# DEVELOPMENT OF SPREADSHEET-TOOL, DESIGN AID AND NEURAL APPROACHES FOR PREDICTING CRACK WIDTH IN CIRCULAR GROUND SUPPORTED REINFORCED CONCRETE AND FIBRE REINFORCED CONCRETE TANKS SUBJECTED TO SEISMIC LOADING

**Tulesh.N.Patel[1], Sandip.A. Vasanwala[2], Chetankumar.D. Modhera[3]**

[1] Ph.D Student, Department of Applied Mechanics, S.V.N.I.T Surat, Gujarat.India.

[2] Professor, Department of Applied Mechanics, S.V.N.I.T Surat, Gujarat, India.

[3] Professor, Department of Applied Mechanics, S.V.N.I.T Surat, Gujarat, India

## ABSTRACT

*The design and computation of crack width in circular Ground Supported Tanks (GST) wall is a time consuming task, which requires a great deal of expertise. It is essential to know crack width of a tank of required capacity and geometry, before its detailed design. In GST, reinforced concrete wall built using high strength deformed bars and designed using Limit State design method were found to have larger crack widths. To enhance durability in reinforced and fibre reinforced concrete wall, these crack widths need to be controlled (limited). It is important to design reinforced concrete structures for parameters like thickness of section, area of steel required, spacing of steel, concrete cover etc., while laying stress on minimal (limited) crack width. Main criteria for limiting the crack width in concrete walls are corrosion and water tightness. A neural network has been considered in the present solution of the analysis problem using a Neuro Solution for excel toolbox, to develop software in spread sheet tool for design and to calculate crack width in circular GST. First spread-sheet tool was developed to compute crack width in reinforced and fibre reinforced concrete wall under seismic loading condition. Design parameters such as hydrodynamic pressure and crack width, which will be affected due to the presence of obstruction inside water tanks, have been thoroughly studied. These spread-sheet tools data were used to develop a graph for controlled crack width of 0.2 mm. From this graph for controlled crack width of 0.2mm in circular and rectangular water tanks with reinforced and fibre reinforced concrete walls for particular diameter of bars using concrete grade M30 and from the resultant bending moment, we got required area of steel and spacing of*

*steel for the selected thickness of wall.*

**Keywords**: Ground Supported Tanks; Reinforced concrete; Fibre reinforced concrete; Crack width; Neural network.

## Introduction

During the preliminary phase, calculation of crack width involves decisions on a number of important factors such as diameters of bars, concrete cover, spacing of steel, concrete grade and depth of section. The outcome of these decisions has a heavy bearing on cost and appearance. However, for competitive bidding and winning contracts, the main objective is to design the circular and rectangular tanks with and without obstruction inside tank under seismic loading with minimal crack width. But analysis and design of such structures is normally time consuming. The configuration processing and data generation process is complicated since large number of nodes, member of nodes and members are involved and approximate methods are needed at preliminary stage of design process to utilize the data generated in the parametric study, for the design of crack width.Water tightness is required in the case of water retaining structures. Corrosion control on the contrary requires increased thickness of concrete cover and better quality of concrete. While water tightness requires control on crack widths and is applicable only to special structures. Hence, a single provision in the code is not sufficient to address the control of cracking possible due to all the above reasons. Unfortunately, the formulae given in the IS code are complex and hence are seldom used in practice. Moreover, recent research has found that there is no correlation between corrosion and crack widths. Also, the results of measured crack widths even in controlled laboratory experiments are immensely diverse.

**Artificial Neural Networks (ANNs)** are amongst the Artificial Intelligence tools in which the human creativity, intuition and past experience can be incorporated in the network training process. Like human experts, ANNs learn from experience and examples. Research has shown that it is possible to model some of the activities of the conceptual design stage of the design process using ANNs. Though plenty of research work has been carried out on ANNs application in structural engineering, very little information is available in published literature for neural network application for determination of crack width under seismic loading. Hence a need is felt to carry out such investigation for calculating crack width with varying design parameters. Therefore researches need to be focussed on developing neural based methodology that can be used for the design of crack width.

**Ground Supported Tank**

Ground supported tanks including on-grade and below grade structures can be classified according to the following characteristics (ACI 350.3-06, 2006):

- Tank configuration (rectangular or circular)
- Wall support condition fixed at base
- Method of construction (reinforced concrete (RC) or fibre reinforced concrete (FRC))

It should be noted that, the most general type of liquid retaining structures are upright rectangular and circular tanks. This study focuses on on-grade open top circular and rectangular tanks with fixed base conditions. Reinforced and Fibre reinforced concrete construction methods are considered in this research study. It should be noted that the use of fibre reinforced concrete is only considered for circular and rectangular tanks with fixed base. *Overall, despite the limitations of ANNs, they have a number of significant benefits that make them a powerful and practical tool for solving many problems in the field of structural engineering. Applied appropriately, neural networks are certainly the key technology for future intelligent civil engineering structures.*

**Polypropylene Fibres**

Polypropylene fibres are gaining in significance due to the low price of the raw polymer material and their high alkaline resistance. Micro synthetic fibres, based on 100% Polypropylene are used extensively in walls & ground-supported slabs for the purpose of reducing, plastic shrinkage cracking and plastic settlement cracking. These fibres are typically 12 mm long and 18μm in diameter.

