11. MODIFICATION OF CRACK WIDTH FORMULA BY INCORPORATING SIZE EFFECT PARAMETER

11.1. COMPUTATION OF MAXIMUM CRACK WIDTH FORMULA

Crack width is a critical criterion under the limit state of Serviceability and Durability issue as per clause 43 of IS: 456[1]. The occurrence of cracks in RCC structures is unavoidable because concrete has low tensile strength of concrete normally 1/10th of the compressive strength of the concrete. Most of the structures are design as basic of cracked section while the water bodies are design as basic of uncracked section. Permissible crack width is 0.2 mm as per IS code. Cracks develops when the tensile stress in concrete exceeds its permissible tensile strength. Limiting crack width is important from the aesthetic point of view to ensure water tightness and to safe guard the reinforcement against corrosion. Literature suggests that this phenomenon has been studied since as early as 1950's and yet the estimation of Flexural crack width still eludes researchers. It is to be noted that none of the expressions are like each other. The crack width equations are not accurate in reasonable range.

Two approaches are available for Estimation of Maximum crack width i.e. Steel stress approach and Fictitious Tensile stress approach. Samaria and Every compared Reinforced tensile specimens with different fiber contents. Longer and thinner fibers are more effective to reduce crack width and crack spacing.

In the present investigation, Crack width and its spacing were observed under variation of load, Different size of beam (Le/D). The effect of fibers (polypropylene & steel) to resist the crack propagation and increase the strength of the section. To comply with the design requirement in present codes of practice the serviceability criteria must be fulfill in limit state method. Crack spacing (minimum, mean or maximum) has little practical significance. The maximum crack width is limited to certain specified values at service load, and exposed environment condition mention in the design codes.

It is observed that crack width is a function of crack spacing and strain in tensile reinforcement. Most of the Researchers had considered this as a basic for finding crack width and develop a new formula by incorporating various parameters in present equations. Here in this Experimental work, size effect parameter incorporated in Crack width equation. Some researchers had given their Modified formulas based on statistical analysis while others have co-related that formula with experimental results obtained. It is also observed that in moderate deep beam, shear crack occurs at D/3 of the beam and propagate upward diagonally between inner side of support to loading point.

The Basic Crack width formula given by Gergely and Lutz [20] is as follows

Gergly and Lutz formula(20) : $W_b = 0.076\sqrt[3]{t_b A} f_s \beta \times 10^{-3} (in)$.

This above formula has to be Modified by incorporating size effect parameter i.e. Diameter of bar to Percentage of Reinforcement (Φ/ρ), Effective length to overall depth ratio (Leff/D) and % of fiber reinforcement. Crack width measured in RCC, PFRC and SFRC specimens during experiment. By incorporating the size effect parameter, the actual modified formula shows exact trend which was obtained by experimental results.

11.2. SIZE EFFECT PARAMETERS CONSIDERED FOR MODIFICATION OF CRACK WIDTH EQUATION.

A lot of works has been done for Maximum crack width equation. Many researchers have considered various size effect parameters only for flexure crack in RCC and Pre-stressed concrete members. While a very little work had been done for Maximum shear crack width formula for Moderate Deep Beam. List of size effect parameters are given below:

- Longitudinal reinforcement ratio (ρ_t)
- Shear reinforcement ratio (ρ_w)
- Steel rebar arrangement
- Grade of steel (f_y)

- Grade of concrete (f_{ck})
- Steel stress (fs)
- Strain in rebar (ε_s)
- Strain in concrete at level of reinforcement (ε_c)
- Concrete cover (Cc)
- Bond factor (bond between steel and concrete at level of reinforcement)
- Duration of load application
- Modular ratio (m)
- **Diameter of bar to Percentage of Reinforcement (Φ/ρ)**
- Strain distribution factor
- Shear span to depth ratio (a/d)
- **Effective length to overall depth ratio (L_{eff}/D)**
- Modulus of Elasticity of steel (E_s)
- Fiber aspect ratio (diameter/length)
- **% of fiber reinforcement**
- Depth of neutral axis (x_u)
- Maximum bar spacing (s)

From the above list of parameters, **Le/D (effective length to Depth ratio), Ratio of diameter of bar to Percentage reinforcement Φ/ρ and Fiber factor as Volume of Fiber and Aspect ratio** were taken into consideration for evaluating the size effect parameter for maximum crack width and crack behavior. Aspect ratio of fiber (Φ/l) and % of fibers were also correlated with the equation obtained for controlled specimen of RCC.

In Concrete section the width of crack depends on Le/D ratio and types of fiber used during construction. At Ultimate load, the crack width compares in RCC and FRC beams. A size effect parameter incorporates in RCC, PFRC and SFRC specimens. Finally, Crack width compares experimentally and with modified equation.

11.3. NON-LINEAR REGRESSION ANALYSIS FOR CRACK WIDTH EQUATION

A statistical technique is used for investigating and modeling the relationship between variables. It is easy to use and applies to many situations. This technique makes possible to estimate the unknown values of one variable from this regression analysis. The variable which is used to predict the variable of interest is called the Independent variable and the variable to be predicted is called the dependent variable. These are widely used accepted methods for performing Regression Analysis. The first, and easiest to implement, is the linear regression. The second one is general method which is known as Non-linear regression.

11.4. NON-LINEAR REGRESSION ANALYSIS

When the model function is not linear in the parameters, the sum of squares must be minimized by an iterative procedure. This introduces many complications which are summarized in difference between linear and nonlinear least squares. The Aim of Non-linear regression is to determine the best fit parameters for a model by minimizing the chosen metric function. Non-linear regression analysis depends on the unknown parameters and the process of merit function. The process starts with some initial estimated value then become a starting point for the next iteration. These iterations continue until the merit function effectively stops decreasing.

Here in this research work, Model equation was generated for Prediction of maximum crack width for Moderate Deep beam using regression analysis in SPSS software. In the equation, dependent variable which is crack width that depends on Le/D and Φ/ρ is taken into consideration with a constant.

$W_{max}/\beta f_s \sqrt[3]{d_c A_o}$ = dependent variable (Y)

$\left(\frac{\Phi}{\rho}\right)\&\left(\frac{L_e}{D}\right)$ = independent variable (x)

Where,

C, B, and K are constants of Regression Analysis. To find out the values of the constant, iterative nonlinear regression analysis was carried out with SPSS software. Iteration starts with 0.1 For C and 0.01 for B and K parameter.

Model Equation:

$$W_{max} = \frac{C\beta f_s \sqrt[3]{d_c A_o}\left(\frac{\Phi}{\rho}\right)^{\left(K * {}^{Le}/_{D}\right)}}{1 + \left(\frac{L_e}{D}\right)^{B}}$$

11.5. ITERATIVE DATA ANALYSIS IN SPSS FOR MODEL EQUATION

The Non-Linear Regression Analysis has been done in SPSS software.

TABLE 11-1SPSS 16.0 Regression Constants

Parameter Estimates				
Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
C	3.217E-5	.000	-.001	.001
B	-1.245	27.709	-66.765	64.278
K	.052	.043	-.050	.154

Table 11-2 SPSS 16.0 ANOVA Results of Nonlinear Regression

ANOVA (Analysis of Variance)			
Source	Sum of Squares	df	Mean Squares
Regression	.000	3	.000
Residual	.000	7	.000
Uncorrected Total	.000	10	
Corrected Total	.000	9	
Dependent variable: Y			
a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .869.			

