CIVIL STRUCTURES FOR BACK-END FUEL CYCLE FACILITIES

Design, Construction and Ageing Management

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ABSTRACT

Nuclear Recycle Group deals with back-end activities of the Nuclear Fuel Cycle aiming at recovery of useful materials by reprocessing of spent fuel and management of radioactive waste generated. Safe operation of these activities requires well designed structures, systems and components to ensure shielding, containment, strength, functionality, and longer service life. Various facilities are operational and are also under planning and construction for carrying the activities related to spent fuel reprocessing, extraction of useful radioisotopes for societal benefits and finally storing/disposing of the processed radioactive waste as per regulatory guidelines. Upkeep of old plants and buildings by assessing their condition periodically and health restoration by undertaking structural repair is also an important activity. This article presents an overview of various aspects of design, construction as well as ageing management of such facilities.

KEYWORDS: Reinforced cement concrete, Radiation shielding, Structural analysis, Condition assessment, NDT techniques, Structural repair, Structural health restoration.

A NUCLEAR facility involves engineering structures, systems and components (SSCs) which collectively ensure its safe and reliable operation. Civil structures play an important role in safety performance of these facilities. Nuclear Recycle Group (NRG), Trombay is entrusted with the responsibility of the back end fuel cycle activities which are of utmost importance under the three stage Indian nuclear power programme. Civil structures in NRG comprise fuel reprocessing facilities, High Level Waste (HLW) immobilization plant, HLW transfer ducts/trench, Low-level Liquid Waste (LLW) treatment & discharge facilities, solid waste storage and Near Surface Disposal Facilities (NSDF). Civil structures for these facilities have been designed and constructed to fulfill the requirements of shielding, containment, strength, functionality and longer service life.

Design of Structures

There are features which are unique to NRG facilities, e.g., irregular shape of civil structures which may require an in-depth study of torsional effects, high degree of confinement, provision of multiple barriers to contain radioactivity, shielding considerations resulting in heavy structures, associated corrosion, ageing problems under toxic and radiation environments, associated chemical and fire hazards and importance of long-term structural integrity[1].

"Defense-in-depth" approach is being adopted in design of the structures to prevent significant failures which could release activity in the environment. This can be achieved by:

i. Robust design and high quality in construction to prevent failures in normal and abnormal events

ii. Multiple engineered barriers

iii. Provision of protection which prevent the breach of any barrier or mitigate the consequences of the breach

Siting is an important aspect of safety which has significant impact on design of structures and has implications of safety with respect to mitigation of consequence of any breach. A suitable site limits the stringent design requirements, release of radioactivity to environment and limits the radiological consequences for the public in accidental scenarios including conditions that may lead to mitigatory actions being taken[2].

Function of multiple engineered barriers is to prevent activity migration and to design such containment, structure that shall perform up to desired strength and serviceability during normal and abnormal events (external events of earthquake, wind and flood). Serviceability criteria of design, limits the excessive deflections and crack-width in RCC members, to ensure prevention of breach of containment and functionality.

For a robust design and to prevent failure in normal and abnormal events, evaluation of external events (EE) exceedance frequency is of prime importance. Considering the hazard potential, a "graded approach" has been adopted for EE categorization of these facilities. The aim of such approach is that, a simplified seismic methodology and optimized return periods of external events could be used for facilities with low inventory or with lower unmitigated hazard consequences. This approach results in radiological hazard criteria categorizing facilities based on their hazard levels as presented in Table 1.

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Table 1: Mean annual frequency of major natural events for different hazard categories of nuclear Facilities (Graded according to hazard potential) [3].

Category	General Characteristics	Mean Annual Frequency of Exceedance		
		Earthquake Ground Motion	Flood/ Rain	Wind
I	Potential for off-site radiological impact	SSE:~1E -4 OBE(NPPs): 1E-2	1E -4	1E-4
II	Potential for on-site radiological impact	4E-4	1E -3	2E-3
III(a)	Potential for radiological impact within plant boundary	DBE using IS-1893(Part-4) with I=1.5 and R'=0.67 x Response reduction factor defined in IS:1893 for structure without any special provision for seismic resistance	1E-2	1E-2
III(b)	Potential for radiological impact within plant boundary and off-site chemical Hazard	MCE using IS-1893(Part-4) with I=1.5 and R'=0.67 x Response reduction factor defined in IS:1893 for structure without any special provision for seismic resistance	1E-2	1E-2
General	Conventional or industrial buildings	DBE using IS-1893(Part-4) with I=1.0 and R'=0.67 x Response reduction factor defined in IS:1893 for structure without any special provision for seismic resistance	1E -2	1E-2

Back-end fuel cycle facilities fall in category-II, III considering "onsite" and "with in plant boundary" radiological hazards. Analysis and design of structures for nuclear facilities are governed by AERB codes and standards[4,5] for category I & II structures. For hazard category-III, facilities are designed according to Indian standards[6,7].