**Seismic Design of Ground Supported Tank**

Hydrodynamic forces exerted by liquid on tank wall considered in the analysis in addition to hydrostatic forces. These hydrodynamic forces are evaluated with the help of spring mass model of tanks.

Dynamic analysis of liquid containing tank is a complex problem involving fluid-structure interaction. Based on numerous analytical, numerical and experimental studies, simple spring mass models of tank-liquid system have been developed to evaluate hydrodynamic forces.

**Spring Mass Model for Seismic Analysis**

When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base. Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented.

Sometimes, vertical columns and shaft are present inside the tank. These elements cause obstruction to sloshing motion of liquid. In the presence of such obstructions, impulsive and convective pressure distributions are likely to change. At present no study is available to quantify effect of such obstructions on impulsive and convective pressures. However, it is reasonable to expect that due to presence of such obstructions, impulsive pressure will increase and connective pressure will decrease.

**Figure 1:** Ground Supported Circular Tanks of 30 metre and 42 metre diameter without Obstruction inside Tank for Effluent Treatment Plant at Surat.

**Figure 2:** Ground Supported Circular Tanks of 30 metre and 42 metre diameter with Obstruction inside Tank for Effluent Treatment Plant at Surat

**Crack Width Control: Spreadsheet Tool**

The design problem is first represented in the spreadsheet. In this spreadsheet tools we shall put input required parameters like size of tanks, Grade of concrete, Grade of steel, height of wall and we get area of steel required, spacing of steel for particular bar diameter, crack width in RC/FRC wall for assume thickness of wall.

The design problem is first represented in a spreadsheet Tool.