From the above Regression Analysis values of the constants obtained are summarized below,

C	B	K
3.217×10^{-5}	-1.245	0.052

Above procedure was repeated for PFRC and SFRC specimens by adding a Fiber factor $(M * \%V_f \sqrt[2]{lf/df})$ with a constant M. Multiple Linear Regression Analysis was adopted to find value of constant M. Values of M are tabulated below,

Constant	M
PFRC	-2/3
SFRC	-3.616

The constant gets minus sign due to reduction of crack width after using PFRC and SFRC Fibers in concrete section. From values it shows that the in SFRC Crack width reduce less compare to PFRC beams.

11.6. DERIVED CRACK WIDTH FORMULAS FOR PREDICTION OF MAXIMUM CRACK WIDTH

A Non-linear Regression Analysis was adopted to Modify the formula given by Gergely and Lutz by taking Le/D and Φ/ρ ratio as size effect parameters.

11.6.1. Derived Equation for Prediction of Maximum Crack Width for RCC Moderate Deep Beam

$$W_{max} = \frac{0.03217 \beta f_s \sqrt[3]{d_c A_o} \left(\frac{\Phi}{\rho}\right)^{\left(0.052 * {Le}/{D}\right)}}{1+\left(\frac{Le}{D}\right)^{-1.245}} \times 10^{-3} \qquad \text{(mm)}$$

Where, W_{max} = Maximum crack width (mm)

$$\beta = \frac{h-x}{d-x}$$

h = Overall depth of beam (mm)

d = Effective depth of beam (mm)

x = Depth of neutral axis (mm)

b = Width of beam (mm)

f_s = Tensile stress in reinforcement (N/mm^2)

d_c = Distance from centroid of reinforcement to bottom of beam (mm)

$A_o = {A_e}/{n}$ = Effective area of concrete around steel bars $\left(2 * d_c * {b}/{n}\right)$ (mm^2)

Φ = Diameter of bar (mm)

ρ = Longitudinal reinforcement ratio

11.6.2. Derived Equation for Prediction of Maximum Crack Width for PFRC Moderate Deep Beam

$$W_{max} = \frac{0.03217\times10^{-3}\beta f_s \sqrt[3]{d_c A_o}\left(\frac{\Phi}{\rho}\right)^{\left(0.052*{Le}/{D}\right)}}{1+\left(\frac{Le}{D}\right)^{-1.245}} - \frac{2}{3}\%V_f{}^{2}\sqrt{{l_f}/{d_f}} \quad \text{(mm)}$$

Where, W_{max} = Maximum crack width (mm)

$$\beta = \frac{h-x}{d-x}$$

h = Overall depth of beam (mm)

d = Effective depth of beam (mm)

x = Depth of neutral axis (mm)

b = Width of beam (mm)

f_s = Stress in tensile reinforcement (N/mm^2)

d_c = Distance from centroid of reinforcement to bottom of beam (mm)

$A_o = {A_e}/{n}$ = Effective area of concrete around steel bars $\left({2 * d_c * b}/{n}\right)$ (mm^2)

Φ = Diameter of bar (mm)

ρ = Longitudinal reinforcement ratio

Le/D = Ratio of effective length of beam to overall depth

% V_f = Percentage of fiber

${lf}/{df}$ = Aspect ratio of fibers

11.6.3. Derived Equation for Prediction of Maximum Crack Width for SFRC Moderate Deep Beam

$$W_{max} = \frac{0.03217\times10^{-3}\beta f_s \sqrt[3]{d_c A_o}\left(\frac{\Phi}{\rho}\right)^{\left(0.052*{Le}/{D}\right)}}{1+\left(\frac{Le}{D}\right)^{-1.245}} - 3.616\%V_f^{\,2}\sqrt{{l_f}/{d_f}} \quad \text{(mm)}$$

Where, W_{max} = Maximum crack width (mm)

$$\beta = \frac{h-x}{d-x}$$

h = Overall depth of beam (mm)

d = Effective depth of beam (mm)

x = Depth of neutral axis (mm)

b = Width of beam (mm)

f_s = Stress in tensile reinforcement (N/mm^2)

d_c = Distance from centroid of reinforcement to bottom of beam (mm)

$A_o = {A_e}/{n}$ = Effective area of concrete around steel bars $\left({2*d_c*b}/{n}\right)$ (mm^2)

Φ = Diameter of bar (mm)

ρ = Longitudinal reinforcement ratio

Le/D = Ratio of effective length of beam to overall depth

% V_f = Percentage of fiber

${lf}/{df}$ = Aspect ratio of fibers

11.6.4. Crack Widths Obtained Analytically and Experimentally

RCC					
BEAM NAME	A2	B	C	D	E
Width of beam (b)(mm)	75	75	75	75	75
Overall Depth of beam(D,h) (mm)	225	275	325	375	425
Effective depth of beam(d) (mm)	200	250	300	350	400
Shear span (a) (mm)	200	250	300	350	400
Ultimate load (tn)	13.5	17.8	19.3	21.9	25.8
lever arm (z) (mm)	181.46	224.57	271.71	319.06	361.05
Depth of neutral axis (x) (mm)	55.63	76.279	84.882	92.812	116.859
Reinforcement cover (dc) (mm)	25	25	25	25	25
Bending moment (M) (N.mm)	13500000	22250000	28950000	38325000	51600000
Bending stress (N/mm^2)	740.43	631.06	678.66	765.08	632.16
B	1.173166	1.143909	1.116215	1.097205	1.088295
Diameter of bars (Φ) (mm)	8	10	10	10	12
No of bars (n)	2	2	2	2	2
Area of Steel (Ast) (mm^2)	100.48	157	157	157	226.08
Effective area of concrete around steel bars(A0) (mm^2)	1875	1875	1875	1875	1875
Le/D	3.56	3.27	3.08	2.93	2.82
Φ/ρ	1194.268	1194.268	1433.121	1671.975	1592.357
Fiber density (kg/m^3)	–	–	–	–	–
Length of fibers (mm)	–	–	–	–	–
Diameter of Fibers (mm)	–	–	–	–	–
Fiber content (V_f) (%)	–	–	–	–	–
Maximum Crack Width Measured (mm)	3.12	2.52	2.39	2.1	1.8
Maximum Crack Width Calculated (mm)	3.10	2.28	2.25	2.39	1.85
% Error	-0.77	-10.72	-6.01	12.27	2.61

RCC					
BEAM NAME	F	A1	H	I	J
Width of beam (b)(mm)	75	75	75	75	75
Overall Depth of beam(D,h) (mm)	175	225	275	325	375
Effective depth of beam(d) (mm)	150	200	250	300	350
Shear span (a) (mm)	300	400	500	600	700
Ultimate load (tn)	7.1	7.3	8.2	9	9.4
lever arm (z) (mm)	134.34	181.46	224.57	271.71	319.06
Depth of neutral axis (x) (mm)	46.99	55.63	76.279	84.882	92.812
Reinforcement cover (dc) (mm)	25	25	25	25	25
Bending moment (M) (N.mm)	10650000	14600000	20500000	27000000	32900000
Bending stress (N/mm^2)	789	800.76	581.43	632.94	656.78
B	1.242695	1.173166	1.143909	1.116215	1.097205
Diameter of bars (Φ) (mm)	8	8	10	10	10
No of bars (n)	2	2	2	2	2
Area of Steel (Ast) (mm^2)	100.48	100.48	157	157	157
Effective area of concrete around steel bars(A0) (mm^2)	1875	1875	1875	1875	1875
Le/D	3.43	3.56	3.64	3.69	3.73
Φ/ρ	895.7006	1194.268	1194.268	1433.121	1671.975
Fiber density (kg/m^3)	–	–	–	–	–
Length of fibers (mm)	–	–	–	–	–
Diameter of Fibers (mm)	–	–	–	–	–
Fiber content (V_f) (%)	–	–	–	–	–
Maximum Crack Width Measured (mm)	3.25	3.29	2.42	2.68	3.02
Maximum Crack Width Calculated (mm)	3.14	3.35	2.45	2.76	2.96
% Error	-3.39	1.74	1.38	3.05	-2.12

