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# DESIGN AND CONSTRUCTION OF RCC WATER RETAINING STRUCTURES

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## INTRODUCTION

Application of reinforced concrete as a structural material has been with us since the beginning of this century, and we as engineers have made rapid strides since then in its application for various types of civil engineering work. But its successful application for the construction of liquid retaining structure took slightly a longer period in view of the problems attached to water-tightness and bursting action of the liquid they contain. One of the early codes of practice for liquid retaining structures was prepared by the Institution of Civil Engineers, London, in 1938. The Indian Code IS:3370 for the storage of liquids was published in 1966, with slight modifications to the British Code CP 2007, to suit the local construction ractices, materials and climatic conditions. This lecture deals mainly on reinforced concrete water retaining structures with relevance to the Indian Code.

## SCOPE

The Code is generally applicable to the storage of aqueous liquids and solutions which have little or no detrimental effect on concrete and steel, and for liquids at ambient temperatures. However, for other structures for conveyance of liquids general provisions of the Code may be used with necessary modifications. The essential requirements in the design of any water retaining structure to function satisfactorily are:

1. A structure which will not allow retained water to leak.
2. A structure which will not allow external ground water to seep into the tank.
3. A structure which is sufficiently strong to withstand the imposed and dead loads.

These objectives can be achieved with due consideration to the following aspects of design and construction.

## CONCRETE

One of the important criteria for a watertight structure is the quality of concrete. The Code recommends concrete quality in the way of concrete grade, minimum and maximum cement content, means of ensuring good placing and thorough compaction so that the resulting concrete has a low permeability. More than strength requirement, except in prestressed concrete work, the whole emphasis is on workability and water-cement ratio. Workability can be defined as the ability of concrete to flow in formwork, through congested reinforcement and to be compacted to a minimum volume. Workability is still controlled generally through observation, but the more scientific methods are the slump test, the compacting factor test and the V-B test. The use of slump test is well known, but it has its limitations since it is liable to random variations except for rather rich mixes. A practical method of controlling workability is to rely on the results of compacting factor test which is the ratio of weight of concrete compacted in the lowest cylinder divided by the weight of the same volume of fully compacted concrete, and this is always less than 1. This factor varies from 0.7 for low workability to 0.95 for high workability. The V-B test, originally developed for research purposes, is used where site laboratory facilities can be available. The test measures the time required to change the shape of concrete from a standard compacted slump core to a flat cylinder, under vibration. The general figures for V-B test are 15 to 20 seconds for low workability and 2 to 3 seconds for high workability.

Ordinary portland cement is still the most commonly used type of cement in India. The use of portland pozzolana cement is also increasing these days, but special attention should be given to longer stripping time of formwork due to slow setting nature of the cement. Portland blast furnace slag cement do match in early strengths of those of ordinary portland cement, and sulphate resistance of slag cements is rated better than OPC. The Code specifies a minimum cement content of 330 kg per cu.m for reinforced concrete work and 380 kg. per cu.m. for post-tensioned prestressed concrete work. With these figures, minimum concrete grades of M20 for RC work and M35 for post tensioned prestressed concrete work can be easily achieved in practice. The Code also specifies the maximum cement content at 530 kg. per cu. m. There is no merit in having a mix which is particularly rich in cement as the problems of early thermal cracking will be accentuated. Admixtures are sometimes used to fill the concrete pores which may be advantageous but it should not compensate for shoddy workmanship. Sometimes these products produce a sense of false security and increasing carelessness. Admixtures containing calcium chloride should not be used as it leads to reinforcement corrosion in the long run.

Aggregates have significant effect on the workability of concrete. The lower the surface area of the aggregates, the lower is demand for mixing water for a given workability. Generally, crushed aggregates consist of rather angular particles having a rough surface texture resulting in a concrete of lower workability but higher strength. Some engineers are of the opinion that round aggregates such as shingle makes a more workable and therefore a more watertight concrete than crushed aggregates.

## CRACK CONTROL

Cracks in concrete form due to two main causes. These are:

1. Structural action from applied loads leading to tensile strains beyond the capacity of the concrete to sustain.
2. Temperature and shrinkage strains, caused by the hardening of the concrete or by environmental conditions.

