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Predicting Crack Width in Circular Ground Supported Reservoir Subject to Seismic Loading Using Radial Basis Neural Networks: RC & FRC Wall

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Abstract: Design and calculation of crack width in circular GSR walls 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 circular GSR 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 wall 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. A back propagation 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 & calculate of crack width circular on ground water tank RC, FRC wall. The main benefit is using a neural network approach is that the network is built directly from experimental or theoretical data using the self-organizing capabilities of the neural network. The input parameters for the software are size of circular tank. 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: Software; Ground supported reservoir; 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 presented in this paper.

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. 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.

Neural computing is defined as the study of networks of adaptable nodes which, through a process of learning from examples. Store experimental knowledge and make it available for use. In other words, neural networks are highly simplified models of the human neural systems. The most important property of neural networks in engineering problems is their capability of learning directly from examples. The other important properties of neural networks are their correct or nearly correct responses to incomplete tasks.

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.

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/m^3 (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 troweled using all normal hand and power tools (Knapton, 2003).

IV. 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).

V. Crack width control: Spread sheet tool

The design problem is first represented in the spread sheet. The main inputs required from the designers are first represented under various sections namely;

- Size of tanks
- Grade of concrete
- Grade of steel
- Diameter of steel
- Spacing of steel
- Cover

VI. 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.

Table 1: Input and output data for circular tank

Crack Width Calculation of Vertical wall for Water Tank

INPUT

diameter: 55.00 mm
 height: 10.00 m
 Cover to reinforcement: 69.00 mm

OUTPUT FOR IRC

Regular Moment: 346.70 kNm
 Depth of the section: 302.17 mm
 Sagd: 509.00 mm
 Overall depth of section: 559.00 mm
 Area of Steel Required As: 6959.57 mm²

USE OF POLYPROPYLENE FIBRE

Diameter of fibre: 0.018 mm
 Length of fibre L: 12.000 mm

OUTPUT FOR IRC

Regular Moment: 346.70 kNm
 Depth of the section: 302.17 mm
 Sagd: 509.00 mm
 Overall depth of section: 559.00 mm
 Area of Steel Required As: 6959.57 mm²

Diameter of bar	Crack Width	spacing
mm	mm	mm c/c
10	0.0777	15.25
	OK	NOT OK
12	0.0766	16.24
	OK	NOT OK
16	0.0751	28.88
	OK	NOT OK
20	0.0750	45.12
	OK	NOT OK
25	0.0775	70.50
	OK	NOT OK
32	0.0863	115.56
	OK	OK

VII. Radial Basis Function (RBF)

We now move on to discuss a class of feed forward neural networks called *Radial Basis Function Networks* (RBFNs) that compute activation at the hidden neurons in a way that is different from what we have seen in the case of feed forward neural networks. Rather than employing an inner product between the input vector and the weight vector, hidden neuron activations in RBFNs are computed using an exponential of a distance measure (usually the Euclidean distance or a weighted norm) between the input vector and a prototype vector that characterizes the signal function at hidden neuron.

The Radial Basis Function (RBF) model is a special type of neural network consisting of three layers: input, pattern (hidden), and output. It represents two sequential mappings. The first nonlinearly maps the input data via basis functions in the hidden layer. The second, a weighted mapping of the basis function outputs, generates the model output. The two mappings are usually treated separately, which makes RBF a very versatile modeling technique. The RBF networks have been successfully employed in areas such as data mining, medical diagnosis, face and speech recognition, robotics, forecasting stock prices, cataloging objects in the sky, and bioinformatics. RBF networks have their theoretical roots in regularization theory and were originally developed by Russian mathematicians in the 1960s.

Function approximation, with RBF networks, in a limited area of the input space requires

- The placement of the localized Gaussians to cover the space
- The control of the width of each Gaussian
- The setting of the amplitude of each Gaussian

Fig.1: Clarifier of 46mt diameter and 7mt vertical wall height under construction.



If we can accomplish these three tasks, we can approximate arbitrary continuous functions with an RBF network.

Broomhead and Lowe used the RBF model for approximation. The RBF network has been proven to be a universal function approximation .It can perform similar function mappings as a MLP but its architecture and functionality are very different. We will first examine the RBF architecture and then examine the differences between it and the MLP that arise from this architecture.

