workers, and needs to be completed within planned time schedule. To maintain such time schedule, construction processes need to be mechanized by deploying construction equipment capable of large production of satisfactory quality. Mechanized construction would require assignment of qualified and skilled workers for carrying out the planned production safely maintaining quality conforming to the specifications, standards, and codes. Not only that, the client should be satisfied with the quality of work produced. This chapter deals with the basics of the construction technology.

1.1 DEFINITIONS AND DISCUSSION

Technology is rapidly shaping and reshaping the world. What appears to be impossible today could be made possible by technology tomorrow. What is this technology that is causing such phenomenal changes and reshaping the world? The dictionary meaning of technology is "The practice, description, and terminology of any or all of the applied sciences which have practical value and/or industrial use" or "systematic application of knowledge to practical tasks in industry." Here knowledge means "ascertained and tested" knowledge.

Decades ago, the editors of a journal, Engineering News Record, asked 32 departmental heads of universities in the USA to define civil engineering. On the basis of the responses received, the editors defined civil engineering as follows:

"Engineering is the application of laws of science, mathematics and economics for the production of things. And civil engineering is the principal branch of engineering concerned with things constructed as opposed to things manufactured, mined, grown, or generated."

Prof. K. A. Padmanabhan of IIT, Kanpur mentioned in an article that "But science is preoccupied with understanding and explaining, while engineering is concerned with doing, realizing and implementing. Thus, the aim of future of engineering education

should be the integration of knowledge, skills, understanding and experience." He further added, "An engineering design integrates mathematics, basic sciences and complimentary studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative, open-ended process subject to constraints, which may be governed by standards or legislation to varying degree depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social or other pertinent factors. Thus, the neat and rigorous' solution obtainable in pure science is mostly unattainable in engineering."

Chancellor T. R. Anantharaman of Ashram Atmadeep, New Delhi clarified in an article that "However, there is a basic difference in approach since the technologist is concerned with the application of science to satisfy or fulfil one or more human or social needs or aspiration, while the scientist pursues knowledge for its own sake . . . The technology developed in a laboratory has to satisfy many special requirements and pass through one or more intermediate developmental stages before it enters the realm of engineering ... Scientists are concerned with concepts, theories, proofs and explanations, while technologists emphasize tangible processes, products and results. Engineers worry about designs, costs, productivity, regulatory decisions and patent protection ... To put in a nutshell, it can be said that the main base of science is original thinking; that of technology, innovative thinking; and that of engineering, practical thinking."

Construction is thus execution of mostly civil engineering work. And construction technology is application of applied sciences in order to enhance productivity and quality. Production evaluated in time scale is productivity.

The end product of construction engineering can be a completed building or a utility or an industry or an infrastructure – something useful and good for a country and its people.

1.2 CONSTRUCTION ACTIVITIES

Construction work comprises many construction activities performed by a few or a great many number of construction workers. Deployment of manpower can be reduced drastically by deploying construction equipment of high capacities. For that, the requirements are: (i) executing agencies must be familiar with the construction technology involved in the work to be implemented, (ii) whether construction equipment necessary for adopting the appropriate technology is/are available or not.

General construction work involves all civil engineering work starting from substructures to reinforced concrete and structural steel superstructures, highways including bridges, airports, silos, dams, etc. In some countries, superstructure frames of buildings are also made of timber. General construction work comprises the bulk of all construction activities.

Specialized construction work involves all mechanical and electrical erection work, sanitary and plumbing work, roofing/insulation work, and other similar work of

specialized nature. In rare occasions, specialized construction work may comprise bulk of the construction activities and general construction work may be of minor nature.

Auxiliary construction work involves preparatory and enabling work that would facilitate general and specialised construction work. Auxiliary work is meant to be of temporary nature. But if any auxiliary work is retained as a necessity, it should be deemed as a part of the general construction work. Sheet piles, for example, are not removed on many occasions after completion of construction work to ensure stability of what they are retaining in place.