PFRC					
BEAM NAME	A2	B	C	D	E
Width of beam (b)(mm)	75	75	75	75	75
Overall Depth of beam(D,h) (mm)	225	275	325	375	425
Effective depth of beam(d) (mm)	200	250	300	350	400
Shear span (a) (mm)	200	250	300	350	400
Ultimate load (tn)	14	18.1	19.3	21.8	26.4
lever arm (z) (mm)	181.46	224.57	271.71	319.06	361.05
Depth of neutral axis (x) (mm)	55.63	76.279	84.882	92.812	116.859
Reinforcement cover (dc) (mm)	25	25	25	25	25
Bending moment (M) (N.mm)	14000000	22625000	28950000	38150000	52800000
Bending stress (N/mm^2)	767.85	641.7	678.66	761.59	646.86
B	1.173166	1.143909	1.116215	1.097205	1.088295
Diameter of bars (Φ) (mm)	8	10	10	10	12
No of bars (n)	2	2	2	2	2
Area of Steel (Ast) (mm^2)	100.48	157	157	157	226.08
Effective area of concrete around steel bars(A0) (mm^2)	1875	1875	1875	1875	1875
Le/D	3.56	3.27	3.08	2.93	2.82
Φ/ρ	1194.268	1194.268	1433.121	1671.975	1592.357
Fiber density (kg/m^3)	910	910	910	910	910
Length of fibers (mm)	6	6	6	6	6
Diameter of Fibers (mm)	0.03	0.03	0.03	0.03	0.03
Fiber content (V_f) (%)	0.7	0.7	0.7	0.7	0.7
Maximum Crack Width Measured (mm)	3.17	2.49	2.37	2.28	1.91
Maximum Crack Width Calculated (mm)	3.14	2.25	2.19	2.32	1.83
% Error	-0.80	-10.75	-8.29	1.58	-4.65

PFRC					
BEAM NAME	F	A1	H	I	J
Width of beam (b)(mm)	75	75	75	75	75
Overall Depth of beam(D,h) (mm)	175	225	275	325	375
Effective depth of beam(d) (mm)	150	200	250	300	350
Shear span (a) (mm)	300	400	500	600	700
Ultimate load (tn)	7.1	7.8	9.7	10.1	11.2
lever arm (z) (mm)	134.34	181.46	224.57	271.71	319.06
Depth of neutral axis (x) (mm)	46.99	55.63	76.279	84.882	92.812
Reinforcement cover (dc) (mm)	25	25	25	25	25
Bending moment (M) (N.mm)	10650000	15600000	24250000	30300000	39200000
Bending stress (N/mm^2)	789	855.6	687.79	710.3	782.55
B	1.242695	1.173166	1.143909	1.116215	1.097205
Diameter of bars (Φ) (mm)	8	8	10	10	10
No of bars (n)	2	2	2	2	2
Area of Steel (Ast) (mm^2)	100.48	100.48	157	157	157
Effective area of concrete around steel bars(A0) (mm^2)	1875	1875	1875	1875	1875
Le/D	3.43	3.56	3.64	3.69	3.73
Φ/ρ	895.7006	1194.268	1194.268	1433.121	1671.975
Fiber density (kg/m^3)	910	910	910	910	910
Length of fibers (mm)	6	6	6	6	6
Diameter of Fibers (mm)	0.03	0.03	0.03	0.03	0.03
Fiber content (V_f) (%)	0.7	0.7	0.7	0.7	0.7
Maximum Crack Width Measured (mm)	3.12	3.72	2.62	2.94	3.24
Maximum Crack Width Calculated (mm)	3.08	3.51	2.84	3.04	3.46
% Error	-1.39	-5.93	7.64	3.17	6.29

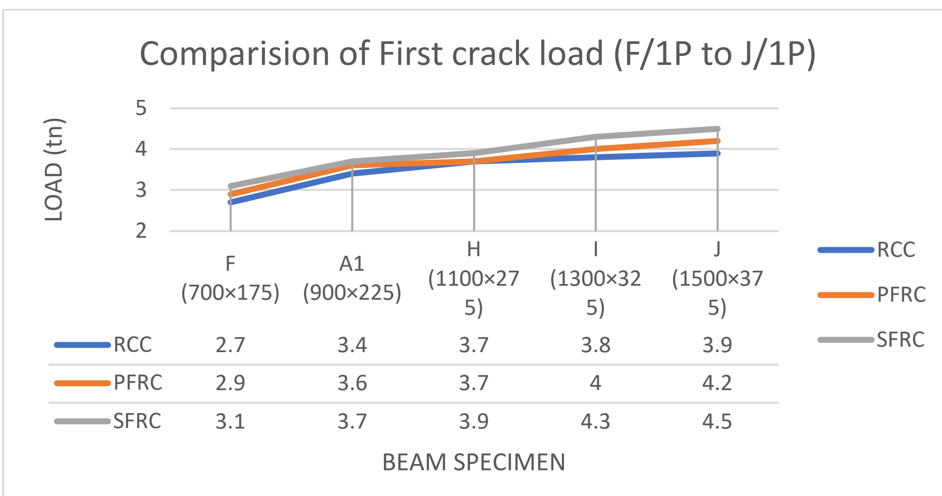
SFRC					
BEAM NAME	A2	B	C	D	E
Width of beam (b)(mm)	75	75	75	75	75
Overall Depth of beam(D,h) (mm)	225	275	325	375	425
Effective depth of beam(d) (mm)	200	250	300	350	400
Shear span (a) (mm)	200	250	300	350	400
Ultimate load (tn)	16.7	19.6	21.7	24.8	29.9
lever arm (z) (mm)	181.46	224.57	271.71	319.06	361.05
Depth of neutral axis (x) (mm)	55.63	76.279	84.882	92.812	116.859
Reinforcement cover (dc) (mm)	25	25	25	25	25
Bending moment (M) (N.mm)	16700000	24500000	32550000	43400000	59800000
Bending stress (N/mm^2)	915.93	694.88	763.05	866.39	732.61
B	1.173166	1.143909	1.116215	1.097205	1.088295
Diameter of bars (Φ) (mm)	8	10	10	10	12
No of bars (n)	2	2	2	2	2
Area of Steel (Ast) (mm^2)	100.48	157	157	157	226.08
Effective area of concrete around steel bars(A0) (mm^2)	1875	1875	1875	1875	1875
Le/D	3.56	3.27	3.08	2.93	2.82
Φ/ρ	1194.268	1194.268	1433.121	1671.975	1592.357
Fiber density (kg/m^3)	7850	7850	7850	7850	7850
Length of fibers (mm)	30	30	30	30	30
Diameter of Fibers (mm)	0.6	0.6	0.6	0.6	0.6
Fiber content (V_f) (%)	0.7	0.7	0.7	0.7	0.7
Maximum Crack Width Measured (mm)	3.54	2.50	2.43	2.24	2.14
Maximum Crack Width Calculated (mm)	3.65	2.33	2.36	2.53	1.96
% Error	3.04	-7.42	-3.15	11.52	-9.02

