



Development of Computation Tool for Controlling Crack Width of High Capacity Circular Water Tank on ground level: RC & FRC Wall

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Abstract: Design and calculation of crack width in high capacity Clarifier reinforced concrete tanks are time consuming task, which requires a great deal of expertise. Many times it is required to know crack width of a tank of known capacity and geometry before its detailed design. In high capacity water tanks reinforced concrete wall built using high strength deformed bars and designed using limit state design method were found to have larger crack widths. To control these crack widths in reinforced and fibre reinforced concrete to enhance durability. The latest revision of the Indian code stresses the importance of durability and has not reduced formulae to calculate the crack widths. In this case it is important to select reinforced concrete structures with minimization of crack width including other parameters, i.e. thickness of section, area of steel required, spacing of steel, cover etc. However, under cases such as severe exposure conditions and in water tanks we may check the crack width by theoretical calculations. Cracks can be produced also by shrinkage and temperature variations. Extra reinforcements to reduce such cracks are always necessary in reinforced concrete. The methods for calculation of widths of cracks due to loads as well as those due to shrinkage and temperature changes are in this tool. Main reasons for limiting the crack width in concrete walls are corrosion and water tightness. The highlights the need of introducing graph in such a way that all design parameters are incorporate in one graph, i.e. diameter of bar, area of steel requirements, spacing of steel, thickness of concrete wall, service bending moment for controlling crack widths in Indian codes on similar lines of the BS code. The crack width in water tank is calculated to satisfy a limit state of serviceability.

Keywords: Clarifier; Reinforced concrete; Fibre reinforced concrete; Crack width.

I. Introduction

Water retaining reinforced concrete structures built using high strength deformed bars and designed using limit state design method were found to have larger crack widths. To control these crack widths and to enhance durability, different codes prescribe limiting crack widths based on the environment in which the structure exists. The latest revision of the Indian code stresses the importance of durability and has not reduced formulae to calculate the crack widths. In this case it is important to select reinforced concrete structures with minimization of crack width including other parameters, i.e. thickness of section, area of steel required, spacing of steel, cover etc. However, under cases such as severe exposure conditions and in water retaining structures we may check the crack width by theoretical calculations. Cracks can be produced also by shrinkage and temperature variations. Extra reinforcements to reduce such cracks are always necessary in reinforced concrete. The methods for calculation of widths of cracks due to loads as well as those due to shrinkage and temperature changes are in this chapter.

The crack width depends on the following quantities.

- 1) Amount of stress in steel
- 2) Thickness of the concrete cover
- 3) Diameter and spacing of main bars
- 4) Depth of member and location of neutral axis

There are three perceived reasons for limiting the crack width in concrete. These are appearance, corrosion and water tightness. It may be particularly mentioned that all the three are not applicable simultaneously in a particular structure. Appearance is important in the case of exposed concrete for aesthetic reasons. Similarly, corrosion is important for concrete exposed to aggressive environments. Water tightness is required in the case of water retaining structures. Appearance requires limit of crack widths on the surface, this can be ensured by locating the reinforcement as close as possible to the surface (by using small covers) which will prevent cracks

from widening. Corrosion control on the contrary requires increased thickness of concrete cover and better quality of concrete. Water tightness requires control on crack widths but applicable only to special structures. Hence, a single provision in the code is not sufficient to address the control of cracking due to all the above three reasons. Unfortunately, the formulae given in the Indian code are complex and are seldom used in practice. However, recent research has found that there is no correlation between corrosion and crack widths. Also, there was a large scatter in the measured crack widths even in controlled laboratory experiments. Hence, a simple formula, involving the clear cover and calculated stress in reinforcement at service load has been included in the latest revision of the IS code. The highlights the need of introducing a simple formula for controlling crack widths in Indian codes on similar lines of the BS code. The crack width in water retaining structure is calculated to satisfy a limit state of serviceability.