The building structure comprising of beams, columns, walls and slabs along with the foundation is modelled as finite elements (FE) such as beam and shell elements. Soil is modelled as spring elements and subsequently structural FE analysis is performed considering soil structure interaction (SSI) for static and dynamic loads. Static analysis is carried out for self-weight, equipment loads, live loads, thermal loads, earth pressure, wind loads etc. and dynamic analysis is performed for seismic loads. Response of soil-structure system is evaluated in terms of deflections, forces, moments, bearing pressure below foundation and foundation uplift.

Design is carried out for worst combinations of these loads to satisfy strength, serviceability and stability criteria as per governing codes and standards.

Construction

Nuclear safety related structures require some special features during construction. Mass concreting is involved wherever shielding requirement using concrete is to be provided. Mass concreting work necessitates (i) providing adequate reinforcement for the stresses induced in the concrete due to heat of hydration, (ii) designing the concrete mix by using suitable pozzolanic ingredient and ice flakes to limit the temperature of concrete (iii) sequencing of the concrete pours to facilitate dissipation of heat and to avoid cold joints (iv) adequate design of shuttering/scaffolding to bear the wet concrete load.

Radiation streaming and leak tightness is another aspect that needs to be taken care of during the execution stage. This involves (i) leak tight joint formation at the interface of any two structures (ii) prevention of cold joint formation during concrete pouring, (iii) providing leak tight construction joint by using bonding agent, water bar etc., (iv) tie rod provision in the shuttering should be made with proper precautions so as not to create any direct path for radiation streaming afterwards, and (v) ensuring leak tightness of the structure/joints by either hydro testing or smoke test.

Industrial safety and quality are maintained at the site with due diligence. Additionally, handling contaminated soil, construction debris and work in areas having radiation field are carried out with strict adherence to radiation protections rules and regulations.

Some of the major civil construction works by NRG Projects at BARC Trombay are described below:

Above Ground RCC HLW Transfer Duct: An above ground duct as shown in Fig.1 has been constructed for transferring high level radioactive waste between AWTF & WIP Pump-house. It has been designed for earthquake load as well as thermal load imposed due to the environmental conditions.

Special Pot type PTFE bearings have been provided between the RCC duct and columns supporting the duct to allow longitudinal movement of the duct due to thermal expansion.

Fig.1: Above ground RCC HLW Transfer Duct from AWTF to WIP Pump House.

RCC Dyke for Disposing Solid Waste: An RCC dyke shown in Fig.2 has been constructed at RSMS, Trombay encircling the old used earthen trenches leading to effective utilisation of NSDF land. It is having an area of 60m x 60m, height of 3.5m and it is adequate for 6-7 years of disposal needs. This dyke has facilitated disposal of odd shaped and big sized consignments as well.

Fig.2: RCC dyke at RSMS Trombay.

Multitier Reinforced Concrete Disposal Module (MRDM): This is 22.6m x 17.5m x 8m deep (5m underground) RCC structure shown in Fig.3 constructed at RSMS, Trombay. The design of this MRDM is first of its kind over the conventional design followed so far and has enhanced land utilisation factor from 1.9 cum/sqm to 5 cum/sqm. This is a nuclear safety related structure, designed for seismic loads and uncracked section to have leak tightness during its service time. Water fill test has been carried out to ensure leak tightness. One unit of MRDM will serve for solid waste disposal needs for about 7 years.

Fig.3: Multitier Reinforced Concrete Disposal Module at RSMS, Trombay.

Tile Holes (TH): Tile Holes are special type of modules which are used in NSDF for disposal of higher surface dose rate (>50R/hr) solid waste. Tile holes are wire wrapped MS cylindrical units coated with 25mm thick cement mortar on outside as well as inside surface to protect it from corrosion. These units are installed in RCC vault with waterproofing on external surface of THs and vault.

Recently a TH battery comprising of 80 Nos. of TH of 710mm ID and 14 Nos. of THs of 950 mm ID has been constructed in RSMS and is shown in Fig.4.

Fig.4: Tile Hole Battery at RSMS, Trombay.