Construction activities cannot be continued indefinitely. Therefore, all construction activities need to be planned sequentially and executed in minimum possible time. Men, machines and materials need to be mobilized for timely execution of all the construction work.

1.3 CONSTRUCTION PROCESSES

The nature of the construction activities involved, the place where construction work is to be carried out and the time available for construction work are the three factors that determine the effective construction process. The sequence of different activities depend on availability of vacant spaces that can be earmarked for allotment to different executing agencies to mobilize men, material and machine for timely implementation of contracted work. Each executing agency has to build its own infrastructures to produce planned output. The owners make provisions for basic facilities (water, communication, access to power, overall security, etc.) so as to enable the construction agencies to perform effectively and efficiently.

Construction process varies worldwide. In India, construction is a very labour intensive process, whereas, it is highly mechanized in western countries. Degree of mechanization, however, depends on the nature of construction work. As time schedule is becoming an important factor in completion of construction activities, the construction process is gradually being mechanized all over the world including India. Machines of very high capacity and output are now available. Nevertheless, construction process still involves a huge labour force in India even now because of availability of cheap labour of all categories.

Construction process can be simple as well as complicated. In a simple process, a worker can execute the entire work involved using a simple tool or machine, for instance, lifting materials onto a platform with the help of a mobile/stationary crane. Such lifting would be complicated if the lifting would depend on another simple process; for instance, lifting a truss connecting two columns. In such a case, more workers would be needed on the columns to place the truss at the precise level and position maintaining correct orientation. If the connection of the truss with the columns is taken up simultaneously, the process would become complex as the columns are to be stiffened laterally by connecting them with adjacent columns.

Executing agencies, in general, are well-experienced, and they decide the construction process according to their convenience, unless the owners have reasons to influence such decision because of unavoidable reasons.

1.4 CONSTRUCTION WORKERS

Human element is an important factor in construction activities. The progress of construction work conforming to the time schedule depends, to a large extent, on the quality and efficiency of workers deployed in actual execution.

The workers deployed at construction sites are generally classified into three categories—unskilled, semiskilled and skilled. They are deployed in different construction activities on the basis of their skill, efficiency, and experience. A worker endowed with only muscle power falls under unskilled category. A smart unskilled worker, who acquires skill after a long tenure at construction sites, falls under semiskilled category. A deserving semiskilled worker may be promoted to skilled category. A worker with appropriate education and training who is deployed in different trades such as welding, gas cutting, carpentry and other specialized work falls under skilled category. Highly skilled workers operate construction equipment at optimum efficiency. Semiskilled workers are often deployed as helpers of skilled workers.

There are many institutes in India where aspiring skilled workers can acquire both theoretical knowledge and practical training to qualify as skilled workers. These trained personnel would have to work at construction sites under strict supervision so as to perform satisfactorily. What they learn at the institutes would be the basis of their employment and assignment at construction sites, and how they actually perform during their assignment would be the basis of their continuity in service and promotion.

Training is important to ensure that the quality of work is maintained at satisfactory level. Construction workers are trained periodically to perform more efficiently. On-job training can be arranged on continuous basis. Apart from that, workers can also be trained at specialized training centres or educational institutions, wherever possible.

Qualified personnel deployed for supervision of construction have to ensure that construction work is carried out as per the drawings and specifications maintaining satisfactory workmanship. Visual supervision may not be good enough to approve executed work. Destructive and/or non-destructive tests are carried out to check quality and integrity of work. Thus the performance of workers would depend on the quality of supervision they would be working under.

Apart from aforementioned supervision, performance of workers would depend considerably on the appreciation of their efforts by the management in the form of remuneration and incentives. A happy worker definitely performs better than an unhappy one.

Agencies responsible for execution of work know the productivity of their workers. They work out the number of different categories of workers to be deployed trade-wise on the basis of quantum of work involved and the time allowed for execution. For occasional high volume work, manpower can be hired from outside.

1.5 CONSTRUCTION ESTIMATING

To turn a concept into a construction project, investment is to be made. For that, construction estimating is necessary.