II. Application of Fibre Reinforced Concrete

Fibre-reinforced concrete has specialized properties and can enhance impact, abrasives, high durability, shatter, and vibration. In beginning, fibre-reinforced concrete were used for pavement and industrial slabs. But recently, applications of fibre-reinforced concrete have wide variety usage in structures such as heavy-duty pavement, airplane runways, industrial slabs, water tanks, canals, dam structure, parking structure decks, water and wastewater treatment plant, pipes, channel, precast panels, structures resist to earthquake and explosives and the techniques of concrete application.

A list of application for Fibre reinforced concrete:

- Floors, walls, driveways and walks to reduce shrinkage and cracking problems are desirable.
- Increase of toughness in fibre-reinforced concrete is ideal for buildings and pavements subject to shatter, impact, abrasion, and shear.
- Its use in crack control and shrinkage for water retaining and reservoir structures to reduce the permeability and freeze-thawing conditions.
- Its replacement for temperature steel in sanitary sewer tunnels prevents corrosion and improves ductility.
- Runways are made more resistant to fuel spills with less permeable and shatter resistant fibre reinforced concrete.
- Pumped concrete project gets easy and safe with fibre, making concrete more cohesive and prevent segregation.

III. Polypropylene Fibres (micro-synthetic fibres)

Polypropylene fibres are gaining in significance due to the low price of the raw polymer material and their high alkaline resistance (Keer, 1984; Maidl, 1995). They are available in two forms i.e. monofilament or fibrillated manufactured in a continuous process by extrusion of a polypropylene homo polymer resin (Keer, 1984; Knapton, 2003). Micro synthetic fibres, based on 100% Polypropylene are used extensively in vertical walls & ground-supported slabs for the purpose of reducing, plastic shrinkage cracking and plastic settlement cracking. These fibres are typically 12mm long by 18µm diameter (Perry, 2003). The addition of polypropylene fibres is at a recommended dosage of approximately 0.90kg/m³ (0.1% by volume) (Knapton, 2003), the fibre volume is so low that mixing techniques require little or no modification from normal practice (Newman et al, 2003). The fibres may be added at either a conventional batching/mixing plant or by hand to the ready mix truck on site (Knapton, 2003).

Concrete mixes containing polypropylene fibres can be transported by normal methods and flow easily from the hopper outlet. No special precautions are necessary. Conventional means of tamping or vibration to provide the necessary compaction can be used. Curing procedures similar to those specified for conventional concrete should be strictly undertaken. While placed fibre-dosed mixes may be floated and towed using all normal hand and poor tools (Knapton, 2003).

IV. Crack width Analysis

Fig.1. Maximum crack width (w)

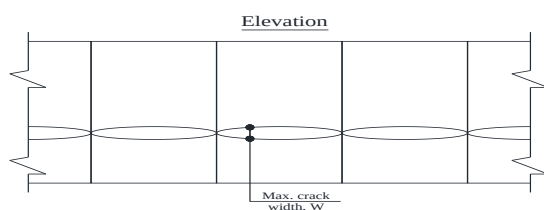


Fig.2. Position of maximum crack width (w)

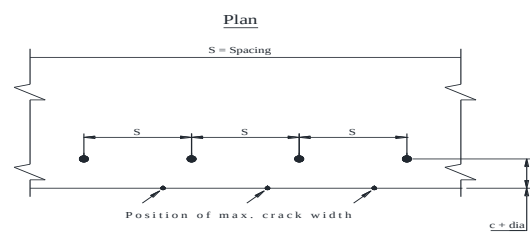


Fig.3. Enlarge part plan of wall

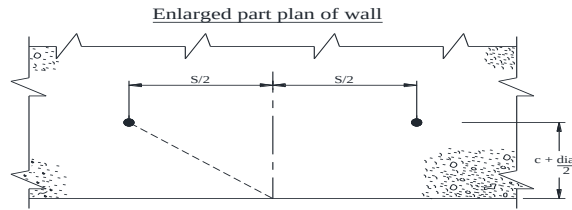
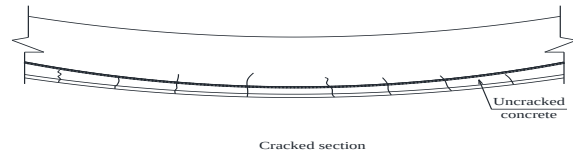