SFRC					
BEAM NAME	F	A1	H	I	J
Width of beam (b)(mm)	75	75	75	75	75
Overall Depth of beam(D,h) (mm)	175	225	275	325	375
Effective depth of beam(d) (mm)	150	200	250	300	350
Shear span (a) (mm)	300	400	500	600	700
Ultimate load (tn)	7.3	7.9	12.2	12.5	13.6
lever arm (z) (mm)	134.34	181.46	224.57	271.71	319.06
Depth of neutral axis (x) (mm)	46.99	55.63	76.279	84.882	92.812
Reinforcement cover (dc) (mm)	25	25	25	25	25
Bending moment (M) (N.mm)	10950000	15800000	30500000	37500000	47600000
Bending stress (N/mm^2)	811.22	866.57	865.05	879.09	950.24
B	1.242695	1.173166	1.143909	1.116215	1.097205
Diameter of bars (Φ) (mm)	8	8	10	10	10
No of bars (n)	2	2	2	2	2
Area of Steel (Ast) (mm^2)	100.48	100.48	157	157	157
Effective area of concrete around steel bars(A0) (mm^2)	1875	1875	1875	1875	1875
Le/D	3.43	3.56	3.64	3.69	3.73
Φ/ρ	895.7006	1194.268	1194.268	1433.121	1671.975
Fiber density (kg/m^3)	7850	7850	7850	7850	7850
Length of fibers (mm)	30	30	30	30	30
Diameter of Fibers (mm)	0.6	0.6	0.6	0.6	0.6
Fiber content (V_f) (%)	0.7	0.7	0.7	0.7	0.7
Maximum Crack Width Measured (mm)	3.05	3.24	3.19	3.32	4.24
Maximum Crack Width Calculated (mm)	3.05	3.44	3.47	3.66	4.10
% Error	0.09	5.94	8.12	9.30	-3.43

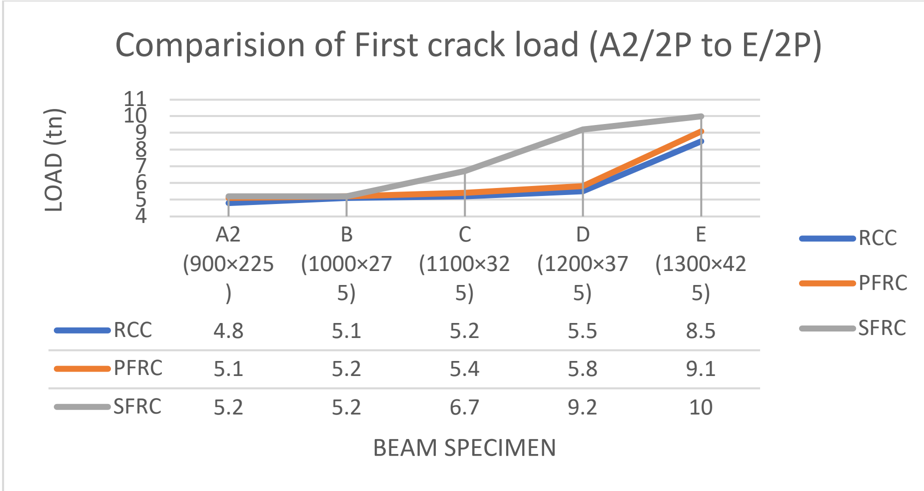
Crack width for the specimens A2 to J (RCC, PFRC and SFRC) is Tabulated below from the obtained results of experimental work. Crack Widths were measured at different load intervals. Crack widths of PFRC and SFRC specimens were compares with RCC specimens.

11.7. RESULTS OF FIRST CRACK LOADS AND ULTIMATE LOAD

Beam Notation	RCC		PFRC		SFRC	
	First Crack Load Ton	Ultimate Load Ton	First Crack Load Ton	Ultimate Load Ton	First Crack Load Ton	Ultimate Load Ton
A2	4.8	13.5	5.1	14	5.2	16.7
B	5.1	17.8	5.2	18.1	5.2	19.6
C	5.2	19.3	5.4	19.3	6.7	21.7
D	5.5	21.9	5.8	21.8	9.2	24.8
E	8.5	25.8	9.1	26.4	10.0	29.9
F	2.7	7.1	2.9	7.1	3.1	7.3
A1	3.4	7.3	3.6	7.8	3.7	7.9
H	3.7	8.2	3.7	9.7	3.9	12.2
I	3.8	9.0	4.0	10.1	4.3	12.5
J	3.9	9.4	4.2	11.2	4.5	13.6



Graph 11-1 Plot of Comparison of First crack load (F/1P to J/1P)

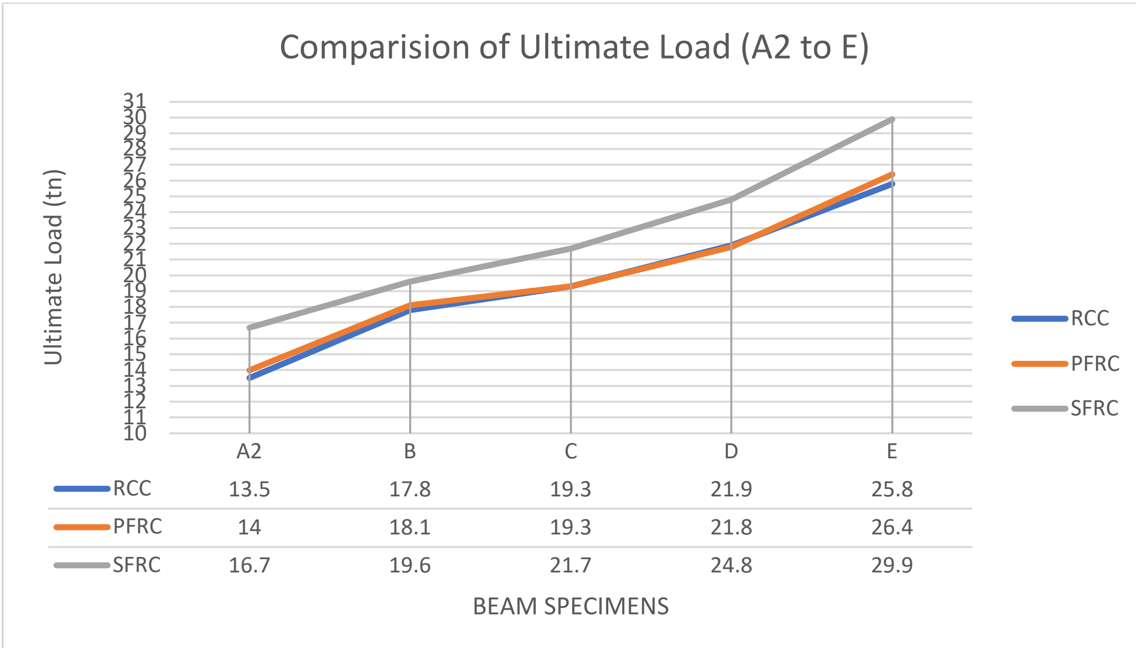


Graph11-2 Plot of Comparison of First Crack Load (A2 to E)

