

CONSTRUCTION ASPECTS OF CONTAINMENT STRUCTURES OF A TYPICAL LARGE ATOMIC POWER PROJECT

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ABSTRACT

The Containment Structure of a Reactor Building in a Nuclear Power Plant is a very important structure as it houses the main reactor. The containment system has to be designed and constructed to withstand high pressures and temperatures released during postulated accidents in case of any accidents and to act as a biological shield against leakage of radiation. Construction of the Containment structure, which is a safety-related structure, is a key activity in the overall project implementation of a Nuclear Power Project.

Typically in India, the containment system consists of a double containment structure with a part-spherical dome on top. Usually the inner containment is in prestressed concrete and the outer containment is in reinforced concrete. Special types of concrete such as High Performance Concrete with temperature control and Heavy Concrete are used in the construction. The need for accurately positioning many special embedded parts and through pipes at various locations poses a challenge.

The construction methodologies, techniques for prestressing, special formwork systems etc need special attention. Other techniques such as mechanisation, use of automated climbing formwork system, increase in height of concrete pours after mock-ups, use of threaded couplers for rebars, etc also merit attention.

The paper also discusses the various safety, quality and construction management systems used at site for better implementation of the projects.

Keywords: Nuclear Double Containment, Concrete Construction, Quality.

1. INTRODUCTION

Infrastructure is the backbone of the economy of any country. Apart from Power being an important component of the infrastructure, the extent of consumption of power is also an indicator of the development of the economy of a country. The demand for power in developing countries is growing steadily and many new power projects are under construction. Apart from the conventional sources of energy covering coal-based thermal power projects and gas-based combined cycle projects, there is a significant growth in recent times in Nuclear and Hydro Power projects and to a lesser extent in non-conventional power projects based on solar and wind power. Of these, Nuclear Power has a significant role for well-known reasons – having a compact source of energy, availability of abundant sources for the fuel, general independence of locational constraints for the projects, etc. Accordingly, in a developing country such as India, the installed capacity of Nuclear power projects is growing

continuously. The unit capacity of the nuclear power projects has also been increasing steadily over the years, from the initial 220 MW units to the present 1000 MW units.

However, nuclear power generation calls for special types of structures from functionality requirements as well as from requirements of a high degree of safety and their design as well as construction need special attention, compared to other routine structures. In the overall process of Project implementation, construction is a very important activity. Constructional aspects have a significant effect on the time period of construction, the quality of the structures including their durability, the safety levels and the overall cost. While the implementation of nuclear power projects used to take over seven to ten years in the past, the time period has now been considerably reduced to about five years in India, with significant advancements in construction engineering, project management and design techniques and on the basis of new initiatives from the Owner agency, Nuclear Power Corporation of India. It is heartening to note that in India recently a 540 MWe project has gone critical in less than 5 years from the first pour of concrete for the raft! In this article, the constructional aspects of the specialized structures for typical 540 MWe Nuclear Power projects in the Indian context are reviewed.

2. SOME SPECIAL ASPECTS OF STRUCTURES FOR NUCLEAR POWER GENERATION

The heart of a Nuclear Power project is the Calandria and it is housed in a Reactor Building typically with a double containment system. Hence the most significant structure for a nuclear power plant is the Reactor Containment Structure. The containment system has to withstand a high pressure (of the order of 1.44 kg/sqcm) during a postulated accident due to rupture of the main steam line. It also has to act as a biological shield during normal operations as well as in the case of the postulated worst accident - Loss Of Coolant Accident (LOCA) - conditions. The functional requirements of the containment structure can be summarised as: housing the reactor, the primary coolant and moderator systems and other systems connected with steam generation; providing adequate shielding to restrict the level of radiation at site within acceptable limits; and containing the radioactive release in the event of a postulated LOCA in the reactor.