In the initial stage, the owner has to be sure about the investment for which the potential cost is to be assessed. Subsequently, more reliable estimate is made on the basis of available information relating to the project. A Detailed Project Report (DPR) contains adequate information to initiate construction estimating. As a project of sizable investment involves work of all disciplines of engineering, the estimating process becomes complex.

In practice, the entire construction work is divided into several discipline-wise packages so that specialized executing agencies may be hired to complete their assigned work within scheduled time without incurring extra expenditure. However, construction estimating being a complex process, unforeseen extra work escalates cost as well as results in time overrun. For proper estimating, the scope of the work involved should be looked into keeping the following in view:

- Technology involved in the construction and installation activities
- Availability of the required materials and construction equipment for planned output
- Critical milestones in the construction schedule
- Manpower requirement for efficient implementation

It takes a lot to transform a design-on-paper into a functioning facility or an infrastructure or a utility or an industry. It involves utilization/consumption of multitude of resources of the following categories:

- Finance
- Materials
- Construction equipment
- Manpower
- Time

The process of cost estimating remains the same as before, but the tools used in the process have changed in recent times. The computer has become a great help for the personnel engaged in construction estimating.

Direct cost is related to the cost of installed equipment, materials and labour involved in actual or physical construction. Indirect cost is related to the costs that are required for the orderly completion of all the construction work.

1.6 CONSTRUCTION SCHEDULE

A project is an undertaking with a defined starting point and a defined completion point. A project has also defined objectives, and the project is regarded as complete only when the objectives are fulfilled. A series of tasks and activities in a project are to be completed with defined and limited resources. All these tasks and activities (distinct and identifiable operations within a project) are to be grouped into a number of

packages. Tasks and activities of different packages are inter-related, and they need to be accomplished in proper logical sequence within project completion schedule taking existing constraints and available resources into consideration. The construction schedule lists all the pertinent activities and indicates the duration of each activity sequentially. The total duration of the project should be equal to the sum of the duration of the individual activities in sequence. Each project is a unique undertaking as no two projects can be exactly similar. Scheduling of a construction project involves determining the time required for each activity within the overall time span of the project. Time span or duration of each activity is determined using the following equation:

$$t = \frac{t_0 + 4t_m + t_p}{6}$$

Where t_0 is the optimistic time, t_p is the pessimistic time, t_m is the most likely time, and t is the time to be used in construction schedule.

Once the activities in a package are determined, they must be arranged into an executing plan in the network logic diagram. Starting from the initial activity in a package, all the remaining activities in a package must fall into one of the three categories:

- Must precede the activity in question
- Must succeed the activity in question
- Can be performed concurrently with the activity in question

Each activity has an early start date and early finish date. Early start is possible only if all preceding activities are already over. The early finish date is the date arrived at by adding duration of an activity with the early start date. The late start date is the latest date by which an activity may be started without delaying the project. The late finish date is the date arrived at by adding duration of the activity with the late start date. Free float is the period by which an activity may be delayed without affecting the early start of the succeeding activity. Total float is the period by which an activity may be delayed from its early start without delaying the project completion date. Independent float is related to a particular activity considering the float between the late finish date of the preceding event and the early start of the succeeding event.

In construction schedule, duration of activities is represented in network form: PERT or CPM. PERT is the abbreviation of Programme Evaluation Review Technique. PERT is more suitable for projects wherein completion periods of various activities may vary considerably because of uncertainties as in research and development projects. CPM is the abbreviation of Critical Path Method and it is extensively used in construction project scheduling. A network diagram (Fig. 1.1) shows periods of different activities. As the activities are inter-related, periods of execution are shown logically and sequentially which ultimately end up as a network comprising lines, arrows, and nodes. Such a network would form a great number of paths leading to completion date. Each path should have key dates on achieving milestones. The paths, which do not have any

