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A Common Mistake in Design of Water Tank

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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***

$$t = \sqrt{\frac{M}{Rb}} + \textit{effective cover and}$$

$$Ast = \frac{M}{\sigma st * j * d}$$

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 equivalent concrete 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-I-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
σcbc = Permissible compressive stress in concrete due to bending.
σcbt = Permissible tensile stress in concrete due to bending.
σst = Permissible stress in steel in tension.
m = Modular ratio.
k = Neutral axis depth factor
j= Lever arm factor
R = Moment of resistance factor
A_T = Equivalent area of transformed Section.
I_T = Equivalent moment of inertia transformed Section about neutral axis
Ast = Area of steel in tension
M = Applied bending moment
M.R. = Moment of resistance
Mcr = Moment of resistance of section considering cracked section
Muncr = Moment of resistance of section considering uncracked 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.
First Approach: Following procedure is adopted to design the wall of the water tank in books -

Modular Ratio (m) = $\frac{280}{3\sigma cbc} = \frac{280}{3*10}$ = 9.33

Neutral axis depth factor (k) = $\frac{m\sigma cbc}{m\sigma cbc + \sigma st} = \frac{9.33*10}{9.33*10+130}$

= 0.418

Lever arm factor (j) = 1- k/3 = 1- 0.418/3 = 0.861

Moment of resistance factor (R) = $\frac{1}{2}\sigma cbc\, kj$

= $\frac{1}{2} * 10 * 0.418 * 0.861$ = 1.8 N/mm^2

Required effective depth of wall (d) = $\sqrt{\frac{M}{Rb}} = \sqrt{\frac{50*10^6}{1.8*1000}}$

=166.67 say 170 mm

Assume effective cover as 60 mm.

Thickness of wall (t) = 170 + 60 = 230 mm

Required area of reinforcement (Ast) = $\frac{50*10^6}{130*0.861*170}$

= 2627.70 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

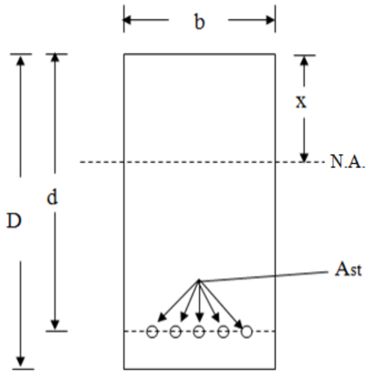


Figure 1: Cross section of cracked section

Depth of neutral axis

b x x/2 = m Ast (d-x)

1000* x^2/2 = 9.33*2627.70 * (170 - x)

x = 70.02 mm

Depth of critical neutral axis

xc = k*d = 0.418 * 170 = 71.06 mm

Since x < x_c, hence section is under reinforced.

Moment considering cracked section

(Mcr) = Ast*σst * (d - $\frac{x}{3}$)

= 2627.70*130*(170 – 70.02/3)

= 50.10 * 10^6 Nmm = 50.10 kNm----(i)

Case-II: Considering uncracked section

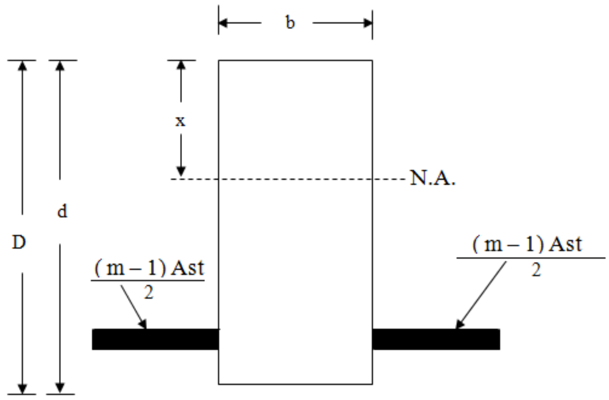


Figure 2: Cross section of uncracked section

Area of Transformed section

(A_T) = bD + (m-1) Ast

= 1000*230 + (9.33 -1)* 2627.70

= 251888.74 mm^2

Depth of neutral axis

x = $\frac{bD\frac{D}{2} + (m-1)Ast\ d}{AT}$ =

= $\frac{1000*230*\frac{230}{2} + (9.33-1)*2627.70*170}{251888.74}$

= 119.78 mm

Moment of inertia of Transformed section about N.A.