For the sake of additional safety, the containment system is conceived as a double containment system and it is expected to satisfy the above requirements with the following specifications:

- a. Not more than 0.3% of enclosed volume should escape in one hour from the inner containment under the design pressure of 1.44 kg / sq. cm. gauge
- b. Not more than 0.3% of enclosed volume should escape in one hour from the volume contained between inner and outer containments under the pressure of 0.13 kg / sq.cm gauge.
- c. The containment has been given a safety classification of Class 2 and SSE category structure (Seismic Classification).

To ensure proper functioning, the containment is tested for leak tightness under pressures of 1.15 times the design pressure. Apart from the pressure and temperature criteria for design of the structures, the design for seismic effects is an important aspect in the engineering of the nuclear power projects and soil and foundation conditions are also considered to be important. Construction methodologies adopted have to ensure that the design objectives are fully met and that design assumptions are fully realised.

Traditionally, the inner containment wall of the double containment is a prestressed concrete structure and the outer containment is a reinforced concrete structure. In view of the circular-shaped wall and the curvilinear dome traditionally adopted, shell-type of structural behaviour is predominant. In view of the high magnitude of applicable forces and effects and to ensure a crack-free structure, there is a need for large prestressing forces and a large quantity of steel reinforcement has to be provided in the structures.

The tolerances for work performance are quite stringent. For instance, critical embedded parts have to be fabricated to a tolerance of 300 microns and placed within a tolerance of 0.5 mm. To achieve close tolerances for the embedded parts, special structural steel jigs and fixtures are often placed in the concrete. The embedded parts are given zinc silicate coating to prevent rusting during construction. Concrete surface finishing calls for a tolerance of 3 mm. Special F3 / U3 finishes are applied to the concrete surfaces. The construction joints require special treatment. A paint coating is also provided on the inner surfaces.

The reactor building base raft and the containment are designed using High Performance Concrete (M60) from the viewpoint of higher structural strengths and better functional performance. Heavy Concrete using Iron Ore aggregate is used for Calandria Vault and Fuelling Machine Vault for the purpose of radiation shielding. To minimize the thermal gradient effects the concrete is produced and placed at 19 deg C.

The structures have to be built to a high degree of quality control to ensure leak tightness under accident conditions. The functional requirements of the structures demand the incorporation of a large number of inserts or embedded parts. All these require a high degree of quality control and deployment of special construction practices to ensure that the desired results are achieved.



Fig.1- Typical Nuclear Power plant buildings



Fig.2 - Typical view of Turbine & Reactor buildings

To reduce the piping and cabling lengths as well as to reduce the maintenance efforts, the plant layouts are made very compact (Fig.1&2). Because of such layout and also due to the requirement of parallel working to save time, material handling for construction becomes very difficult. Very high safety and quality standards have to be maintained for the construction along with high standards for housekeeping also.

3. SALIENT FEATURES OF TYPICAL CONTAINMENT STRUCTURES

3.1 General structural details

The Double Containment System consists of an Inner Containment Wall with an internal diameter of 49.5m and an Outer Containment Wall with an outer diameter of 56 m, with an annular gap between the two walls of 1860 mm. Both the walls are connected to the base raft at about 15 m below ground level. The Inner Containment Wall continues for a height of 55 m. The Inner Containment is covered by an inner dome springing at its top. The Outer Containment wall continues upto the outer dome springing point. The outer dome crown is about 65 m above ground level. The containment walls are pierced by three large openings for the three air locks- Main, Emergency and Fuelling Machine with sizes ranging from 3m dia to 7.7 x 8.8 m. The airlock barrels are connected to the containment by leak-tight flexible joints. The reactor building is founded about 20 m below the ground level on very hard rock strata and also anchored down using ground anchors to provide additional safety during severe earthquakes.

3.2 Typical details of structures

3.2.1 Inner Containment

The prestressed primary containment, or the Inner Containment provides primary leak tightness. It has a cylindrical structure with an Inner Containment Wall (Fig.3) covered with a part-spherical shaped dome, the Inner Containment Dome. The Inner Containment Wall has a general thickness of 750 mm and is thickened locally around large openings for the air locks. Four vertical stressing ribs are provided on the outer side where total thickness is of the order of 1395mm. The Inner Containment Wall is monolithically connected to the base raft where it is thickened for a height of about 4.2m above top of raft to 1400 mm.