Fig.4. Cracked & Un-cracked concrete



The formula is IS 3370 for crack width in water tanks as follows:

$$w = \frac{3.0 a_{cr} \varepsilon_m}{1 + 2(a_{cr} - c_{min})/(h - x)}$$

$$\text{Where } \varepsilon_m = \varepsilon_1 - \frac{0.7 b_t h (a' - x)}{A_s f_s (h - x)} 10^{-3}$$

w = Crack width at the point considered for crack width

a_{cr} = Distance of the nearest bar from the point.

c_{min} = Minimum specified cover

ε_m = Average strain with stiffening effect

h = Overall depth of member

x = Depth of neutral axis calculated by assuming $m = E_s/0.5E_c$

ε_1 = Strain at level consideration

b_t = Width of section of centroid of tension steel

a' = Distance of compression face from the point considered for crack width

A_s = Area of steel

f_s = Service stress of steel

Here, the value of E_c is taken as one-half the instantaneous value for calculation of m .

V. Crack width Analysis in FRC

Crack control is only possible if at least one of the conditions mentioned below is satisfied.

- Presence of conventional steel bars,
- Presence of normal compressive forces (compression – pre stressing),
- Crack control maintained by the structural system itself (redistribution of internal moments and forces limited by the rotation capacity).

The calculation of the design crack width in steel fibre reinforced concrete is Similar to that in normal reinforced concrete. However, it has to be taken into account that the tensile stress in fibre reinforced concrete after cracking is not equal to zero but equal to $0.45 f_{Rm,1}$ (constant over the cracked part of the cross section).

Formula can be used to calculate the reinforcement A_{sf} (mm^2) which satisfies the crack width limit.

$$A_s = (k_c k_p f_{fct,ef} - 0.45 f_{Rm,1}) \frac{A_{ct}}{\sigma_s} \quad (\text{mm}^2)$$

With $\gamma_R = f_{yk} / \sigma_s = 1.4$ the crack width is approximately limited to 0.20 mm

$$\frac{A_{sr}}{A_{ct}} = \frac{(k_c k_p f_{fct,ef} - \frac{0.45}{1.4} f_{Rm,1})}{\frac{f_{yk}}{1.4}}$$

In ordinary reinforced concrete, the following formula is used:

$$w_k = \beta s_{r,max} (\varepsilon_{sm} - \varepsilon_{cm})$$

Where

w_k = Design crack width (mm)

β = A coefficient relating the average crack width to the design value.

$s_{r,max}$ = Average final crack spacing (mm)

ε_{sm} = Mean steel strain in the reinforcement allowed under the relevant combination of loads for the effects of tension stiffening, shrinkage, etc.

$$(\varepsilon_{sm} - \varepsilon_{cm}) = \frac{\sigma_s - k_t \frac{f_{ct,eff}}{\rho_{p,eff}} (1 + \alpha_e \rho_{p,eff})}{E_s} \geq 0.6 \frac{\sigma_s}{E_s}$$

σ_s = Stress in steel assuming cracked section

α_e = Ratio E_s/E_{cm}

$\rho_{p,eff} = \frac{A_s}{A_{c,eff}} = \text{Effective reinforcement ratio}$

- The use of a factor of safety $f_s = 1.5$ for liquid loads.
- The use of concrete grade M-30 (with a maximum water/cement ratio of 0.55 and a minimum cement content of 400 kg/m^3 - that is, durability performance comparable to grade M-30).
- The use of a minimum cover of 45mm owing to assumed severe exposure condition on internal and at least one of both faces.
- Maximum crack width limited to 0.2mm unless the aesthetic appearance is critical, when 0.1mm is used to void staining of the concrete.
- Maximum bar spacing of 300mm.
- For a wall thickness exceeding 200mm and floor thickness exceeding 300mm, reinforcement should be in two layers.
- Anchorage bond stress for straight horizontal bars in sections subjected to direct tension must be reduced to 70 percent of the usual values.
- At least 75mm blinding concrete is required below ground slabs.