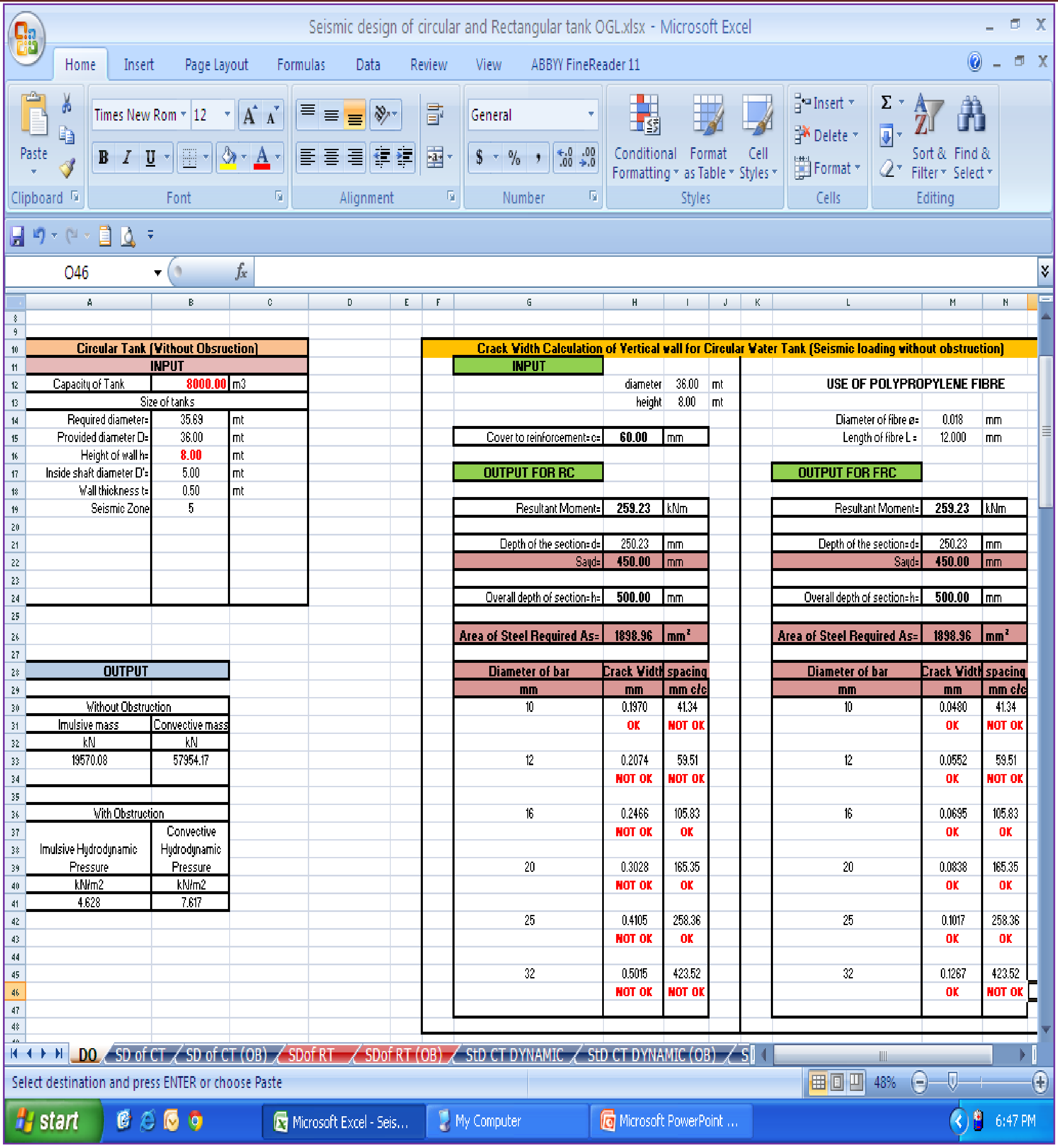


**Figure 3:** Crack Width Calculation Spreadsheet Tool for Circular Tank Without Obstruction

**Development of Tables**

The data illustrate in this table of masses in impulsive and convective mode with or without obstruction in circular as well as rectangular tank and also shown effect on impulsive and convective hydrodynamic pressure on wall.

**Table 1**. Impulsive and Convective Mass in Circular Tank With and Without Obstruction for Wall Height 5.0 m

| Capacity of Tank | Tank Wall Height | With Obstruction | | Without Obstruction | | Increase of Impulsive Mass | Decrease of Convective Mass |
|---|---|---|---|---|---|---|---|
| | | Impulsive Mass | Convective Mass | Impulsive Mass | Convective Mass | | |
| $m^3$ | m | kN | kN | kN | kN | % | % |
| 1000 | 5.00 | 3586.84 | 5988.12 | 3249.50 | 6375.64 | 3.37 | 3.88 |
| 2000 | 5.00 | 5603.35 | 14467.06 | 4689.62 | 15057.74 | 9.14 | 5.91 |
| 3000 | 5.00 | 5816.54 | 22651.48 | 5710.50 | 23380.84 | 1.06 | 7.29 |
| 4000 | 5.00 | 7023.81 | 30436.80 | 6526.50 | 31275.22 | 4.97 | 8.38 |
| 5000 | 5.00 | 8367.08 | 39308.11 | 7342.36 | 40254.64 | 10.25 | 9.47 |
| 6000 | 5.00 | 9658.89 | 47955.26 | 8056.22 | 48995.91 | 16.03 | 10.41 |
| 7000 | 5.00 | 10854.80 | 56021.67 | 8668.08 | 57142.75 | 21.87 | 11.21 |
| 8000 | 5.00 | 12133.77 | 64690.76 | 9279.95 | 65892.12 | 28.54 | 12.01 |
| 9000 | 5.00 | 13263.62 | 72374.63 | 9789.84 | 73642.79 | 34.74 | 12.68 |
| 10000 | 5.00 | 14452.10 | 80475.85 | 10299.73 | 81810.75 | 41.52 | 13.35 |

**Table 2**. Impulsive and Convective Hydrodynamic Pressure in Circular Tank With and Without Obstruction for Wall Height 5.0 m

| Capacity of Tank | Tank Wall Height | With Obstruction | | Without Obstruction | | Increase of Impulsive HD Pressure | Decrease of Convective HD Pressure |
|---|---|---|---|---|---|---|---|
| | | Impulsive HD Pressure | Convective HD Pressure | Impulsive HD Pressure | Convective HD Pressure | | |
| $m^3$ | m | $kN/m^2$ | $kN/m^2$ | $kN/m^2$ | $kN/m^2$ | % | % |
| 1000 | 5.00 | 11.181 | 4.982 | 9.967 | 5.569 | 0.012 | 0.006 |
| 2000 | 5.00 | 8.242 | 5.346 | 7.380 | 5.954 | 0.009 | 0.006 |
| 3000 | 5.00 | 6.918 | 5.477 | 6.209 | 6.094 | 0.007 | 0.006 |
| 4000 | 5.00 | 6.127 | 5.545 | 5.507 | 6.168 | 0.006 | 0.006 |
| 5000 | 5.00 | 5.497 | 5.594 | 4.946 | 6.220 | 0.006 | 0.006 |
| 6000 | 5.00 | 5.043 | 5.625 | 4.542 | 6.254 | 0.005 | 0.006 |
| 7000 | 5.00 | 4.709 | 5.647 | 4.244 | 6.277 | 0.005 | 0.006 |
| 8000 | 5.00 | 4.417 | 5.664 | 3.982 | 6.296 | 0.004 | 0.006 |
| 9000 | 5.00 | 4.200 | 5.677 | 3.788 | 6.309 | 0.004 | 0.006 |
| 10000 | 5.00 | 4.002 | 5.687 | 3.612 | 6.321 | 0.004 | 0.006 |

**Development of Graphs**

Here are the extremely easy and user friendly four way developed graph from which we can get directly area & spacing of steel for required resultant bending moment at assume thickness of wall such that not more than 0.2 mm crack width can generated for fibre reinforced concrete wall of particular diameter of bar at concrete cover 60 mm.