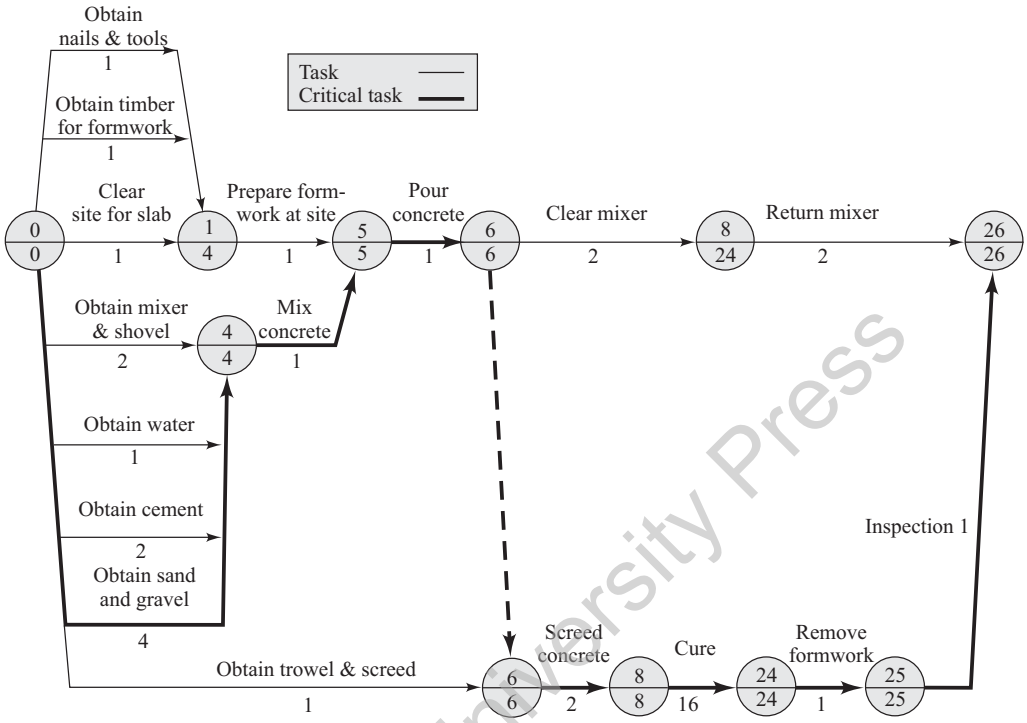

Fig. 1.1 Typical network diagram

float, are the critical paths and would require special attention so that the completion date does not slip. All activities in critical paths may be expedited by crashing, that is, by employing more resources such as men, materials, machines, money, and moments (overtime). Crashing is possible only at extra cost.

$$\text{Daily crashing cost} = \frac{\text{Cost increase due to crashing}}{\text{Time decrease due to crashing}} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$$

A realistic construction schedule, which is agreed upon by the owner and the executing agency, should be the yardstick for progress measurement. Such agreed construction schedule should not have any negative floats. In case the finish dates are delayed, possible measures to be taken are:

- Overlapping activities in critical paths, wherever possible, irrespective of preceding and succeeding activities
- Working overtime
- Mobilizing more resources by deploying more men and construction equipment
- Re-allocating resources from non-critical areas to critical areas.

Expediting action is to be taken only on the basis of project progress reports:

- Actual start dates of critical activities
- Remaining duration
- Quantum of balance work, percentage wise
- Projected completion dates on the basis of actual progress.

All participating executing agencies must submit periodical progress reports containing information on:

- Time overrun, if any
- Areas of concern
- Progress achieved in percentage
- Dates of key/milestone achievements
- Trend

In construction work, adverse weather and strikes are the two most common unforeseen constraints apart from cash crunch.