VII. Advantages of the Program

- User can perform what if analysis, i.e., user can experiment effect of geometric and dimension on cost
- User will be able to watch intermediate calculations, hence better control over redesign process.
- User can easily modify the logic at later date if necessary as per revision of design course.
- As the output result will be generated in excel sheet format, construction of graphs are easily carried out for data interpretation.
- There is complete transparency of calculation of the user.

VIII. Salient Features of the program

- The develop sheet cover the method of design, i.e., Limit State Method.
- The sheet covers
- IS 456 (2000), Code of Practice for Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi.
- IS 3370(2009), Code of Practice for Concrete Structures for Storage of Liquids, Parts 1-4, Bureau of Indian Standards, New Delhi.
- British Standards Institution (1985) .BS 8110: Structural use of concrete, British Standard Institution, London.
- British Standards Institution (1987) .BS 8007: Design of concrete Structures for retaining aqueous liquids, British Standard Institution, London.
- Eurocode2 (2008): Design of concrete structures
- The sheet checks for validity of input data before executing the design
- The sheet considers predicted aspect of detailing while deciding spacing of bars and dimension of concrete.

Fig.5. Clarifier of 46mt diameter and 7mt vertical wall height under construction.



**Table 2: Crack width in Reinforced & Fibre Reinforced Concrete at 60 mm concrete cover
RBM 150 kNm**

Resultant bending moment	For concrete cover 60 mm /Crack width (mm)											
	Diameter of bar											
	10		12		16		20		25		32	
150 kNm												
wall thickness mm	RC	FRC	RC	FRC	RC	FRC	RC	FRC	RC	FRC	RC	FRC
300	0.190	0.028	0.188	0.032	0.190	0.039	0.198	0.047	0.216	0.056	0.246	0.069
350	0.153	0.028	0.153	0.032	0.157	0.040	0.167	0.048	0.189	0.058	0.223	0.072
400	0.127	0.027	0.127	0.031	0.132	0.039	0.144	0.048	0.166	0.058	0.201	0.073
450	0.101	0.025	0.102	0.029	0.107	0.037	0.119	0.045	0.140	0.055	0.175	0.069
500	0.083	0.023	0.083	0.027	0.089	0.035	0.100	0.043	0.120	0.052	0.151	0.066
550	0.067	0.021	0.067	0.025	0.072	0.032	0.082	0.039	0.100	0.048	0.128	0.060
600	0.048	0.017	0.049	0.020	0.053	0.026	0.061	0.032	0.075	0.039	0.097	0.049
650	0.033	0.013	0.034	0.015	0.037	0.020	0.043	0.024	0.053	0.030	0.070	0.038

**Table 3: Crack width in Reinforced & Fibre Reinforced Concrete at 60 mm concrete cover
RBM 450 kNm**

Resultant bending moment	For concrete cover 60 mm /Crack width (mm)											
	Diameter of bar											
	10		12		16		20		25		32	
450 kNm												
wall thickness mm	RC	FRC	RC	FRC	RC	FRC	RC	FRC	RC	FRC	RC	FRC
500	0.089	0.010	0.088	0.011	0.086	0.013	0.084	0.016	0.083	0.018	0.087	0.022
550	0.078	0.009	0.077	0.011	0.075	0.013	0.074	0.015	0.074	0.018	0.078	0.022
600	0.069	0.009	0.068	0.010	0.066	0.012	0.065	0.015	0.065	0.017	0.069	0.021
650	0.061	0.008	0.060	0.010	0.059	0.012	0.058	0.014	0.058	0.017	0.062	0.021
700	0.055	0.008	0.054	0.009	0.052	0.011	0.052	0.014	0.052	0.016	0.056	0.020
750	0.049	0.008	0.048	0.009	0.047	0.011	0.046	0.013	0.047	0.016	0.050	0.019
800	0.043	0.007	0.042	0.008	0.041	0.010	0.041	0.012	0.041	0.015	0.045	0.018
850	0.038	0.007	0.038	0.008	0.037	0.010	0.036	0.012	0.037	0.014	0.040	0.017
900	0.034	0.006	0.033	0.007	0.033	0.009	0.032	0.011	0.033	0.013	0.036	0.016