Fig.2: Neuro Solution software for Circular Tank (Radial Basis Function)

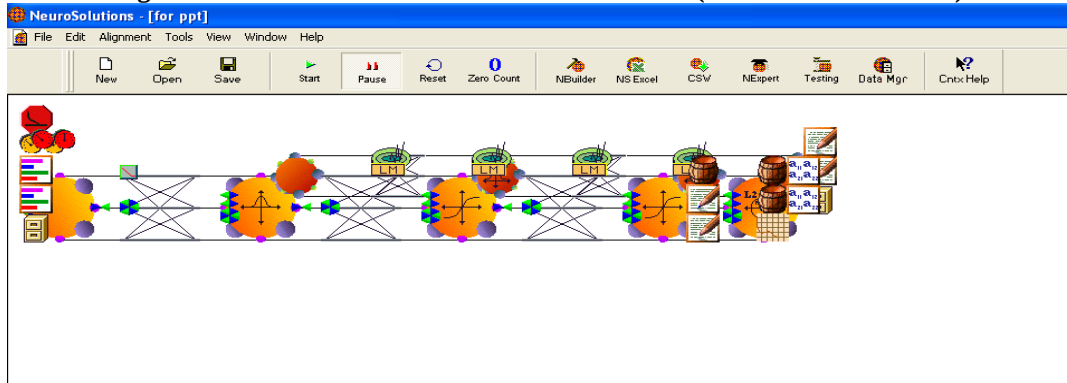


Table 2: Training data for Crack width in Circular Tank with obstruction

Capacity of tank	Wall thick	Ht. of wall	Bar dia	RC CW Desired	RC CW Predicted	RC % Error	FRC CW Desired	FRC CW Predicted	FRC % Error
m ³	mm	mt.	mm	mm	mm		mm	mm	
7000	700	10	12	0.161	0.165	2.427	0.042	0.041	-2.569
7000	700	6	12	0.190	0.176	-7.691	0.068	0.065	-4.170
7000	700	10	16	0.199	0.208	4.276	0.054	0.052	-4.496
7000	700	5	16	0.467	0.473	1.116	0.166	0.164	-1.279
7000	700	5	20	0.585	0.596	1.852	0.206	0.206	0.180
7000	700	8	20	0.084	0.079	-7.100	0.024	0.023	-6.497
8000	750	8	12	0.012	0.012	-1.423	0.004	0.004	6.707
8000	750	8	16	0.016	0.017	5.019	0.005	0.005	6.606
8000	750	7	25	0.205	0.221	7.204	0.063	0.067	6.085
8000	750	9	12	0.091	0.083	-9.504	0.027	0.026	-0.454
8000	750	6	32	0.582	0.576	-1.077	0.197	0.188	-4.746
8000	750	8	32	0.032	0.031	-1.569	0.009	0.009	-2.486
8000	750	8	20	0.020	0.020	-0.538	0.006	0.006	4.733
8000	750	10	25	0.270	0.287	5.936	0.068	0.071	5.112
8000	750	9	32	0.239	0.240	0.378	0.065	0.063	-3.829
8000	750	6	16	0.308	0.309	0.396	0.102	0.102	0.175

Table 3: 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	RC % Error	FRC CW Desired	FRC CW Predicted	FRC % Error
m ³	mm	mt.	mm	mm	mm		mm	mm	
7000	700	7	12	0.146	0.148	1.139	0.039	0.040	0.838
7000	700	5	12	0.117	0.127	7.910	0.042	0.043	2.094
7000	700	6	12	0.061	0.057	-6.464	0.019	0.018	-3.825
8000	750	10	32	0.484	0.472	-2.459	0.079	0.079	-0.309
8000	750	10	16	0.253	0.250	-0.951	0.054	0.053	-1.770
8000	750	7	25	0.233	0.217	-7.395	0.059	0.057	-4.430
8000	750	9	12	0.203	0.197	-3.071	0.043	0.041	-4.510
8000	750	7	12	0.113	0.105	-8.109	0.031	0.030	-3.707
8000	750	8	20	0.251	0.257	2.324	0.062	0.064	3.206
8000	750	6	25	0.035	0.033	-6.116	0.010	0.011	5.724
8000	750	7	16	0.144	0.139	-3.116	0.040	0.039	-2.795
8000	750	5	16	0.226	0.207	-8.946	0.074	0.073	-1.580
8000	750	8	25	0.321	0.329	2.426	0.076	0.074	-1.691
8000	750	6	16	0.022	0.023	6.250	0.007	0.006	-7.967
8000	750	6	12	0.016	0.017	4.836	0.005	0.005	-6.887
8000	750	10	12	0.229	0.216	-6.088	0.043	0.042	-2.106
8000	750	5	20	0.287	0.299	3.722	0.092	0.098	6.710
8000	750	10	25	0.370	0.362	-2.050	0.079	0.074	-6.773