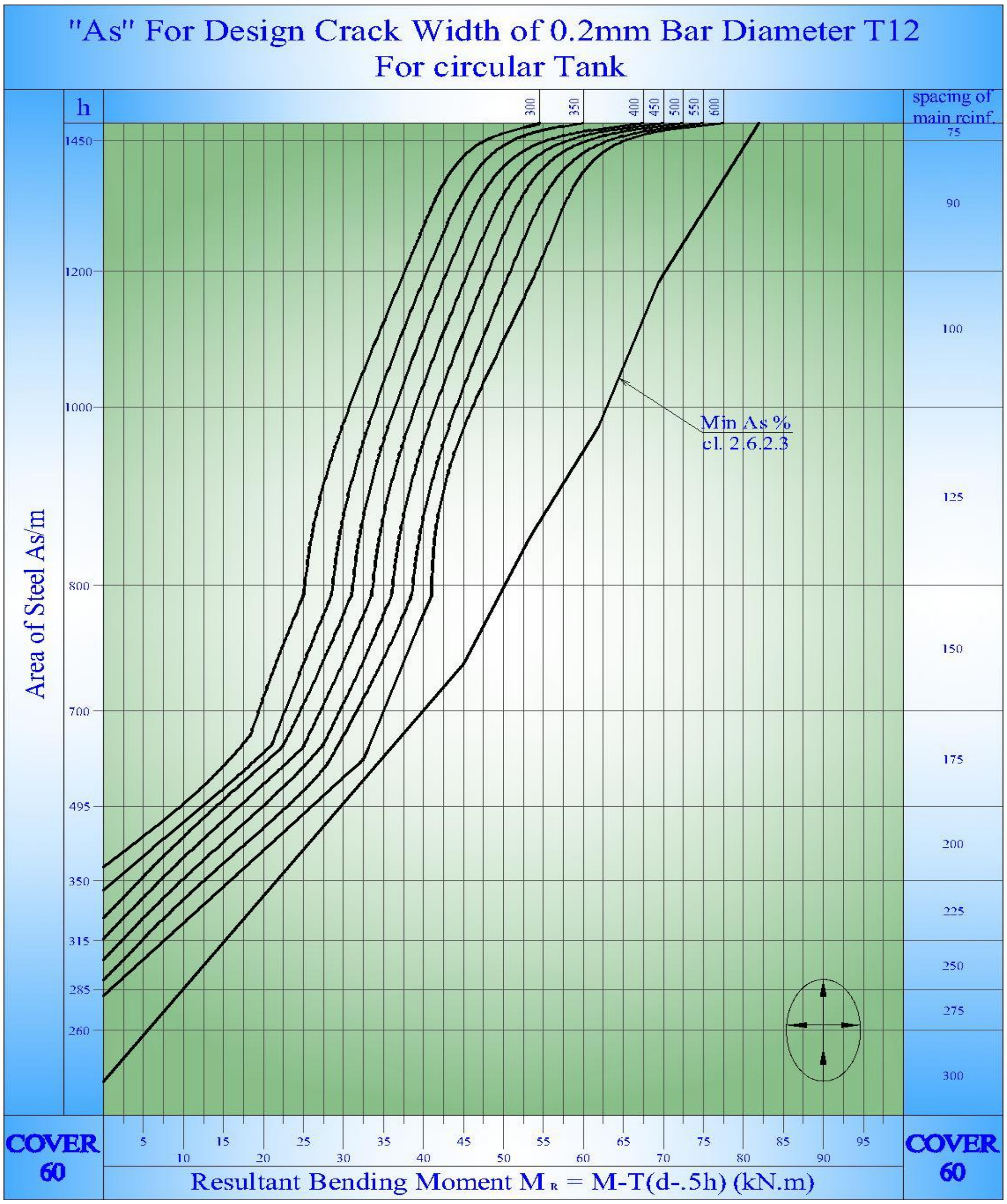


**Figure 4:** Area of Steel Required for Design Crack Width (w) 0.2mm with having Cover $(c)$ 60 mm and Diameter of Reinforcement $(\emptyset)$ 12mm, Spacing of Bars (s).