**Table 4: Crack width in Reinforced & Fibre Reinforced Concrete at 60 mm concrete cover
RBM 250 kNm**

Resultant bending moment	For concrete cover 60 mm /Crack width (mm)											
	Diameter of bar											
	10		12		16		20		25		32	
250 kNm												
wall thickness mm	RC	FRC	RC	FRC	RC	FRC	RC	FRC	RC	FRC	RC	FRC
400	0.152	0.024	0.151	0.027	0.150	0.033	0.154	0.040	0.167	0.048	0.196	0.059
450	0.130	0.023	0.129	0.026	0.130	0.033	0.135	0.040	0.148	0.048	0.178	0.059
500	0.113	0.023	0.112	0.026	0.113	0.033	0.119	0.040	0.134	0.049	0.164	0.061
550	0.098	0.022	0.098	0.026	0.099	0.033	0.106	0.040	0.120	0.049	0.150	0.061
600	0.083	0.021	0.083	0.024	0.084	0.031	0.090	0.037	0.104	0.046	0.131	0.057
650	0.070	0.019	0.070	0.022	0.071	0.029	0.077	0.035	0.089	0.043	0.114	0.054
700	0.057	0.017	0.057	0.020	0.059	0.026	0.064	0.032	0.075	0.039	0.097	0.049
750	0.047	0.015	0.047	0.018	0.048	0.023	0.053	0.028	0.062	0.035	0.081	0.044
800	0.035	0.012	0.035	0.014	0.036	0.018	0.039	0.022	0.047	0.028	0.061	0.035

Fig.6. Area of steel required for design crack width (w) 0.2mm with having cover (c) 60mm and diameter of reinforcement (ϕ) 16mm, spacing of bars (s) for Circular Tank.

