20th WEDC Conference
AFFORDABLE WATER SUPPLY AND SANITATION
Colombo, Sri Lanka, 1994

Lest the water tanks should fall

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THE NEED FOR a 'check list' to ensure a safe and dependable construction of a "reinforced concrete elevated service reservoir" has been long felt in the developing countries, although codes covering the design and construction of reinforced concrete structures for storage of liquids exist. These codes provide general requirements of design and construction for such structures assuming that the execution of the work shall be carried out under the direction of an experienced supervisor and design shall be entrusted to a qualified engineer. But inspite of available codes for guidance, it is always a thrilling sensation to fill a newly constructed elevated tank for the first time. In past few years, with new water supply schemes coming up in developing countries, the instances of collapse of water tanks during testing itself are also often in news. These instances have resulted not only delay in commissioning of the water supply schemes but also casualties in the vicinity of the tank causing serious law and order problems. Later on all these failures causing collapse of the water tanks are attributed to some critical lapse on part of the designer or to faulty construction.

This clearly indicates some lacuna in the standards adopted for design and construction of such a vital structure. Why the structures fail , if the "safety margin" considered is really adequate? A general blame as a answer to this question is casted on poor quality of construction which may be true to a certain extent. But then, why we shouldn't adopt the standards to match our status of constructional activities? In developing countries, the infrastructure for construction are so poor that the quality is solely an individual performance of agencies involved. Generally the works are executed on contractual basis. So quality of construction varies with awareness, performance and facilities available with the contractors. Sometimes the financial constraints due to competitive bid for taking the contract make the contractor to compromise the quality of construction. This way we can conclude that the poor quality of construction which may be due to lack of awareness, supervision or facilities of construction reduces the "safety margin" considerably and any further lapse proves to be fatal to the structure.

So to maintain a minimum level of "safety margin" and ascertain a dependable structure, it needs serious considerations right from site selection to design, construction and testing. Besides some special requirements are also suggested based on the experiences of past failures to cope with the constructional slackness in the developing countries. During five years service with P.H.E. Department in M.P. (India), I had opportunity to construct three R.C.C. elevated service reservoirs of 1500 KL capacity each with staging varying from 15 to 20 m. During the construction of these tanks, I had opportunity to associate myself with field personnel and go through the details of some past failures and suggestions of the experts on above issues. Based on above experience and suggestions of the experts, I have tried to list the 'Check Points' and special requirements as given below on design and constructional aspect of a R.C.C. elevated service reservoir which may help in achieving a minimum level of "safety margin" and ascertain a dependable structure.

Site selection

Site selection for an elevated service reservoir (E.S.R.) is of prime importance. Most of the failures reported in past are due to selection of a faulty site. The designer was supplied with the value of "Safe bearing capacity" (S.B.C.) of the founding strata at the time of the plate load bearing test or some other tentative test and the design is carried out in the office on that basis only. But the nature of underground supporting strata and conditions of ground water table is not assessed properly which affects the S.B.C. significantly.

Check points

- As far as possible, the foundation of an E.S.R. shall not lie on a water logged ground.
- The site shall also not lie on a filled up ground
- The designer should visit the site personally and he should also be present during testing to assess S.B.C. or he should at least ascertain the parameters like unground supporting strata and condition of ground water table in all weathers before arriving at the value of S.B.C. for design purpose.
- The ground slope of the site should be such that the rainy water or the leakage water from pipelines shall not retain over the foundation area. If unavoidable, the ground surface should be filled during construction in required slope and flag stone flooring shall have to be done below the reservoir extending at least 2.0 m. away from the outer periphery of column staging to avoid infiltration of water into the foundation.
- The record of ground water table for all seasons is to be obtained before deciding the S.B.C. and if the foundation is in waterlogged area or likely to be submerged in ground water table, the value of S.B.C. needs to be modified accordingly. This needs detailed

investigation and expert opinion before arriving at the value of S.B.C. for design purpose.

- The supporting strata below founding level must extent upto the significant depth up to which the load distribution takes place. Many failures have been reported where the foundations were rested on rock but the continuity of the rock upto significant depth was not assessed. So the trial bores of 100 mm dia by a rotary drilling machine shall be taken at minimum 3-4 points over the foundation area up to a depth of 20.00 m to assess the continuity of the supporting strata and the core samples collected shall be kept for record.
- In rural water supply schemes where the source is gravel packed tubewell, the tank site shall be kept at least 200 metres away from the tubewell site, as there is possibility of cavity formation in due course with drawal of water.