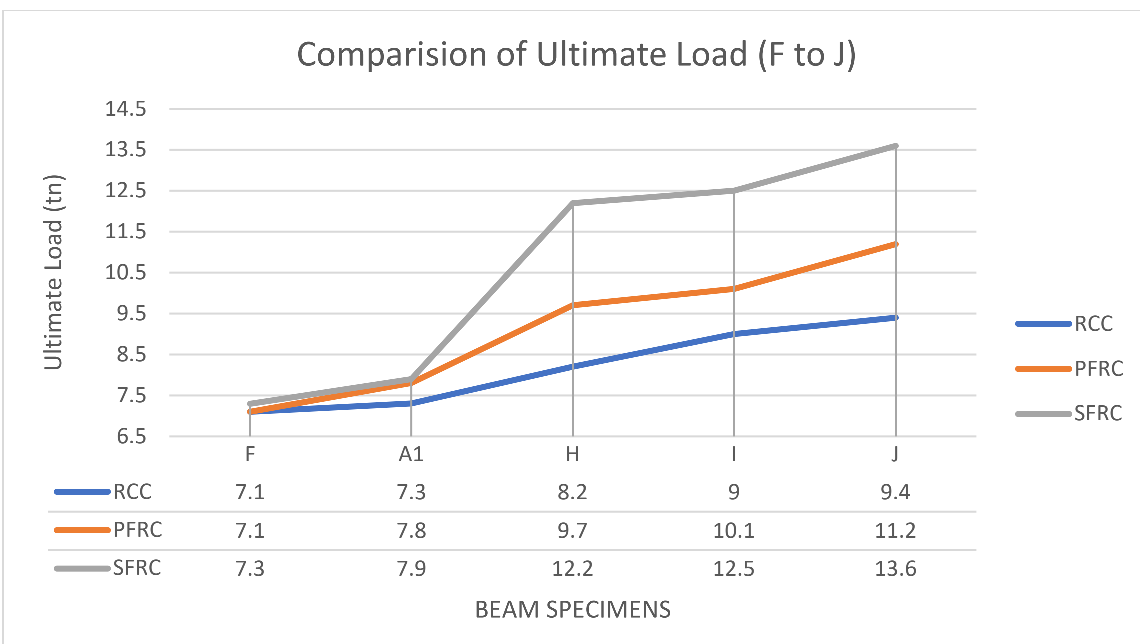
To predict First crack load is very much important to predict its Ultimate strength and structural behavior of the member. The First crack load was different for different size of beam specimens. Central point load applied in beam type F to J. It is observed that the First Crack load is almost similar in PFRC and RCC beam specimen. While First crack load increase in SFRC beam because of due to steel fiber used in specimen.

In Two-point load condition on applied beam type A2 to E. It is observed that the First Crack load is almost similar in PFRC and RCC beam specimen. While First crack load slightly increases in SFRC beam because of due to steel fiber used in specimen. It is also a highlighting point that in the case of two-point load system, specimens show higher values of first crack load compared with one-point loading system.

In the Specimen A2 and A1, Range of First crack loads are 5ton and 3 ton, respectively. Which reveals that the same size of beam tested under two-point load system have higher initial load carrying capacity compared to one-point loading system. Initial load carrying capacity of RCC and PFRC are almost equal with a slight increment in PFRC values. SFRC specimens' first crack loads were higher compared to RCC and PFRC. In SFRC specimen first crack develop at higher load and it delay the crack propagation. In RCC and PFRC crack propagates in short time thus air enters into concrete and it leads to corrosion of reinforcement and finally failure takes place in beam.



Graph11-3 Plot of Comparison of Ultimate Load (A2 to E)



Graph11-4 Plot of Comparison of Ultimate Load (F to J)

Ultimate load carrying capacity of a member is depends upon the ascertain failure properties of the member. In the experimental work conducted in this research shows that the Ultimate load carrying capacity of RCC, PFRC and SFRC specimens are in a narrow range with lower value for smaller beams sizes.

Comparing the graphs (11-1 to 11-4) it is observed that RCC and PFRC follows nearly equal pattern of First crack load and Ultimate load in central point load and two-point load. Graph 11-3 and 11-4 SFRC specimens gives higher value of Ultimate load than RCC and PFRC.

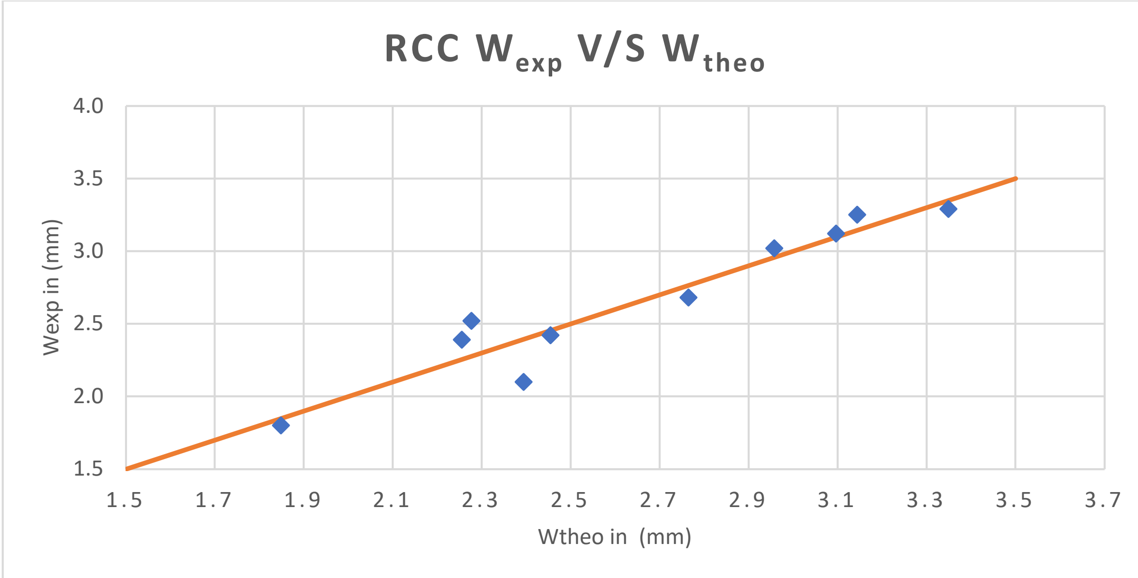
End hook type steel fiber bond the cement mortar. Initially the stain develops in concrete then after in in Steel fiber. Due to arresting property in fiber it resists the load and reduce the propagation of crack in SFRC specimens compared to RCC and PFRC.

In case of PFRC beam specimens, Ultimate load is higher than RCC but it is lower than SFRC. Polypropylene fibers actively participate in reducing initial load carrying capacity but its effect on Ultimate load capacity is nearer to RCC with a slight incremental value.

It is observed that in case of two-point loading system, as Le/D ratio decreases, Ultimate load carrying capacity increases. While opposite trend is observed in case of one-point loading system that is as Le/D increases, Ultimate load carrying capacity decreases.

