A Common Mistake in Design of Water Tank

Gajendra Verma

Rajiv Gandhi Technical University, Sri Aurobindo Institute of Technology, Indore Madhya Pradesh (India)

Abstract: In this paper a common mistake in calculating the thickness the wall and corresponding area of reinforcement in the water tank by working stress method have been discussed. Due to water pressure, wall of the water tank is subjected to Tension and Bending Moment. In most of the books, the thickness of the wall and area of reinforcement for bending moment is calculated by following formulae considering cracked section

\[
t = \frac{M}{R} + \text{effective cover and}
\]

\[Ast = \frac{M}{\sigma_{cbt}}\]

When the moment of resistance of wall section (which is the least moment of resistance of wall considering as cracked and uncracked section) is calculated from the above values of “t” and “Ast”, it comes out less than the applied moment, hence design is not safe. Therefore, it is necessary to determine thickness and corresponding area of reinforcement of wall section in such a manner so that it remains safe in cracked as well as in uncracked condition. To overcome this problem, a simple procedure for calculating the thickness the wall and area of reinforcement in the water tank by working stress method have been discussed. In this paper, the thickness of wall is calculated considering it as an uncracked section ignoring area of reinforcement and area of reinforcement considering it as a cracked section. At the end, effect on area of reinforcement due reduction in thickness of wall of tank have been also discussed.

Keywords: Working stress method, Area of reinforcement, Thickness of Wall, Cracked section, Uncracked section

1. Introduction

The liquid retaining structures are used to store liquid like water, diesel, petrol etc. A water tank is used to store water to tide over the daily requirements. In general, water tanks can be classified under three heads: (i) tanks resting on ground (ii) elevated tanks supported on staging, and (iii) underground tanks. From the shape point of view, water tanks may be classified as Circular tank, Rectangular tank, Spherical tank and Intze tank. The liquid retaining structures are designed as a crack free structure and hence their designed is different from others R.C.C. structures. For crack free structure, the tensile stresses in concrete calculated on uncracked section should be within permissible limits as given in IS:3370-II-2009. In order to avoid leakage and to impart impermeability to the concrete, concrete of grade M-30 (M-25 for smaller tank up to capacity < 50 m\(^3\)) and above is recommended for liquid retaining structures according to IS: 3370-1-2009. The Indian standard code (IS:3370-I-2009) suggested minimum cement content 320 kg/m\(^3\) in order to have impermeable concrete and to keep shrinkage low. As per the provisions of the code (IS 3370-II-2009), the water tanks may be designed by

- Working stress method
- Limit State method

2. Symbols Used

- \(b\) = Breadth of the section
- \(t\) = Overall thickness of the section
- \(d\) = Effective depth of the section
- \(\sigma_{c}\) = Permissible compressive stress in concrete due to bending.
- \(\sigma_{cbt}\) = Permissible tensile stress in concrete due to bending.
- \(\sigma_{st}\) = Permissible stress in steel in tension.
- \(m\) = Modular ratio.
- \(k\) = Neutral axis depth factor

\[M = \text{Applied bending moment}\]

\[M_{ncr} = \text{Moment of resistance considering cracked section}\]

\[M_{ucr} = \text{Moment of resistance considering uncracked section}\]

\[\sigma_{cbt} = \text{Permissible tensile stress in concrete due to bending.}\]

\[\sigma_{st} = \text{Permissible stress in steel in tension.}\]

\[\text{Effective cover and }\]

\[\text{Neutral axis depth factor}\]

\[\text{Lever arm factor}\]

\[\text{Moment of resistance factor}\]

\[\text{Equivalent area of transformed Section.}\]

3. Problem Formulation

A numerical problem is taken for discussion in which wall of the tank is designed by working stress method for a given bending moment using the procedure given in most of books. Then moment of resistance of wall section is determined considering cracked and uncracked section. It is found that design fails as its moment of resistance comes out less than applied moment. A second approach is discussed for determining thickness and area of reinforcement in order to make it safe.

In the same numerical, area of reinforcement is calculated by reducing the thickness as obtained in second approach.