$I_T = \frac{bx^3}{3} + \frac{b(D-x)^3}{3}$ + (m-1) Ast (d-x) ^{2}

= $\frac{1000*119.78^3}{3} + \frac{1000*(230-119.78)^3}{3}$

+ (9.33 – 1)*2627.70(170 – 119.78)^2

= 1074376263 mm^4

Moment considering cracked section

Muncr = $\frac{IT}{(D-x)} * \sigma cbt$

= $\frac{1074376263}{(230-119.78)}$ * 2

= 19.50*10^6 N-mm = 19.50 kNm --- (ii)

Hence moment carrying capacity

= Least in (i) and (ii)

= 19.50 kNm < 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-

$$M = \frac{I}{y_{max}} \sigma_{cbt}$$

where I = M.I.of the section about N.A. ignoring area of reinforcement

$$= \frac{bt^3}{12}$$

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

σ_{cbt} = Permissible tensile stress in concrete in bending

= 2 N/mm^2 for M-30

$$M = \frac{bt^2}{6}\sigma_{cbt}$$

OR t = $\sqrt{\frac{6M}{b*\sigma cbt}} = \sqrt{\frac{6*50*10^6}{1000*2}}$

= 387.29 mm say 390 mm

Assume effective cover as 60 mm.

Available effective depth (d) = 390 – 60 = 330 mm

Required area of reinforcement (Ast) = $\frac{50*10^6}{130*0.861*330}$

= 1353.66 mm^2

Moment of resistance of cracked section

= 53.41 kNm --------- (i)

Moment of resistance of uncracked section

= 53.80 kNm ----- (ii)

Hence moment carrying capacity

= Least in (i) and (ii)

= 53.41 kNm > 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 (Ast) = $\frac{50*10^6}{130*0.861*310}$
= 1440.99 mm^2

Moment of resistance of cracked section
= 53.15 kNm (i)
Moment of resistance of uncracked section
= 48.63 kNm (ii)
Hence moment carrying capacity
= 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 –

$$A_T = bD + (m-1)\,Ast$$

$$x = \frac{bD\frac{D}{2} + (m-1)Ast\,d}{AT}$$

$$I_T = \frac{bx^3}{3} + \frac{b(D-x)^3}{3} + (m-1)\,Ast\,(d-x)^2$$

$$M = \frac{IT}{(D-x)} * \sigma cbt$$

Required area of reinforcement (Ast) = 2115 mm^2
Moment of resistance of cracked section
= 76.45 kNm (i)
Moment of resistance of uncracked section
= 50.01 kNm (ii)
Hence moment carrying capacity
= 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

6. Discussion

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

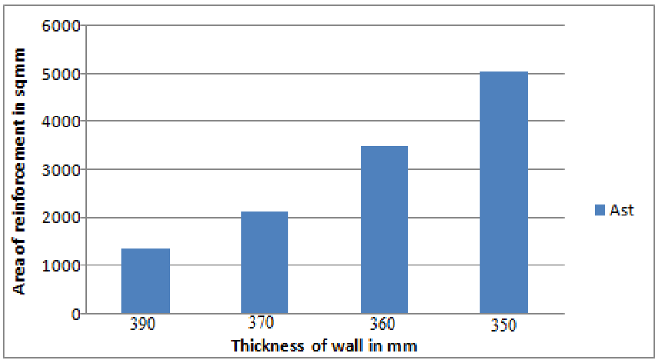
TABLE – 1 (Moment of Resistance of wall section)

	M	t	Ast	Muncr	Mcr	M.R.
	(kN-m)	mm)	(mm^2)	(kN-m)	(kN-m)	(kN-m)
First Approach	50	230	2627.70	19.50	50.10	19.50
Second Approach	50	390	1353.66	53.80	53.41	53.41

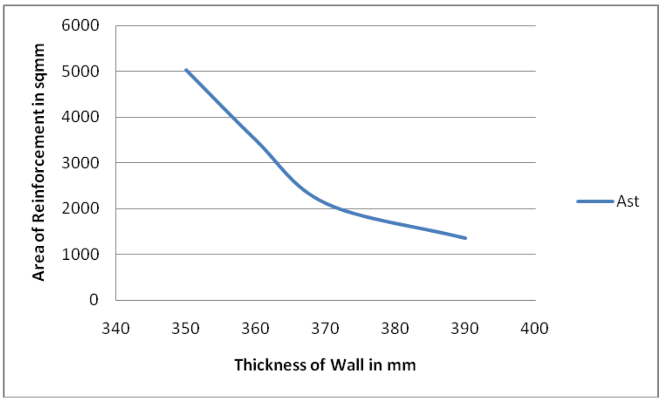
It is clear from table-1 that second approach is correct as moment of resistance obtained is more than the applied moment.

Table 2: Area of reinforcement in wall section

Bending Moment (M)	Thickness of wall (t)	Effective depth of wall(d)	Required area of reinforcement (Ast)	% decrease in thickness of wall	% increase in area of reinforce -ment
kN-m	mm	mm	mm^2		
50	390	330	1353.66		
50	370	310	2115	5.13	56.24
50	360	300	3495	7.69	158.19
50	350	290	5030	10.26	271.59



Graph 1: Variation in area of rainforcement



Graph 2: Variation in area of rainforcement

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.

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

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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.