Fig.3- IC Wall Construction in progress



Fig.4 -Reactor building internals- structural steel framework

The Inner Dome is of prestressed concrete and the junction of Inner Containment Wall and Inner Dome is thickened to resist the thrust on wall from the dome as well as to accommodate the anchorages of prestressing cables of Dome and Inner Containment Wall. Two Circular openings of 4500 mm clear diameter in a direction normal to the dome are provided in the Dome to facilitate lowering of the Steam Generator subsequent to the construction of the Containment structure. The thickness of the dome is generally 650mm and thickened locally around the Steam Generator openings. Similarly, it is gradually thickened at springings of the dome to 1650 mm.

Structural steel columns and composite concrete slab floor systems are provided inside the containment to construct the various operating floors (Fig.4). The concrete quantity in the Outer Containment is about 17000 cum.

3.2.2 Outer Containment

The inner containment structure is fully enveloped by a RCC secondary containment called Outer Containment. The general thickness of Outer Containment Wall is 610 mm. The reinforced concrete Outer Containment Wall is monolithic with the base raft, where it is uniformly thickened to 1200 mm up to a height of 4.2m above top of base raft. It is thickened locally around major openings mainly to accommodate expansion joints with bellows. The Outer Dome over Outer Containment Wall is of reinforced concrete, forming a part of the Outer Containment. The wall and the dome are thickened at the junction. Prestressing ring cables are placed at this junction to counteract the thrust of the dome on the wall and thus eliminating a heavy ring beam. The outer dome too has two 5750mm dia circular openings concentric in plan with those in inner dome for erection of steam generators which will be closed by a hatch cover made of steel plates. Polyurethane foam is used as a lightweight material for waterproofing over the dome and also as an insulation layer. About 12000 cum of concrete is involved in the Outer Containment.

3.2.3 Raft

The containment structure is supported on a common foundation raft having a diameter of 62 m and thickness of 5.5m. The grade of concrete for the raft is M60. This raft is anchored to the rock below by means of 200 pre-

stressed rock anchors of 27K13 system. The total concrete quantity is 17000 cum, placed through a number of pours.

Due to limitation of earth fill involving long compaction / consolidation time periods and area constraints for movement of earthmoving machines, Sand-cement fill which could be pumped was adopted. This resulted in faster filling and could be pumped to locations where approach was a constraint.

To suit the site conditions, a boom placer was erected within the pour of the Reactor building raft by burying left- in stools (modified base) inside the raft. To facilitate cleaning of the areas high pressure pumps capable of developing 125 bars pressure and which were easy to handle on account of their lightweight were used.

3.3 Design principles for the containment system

The principle of Double Containment has been adopted for designing the containment structure for 540 MWe units. The details are as below:

a) Inner principal barrier of prestressed concrete remains free of cracks under design loads and renders the general concrete section leak-tight. It is covered with a surface coating for purposes of facilitation of decontamination, which further adds to the leak tightness of the surface.

Prestressed concrete has been chosen as the material for the principal barrier since for cylindrical and spherical shapes, the predominant state of stresses under LOCA is that of membrane stresses in tension which can be effectively and conveniently resisted by membrane stresses in compression induced by prestressing.

All concrete structures have a tendency to crack under action of internal forces due to shrinkage and creep. This tendency can be controlled by adopting prestressing. At an early age of concrete between 3 to 7 days after casting, a small amount of compressive force is introduced by prestressing the wall in the circumferential direction. The subsequent tensile stresses which may result in the structure from the restraint offered to shrinkage movements are lesser in magnitude than the initial compression and hence no net tensile stresses are allowed to be developed, thus avoiding any through cracking due to shrinkage effects.

b) An outer barrier in reinforced concrete encloses the volume of air between the inner and outer containment. This volume of air is not in direct communication with the outside atmosphere but communicates with it in a controlled manner, through a tall stack.