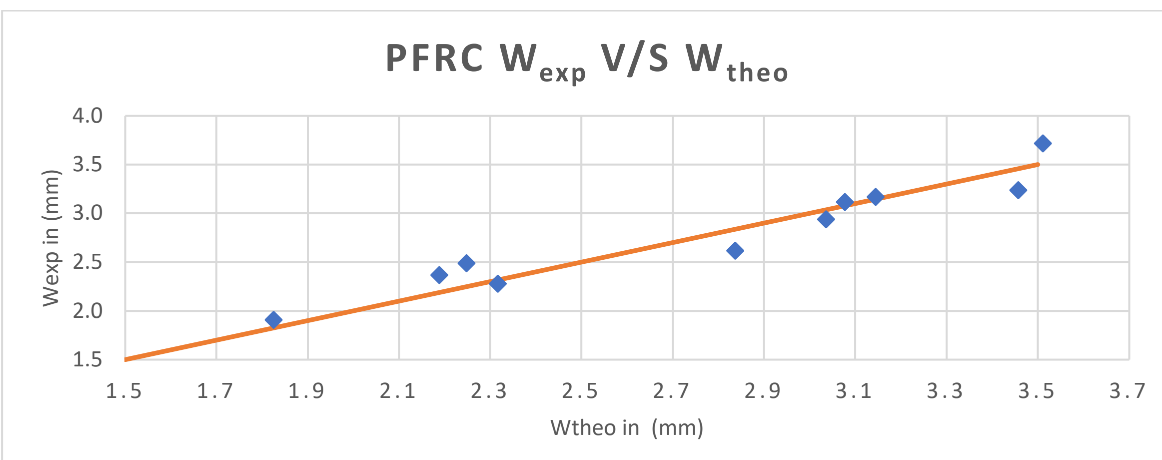
11.8. RESULTS OF CRACK WIDTH OBTAINED EXPERIMENTALLY AND THEORETICALLY

Above mentioned specimens of Moderate Deep beams of various sizes were experimentally investigated for the Analysis of Maximum crack width. The theoretical expression had been derived to predict the crack width. Obtained results shows scattered values with maximum error around ±15%. Graph 11-5 shows that W_{exp} values and W_{theo} values are almost equal.

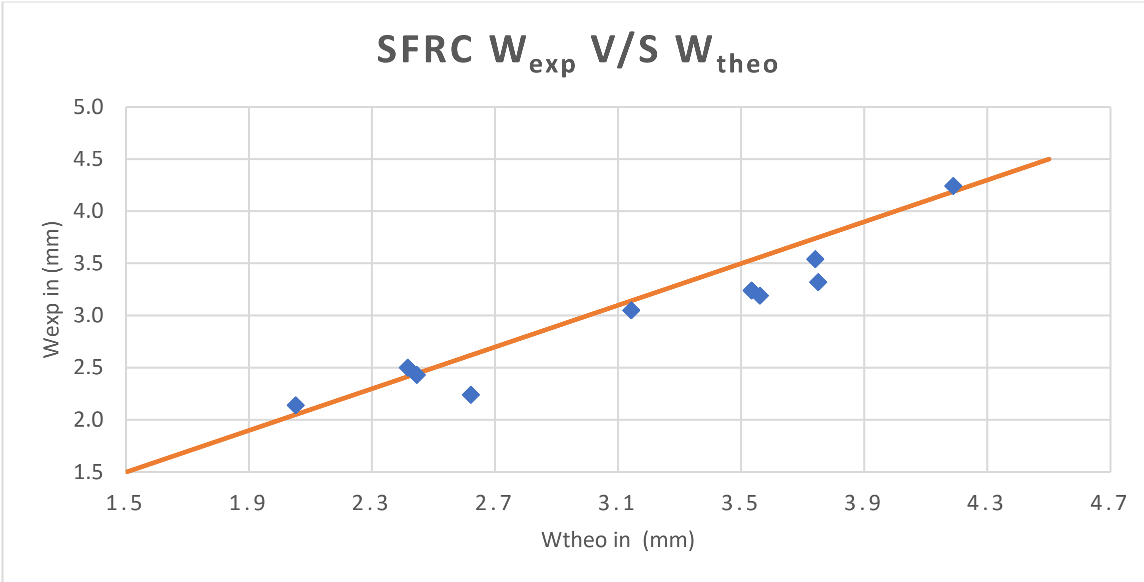


Graph 11-5 Comparison of Experimental Crack Width Vs Predicted Values (RCC)

PFRC and SFRC specimens also shows same trend as of RCC specimens. Results of PFRC specimens fluctuate around ±10%. In SFRC material reduces crack width thus in Modified equation of RCC, a Fiber factor is deducted to get the crack width for SFRC material which offers satisfactory results with minimum errors. In case of SFRC results of W_{exp} Vs W_{theo} fluctuate around 11%. Crack width decreases in PFRC material compared to RCC. In SFRC, lowest crack width was observed with respect to RCC & PFRC.



Graph 11-6 Comparison of Experimental Crack Width Vs Predicted Values (PFRC)

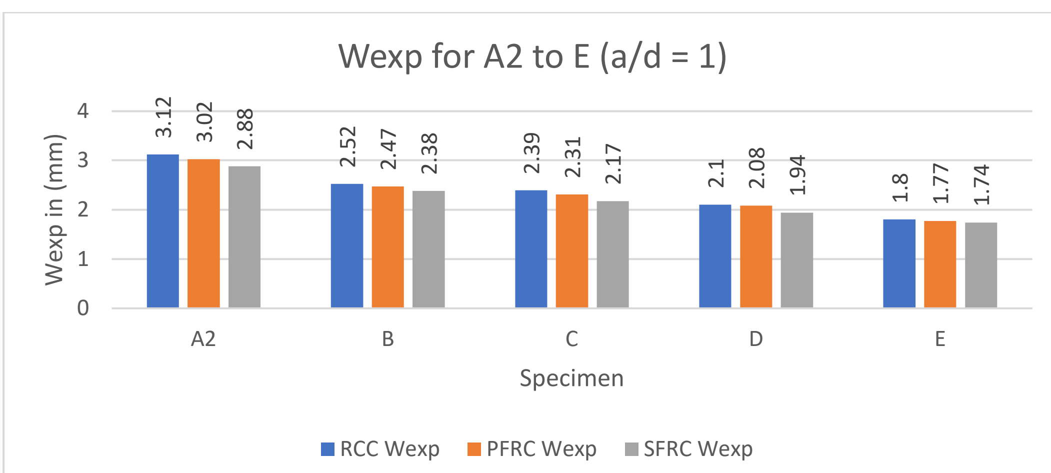


Graph11-7 Comparison of Experimental Crack Width Vs Predicted Values (SFRC)

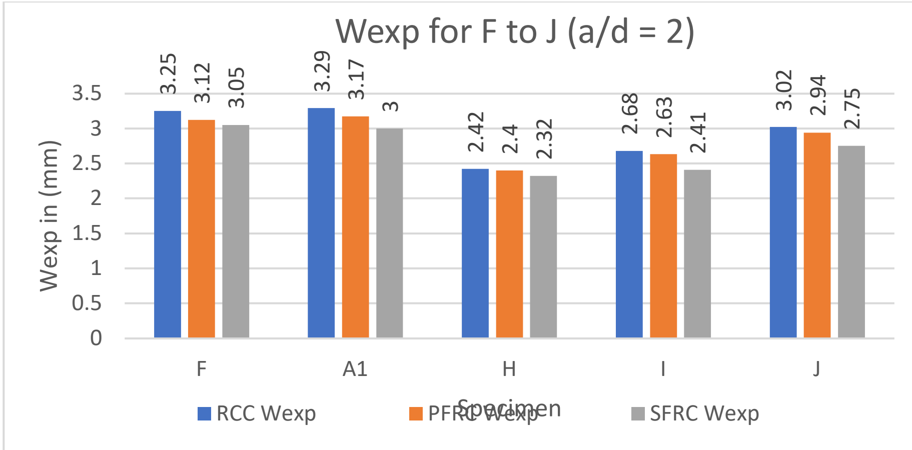
11.9. COMPARISON OF CRACK WIDTH FOR CONVENTIONAL AND FIBEROUS CONCRETE.