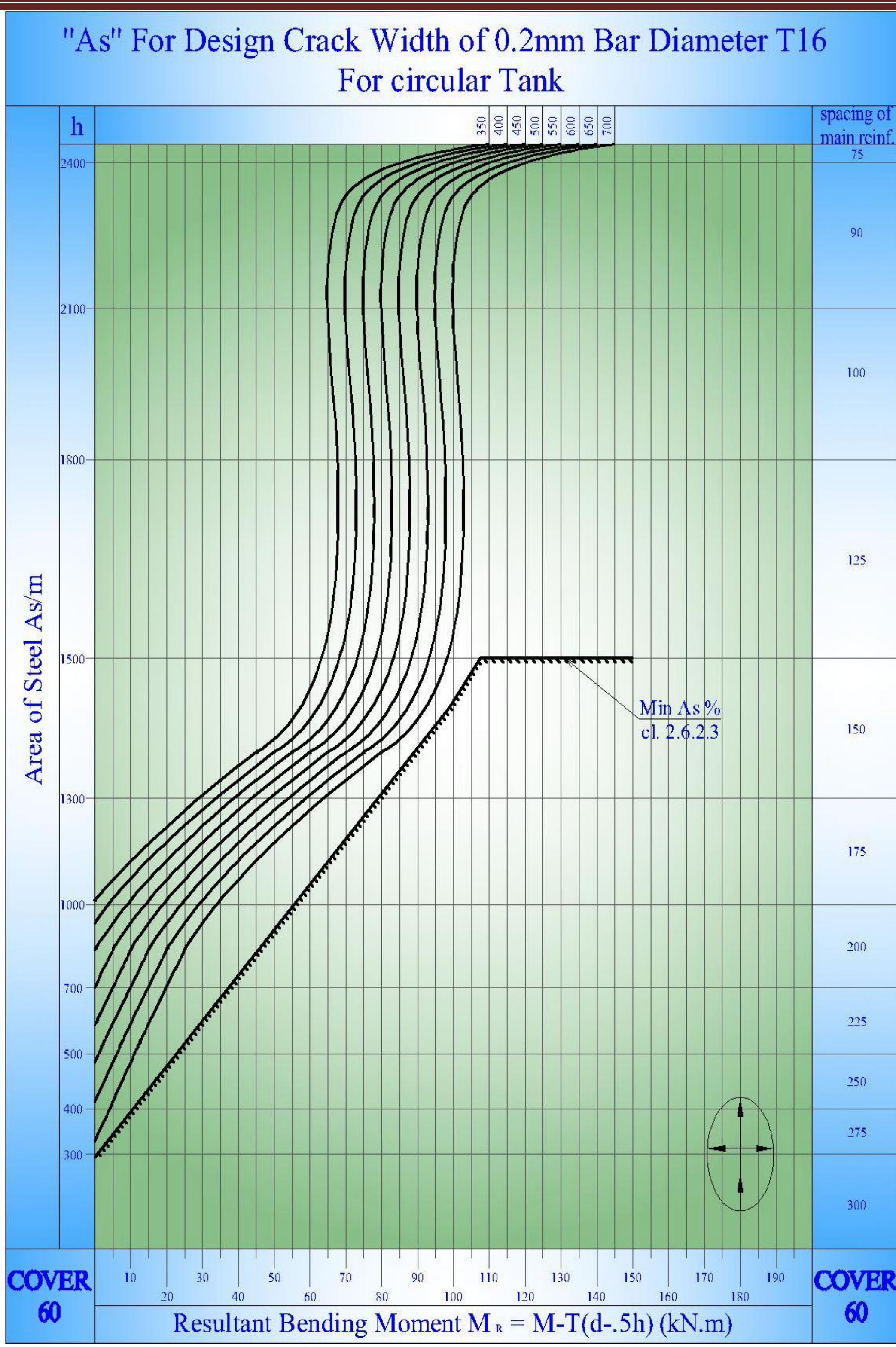


**Figure 5:** Area of Steel Required for Design Crack Width (w) 0.2mm with having Cover $(c)$ 60 mm and Diameter of Reinforcement $(\emptyset)$ 16mm, Spacing of Bars (s).

**Artificial Neural Networks (ANN)**

Artificial neural networks are parallel computing devices consisting of many interconnecting simple processors. These processors are quite simplistic, especially when compared with the type of processors found in a computer. Each processor in a network is only aware of signals it periodically receives and the signals it periodically sends to other processors and yet such simple local processors are capable of performing complex tasks when placed together in a large network of orchestrated cooperation. The word 'artificial' is sometimes used to make it clear that the discussion is about an artificial device and not about the real biological neural networks found in humans.

**Input parameters of ANN**

- Capacity of tanks, Wall thickness, Height of wall, Bar diameter,

**Output parameters of ANN**

- Crack width in RC wall and FRC wall

**Neuro Solution Software**

Following are the pictorial output of Neuro Solution Software for Excel used for these crack width designing for cricular and rectangular tank with or without obstruction present inside tank under seismic loading.

For each tank case, the topology of the networks contains four inputs nodes, two outputs nodes, one pattern layer (Gaussian) as illustrated.