This building is designed and constructed to withstand seismic effects under Safe Shut-down Earthquake as well as Operating Basis Earthquake. These structures are expected to remain functional even in the event of a severe earthquake so that the system that is housed in these structures can be safely shut down during and after a seismic event.

4. CONSTRUCTION METHODOLOGIES AND RELATED ASPECTS

4.1 Concrete for the various structures

Generally concrete is produced in computer-controlled batching plants and transported to site using transit mixers. Concrete is placed in locations using tower cranes and concrete pumps with boom placers. The fast speed of construction is achieved in three ways - use of more machinery than for conventional construction, use of system form work and use of systems in construction. Faster concrete construction is facilitated by increasing the lift height of columns / walls to a height of 2.4m which also reduces the number of construction joints.

4.1.1 High Performance Concrete

The severity of applicable design effects calls for materials with high quality, high strength and high durability. The high strengths also result in lesser quantities of materials, which enables reduction of construction time period and cost. Accordingly High Performance Concrete (HPC) was selected. HPC distinguishes itself from

normal concrete mainly in the following properties: high compressive strength, high durability, high workability and reduced permeability. HPC is essentially ensured by adopting a proper mix design, use of carefully selected materials and special admixtures as well as good production techniques. Some of the special materials include micro silica for increased density and higher strength as well as high range super plasticizers for better workability and retardation. The water-cement ratio is generally kept in the order of 0.3. The structures are usually highly reinforced and due to the high degree of congestion, concrete of highly flowable consistency is used.

Trials are required in advance to ensure proper compatibility of the admixture with cement and micro silica. Dispersion of micro silica in HPC is very important and hence proper mixing is essential. A Pan type mixer is considered desirable for production of HPC, to attain an effective dispersion of micro silica. Specific mixing sequences are to be followed and increased mixing time is desirable. In the plastic stage the concrete is characterized by high flowability and stickiness. The set concrete exhibits the following special properties: minimum capillary pores with concomitant high impermeability to water and gases, reduced or little carbonation, better resistance to mechanical attack and high abrasion resistance and better resistance to freeze thaw cycles, alkali-aggregate reaction and sulphate attack.

In hot climates, high air temperatures coupled with higher wind velocities can result in fast shrinkage cracking for the rich mixes. Specific precautionary measures such as protecting the concrete by covering the surfaces, covering with wet burlap within two hours of placement, etc are followed.

Another requirement for the concrete is temperature control. To counter the increase in temperature due to rapid release of heat of hydration from the high cement content as well as to contain cracking due to temperature differential between the mass of concrete and the outside atmosphere, concrete is normally placed at temperatures below about 19 deg.C. This is achieved by the use of flaked ice and chilled water. Separate ice plant and water chiller plant are used. The transit mixers are provided with polyurethane foam insulation to reduce the temperature losses during transit. The pipes carrying concrete are also insulated and during concreting these pipelines are covered with wet burlap to avoid increase in temperature of the concrete. In summer weather conditions additional precautionary measures for hot weather concreting are adopted such as pre-cooling of the aggregates, choosing cooler periods of the day for concreting, shading the materials, etc.

Usually M60 concrete is designed with 475 kg cement per cum. To meet the need of low heat of hydration trials were conducted with lesser quantity of cement and M60 mix with 425 kg of cement was developed. Generally 43 grade cement is used to reduce the heat of hydration.

To facilitate curing of containment wall a peripheral curing pipe with perforations was installed on top of the wall.

The containment and the underground structures have to be highly water tight and airtight and the construction joints are vulnerable parts of the structure. Surface retarders are used for preparation of the construction joint by washing off / green cutting the surface after the final setting time using air and water jet. Water stops are also provided in the wall construction joints. 'V' grooves of 25 x 25 mm size provided in these construction joints are caulked with a polysulphide compound.

4.1.2 Heavy / Haematite Concrete

The functional performance of Nuclear Power Projects requires biological shielding to be provided and this is efficiently done using heavy concrete produced with high density aggregate, with an overall density of 4.4 t/cum. The concrete is produced using haematite aggregate and haematite sand in place of normal aggregate and sand.