Comparison of crack widths between RCC, PFRC and SFRC based on various stages of loads are shown below,

11.9.1. Based on Ultimate load of RCC



GRAPH 11–8 Comparison of W_{exp} At Ultimate Load Of RCC (A2 to E)



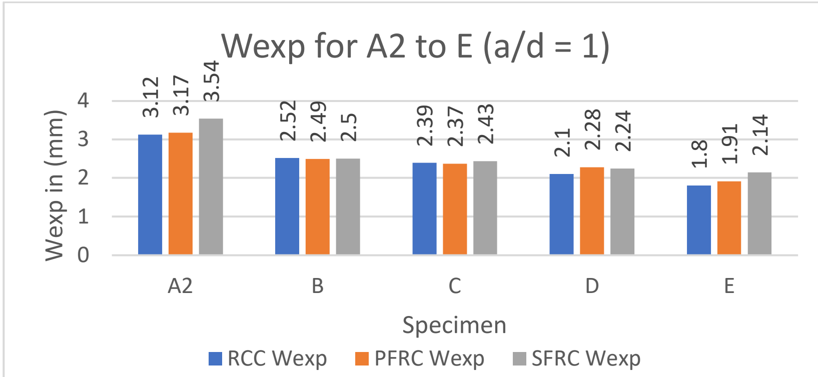
GRAPH 11-9 Comparison of W_{exp} At Ultimate Load Of RCC (F to J)

Ultimate load carrying capacity of specimens varies for different sizes and materials. Load carrying capacity of fibrous material is higher than the normal concrete. SFRC reflects higher value of Ultimate load than PFRC and PFRC shows higher value than RCC. Crack width is in direct proportion with steel stress (f_s). The steel stress depends on bending moment of cracked section thus crack width depends on Ultimate load of a member.

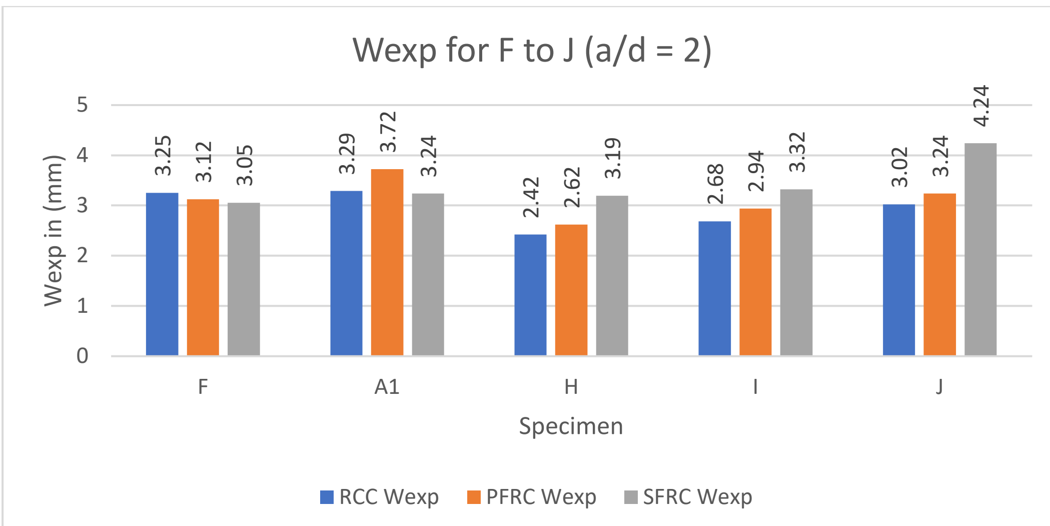
Graph 11-8 & Graph 11-9shows the Results of crack width obtained at Ultimate load of RCC. Results shows that crack widths are in declining trend. In all specimens, RCC beam's crack widths were compared to PFRC and SFRC. At Ultimate load of RCC, crack width of PFRC specimens is lesser than RCC and at the same load, In SFRC specimen the crack width is lowest among RCC and PFRC specimens.

SFRC gives better results for crack arresting and to reduce widening. PFRC specimens shows little increment in load carrying capacity than RCC. It shows better results for reducing crack widths. In SFRC specimens, crack initiates at half of the Ultimate load of RCC. Fibers are arresting the propagation of crack and control the opening of crack width. Resulted in increasing load carrying capacity of the same size of the specimen.

Based on Ultimate load of RCC, PFRC, and SFRC



Graph 11-10 Comparison Of W_{exp} At Ultimate Loads (A2 to E)



Graph 11 -11 Comparison of W_{exp} at Ultimate loads (F to J)

Above results represented by column graph represents the crack widths obtained at Ultimate load of the individual specimens. Incorporation of fiber increases Ultimate load carrying capacity. An unpredicted trend for crack widening at Ultimate load was observed from above Graph 11-11. In some specimens of three different compositions, crack width decreases for SFRC than PFRC and RCC specimens. In Smaller depth F type beam F crack width reduces in SFRC specimens. In Larger depth of J type beam the crack width increase in SFRC beam at its Ultimate load.

Experimental values of crack widths decrease as the beam size increases in two-point loading system while specimens tested under one-point loading system shows that widths increase as depth of specimens increases.

11.10. CRACK DEVELOPMENT IN SPECIMENS WITH a/d=2 (ONE POINT LOADING)

Most of the Beam specimens had failed in shear though flexure cracks were also observed at initial stages of loading. Flexure shear crack was a significant one for the failure of beams. As shown in Figure 11-7 Pattern of cracking remains same irrespective of length and depth of beams while in case of crack width, Because of due to different size of beam the variation was observed.

In the specimen F, first crack occurs in flexure zone while Ultimate failure crack occurs in shear zone. Crack named as A&C in the beam F (700×175×75 mm) starts from a same location in all the three composition. Pattern of cracks, named as A & C in the beam F, for PFRC and SFRC, exactly follows the pattern obtained in RCC while crack widths were different.

For beam A1-RCC, crack initiates at 3.4-ton (RCC) ,3.6 ton (PFRC) and at 3.7 ton (SFRC) specimen. In most of RCC specimens, closer cracks were existing while in Fibrous concrete specimens absorbs more energy compared to RCC specimens. Crack spacing is a main function for finding crack width. In Fibrous concrete beam the lowest crack width and crack spacing observed in specimens.

In H type of beams, RCC and PFRC specimens two main cracks occurs at Ultimate Load. While in SFRC, at the bottom of specimen, number of hair cracks were found. The failure crack was one which is same as of other two compositions. As the beam size increases from F (700×175×75 mm) to J (1500×375×75 mm), failure cracks maintain their pattern, but widths were different according to depth and material used. Shear cracks initiates at middle one third heights of beam and propagate one sides from support to loading point.