The CPM construction schedule fails to serve its purpose when the original schedule is not revised and updated to reflect the actual progress. Eventually, the construction schedule becomes invalid and is discarded. If the construction schedule is updated from time to time, it would be a useful and dynamic management tool. The reasons that call for revision of the CPM construction schedule are:

- Revision of project completion date if such revision is inevitable
- Changes in project plans, specifications, or site conditions
- Activity durations not equal to planned durations
- Construction delays due to weather, delayed delivery, subcontractors' lapses, labour problems, natural disasters, owners' indecision

BUILDING PROJECT WORK SCHEDULE

Task name	Duration in weeks
(1) Pile cap and beam	
Earthwork in excavation	7
Brickwork	4
Reinforcement	4
RCC M25	4
Earth/sand filling	2
(2) RCC M25 in superstructure	
RCC M25 up to El (+) 3.2	4
Ground floor slab	3
RCC M25 up to El (+) 6.5	4
RCC M25 up to El (+) 9.8	4
(3) Brickwork	
Brickwork in foundation	2
Brickwork in ground floor	3
Brickwork in superstructure up to El (+) 3.2	3

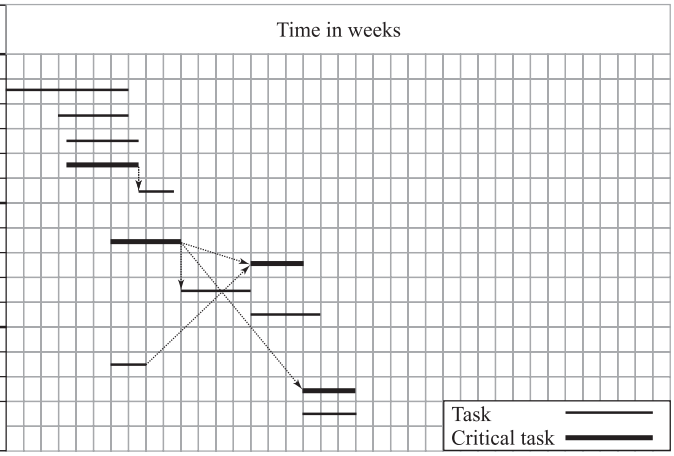

Fig. 1.2 Construction schedule in Gantt form

In practice, construction schedule is generally prepared package wise in bar-chart form. Arrows connect inter-related activities. Critical tasks are shown in thicker lines as shown in Fig. 1.2.

1.7 PRODUCTIVITY AND MECHANIZED CONSTRUCTION

The productivity of any construction equipment is a term that indicates how many units of output the equipment produces in an hour depending on the job conditions and management as well as the operator's skill, persistence and co-ordination with other construction forces.

Productivity signifies the rate at which things are produced. Technology, competitive design, external constraints, human elements, managerial efficiency; and most importantly, uninterrupted financing contribute to productivity. In simple terms, productivity refers to the ratio of output versus input (output/input). Output here has to be of specified quality produced within scheduled time. Input are the resources deployed for achieving the desired output.

Construction schedule shows the time allotted for each and every construction activity. For speedy execution of construction activities, larger targets are planned. Construction equipment of high capacity are mobilized and pressed into service to achieve such large targets consistently. In voluminous construction work where large targets are planned, the only factor that would necessitate the use of construction equipment is human fatigue. As humans get easily tired, deployment of construction equipment becomes necessary to leap ahead and achieve targeted output and maintain scheduled dates. Other problems concerning manual efforts are related to job dissatisfaction, militancy, and slackness. Deployment of construction equipment eliminates such uncertainties in production.

Mechanization means deployment of machines, or getting the work done by machines rather than human beings. Since lever, pulley, screw are all simple machines, a bit of mechanization would always be there. However, what we really mean by mechanization is the large-scale deployment of construction equipment to significantly increase the rate of output of construction activities.

1.8 CONSTRUCTION DOCUMENTS

Once a new undertaking is conceived, it is necessary to check its feasibility. Owners' engineers can do this. If owners' engineers do not have the necessary knowledge and experience, then specialists or consultants can do the job on their behalf. On approval of the *Feasibility Reports*, Project Reports are prepared. The Feasibility Report, depending on its contents, is sometimes called *Pre-feasibility Reports*. The Project Report, also depending on its scope and contents, is sometimes called Detailed Project Report. Thus the owners may have two, three or four reports to suit their requirement.