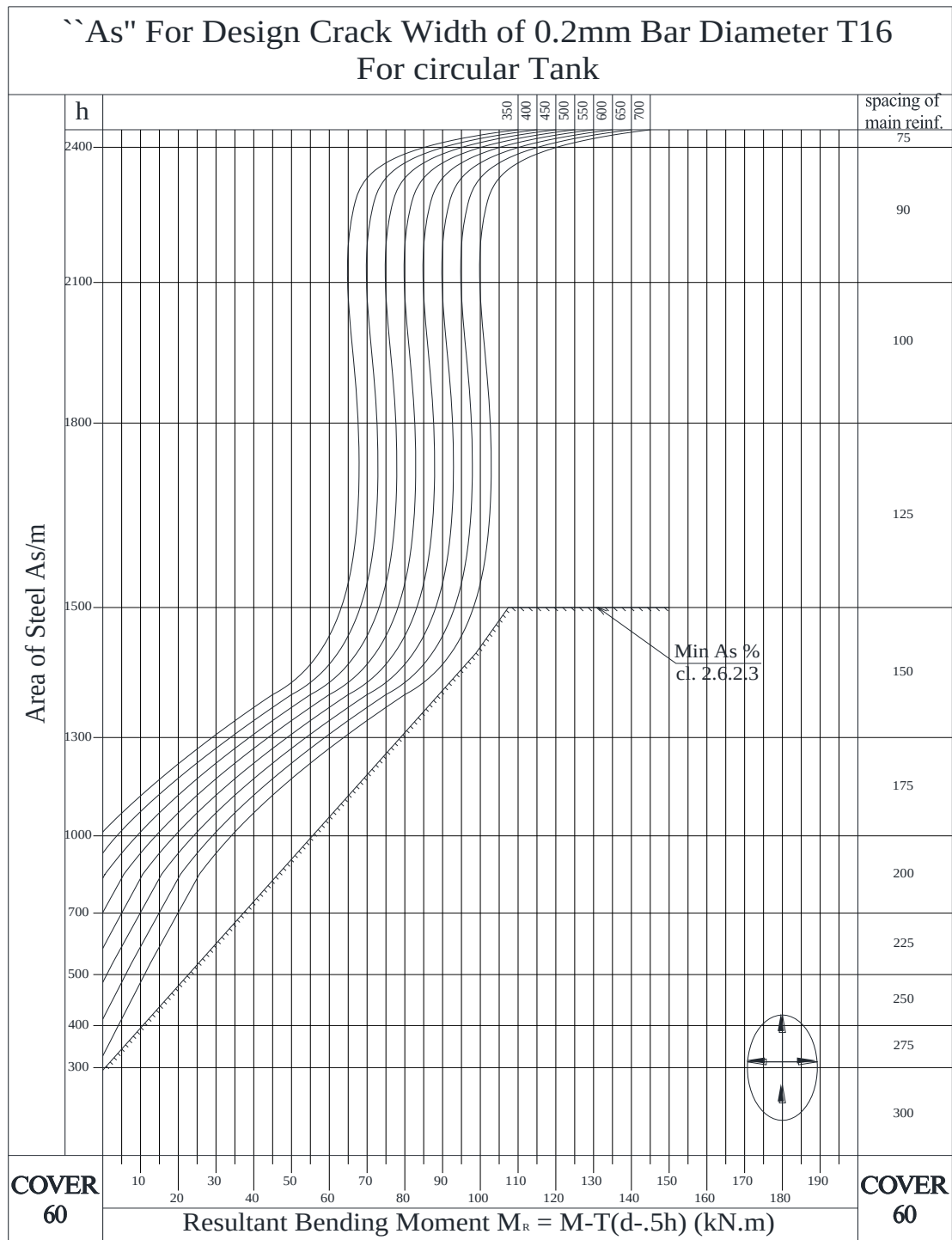


Fig.7. Area of steel required for design crack width (w) 0.2mm with having cover (c) 60mm and diameter of reinforcement (ϕ) 20mm, spacing of bars (s) for Circular Tank.