4. Analysis and Design of Tank Wall

Let us design the wall of the water tank subjected to bending moment 50 kNm using M-30 concrete and Fe-415 steel.

\[\text{Modular Ratio (m) = } \frac{280}{2\sigma_{cbt}} = \frac{280}{2 \times 9.33} = 9.33\]

Neutral axis depth factor \(k\) = \[\frac{9.33}{10 + 2.23 + 0.005} = 0.22\]

Volume 6 Issue 1, January 2017

www.ijsr.net

Licensed Under Creative Commons Attribution CC BY

Paper ID: ART20164696
Lever arm factor \( (j) = 1 - \frac{k}{3} = 1 - \frac{0.418}{3} = 0.861 \)

Moment of resistance factor \((R) = \frac{1}{2} \sigma_{bc} k j \)

\[ R = \frac{1}{2} \times 10 \times 0.418 \times 0.861 = 1.8 \text{ N/mm}^2 \]

Required effective depth of wall \((d) = \frac{E}{R} = \frac{20 \times 10^6}{18 + 1000} \]

\[ d = 166.67 \text{ say 170 mm} \]

Assume effective cover as 60 mm.

Thickness of wall \((t) = 170 + 60 = 230 \text{ mm} \)

Required area of reinforcement \((A_{st}) = \frac{133.85^{0.5} \times 170}{2627.70} \]

\[ A_{st} = 2627.70 \text{ mm}^2 \]

Now let us calculate the moment carrying capacity of wall section

The moment carrying capacity of wall is calculated by considering following two cases and lesser is adopted as moment carrying capacity of the section.

**Case-I: Considering cracked section**

\[ b x x/2 = m A_{st} (d-x) \]

\[ 1000 \times x^2/2 = 9.33 \times 2627.70 \times (170 - x) \]

\[ x = 70.02 \text{ mm} \]

Depth of neutral axis \( x_c = k \times d = 0.418 \times 170 = 71.06 \text{ mm} \)

Since \( x < x_c \), hence section is under reinforced.

Moment considering cracked section \((M_{cr}) = A_{st} \sigma_{st} (d-x) \)

\[ M_{cr} = 2627.70 \times 130 \times (170 - 70.02/3) \]

\[ M_{cr} = 50.10 \times 10^6 \text{ Nmm} = 50.10 \text{ kNm} \] ---- (i)

**Case-II: Considering uncracked section**

Area of Transformed section \((A_{tr}) = bD + (m-1)A_{st} \)

\[ A_{tr} = 1000 \times 230 + (9.33 - 1) \times 2627.70 \]

\[ A_{tr} = 251888.74 \text{ mm}^2 \]

Depth of neutral axis \[ b x^3 + (m-1)A_{st} (d-x) \]

\[ b x^3/3 + (220 - 170) \times 2627.70 \times (170 - 119.78)^2 \]

\[ M_{uncr} = 19.50 \times 10^6 \text{ N-mm} = 19.50 \text{ kNm} \] ---- (ii)

Hence moment carrying capacity = Least in (i) and (ii)

\[ M_{cr} = 19.50 \text{ kNm} < \text{Applied moment (50 kNm)} \]

Hence design is not safe.

**Second Approach:** To overcome this problem, the thickness of wall of tank is calculated from theory of uncracked section and then amount of reinforcement is calculated using theory of cracked section. Moment of resistance of a uncracked section ignoring the area of reinforcement is calculated by following formula-

\[ M = \frac{I}{y_{\text{max}}} \sigma_{cbt} \]

where \( I = \text{M.I. of the section about N.A. ignoring area of reinforcement} \)

\[ y_{\text{max}} = \text{Distance of extreme tension fibre from N.A.} = t/2 \]

\[ \sigma_{cbt} = \text{Permissible tensile stress in concrete in bending} \]

\[ = 2 \text{ N/mm}^2 \text{ for M-30} \]

\[ OR \ t = \sqrt{\frac{6M}{b \times \sigma_{cbt}}} = \sqrt{\frac{6 \times 387.29 \times 10^6}{289}} \]

\[ t = 387.29 \text{ mm say 390 mm} \]

Assume effective cover as 60 mm.

Available effective depth \((d) = 390 - 60 = 330 \text{ mm} \)

Required area of reinforcement \((A_{st}) = \frac{133.85^{0.5} \times 330}{2627.70} \)

\[ A_{st} = 53.80 \text{ kNm} \]

Hence moment carrying capacity

\[ = \text{Least in (i) and (ii)} \]

\[ = 53.80 \text{ kNm} > \text{Applied moment (50 kNm)} \]

Hence design is safe.
5. Effect on Area of Reinforcement due to Reduction in Thickness of Wall

Let us see the effect on area of reinforcement due to reduction in thickness of wall as calculated in second approach.

Assume thickness of wall as 370 mm.

Effective depth \( (d) \) 370 – 60 = 310 mm

Required area of reinforcement \( (A_{st}) \) = \( \frac{50 \times 10^{-6}}{130 + 0.561 \times 110} \) = 1440.99 mm\(^2\)

Moment of resistance of cracked section

\( = 53.15 \text{ kNm} \) (i)

Moment of resistance of uncracked section

\( = 48.63 \text{ kNm} \) (ii)

Hence moment carrying capacity

\( = \text{Least in (i) and (ii)} \) = 48.63 kNm < Applied moment (=50 kNm)

Hence design is not safe.