What is conceived (the ideas on paper) becomes a project when personnel are assigned and investment is made for implementation. The documents required by engineers for supervising the construction work are:

- Project reports/detailed project reports
- Contract documents
- Specifications
- Design and detailed drawings
- Erection manuals
- Relevant Indian and international standards
- Documents containing applicable statutory rules and regulations
- Quality assurance documents
- Safety system documents
- Copies of statutory rules and regulations

1.9 CONSTRUCTION RECORDS

On completion of project work, the owners must have the following records at the time of handover. Records are documents, which are to be preserved for future reference as evidence of conformance to the contractual provisions, specifications, codes and national/international standards. The records as mentioned below are documents, which cannot be revised or modified. A document, which is not a record, can be revised or modified if required. Records would be different depending on the nature of projects. Compared to an industrial project, a housing project generates very few records. A utility project like building a power station generates very many records vis-à-vis an industrial project. An infrastructure project like construction of highways stretching on shore and off shore may generate very many or few records depending on the route lengths.

- Updated contract documents
- Updated specifications
- Soil investigation reports/ground water data
- As-built drawings and sketches
- Updated erection manuals
- Updated operation and maintenance manuals
- Approved contractors' logs
- Procurement documents of bought-out items
- Material qualification records
- Skilled workers' qualification records
- Meteorological data
- Inspection and test records
- Quality system records
- Safety records including accident records, if any
- Statutory clearance records
- Commissioning check lists and protocols

- Performance test records
- Handing over protocols
- Storage and preservation records
- Equipment data
- Important correspondences

1.10 QUALITY

Quality should be the most important consideration in all construction activities. Reliability, durability, and safety of constructed work depend mostly on quality. Reliability is the probability that a product, system, or service will perform its intended function satisfactorily over a stipulated period of time under specified conditions.

According to traditional definition, "Quality is the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs."

Different authors have defined quality in different ways. Quality does not mean quality of the highest level, but it means a predictable degree of uniformity and reliability. The definition would be more meaningful if quality is defined in measurable terms. Thus, quality should mean conformance to drawings, specifications, codes and statutory regulations. Degree of such conformance could be measured, and it should be satisfactory to the owners/customers.

According to traditional definition, quality assurance (QA) is defined traditionally as 'all those planned and systematic actions necessary to provide adequate confidence that a structure, a system or a component will render or perform safe and trouble-free services and satisfy specified requirements.' QA is a management tool. The owners or their representatives are responsible for quality assurance.

Quality control (QC) is traditionally defined as 'Those QA actions required to keep control and regulate factors to attain predetermined qualitative characteristics related to materials, processes, and services.' Executing agencies use operational techniques and activities to fulfill the requirements for quality. As rectification of unsatisfactory work would escalate cost and delay the progress of construction activities, executing agencies need to pay utmost attention to quality control so as to avoid subsequent rectification/reworking. QC is a production tool.

The basic purpose of QA is not only to assure quality, but also to ensure continual improvement by rigorous control and training of personnel engaged in construction activities (vide Chapter 14).

Training programmes should be structured for different categories of employees to ensure that they are adequately qualified for the work they do. They must have appropriate education, experience, and training. A procedure is to be worked out to identify the training requirements and then regular training is to be arranged on-job, in-house or outside to inculcate a sense of excellence among the employees.

1.11 SAFETY

Risk is an inherent part of all construction activities. Risk is traditionally defined as 'a combination of probability of an abnormal event or failure and the consequence of that event or failure to a system's operators, users, or its environment.' Event is traditionally defined as "an internal or external occurrence involving equipment performance or human action that causes a system upset." Risk is likely to affect safety, health, and environment (vide Chapter 15).

Safety depends on human attitude. Construction activities expose both men and material to risks. Faulty attitude is inherent in inaction, lack of interest, worry, and impulsiveness. Faulty attitude may cause serious accidents. A judicious combination of application of behavioural science and appropriate technology is essential for preventing such accidents. Modern concept of safety relies more on involving construction workers directly in safety efforts apart from their adhering to prescriptive approach. If construction workers identify hazardous situation ahead and take necessary corrective action, probability of accidents at construction sites would be drastically reduced.