Haematite boulders are obtained from special quarries and crushed and sieved at site to obtain aggregates of the required grading. The density of aggregate is around 4.65 T per cum. Placement of such concrete by the traditional methods (Crane-Bucket) is difficult and slower due to the high density of the concrete. Normally, the heavy concrete cannot be pumped and has to be placed by using other methods which are inherently slower than pumping. However, after sustained efforts and trials it was possible to pump the heavy concrete using standard concrete pumps. Use of special water retarding admixture and micro silica helped to produce a pumpable

concrete mix.. While such pumping saves time, it also causes very high wear and tear to the pump as well as to the pipe line and special precautions (such as higher wall thickness of first few pipes) are taken.

4.2 Form work systems

The use of system formwork permits the casting of larger elements in a single pour. Such formwork systems have a number of advantages: They are stiffer and stronger than conventional formwork, are amenable to systematic design, permit large number of repetitions, can be easily and speedily erected and dismantled by less skilled crews, etc. All this leads to overall economy and faster construction as well as high quality of construction. For instance, the L&T Doka system formwork permits the casting of columns and walls upto 7 m height in a single pour. Tremie pipes are used for placing of concrete by crane bucket and for pumped concrete an elephant trunk is used. Needle vibrators with extra long cables are used for effective vibration. While conventional methods of formwork for casting slabs demand provision of scaffolding or staging from the floor below, use of left-in, self-supporting steel formwork enables faster construction. While in the former case the floor below cannot be used for any other purpose as long as the staging is in place till completion of curing, the latter method helps in early release of the floor below for other activities.

For faster construction, the inner containment wall is constructed using automated self-climbing form work (Fig.5) with pour height of 3.5m. This system avoids the provision of staging from the ground level and shuttering for higher levels is supported on fixtures provided in the lower pours. Tower Cranes are used for lifting of the shutters, for handling the reinforcing bars and cables and for moving around the buckets for concreting. It is difficult to adopt slipforming for this wall as a large number of circumferential and vertical prestressing cables, many embedded parts and through penetrations have to be provided. The prestressing cables have to have deviations from regular geometries wherever they clash with embedded parts or penetrations. The embedded parts have to be placed with a very high degree of accuracy. However, slipforming is adopted for the construction of ventilation stacks which are usually of a height of the order of 100 m or for tall water tank towers in the project. The Outer Containment wall is also constructed with pour heights of 3.5m.



Fig.5 - IC wall - Automated self- climbing formwork system



Fig.6- Construction equipment in use

4.3 Special equipment used

To improve the quality of construction and to reduce the time of construction mechanisation (Fig.6) is resorted to. Due to the compact layout of the plant, higher capacity Tower Cranes are deployed for material handling. Batching plants are housed a little away from the main plant to provide clean conditions. For fast track construction, concrete production is carried out using large size computer-controlled batching plants which provide large volumes of concrete in short time periods with a very high degree of quality control. These batching plants permit a high degree of consistency in the required quality and permit fast changes in design mixes required for various applications within the project. High capacity stone crushers are specially provided for the Project to ensure speedy and economical production of the various sizes of aggregates required in large quantity and to proper quality. Concrete is transported to the pour location in Transit Mixers of large capacity.

The final placing of concrete is generally carried out by using Tower Cranes and concrete buckets or by using concrete pumps. Conveyor Belts are also used in some cases. Boom placers are used for pouring concrete in interior locations well away from the location of the concrete pump as well as for location with inconvenient access. Vibration is carried out using immersion vibrators as well as form vibrators. The requirements for heavy concrete and temperature-controlled concrete place considerable constraints on the manufacture, transportation and placement of concrete and appropriate methods of construction have to be employed. Specially modified mixers and pumps, ice plants and chillers are some of the equipment thus required. Diesel-based generator sets are also provided to provide power in case of power failure.