It is known that cracks of the order of 0.1 to 0.2 mm do not necessarily allow liquid to leak. Cracks due to structural action can be restricted by limiting the tensile stress in concrete. Early thermal and shrinkage cracking can be controlled by proper distribution and spacing of reinforcement. If concrete members are restrained externally, cracking can occur as the heat of hydration is dissipated, the concrete cools and contracts. Such restraint may arise from:

1. Interaction between reinforcement and concrete during drying shrinkage.
2. Boundary conditions at the foundations or other parts of the structure. Restraint can be minimised by the provision of a sliding layer.
3. Differential conditions through large thickness of massive concrete. Thick sections which the Code defines as

the one greater than 450 mm are prone to thermal and shrinkage cracking which are not easy to control by reinforcement. Temperature rise may be restricted by casting the concrete in shallow lifts at intervals of a few days.

## JOINTS

The risk of cracking can also be minimised by reducing the restraints on the free expansion or contraction of the structure, by judicious provision of joints in the structure wherever possible. Two basic types of joint are provided, movement joints and construction joints.

### Movement joints are of three types:

1. Contraction joints:
   These are intended to allow constraction of the concrete with deliberate discontinuity but without initial gap. Water bar or a sealing strip is provided at the joint. Contraction joints are generally spaced at not more than 7.5 m apart. Joints in wall and floor are to be in the same line.
2. Expansion joints:
   These are provided with complete discontinuity in both reinforcement and concrete, and are intended to allow either expansion or contraction of the structure. It requires provision of an initial gap between adjoining parts of a structure which is filled with a joint filler and sealed with joint sealing compound. Water bar is also provided at the joint. Expansion joints are normally provided at 30 m intervals.
3. Sliding joints:
   These are provided with complete discontinuity in both reinforcement and concrete at which provision is made to facilitate relative movement. This is generally provided between wall and floor in some cylindrical tanks.

Construction joints are a convenience in construction for which arrangements should be made to ensure that complete continuity between the two sections at the joint is provided. The position and arrangement of these joints are predetermined by the engineer and these numbers are to be kept to a minimum. Preparation of the surfaces at construction joints is very important in order to provide good bond between the old and new concrete. It cannot be too strongly emphasised that the majority of problems with honeycombed concrete have occured in the vicinity of the construction joints. In horizontal construction joints it may be necessary to increase the concrete mix slightly by reducing the amount of coarse aggregate.

## JOINTING MATERIALS

The joint fillers should be non-absorbant type like the non-rotting cork based joint fillers, but the filler materials available at present cannot by themselves function as watertight expansion joints unless they are sealed with a non-absorbant type sealing compound. Sealing compounds are commonly based on asphalt, bitumen or coal tar pitch with or without fillers. Although all these materials should be capable of adhering to damp concrete, it is always preferable to dry the surfaces as far as possible before applying the seal. Suitable primers are available for these materials also.

Water bars are preformed strips, usually of rubber or PVC. The most usual forms of water bar is the dumbell type for construction and contraction joints, and the same with a centre-bulb type for expansion joints. Nowadays water bars with eyelet pattern are available which are easy to place in the correct position by tying them to reinforcement. For a joint in a floor slab resting on soil, the underslab external type of water bar is to be preferred since there is difficulty in maintaining a centrally placed water bar in a flat horizontal position during concreting. PVC water bars are usually recommended for movements not exceeding 10 mm whereas rubber water bars are recommended for higher movements upto 50 mm. But the quality of rubber water bars generally available in India are not upto the standards since these are made by revulcanisation and such water bars should be used with caution. The quality of PVC water bars should conform to the specifications laid out by the Central Water Commission. Water bars of copper strips and GI sheets are also used. We in Gammon India, have successfully used GI waterstops in construction joints in many water retaining structures, which are usually made of 24 gauge sheet, 200 mm wide, perforated with 25 mm dia. holes for better bonding of the waterstop with concrete. With all water bars, it is important to ensure proper compaction of concrete in the region of joints.

## DESIGN

In order to achieve watertight structure, atleast three major considerations must be satisfied in the design. These are:

- The stresses in the concrete and steel must be kept within reasonable limits.
- The adhesion of anchorage between concrete and steel must be adequate.
- Reasonable attention must be given to shrinkage and temperature stresses.