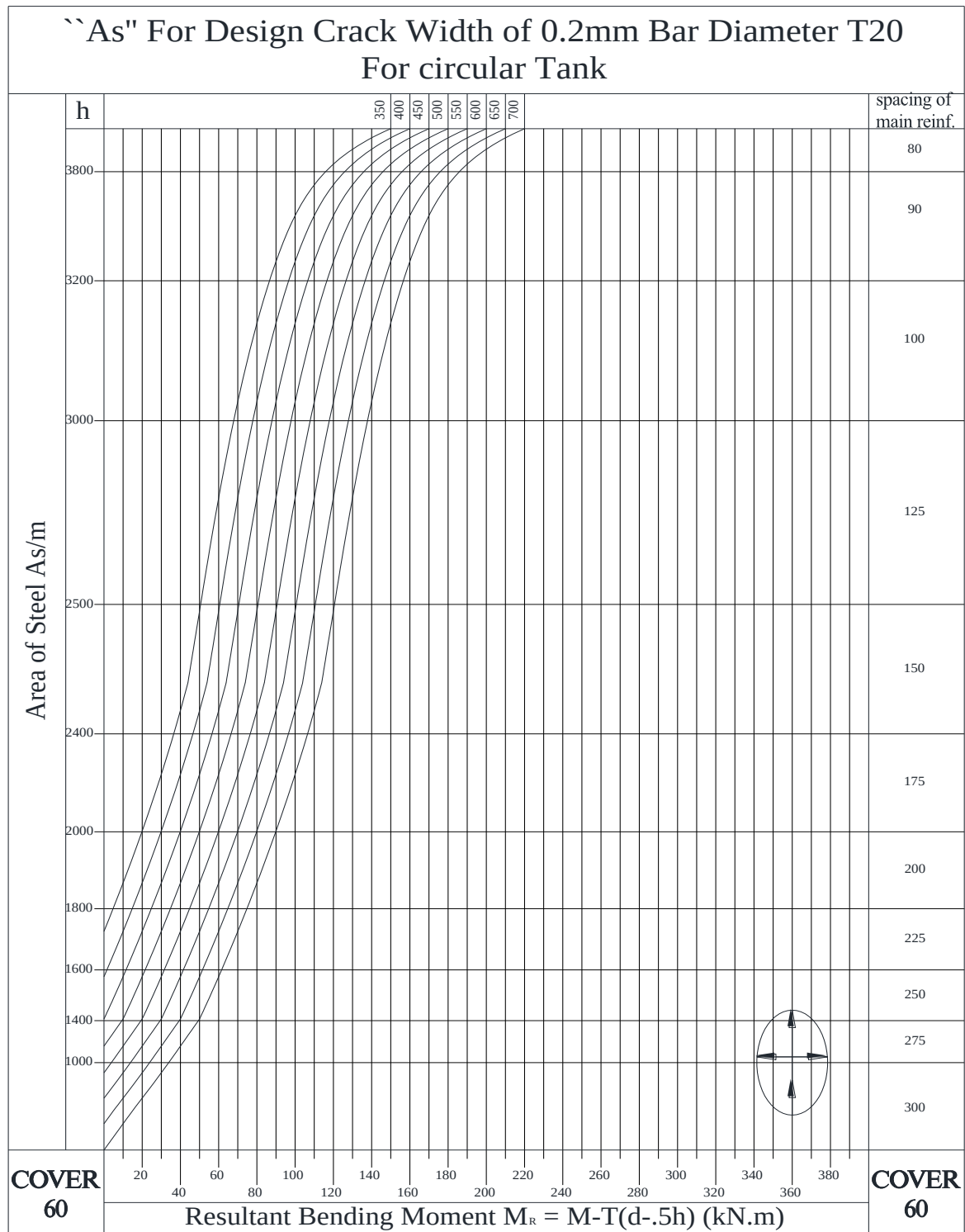
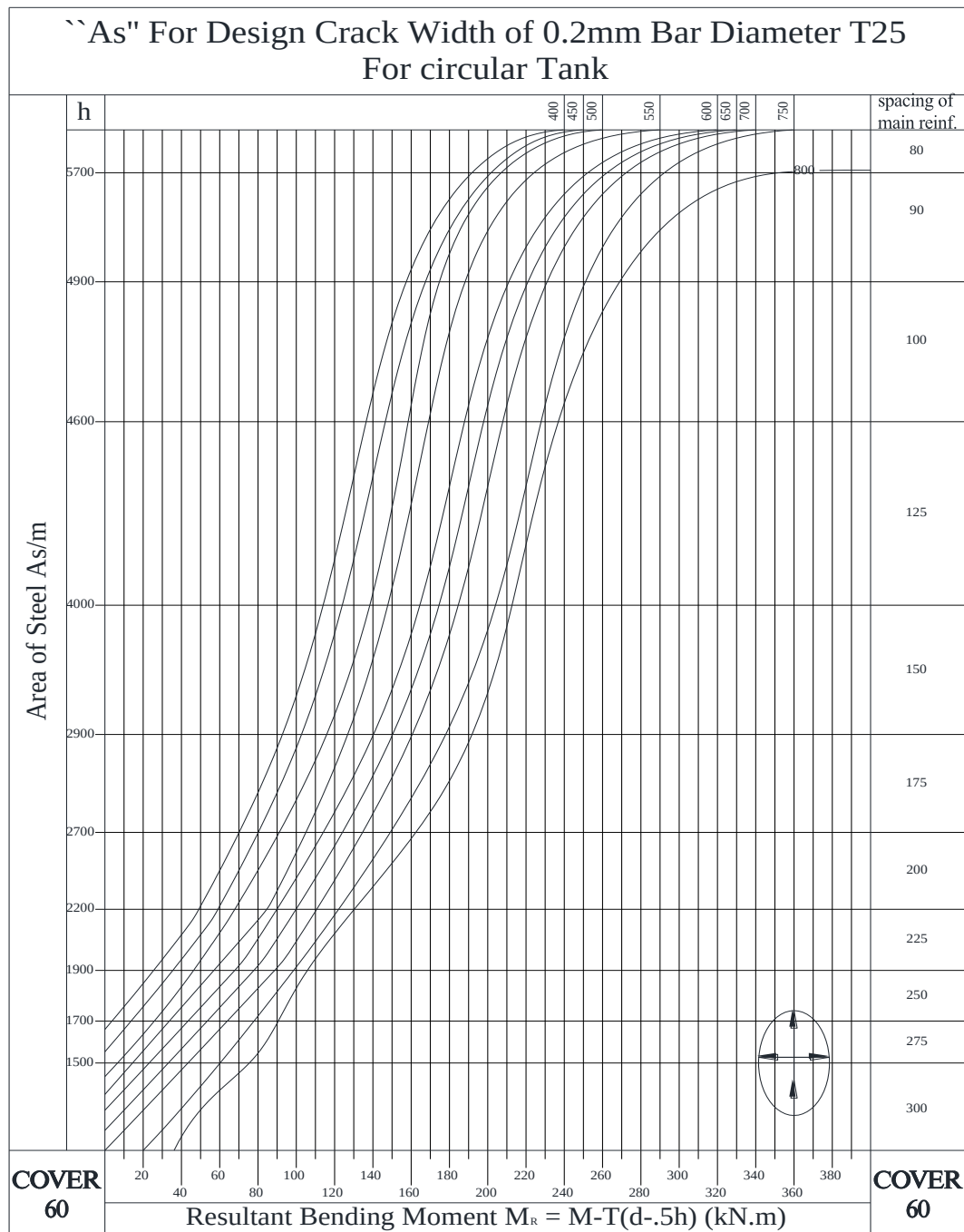