Due to the compact plant layout the transit cars and mobile placers may not be able to reach nearer to the placement area and stationary boom placers are used in such cases to place the concrete. These placer booms are installed on the structure with the help of a tower crane and moved from place to place whenever required. For concreting of the containment dome two stationary boom placers were placed on a structural platform at a height of 50m above ground. Tower Cranes are used for shifting prefabricated reinforcement cages and shuttering panels of larger size to the actual locations.

Surface grinders / sanders were used instead of chipping of concrete by machine grinding, thereby reducing the time for finishing of concrete surfaces, especially at the joints.

4.4 Prestressing

Prestressing using high tensile steel cables is adopted in the inner containment structure to ensure the integrity of the containment so that micro cracks do not develop even during accidents. Circumferential cables are provided in the containment wall along with vertical cables stretching between the stressing gallery located in the base raft and the ring beam located at the junction with the dome. The dome is prestressed with cables aligned in three directions. The dome for the containment is cast on formwork supported by a framework in structural steel. The framework consists of a number of radial trusses with circumferential stiffener members. The framework is supported on a number of brackets fixed to the containment wall. The formwork supporting structure is first assembled on the ground to avoid any mis-match and the erection inside the reactor building is carried out later in segments (Fig.7). After erection of the formwork supporting structures, formwork and rebar are laid in place (Fig.8).



Fig.7 Erection of dome formwork supporting structure



Fig.8 Dome formwork fixing

Rock anchors are provided for anchoring the base raft to the rock below, to provide for safe performance during high seismic activity. The foundation raft also has a stressing gallery within to facilitate the stressing of the vertical and dome cables.

The inner containment is prestressed by using 19K13 system (355 T UTS) with 80 mm ID ducts. These cables are made up of 12.7mm nominal diameter high strength low relaxation strands conforming to IS: 14268 with a total tonnage of 2000 MT. Inner Containment Wall is prestressed by horizontal ring cables, each ring consisting of two semi-circular cables anchored in pair of diametrically opposite stressing ribs with a small overlap. The second pair of stressing ribs is offset by 90 degrees in plan from the first pair and holds alternate rings. 178 horizontal cables and 178 vertical cables in the wall and 182 cables in the dome are provided.



Fig.9- Layout of prestressing cables in dome



Fig.10- Typical view of completed containment structures

In the wall, the vertical cables are spaced alternatively at inner and outer face of the wall. Some of these cables are anchored at top of the thickening at junction with inner dome at one end and in the soffit of the stressing gallery at the other end, which is accessible from the annular spaces between Inner Containment Wall and Outer Containment Walls at their lower end and communicating with the enclosed volume. The remaining cables are taken throughout the dome forming inverted “J” shaped and anchored near springing of the dome at other side.

The inner dome is prestressed by orthogonally placed cables in two layers (Fig.9). There are circumferential cables in the thickened portion provided at the junction of Inner Containment Wall and inner dome.

Conventional J-600 grouting pumps were unable to pump the grout to distant locations and high capacity mud pumps facilitated successful pumping of grout in prestressing cable ducts from a centralised location. To avoid frequent handling of the power pack of the prestressing jacks, long hydraulic hoses were used. This enabled more stressing operations to be carried out from the same location of the power pack.

4.5 Steel Reinforcement

Mechanical splicing is a time consuming activity and difficult to be adopted on vertical reinforcing bars. Threaded couplers are a better alternative for mechanical splicing of larger diameter rebars. The joint consists of a threaded sleeve made of special steel. The bar ends are forged and then threaded to ensure no reduction in cross section of rebar due to threading. Threading is done in specially designed machines. Use of above techniques not only reduces congestion but also helps in reducing the length of projection of bars beyond the construction joints. Threaded Couplers are also provided on the face of construction joints to permit the use of full form work panels without cuts to permit the penetration of rebars for lapping. These couplers are duly tested before use and some samples of the joints are also tested, to ensure that the failure strength of the joint is higher than the strength of the parent material.