Fig. 3: Net training performance of crack width in Circular Tank RC wall without Obstruction

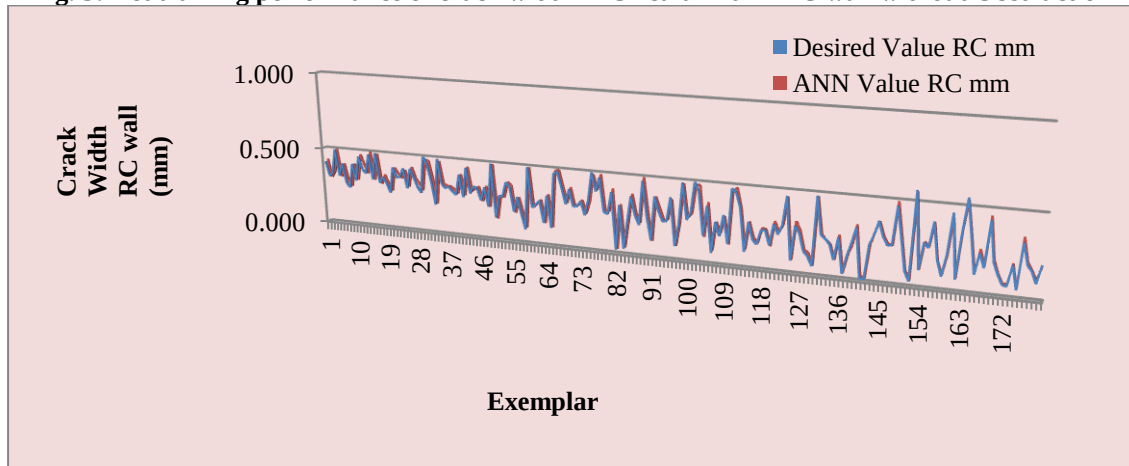
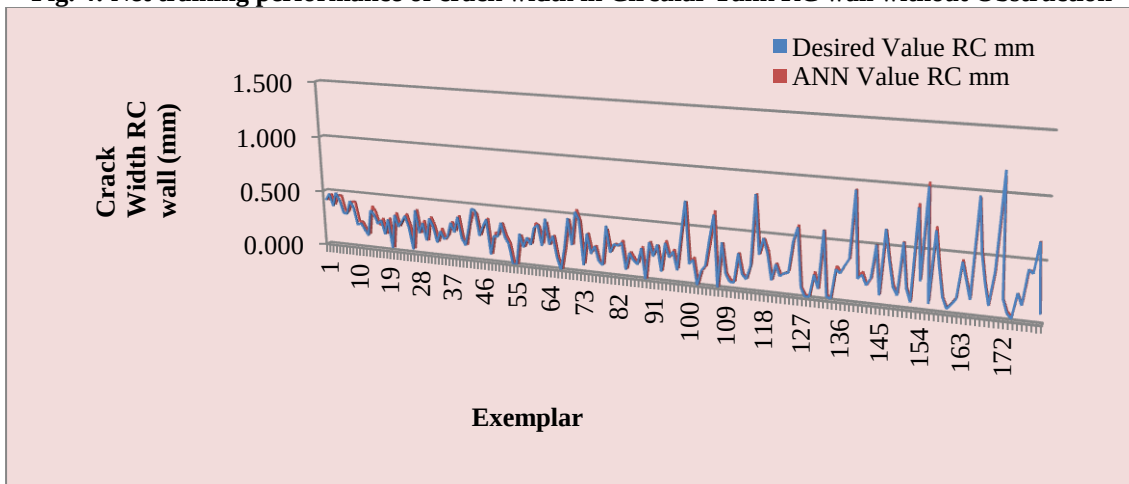


Fig. 4: Net training performance of crack width in Circular Tank RC wall without Obstruction



VIII. Conclusion

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.

Neural network tool has been developed considering supervised learning methodology using Levenberg Marquardt algorithm for back propagation and radial basis function. It has been observed that for circular tank with & without obstruction the best neural architectural form is 5 neuron in hidden layer gives optimum solution also coefficient of correlation is 0.9969 & absolute maximum error during training is 7.714 & testing is 8.087.

The absolute maximum error for both class of tank in testing phase is below 10%. The developed neural network tool can be readily used in the field for preliminary design in reference to crack width of circular under seismic loading.

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

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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