Fig.8. Area of steel required for design crack width (w) 0.2mm with having cover (c) 60mm and diameter of reinforcement (ϕ) 25mm, spacing of bars (s) for Circular Tank.



IX. Conclusion

The deterioration of modern concrete structures resulted in the inclusion of durability concepts in the recent revision of the Indian code. Though several factors affect the durability, it was thought that by controlling the crack widths, the durability can be enhanced. In the recent revision an appendix was added to calculate the crack width of flexural and tension members. However, due to the complexity of the equations, the design engineers seldom do these calculations.

Hence an attempt is made in this work to develop crack width control tool using spread sheet (MS-Office). This tool will be very useful for structural consultant for checking serviceability design criteria for reinforced concrete elements, particularly for design of water tanks.

Addition of polypropylene fibers improves the cracking behavior of concrete walls reinforced with tension bars. The inclusion of polypropylene fibres decreases both the crack spacing and crack width. A greater reduction of the crack width, the crack spacing respectively, can be noticed if polypropylene fibres with an appropriate aspect ratio are used.

For design purpose, a simple empirical expression has been established graph to predict the mean final crack spacing of polypropylene fibre reinforced members. Using this graph in the model results gives much better design for controlling the crack width.

Fibre reinforcement could be an attractive alternative to crack-controlling conventional reinforcement. The price for the concrete is increased; however, casting FRC is a much less labor-intensive operation than placing and tying conventional crack-controlling reinforcement. Conclusively, one can say that fibre reinforcement could be a new cheap crack controlling reinforcement.

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