Large diameter bars (45 mm dia.) required to be used in zones of high stresses pose problems for lapping which would result in a high degree of congestion. Hence splicing full penetration butt welding is done for joining rebars. Welding is also found to be cost effective for the large diameter bars. Special care is taken during the welding and the weld samples are tested regularly and the welding is carried out under very close supervision. Low hydrogen electrodes are deployed for welding and the welded joints are also thoroughly tested.

The lengths of jointed rebars used for Reactor Building raft and dome were to the tune of 40 mtr. To facilitate handling of these long rebars by the Tower Crane, a lightweight pipe truss serving as a strong back was used. Fe 415 class of rebars with TMT process for corrosion prevention are used.

5. VARIOUS CONSTRUCTION SYSTEMS ADOPTED

Fast track construction with high quality and safety is ensured by adopting a number of systems, as explained below.

5.1 Construction and Project Management Systems

Planning is the first step in Construction and the development of detailed Method Statements ensures that the objectives for the construction of any structural component are properly brought out, the construction methods are well studied and developed and resources required are identified. The site Planning Engineer and the Construction Methods Planning Cell are important cornerstones of systematic construction. The Management Planning and Control System adopted for project management supplemented by Management Information System documentation ensures that overall progress is well monitored, required inputs are made available well in time and that overall cost economy is maintained with adequate momentum of implementation.

To ensure that the planned construction time schedule is really achieved, a high quality and time-tested Management Planning and Control System is used by the construction agency. The back bone of this system is the project schedule or the master network from which targets are derived for each month, week and day. Milestone events are identified and tracked. Activities are prioritised based on the critical path. Periodic progress reviews are held. All vendors and sub-contractors are closely monitored. Re-scheduling and catch-up plans are worked out to ensure planned progress. Sophisticated software such as MS Projects is used for planning and monitoring the construction. A separate project management cell is created at site to ensure proper project management. Monitoring is also carried out from the regional office and head office of the construction agency routinely to ensure that objectives are met all the time with respect to quality, speed and economy of construction.

5.2 Quality Management System

Nuclear Power Plants require a very high degree of Quality Assurance and Quality Control. In earlier systems there used to be multiple levels of Quality Control with the construction agency carrying out its own checks and the client carrying out independent series of checks. This was time consuming and used to result in duplication of work. The current system places the onus of quality on the construction agency with Quality Surveillance / Audits being performed by the client. This system results in much better efficiency and effectiveness.

The Project Quality Plan Is prepared in line with ISO-9000 requirements to implement, monitor and maintain the Quality System during construction. Work procedures and QA plans are prepared for each activity and the activities executed accordingly. A separate QA / QC set-up, independent of the routine construction set up, is maintained to ensure independent checks for the quality. Many awareness programmes are conducted for all staff and workmen. Periodic training is imparted to workmen in their respective trade and they are qualified based on their performance. Work instructions are given to the workmen in the local languages. Vendors are evaluated and qualified before orders are placed on them for materials. All materials are checked, inspected and tested-often in the manufacturing locations themselves to save time and to avoid undesirable materials from entering the site of construction- before incorporation in the works. All materials were tracked from the raw materials stage to the final product stage. For each grade of concrete, comprehensive mix designs are established. Concrete is monitored before and during production stage as well as at the time of pouring and post-curing.

Mock-ups are carried out for all special/ critical activities to spot potential problems and to evolve procedures for tackling the same. Mock-ups are also carried out to address issues of congestion related to placement of reinforcement and prestressing cables. Study of threading and grouting of prestressing cables in zones of

congestion is also carried out. Actual frictional losses during prestressing are established by carrying out site testing using actual materials employed in the construction. For each activity stage-wise inspection is carried out to reduce re-work and to increase productivity. To ensure good quality, each concrete pour is cleared for placement only after thorough inspection of all embedded parts, rebars and form work. For all welding only prequalified welders are employed. Non-destructive and destructive tests such as dye penetration, radiography and mechanical testing are conducted on the weld joints. Regular auditing is carried out to check the effectiveness of the quality systems. Wherever non-conformity is foreseen, immediate correction and preventive actions are taken up. Regular Management reviews are held and Quality Rating system is followed.