Safety is to be viewed not as add-on expenditure but as another consideration just like operability, security, maintainability etc. Personnel to be deployed to assure safety should be properly selected. They must ensure that workers are well-trained and not overworked.

Training is a mode of learning that changes behaviour and attitude. If attitude has a bearing on safety, then training is essential for correcting faulty attitude. Training also motivates the workers to excel in performance.

A number of agencies are involved in construction activities. These agencies must state their safety policies and adopt construction methods inline with their stated safety policies. Since these agencies execute inter-dependent activities, it would not be possible for any agency to formulate its safety policy independently. The owners or customers would have to conscientiously frame comprehensive safety policies and form Safety Committees at sites, thereby allowing all agencies to interact and resolve interdependent constraints. Overlapping of responsibilities should be avoided. The owners' representatives should head such safety committees. The safety status of work of all agencies is to be reviewed in periodic meetings and follow-up action is to be taken to resolve all kinds of problems and setbacks.

As accidents resulting from risks involved in construction activities may cause bodily injury/death, delay in project implementation as well as cost escalation, the onus of safe execution of construction activities rests with the owners/customers. Executing agencies would follow the lead taken by the owners on safety. The causes of accidents at construction sites are listed below:

- Fall from height—persons or materials
- Slip or fall at the same level
- Struck by falling, speeding, or moving objects
- Injury due to projected reinforcing steel bars

- Electric shock—contact with electric current
- Injury due to welding, loose scaffolding, machinery, tunnelling, poisonous gas, toxic material, impact noise and excavators
- Cave in
- Caught in or between objects or machinery
- Striking against objects
- Contact with high temperature
- Exposure to or contact with potentially harmful substances
- Environmental problems—noise, dust, radiation, toxic materials, heat and cold
- Drowning
- Fall into pits
- Overexertion

As risk cannot be totally eliminated, accidents may take place without warning. Both owners and executing agencies should, therefore, make provisions for first aid and subsequent medical treatment at sites or avail services of nearby hospitals/nursing homes for which ambulances should be available.

Post-accident investigation reports should be comprehensive so that preventive measures can be taken in subsequent construction activities. The present trend is to assure even off-the-job safety of all personnel involved in construction work.

1.12 CODES AND REGULATIONS

For design and construction of projects, conformance to various codes, regulations, statutes, laws, and guidelines is mandatory. The owners' or their consultant's engineers are required by law to carry out design work complying with the applicable laws and regulations, which vary from one jurisdiction to another. If relevant, sophisticated codes are not available under any jurisdiction, then recognized national or international codes should be followed. This should be agreed upon by all concerned at the onset of a project so that everyone understands the rules that would govern the design and construction.

SUMMARY

Project implementation involves multifarious activities that could be executed only by experienced and knowledgeable personnel following processes of diverse nature. Estimating, planning, mobilizing (men, material and plants) are essential preparatory work on which successful implementation could be based. However, actual execution would depend on various documents such as contracts, specifications, drawings, and standards. All these documents must be preserved as records for future reference. The execution processes could be hazardous, and accidents at construction site cannot be forecast. Therefore, safety deserves utmost attention. As for quality, it can be controlled progressively by carrying out destructive and non-destructive tests. The owner must feel assured that the project as a whole has been completed conforming to the contractual provisions on quality.

REVIEW QUESTIONS

1. How is technology related to science and engineering?
2. How would you differentiate between general, specialized, and auxiliary construction activities?
3. Why is construction process being increasingly mechanized in India?
4. Who could be designated as a skilled worker?
5. What has made project estimating much easier now?
6. How does crashing help in expediting all the activities in critical paths?
7. What does mechanization truly mean?
8. List the documents required for actual project implementation.
9. What is the difference between a record and a document?
10. List the documents the owners must have at the time of handover on completion of the project work.