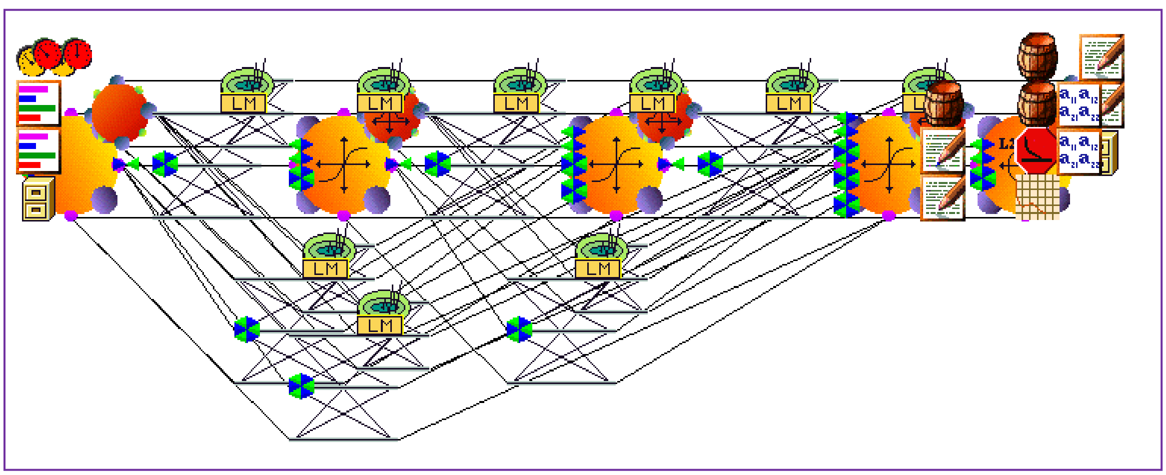

**Figure 6.** Neuro Solution Software for Circular Tank (Multilayer Perceptron)

Now here we have table showing predicted crack width using MLP and RBF training and testing data for given capacity of tank, wall thickness, height of wall and bar diameter in RC and FRC circular as well as rectangular tank with or without obstruction. These compared with the crack width we got using the developed spreadsheet tool.

**Graphical Presentation of Crack width Prediction for Circular Tank RC & FRC Wall With Obstruction (Testing and Training).**

The following are graphically shown of percentage of error for crack width in training and testing for circular tank with or without obstruction.