5.3 Safety Management System

Safety during construction is given utmost importance in the Nuclear Power Projects, particularly in view of the compact layout of the facility and parallel working in a number of fronts to save time. To ensure safety, a well-established safety system is adopted and safety systems are integrated right from the planning stage. Prior to commencement of the work a Site Safety Plan is prepared. Monthly safety plans, Job Safety Analysis, Safety procedures pertaining to critical activities etc. are prepared during construction and informed to all concerned. A well-equipped safety training center is set up for training of workmen. Screening of workmen is done before induction into the job. Working pass is given to workmen only after induction training followed by a medical test. Apart from the initial training, periodic training is imparted during the course of the project. Height pass is issued to workmen who have to work at heights only after they are found fit after a height permit test.

Personal Protective Equipment such as helmets, shoes, goggles, safety belts, etc are provided to all involved in the performance and supervision of construction. Special emphasis is given to working at height by providing double lanyard safety belt and fall arrester, as well as static lines for clipping on safety belts. Smoking and use of tobacco are banned at site. Daily pep talks, warm-up exercise, safety drills and safety circles are conducted. Identification of a worker by trade is done by providing coloured helmet, stickers on the helmet and jackets. For specialized work boiler suit and uniform are provided to staff and workmen.

Automated housekeeping has been introduced i.e. whenever a workman comes out of his workplace, he brings out some scrap / waste / unrequired material and dumps the same at the designated place and in the process the working place gets cleaned systematically.

Motivation programmes such as safety presentations, rewarding a safe working practice, distribution of Safety Awards, Safety competitions and quizzes, etc. are regularly conducted. A separate and independent safety team is incorporated in the site organization to ensure the implementation of the safety systems. Safety Committees are constituted and regular meetings are held to discuss and implement practices for improving safety.

In India Atomic Energy Regulatory Board (AERB) is the agency which reviews all safety and quality related issues connected with the engineering and construction of nuclear power projects and it works closely with NPCIL to ensure safe construction of such projects.

6. CONCLUSION

Construction is a very important stage in the course of realization of large infrastructure projects and as much care has to be devoted to this stage as to the Planning and Engineering stages. A well executed construction project has a number of concomitant benefits such as earlier availability of projects benefits, reduced cost of the project, lower Interest During Construction, better quality, increased durability and longevity and overall satisfaction for all the stake-holders. The relevance of nuclear power projects today has considerably increased with reduction in construction time period and cost. Such requirements for reduction in construction time period again call for specialized and systematic construction methods and project management techniques. Modern construction envisages well co-ordinated work covering a large number of sophisticated plant and machinery, well experienced and expert planning and construction personnel, efficient computer based project management techniques, innovative construction methods and advanced materials of construction.

A typical 2 x 540 MW nuclear power project (Fig.10) would require approximately 3,30,000 cu.m of concrete, 70,000 t of reinforcing bars and 2300 t of prestressing steel. Recently the first 540 MWe unit of a nuclear power

project was commissioned within five years of the first concrete pour. The Containment structure passed the leak tightness test in the very first attempt, attesting to the high quality of construction. It also won an award from Indian Concrete Institute. The owner agency, Nuclear Power Corporation of India Limited, has done a highly commendable job in master-minding the whole programme, in carrying out good planning, motivating all the agencies involved and carrying out excellent project management. Such successes augur well for the rapid development of nuclear power in the country.

REFERENCES

1. N.Raghavan, (2003), Construction of special structures for Nuclear Power Projects, Journal of Structural Engineering, Vol.30, No.1, April-June, No.30-8, pp-51-56.
2. H.T.Jagadish, (1998), The making of Kaiga: The Inner Containment Dome, Nu-Power, Vol 12, No2.
3. Amit Mittal, (1998), Construction of prestressed concrete dome using high performance concrete, The Indian Concrete Journal, July 1998, pp-342-348.