In order to make it safe, area of reinforcement must be increased. There is no direct approach for calculating the area of reinforcement in uncracked theory. It may be calculated by trial and error by using the following formulae:

\[ A_T = bD + (m-1) A_{st} \]

\[ x = \frac{bD + (m-1) A_{st}}{2} \]

\[ I_T = \frac{D^4}{3} \left( O-D-x \right) + (m-1) A_{st} (d-x)^2 \]

\[ M = \frac{D^2}{2} \sigma cbt \]

Required area of reinforcement \( (A_{st}) \) = 2115 mm\(^2\)

Moment of resistance of cracked section

\( = 76.45 \text{ kNm} \) (i)

Moment of resistance of uncracked section

\( = 50.01 \text{ kNm} \) (ii)

Hence moment carrying capacity

\( = \text{Least in (i) and (ii)} \) = 50.01 kNm > Applied moment (=50 kNm)

Hence design is safe.

Similarly area of reinforcement is calculated for other thickness 360 mm and 350 mm and tabulated in Table-2.

### Table 2: Area of reinforcement in wall section

<table>
<thead>
<tr>
<th>Bending Moment (M) (kN-m)</th>
<th>Thickness of wall (t) (mm)</th>
<th>Effective depth of wall (d) (mm)</th>
<th>Required area of reinforcement (A(_{st})) (mm(^2))</th>
<th>% decrease in thickness of wall</th>
<th>% increase in area of reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>390</td>
<td>330</td>
<td>1353.66</td>
<td>5.13</td>
<td>56.24</td>
</tr>
<tr>
<td>50</td>
<td>370</td>
<td>310</td>
<td>2115</td>
<td>5.13</td>
<td>56.24</td>
</tr>
<tr>
<td>50</td>
<td>360</td>
<td>300</td>
<td>3495</td>
<td>7.69</td>
<td>158.19</td>
</tr>
<tr>
<td>50</td>
<td>350</td>
<td>290</td>
<td>5030</td>
<td>10.26</td>
<td>271.59</td>
</tr>
</tbody>
</table>

### Graph 1: Variation in area of reinforcement

From table -2, it is clear that if thickness is reduced by 5.13 %, the area of reinforcement increases by 56.24 %. Similarly, if the thickness is reduced by 7.69 % and 10.26 %, the corresponding increase in area of reinforcement is 158.19 % and 271.59 % respectively. Also, it is clear from Graph-2 that rate of % increase in area of reinforcement increases rapidly as thickness of wall goes on reducing. Hence, a small decrease in thickness requires large amount of reinforcement which makes the design uneconomical.

### 6. Discussion

The results of first and second approach are given in Table – 1.

#### TABLE – 1 (Moment of Resistance of wall section)

<table>
<thead>
<tr>
<th></th>
<th>M (kN-m)</th>
<th>t (mm)</th>
<th>Ast (mm(^2))</th>
<th>Muncr (kN-m)</th>
<th>Mcr (kN-m)</th>
<th>M.R. (kN-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Approach</td>
<td>50</td>
<td>230</td>
<td>2627.70</td>
<td>19.50</td>
<td>50.10</td>
<td>19.50</td>
</tr>
<tr>
<td>Second Approach</td>
<td>50</td>
<td>390</td>
<td>1353.66</td>
<td>53.80</td>
<td>53.41</td>
<td>53.41</td>
</tr>
</tbody>
</table>

It is clear from table-1 that second approach is correct as moment of resistance obtained is more than the applied moment.

### 7. Conclusion

From the above results, following conclusions are extracted-

1) The second approach is logically correct.
2) The thickness of wall of water tank should be selected carefully otherwise section may be uneconomical.

### References

[6] O.P Jain and Jai Krishna Plain and reinforced Concrete Volume-II.

Author Profile

Gajendra Verma obtained the Bachelor degree in Civil Engineering and Master Degree in Structural Engineering from Government Engineering College, Ujjain, Madhya Pradesh (India) in 1987 and 2010 respectively. He served the various Engineering Colleges. Currently he is working as an Associate Professor and HOD in the Department of Civil Engineering, Aurobindo Institute of Technology, Indore Madhya Pradesh (India). He has over two decades of teaching experience. His research interest is in the area of Structural designs. He is also a Member of Institute of Engineers and Indian Society for Technical Education.