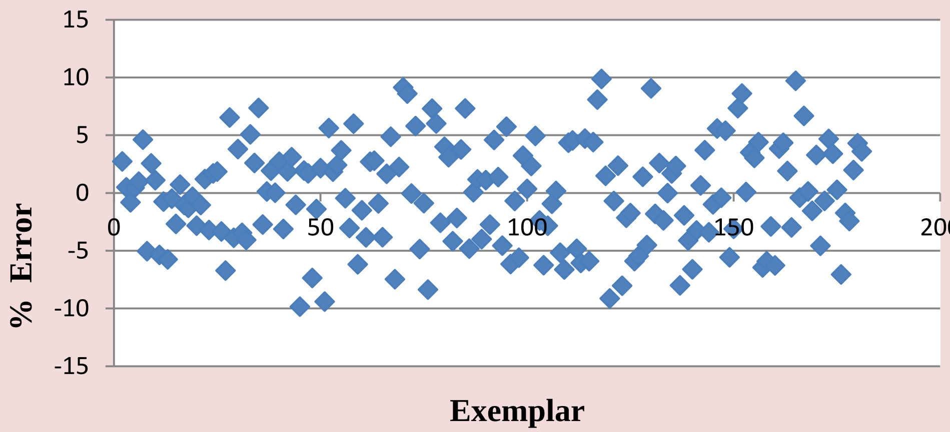


**Fig 7:** Percent error for prediction of crack width in circular tank RC wall with obstruction (Training)

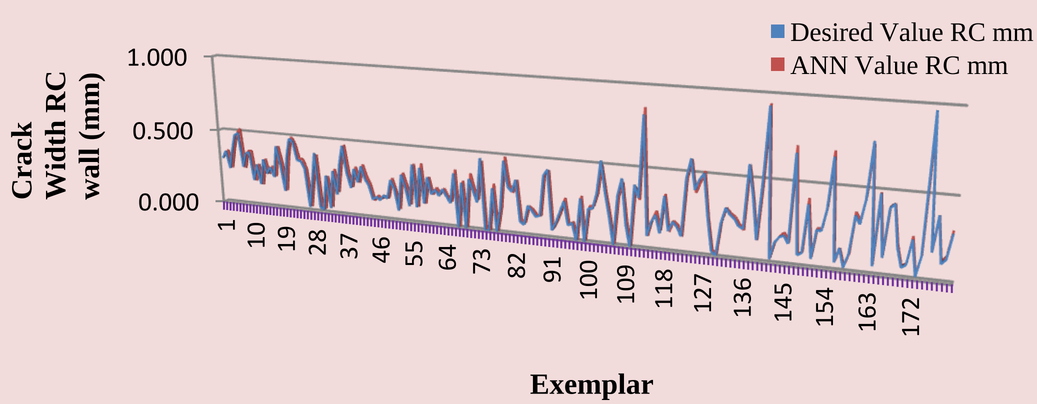


**Fig 8:** Net training performance of crack width in circular tank RC wall with obstruction

**Observation of Graphs**

Percentages of error in these graphs are for predicting crack width in circular tank with and without obstruction. As we can see there is maximum error about 10% below. These graphs shows the desired and predicted crack width by spreadsheet tools and using MLP training, as two lines are almost coinciding, we can conclude that the result obtained the spreadsheet tool are verified.The following tables showing comparison between desired crack widths obtained from spreadsheet tool, predicted from MLP and RBF.

**Table 3:** Comparison of Training Data for Crack width in Circular Tank With Obstruction

| Capacity of Tank | Wall Thick | Ht. of Wall | Bar Dia | RC CW Desired | RC CW Predicted by RBF | RC CW Predicted by MLP | FRC CW Desired | FRC CW Predicted by RBF | FRC CW Predicted by MLP |
|---|---|---|---|---|---|---|---|---|---|
| $m^3$ | mm | m | mm | mm | mm | mm | mm | mm | mm |
| 1000 | 400 | 10 | 25 | 0.414 | 0.420 | 0.409 | 0.121 | 0.125 | 0.115 |
| 2000 | 450 | 5 | 16 | 0.028 | 0.026 | 0.026 | 0.013 | 0.014 | 0.013 |
| 3000 | 500 | 10 | 16 | 0.268 | 0.267 | 0.278 | 0.070 | 0.071 | 0.073 |
| 3000 | 500 | 5 | 12 | 0.125 | 0.127 | 0.113 | 0.055 | 0.056 | 0.050 |
| 4000 | 550 | 8 | 20 | 0.244 | 0.266 | 0.249 | 0.074 | 0.077 | 0.074 |
| 4000 | 550 | 5 | 16 | 0.237 | 0.247 | 0.254 | 0.097 | 0.102 | 0.097 |
| 5000 | 600 | 5 | 32 | 0.531 | 0.544 | 0.570 | 0.249 | 0.253 | 0.237 |
| 5000 | 600 | 5 | 25 | 0.467 | 0.447 | 0.486 | 0.196 | 0.194 | 0.197 |
| 6000 | 650 | 6 | 25 | 0.272 | 0.278 | 0.271 | 0.098 | 0.104 | 0.102 |
| 7000 | 700 | 8 | 32 | 0.130 | 0.124 | 0.118 | 0.038 | 0.039 | 0.036 |
| 8000 | 750 | 8 | 12 | 0.012 | 0.012 | 0.012 | 0.004 | 0.004 | 0.004 |
| 8000 | 750 | 8 | 16 | 0.016 | 0.017 | 0.015 | 0.005 | 0.005 | 0.005 |
| 9000 | 800 | 7 | 16 | 0.179 | 0.182 | 0.179 | 0.056 | 0.056 | 0.055 |
| 9000 | 800 | 9 | 25 | 0.108 | 0.116 | 0.102 | 0.028 | 0.029 | 0.025 |
| 10000 | 850 | 10 | 20 | 0.140 | 0.146 | 0.146 | 0.036 | 0.036 | 0.037 |
| 10000 | 850 | 5 | 25 | 0.970 | 0.951 | 0.902 | 0.296 | 0.290 | 0.296 |