Design requirement

Strength of concrete and water cement ratio

The prevalent codes permit the use of concrete of grade M-15 for general R.C.C. construction and M-20 for components in contact with water or enclosing the space above water without restriction on maximum water cement ratio (W/c ratio) whereas w/c ratio is a prime factor as far as durability of the structure is concerned. Besides, if the w/c ratio is not checked, it is observed that the construction is done to achieve maximum workability with a w/c ratio as high as 0.8 to 0.85 resulting in poor strength of concrete and a lesser durable structure. But an E.S.R. undergoing filling and emptying each day experiences the most frequent reversal of loads and hence needs more consideration for durability rather than the strength of concrete only. The exposure to the structure is to be considered "most severe". Practically it is more critical as we look to the status of present construction activities where there is hardly any quality control at site construction. So besides the stipulation of the codes some special requirements of concrete are suggested which would help to achieving the targeted "minimum level of safety margin".

If restriction on maximum w/c ratio is strictly observed, the quality of construction would definitely be checked. However in the practical field conditions, it is very difficult to achieve workability with w/c ratio restricted to 0.45 and 0.40 as mentioned above.

This problem could be overcome with:

- Use of plasticiser or suitable admixtures to increase the workability.
- Use of mechanical hoisting arrangements for placing of concrete to reduce the time of placement.
- However if it is felt necessary to increase the workability by adding the most easily available resource i.e. water (which is general practice), it is to be added with addition of extra cement in proportion to the w/c ratio. This concept could be illustrated to the field personnel in terms of simple calculations e.g. while placing the concrete of tank wall restricting w/c ratio to 0.40; One litre of water could be permitted along the addition of 2.5 Kg. of cement while mixing the concrete. This check, I found most effective while construction of two tanks myself with sticking to above requirements.

Table 1: Strength of concrete

Unit	Minimum strength	Size of aggregate	Minimum cement content	Maximum w/c ratio
Columns staging or roof slab	M-25	20 mm down	325 Kg.	0.45
Tank walls and bottom slab	M-30	20 mm down	360 Kg.	0.40

Minimum dimensions

For proper placing and vibration of concrete it is very essential to adopt minimum thickness for tank wall, base slab and roof slab of an E.S.R. which after considering the minimum cover to be adopted, the usual dia of reinforcement bars and size of aggregates and field conditions are suggested below:

- Minimum thickness of water retaining tank wall and its base slab shall have to be 150mm.
- Minimum thickness of roof slab shall have to be 120 mm.

Similarly looking to the past failures due to accentricity of columns and incorrect assessment/uncertain behaviour of the windload, the minimum dimensions of columns and beams are suggested below:

- Minimum dimension of columns - 400mm.
- Minimum width of beam - 400mm.

Minimum reinforcement (HSD Bars)

Columns vertical steel - 0.4% of gross cross-section
Minimum steel in slab - 0.12% in any direction
Beam - 0.2% on tension face below neutral axis.
Column link - Not less than 8 mm dia. spacing not more than 12 d (d is smaller diameter of vertical steel)
Any concrete surface - Not less than 250 mm^2 per m^2 in any direction i.e. 8mm bars @ 200 c/c or 10 mm bars @ 300 c/c both ways.
Maximum spacing of steel - Main steel tension zone - 150mm. Distribution steel, column vertical steel, column links or any other steel - 200mm. Minimum cover: 40mm for slabs, 30mm for beam, 40mm for columns.

Water load

Water load shall have to be treated as live load as it undergoes variation as water is pumped in or let out.

Detailing of reinforcement

- Profile of every type of bar used, its length spacing and number of bars should clearly be mentioned in drawing. The orientation should be shown below the plan or section of structural element.
- High strength deformed bars shall not be bent through more than 90^o angle.
- Bars in predominant compression should not be bent except at ends.