The design of liquid retaining structures should give due consideration to the effects of monolithic construction in the assessment of bending moment and shear. Redistribution of bending moments in the adjacent spans or members to the extent of ± 15% which is allowed in IS: 456-1978, is not applicable to liquid retaining structures. In the design of walls or slabs, there are three principal cases to consider, namely:

1. Members subjected to bending only.
2. Members subjected to direct tension only.
3. Members subjected to bending and direct tension

Where the tensile strain occurs at the face in contact with liquid, and the member is less than 225 mm thick, the basis of design is to resist cracking by limiting tensile stress in concrete considering an uncracked section, and also reinforced sufficiently under reduced stresses. If the member is more than 225 mm thick and the tensile strain is at the face remote from the liquid, the method of design will be based on strength calculations, similar to IS: 456, however steel stresses specified in this code are slightly lower than the corresponding figures of IS:456. With restricted steel stresses, there is apparently little incentive to use high yield deformed bars such as torsteel. Since the cost difference between mild steel and high yield deformed steel has narrowed in the recent years, it would be advantageous to use deformed bars in view of the superior bond properties allowing shorter laps and providing better crack distribution even if the tensile strees is restricted. The code recommends minimum reinforcement in concrete section for varying thickness and for mild steel and deformed steel bars. The code recommends minimum 25 mm cover or the diameter of bar whichever is greater. In corrosive and marine conditions and near soil face, the minimum cover is 37 mm, but this additional 12 mm is not to be considered in design calculations. In practice, there is a tendency to specify too much cover to reinforcement, i.e. around 75 mm and over. This excess cover is self defeating since thermal and shrinkage cracks do occur and penetrate deep enough to cause rusting of steel in course of time. To maintain the required cover, in addition to cover blocks, tie reinforcement between layers of steel near the inner and outer surface is very much essential. These are generally 6 mm or 8 mm dia bars in mild steel spaced at about 1 meter centres in both directions. Unfortunately, such tie reinforcement is missed out in detail drawing, and if this is not provided in the work, it may lead to too much or too less cover than specified.

Detailing of reinforcement for water retaining structures is as important as several design considerations mentioned hitherto. For crack resistance and control of cracking, proper bond and anchorage of reinforcement is essential. Where laps are provided it should be staggered in groups of two or three. The code also specifies that local stresses on concrete at bends of reinforcing of bars should not be more than three times the value permitted in direct compression. Many designers seem to overlook this requirement and provide normal radius bends i.e. 2 dia for MS bars and 4 dia for HY deformed bars, irrespective of the stress in the bar at the point of bend. In thin sections it is found that larger bends are required to limit the local stress in concrete and thus able to provide the required anchorage. In rectangular tanks, at the wall corners and at the junction of base and wall, it is a good practice to provide splays with diagonal reinforcement although this complicates the formwork a little. This detail makes the corner sufficiently strong.

## WATER RETAINING STRUCTURES

### Water Towers:

The size of tank depends on the quantity of water to be stored, the height of tower depends on the pressure head required, and the shape may depend on economics. If aesthetic aspect is taken into account, it may affect the cost. Generally, geometrical shapes giving the smallest combined areas of wall, floor and roof seldom give the most economical solution. The cost of foundations and staging also govern the economics. Generally speaking, for tanks upto 1000 cu. m. capacity, circular tanks or of the Intze type would be economical. For large tanks to hold 10,000 cu. m. of water, a square plan with a flat floor flat roof might be cheaper.

In rectangular tanks, the walls are designed as one way or two way acting slabs depending on length and height of the wall. In addition to bending moment due to water pressure, the walls are subjected to direct tension due to water pressures acting on the side walls. The walls of cylindrical tank are primarily designed to resist direct tension due to water pressure. In addition to hoop tension, bending moments are produced by the restraint at the base of the wall. The type of bottom of elevated water tanks depend on the tank size and the depth of water. For small tanks, a flat beamless slab can be provided. Savings in steel and concrete can often be obtained by providing a domed bottom or the combination of conical bottom with a dome as in the Intze type tank. In case of water tanks intended for domestic purposes, the roof must be made watertight by limiting the stresses as in the rest of the tank or by providing a waterproof treatment.

Columns supporting elevated tanks should be designed as per IS:456, with considerations to bending moments, forces and shears due to wind or seismic forces in addition to vertical loads from the tank.

Where the tower is high, the columns are to be braced in horizontal plane in both directions, at regular intervals along its height, and due consideration in regard to its effective length should be given as per IS:456, for a case not restrained against sway, in the calculation of permissible loads and moments. Battered columns, although provide more stability for high towers, are much more difficult to construct. Instead of a system of columns and braces which slows down the construction speed, sometimes it is advantageous to provide a simple circular shaft which is aesthetically better than tower with columns. If the shaft height is more than 20 m it may be advantageous to construct the shaft by slipform technique. The rate of slipforming is generally between 3 to 5 meters per day.