**Table 4:** Comparison of Training Data for Crack Width in Circular Tank Without Obstruction

| Capacity of Tank | Wall Thick | Ht. of Wall | Bar Dia | RC CW Desired | RC CW Predicted by RBF | RC CW Predicted by MLP | FRC CW Desired | FRC CW Predicted by RBF | FRC CW Predicted by MLP |
|---|---|---|---|---|---|---|---|---|---|
| $m^3$ | mm | m | mm | mm | mm | mm | mm | mm | mm |
| 1000 | 400 | 7 | 25 | 0.410 | 0.422 | 0.411 | 0.111 | 0.113 | 0.114 |
| 2000 | 450 | 8 | 32 | 0.494 | 0.485 | 0.495 | 0.102 | 0.101 | 0.102 |
| 3000 | 500 | 6 | 20 | 0.319 | 0.316 | 0.325 | 0.097 | 0.099 | 0.099 |
| 3000 | 500 | 8 | 16 | 0.290 | 0.299 | 0.294 | 0.068 | 0.067 | 0.697 |
| 4000 | 550 | 6 | 25 | 0.358 | 0.363 | 0.354 | 0.112 | 0.106 | 0.108 |
| 4000 | 550 | 5 | 32 | 0.201 | 0.187 | 0.181 | 0.066 | 0.066 | 0.064 |
| 5000 | 600 | 10 | 20 | 0.311 | 0.312 | 0.313 | 0.066 | 0.067 | 0.068 |
| 5000 | 600 | 8 | 12 | 0.225 | 0.228 | 0.225 | 0.050 | 0.049 | 0.052 |
| 6000 | 650 | 10 | 16 | 0.260 | 0.271 | 0.268 | 0.053 | 0.054 | 0.055 |
| 6000 | 650 | 5 | 25 | 0.109 | 0.100 | 0.108 | 0.039 | 0.037 | 0.398 |
| 7000 | 700 | 9 | 32 | 0.479 | 0.458 | 0.480 | 0.083 | 0.082 | 0.083 |
| 8000 | 750 | 10 | 16 | 0.253 | 0.250 | 0.247 | 0.054 | 0.053 | 0.052 |
| 9000 | 800 | 8 | 20 | 0.237 | 0.228 | 0.235 | 0.059 | 0.055 | 0.059 |
| 10000 | 850 | 5 | 25 | 0.550 | 0.531 | 0.528 | 0.160 | 0.152 | 0.154 |

**Experiment Works**

**Figure 9.** Crack width measurement using microscope 40-X on ground supported rectangular and circular tank at Surat near Kadoara –Ahmedabad national highway for Effluent Treatment Plant.

The following tables showing comparison between desired crack width obtained from spreadsheet tool, measurement from crack width microscope (40X) , predicted from Multilayer Perceptron and Radial Basis Function.

**Table 5:** Comparison of Crack Width Data at Feild in Circular Tank With Obstruction

| Capacity of Circular Tank | Wall Thick | Ht. of Wall | Bar Dia | Crack Width (With Obstruction) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Spread Sheet tool | ANN | | On Field |
| | | | | FRC | FRC by RBF | FRC by MLP | FRC |
| $m^3$ | mm | mt. | mm | mm | mm | mm | mm |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.110 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.080 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.120 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.130 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.090 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.140 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.135 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.090 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.150 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.140 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.110 |
| 10000 | 850 | 6 | 16 | 0.126 | 0.127 | 0.120 | 0.130 |

**Conclusions**

First data were generated using spreadsheet tool, graphs and calculated crack widths of the circular tanks with & without obstruction under seismic loading. Following observations have been made for finding solutions to preliminary crack width design problems using artificial neural network

- The primary benefit from simulating structural analysis with neural network is the ability to obtain crack width in less time.
- An attempt has been made to develop spreadsheet tool to predict crack width for ground supported rectangular and circular tank with and without obstructions, also seismic loading has been considered. These spread sheet tools will be very helpful to the designer taking cost effective decision at conceptual design stage.
- It is to be noted that the designer can be use these spreadsheet to carry out detail design of GST under seismic loading.
- As on today no such design tool is available in global contest. This is of immense help to the designer to perform what is analysis to take right decision during the design stage of GST.
- The performance obtained of neural networks for pilot study shows the potentiality of application of ANN technology for preliminary design of crack width in GST. This can be of immense help for accurately predicting of crack width with or without obstruction.
- Overall, despite the limitations of ANNs, they have a number of significant benefits that make them a powerful and practical tool for solving many problems in the field of structural engineering. Applied appropriately, neural networks are certainly the key technology for future intelligent civil engineering structures.

**References**

[1] B. Chiaia, A. P. Fantilli and P. Vallini (2008): *"Crack Patterns in Reinforced and Fibre Reinforced Concrete Structures". The Open Construction and Building Technology Journal*, 146-155.

[2] D. Pettersson and S. Thelandersson, (2001): **"***Crack development in concrete structures due to imposed strains - Part I: Modelling".* Vol. 34, pp 7-13.

[3] Haroun, M. A. and Housner, G. W. (1984), *"Seismic design of liquid storage tanks"*, Journal of Technical Councils of ASCE, Vol. 107, TC1, 191-207.

[4] Henrik Stang & Tine Aarre. (1992): "*Evaluation of Crack Width in FRC with Conventional reinforcement*" Cement & Concrete Composites 14 143-154.

[5] Hong Sung Nam and Han Kyoung Bong. (2008) :"*Estimate of Flexural Crack Width in Reinforced Concrete Members*." The 3rd International Conference B 19 752-758.

[6] Housner, G. W.,(1963)a, *"Dynamic analysis of fluids in containers subjected to acceleration",* Nuclear Reactors and Earthquakes, Report No. TTD 7024, U. S. Atomic Energy Commission, Washington D.C.s

[7] J. Zhang1 and H. Stang,(1998): "*Application of stress crack width relationship in predicting the flexural behavior of fibre-reinforced concrete*". Cement and Concrete Research, Vol. 28, No. 3, pp. 439–452.