Low Level Liquid Waste (LLW) Transfer Line: Low-level Liquid Waste transfer pipelines (150 mm NB, carbon steel) from Reprocessing Plant to Effluent Treatment Plant (ETP) have been laid along the Security Road of BARC covering a total distance of 2.7km connecting various facilities en-route. All pipelines are covered by RCC precast half round cover (shroud) on top and precast slabs from bottom. These shrouds, bottom precast slabs and waste transfer pipelines are supported on RCC pedestals having 3-meter c/c spacing. These pipelines crossed difficult terrain and are laid underground at various locations, while at few other locations, they have been bridged over drains and nallahs.

Ageing Management

Condition Assessment: Assessment of the structural condition and necessary rectifications/retrofitting of the existing old RCC structures of NRG was carried out as a part of ageing management. Various standard Non-Destructive Techniques (NDT) have been utilised without affecting the safety and functionality of these structures. The NDT methods employed for condition assessment are visual inspection[8], Rebound Hammer Test[9], Ultrasonic Pulse Velocity Test[10], Half Cell Potential Test/Corrosion probability test[11], Core Extraction and Testing[12], Chemical analysis of concrete dust samples for Chloride and sulphate content determination, carbonation depth test, Concrete Cover test and Resistivity test. Various structures such as Stack, water tank, LLW tanks, chimney foundations, Material Handling Equipment (MHE) support structures, Office buildings etc. have been condition assessed as shown in Fig.5.

Rebound Hammer Test — *Corrosion Probability Test at Chimney foundation* — *Electrical resistivity test*

Ultrasonic Pulse Velocity test — *Collection of concrete dust samples for chemical tests* — *NDT & Repair of 135m high RCC chimney*

Fig.5: NDTs of different structures in NRG facilities.

Structure Health Restoration: Based on the findings of condition assessment, structural health restoration carried out is briefly described below:

i. 135 m High Stack: The 135 m stack of FRD plant was nearly 50 years old at the time of its restoration. The structure was showing signs of distress due to ageing as shown in Fig.6(a). To carry out the condition assessment and repair of 135m high stack, special scaffolding erection and its dismantling arrangements were made. The scaffolding design was carried out and vetted by the experts in the field. Structural repair was carried out using special repair mortar, replenishing exposed/corroded reinforcements, injecting low viscous grout for repairing cracks in concrete and finally an UV resistant anti-carbonation coating was applied on the complete outer stack surface. Personnel qualified with rigorous health checks ascertaining their capability for working at higher elevations were only deployed for carrying out this work. The restoration work was accomplished successfully without any safety related incidence.

ii. Underground Water Tank: This is a circular tank with annular partition having a tank inside tank (12m Ø internal tank and 18m Ø outer tank) having two openings of 600mm Ø in each tank. Spalling concrete and exposed reinforcement were observed during its condition assessment as shown in Fig.6(b). Outer tank repair in restricted annular space of 3m width with humid environment inside resulted in tough working conditions. Continuous seepage of groundwater from the walls and floor of the tank necessitated grouting the cracks in the wall with polyurethane for ensuring leak tightness of the

Fig.6: (a) 135m high stack. (b) Underground water tank. (c) LLW Tanks.

structure during repair work. Micro-concrete was used for filling the pits in the concrete slab. Crystalline coating was applied on the inner surface of the tank to increase its leak tightness. Finishing coat of food grade epoxy coating was provided on the inner surfaces as this tank stores potable water. The tank was repaired successfully and is functional now.

iii. LLW Tanks: MS lined RCC underground LLW treatment tanks at ETP are more than 60 years old. Condition assessment of 02 Nos. of LLW tanks revealed that these structures are in distressed condition. These structures have been restored by removing MS lining, structural repairs, grouting and increasing RCC wall & raft thickness by providing layer of RCC as shown in Fig.6c. New and old RCC members were connected by using shear connectors. SS lining has been provided on internal surface of the tanks. With this restoration, the tank life has been enhanced for uninterrupted operations of the LLW treatment.

Conclusions

Back-end fuel cycle civil structures assure safe environment to all the systems, equipment, components during their service life. To achieve such level of safety assurance, systematic & methodical approach during all the stages i.e. design, construction, periodic condition assessment and remedial measures are exercised. To ensure the performance of the structure up to expected level of strength and serviceability during normal and abnormal events, severest of all the load combinations of operational loads, wind loads, seismic loads, thermal effects and structure specific internal environmental exposure and shielding requirements are considered. During construction stage, rigorous quality assurance followed to ensure that the structure satisfy design intents. Under aging management, condition assessment & restoration is practiced for existing civil structures to ensure safe and continued operation of the facilities. Satisfactory performance of the newly designed and constructed structures as well as old structures of NRG strengthens this approach and drives towards continuous upgradation of latest know how and technologies in the field of civil engineering.

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