Column foundations could be individual square footings where soil bearing capacity is good. But it is considered a good practice to provide a continuous strip or a raft to minimise the effects of any unequal settlement that may occur, particularly in tanks with partitions where it could be filled with water in one portion only and thus cause unequal loading.

### Underground Tanks:

For large reservoirs and tanks, the most economical structure is where the wall height is kept to a minimum by having a sloping floor area in the perimeter. For large circular tanks, such as tanks more than 20 m diameter and tanks deeper than 6 metres, it would be economical to construct in prestressed concrete. In underground tanks, walls are designed for internal water pressure, and relief from external pressures due to surrounding earth should not generally be relied upon. Walls should be checked for external pressures under empty condition. For walls monolithic with floor and roof, where lateral movement of the wall is minimal, the external earth pressure calculation should be based on pressure at rest which is higher than the pressure based on Rankine's theory which is applicable to cantilever type walls. If the tank is submerged or is in a water logged ground, the structure should be investigated against floatation when it is empty.

In large size and deep tanks and where ground water table is also high, generally it is not possible to provide stable equilibrium by gravity weight only, and in such cases the tank floor is to be anchored down by rock anchors or piling. Alternatively, a permanent well-point system with drainage around can be adopted to reduce the ground water table although this becomes sometime a costly proposition. The code recommends a factor of safety of 1.2 against uplift. Where injurious soils such as sulphate exist, sulphate resisting cement is to be used. Coats of bitumen with polythene sheets also provide protection to tank. The backfilling behind walls should be select backfill from the excavated soil, preferably gravel or sand, and soil with clay content should not be used. Backfilling should be carefully deposited in thin horizontal layers not exceeding 300 mm thick.

## TEMPORARY WORKS

Construction of water towers and reservoirs require careful and detailed planning of temporary works. For rectangular shaped sections, standard steel shutters could be used as much as possible. Where the tanks are curved and are of special shapes and odd sizes, and reuses are not envisaged, plywood shuttering is most ideal and economical. Regarding scaffolding and staging, there is much to be desired the way these are put up for construction in our country. Too often the importance of scaffolding and staging is insufficiently recognised. If these fail, it can result in death or injury, and permanent or temporary collapse of the structure it is supporting. Most of the failures in scaffolding and staging occur due to lack or improper way of bracing to take care of sway forces which occur in all construction work. Where timber is employed to carry substantial loads, it should be designed properly with bolted or split-ring connectors instead of flimsy nails and hessian ropes. In these cases, scaffolding and staging made of tubular steel is a must, although the initial investment is more, but it has its advantages in case of erection and dismantling and in repeated use. Although design of formwork and staging uses the same structural principles as design of permanent works, reuse of forms, scaffolding and staging implies wear and misuse which must be allowed for, offset by the possibility of inspection between uses.

## REPAIRS

Repairs to reinforced concrete are always expensive and often unsatisfactory. If the design is at fault it is usually because of a fundamental error such as under-estimation of lateral pressures or over estimation of the safe bearing capacity of soil. Mistakes in detailing such as overcrowding of bars and lapping of bars at critical locations are more frequent. Common mistakes in construction are poor workmanship at joints, inadequate cover, poor consolidation of concrete and inadequate curing.

The most common cause of leakage is at the opening of construction joints, generally at the lowest horizontal joint where the water pressure is high. Repairing is done by cutting the joint to a depth of 25 to 40 mm to form a wedge shaped groove. The groove is coated with mastic or bitumen and then filled with joint sealers preferably of synthetic polymers. If there is leakage from the subsoil into empty tank, grouting tubes are driven outside the tank and cement grout is pumped into the ground to form an outside repair. If the reinforcement is too close to the surface and has commenced rust, causing spalling, the repairing is done by cutting the area to a minimum thickness of 40 mm and reinforced with steel mesh and guniting the area. The provision of impermeable linings such as asphalt, bituminuous sheeting, PVC, tarred felt should only be necessary in case where good workmanship is unlikely to be obtained.

## CONCLUSION

Design and construction of water retaining structures require careful application of good engineering practices at all stages of the work. If the fault lies in any aspect of the work, leaks and failures are likely to take place and many a time it is immediately noticeable in the service condition. Needless to say, the work both in design and construction, should be entrusted to persons with experience in this field and should be executed under strict supervision of qualified engineers.