With addition of the above special requirements, the cost of construction may be higher due to more consumption of cement and steel. However it has been observed practically that this cost variation remains within 15-20% of the value of work. But this provides the adequate margin of safety and hence worth adopting. The two reservoirs constructed in Rajnandgaon town to these specifications are found completely water-tight and safe after testing to the satisfaction of the department.

Constructional procedures and sequences

- The relevant codes are silent on fixing of inlet, outlet, overflow and scour pipes to the tank. All the pipes are to be connected at the bottom slab using puddle collars keeping the collars embedded in centre line of the slab. But generally the slabs are casted leaving the holes for the puddle collars / pipes which are later fixed and grouted in the bottom slab. If they are not properly grouted, there is always possibility of constant leakage through the junction point. So it is necessary that all pipes are fixed on duck foot bend and grouted in its foundation and their lengths in pieces are so adjusted that the puddle collar shall lie in centre of the bottom slab and this should be done before the casting of the bottom slab. Then only the puddle collars / pipes could be casted monolithic with bottom slab and the possibility of any leakage through the junction point is completely checked.
- For casting of columns, the shuttering height is generally kept 3.0m and the concrete is placed from top resulting in segregation of concrete at bottom. So the shuttering should have gated window for placement of concrete at every 1.0 m height to avoid this segregation of concrete and it would also result in more effective compaction with the help of needle vibrators which could be well operated through these windows.
- The curing of concrete shall have to be done with suitable pumping arrangement only, as it is not possible to cure the concrete properly by manual labour when the height of structure exceeds 3.0m.
- One of the cubes for testing of concrete shall have to be kept hanging along with respective component of structure and shall be cured at the same rate at which the structure is being cured. The strength of this cube shall have to be compared with the rest of the cubes cured as per cube testing standards before accepting the strength of the component and allow further construction.
- The shuttering and scaffolding shall have to be designed along with the structural design. It should be capable enough to withstand the concrete load, live load of labours and all other force to come. Generally the shuttering and scaffolding are not designed properly and it is done as per the availability of materials with contractor based on experience only. Many failures are reported because of the inadequate strength of shuttering an scaffolding resulting in collapse of the builtup structure during construction itself. The shuttering shall have to be perfectly smooth and there shall be no loss of cement slurry through it while compacting the concrete. Otherwise a low density polyethlene sheet should be laid over the surface of the shuttering to make it smooth and prevent the loss of cement slurry through it.
- The verticality of the column staging is generally checked by plumb bob. But when height of staging is more, the plumb bob suspended through thread doesn't lie still due to wind pressure. So the verticality should be checked with theodolite.
- During construction itself, the settlement of the structure shall have to be checked from time to time by theodolite and records are to be maintained.
- 30 x 30 mm chamfers shall have to be provided at all exposed corners of concrete elements of water retaining portion.
- Cover blocks shall be casted in advance to match the strength of concrete to ascertain uniform cover throughout.
- No mining activity is to be allowed around the tank site.
- Lightening arrester with proper earthings should be invariably be installed and maintained to avoid collapse due to lightening.
- All the joints like contraction joints, movement joints, expansion joints, sliding joints, construction joints etc. should be made as per the design strictly sticking to the relevant specifications.

Testing of the structure

- The structure should not be kept empty for a longer time after the construction.
- The filling of the tank for testing have to be done gradually and not more than 30 cm height at time in one day to allow for release of stresses for sufficient time before loading the tank fully.
- While filling the tank, the record of settlement should be taken daily by theodolite to avoid any accident during testing itself. Further filling shall only be continued after analysing the records of settlement.

Conclusion

Besides above check points, all other codal requirements and constructional aspects are to be observed. The above check points are just the points where we have to be particular because of the past failures. But still the variable factors are numerous and any unusual circumstances shall have to be dealt with adequate safety analysis or test or by both.

References

[1] Indian standard code of practice for concrete structures for the storage of liquids: IS:3370 (Part I and II) - 1965. Indian standard code of practice for plain and reinforced concrete. IS:456-1978.

[2] Technical circular of E in C, P.H.E.D., M.P. vide endorsement No. 10766 dated 23/11/89 on recommendation of Mr. C.V. Kand, Retd. Chief Engineer, PWD, M.P. on water retaining concrete structures.

[3] Technical circular of E in C, P.H.E.D., M.P. vide No. 110/91 Bhopal dated 22/3/91.