Due to central-point loading system, measurable amount of flexure cracks was observed but when the same size of beam tested in two-point loading system, hair cracks occur and remains up to the failure of beam.

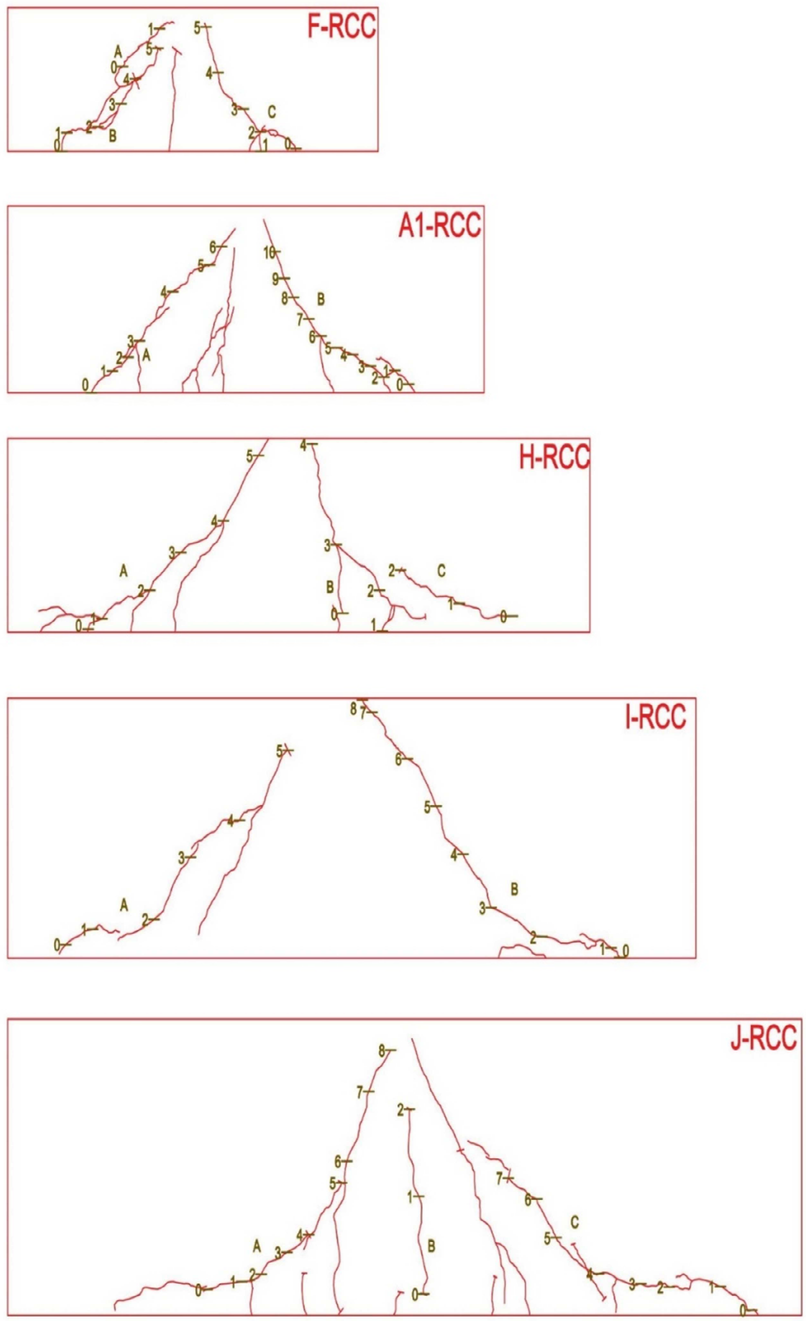


Figure 11-1 Crack Pattern of F To J RCC/1P

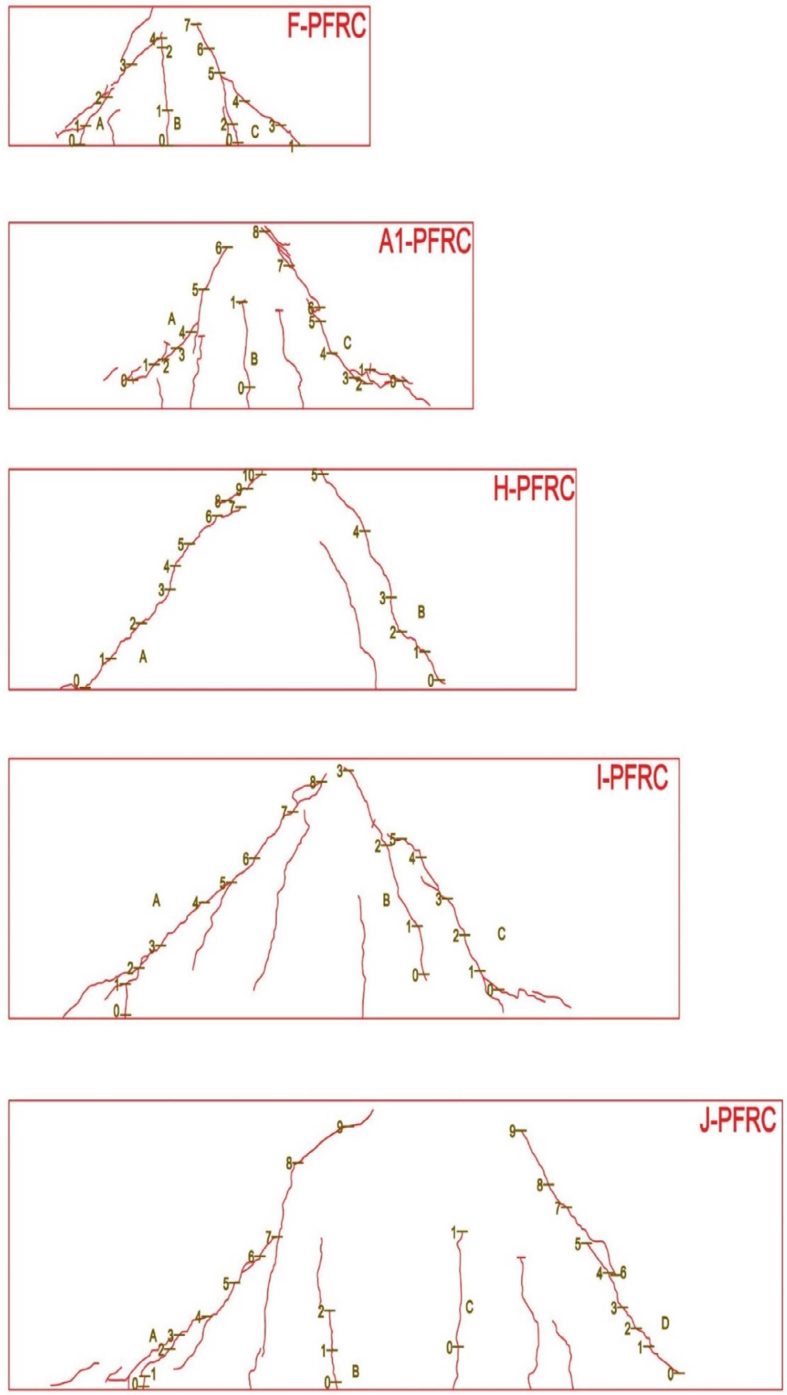


Figure 11-2 crack Pattern of F To J PFRC/1P

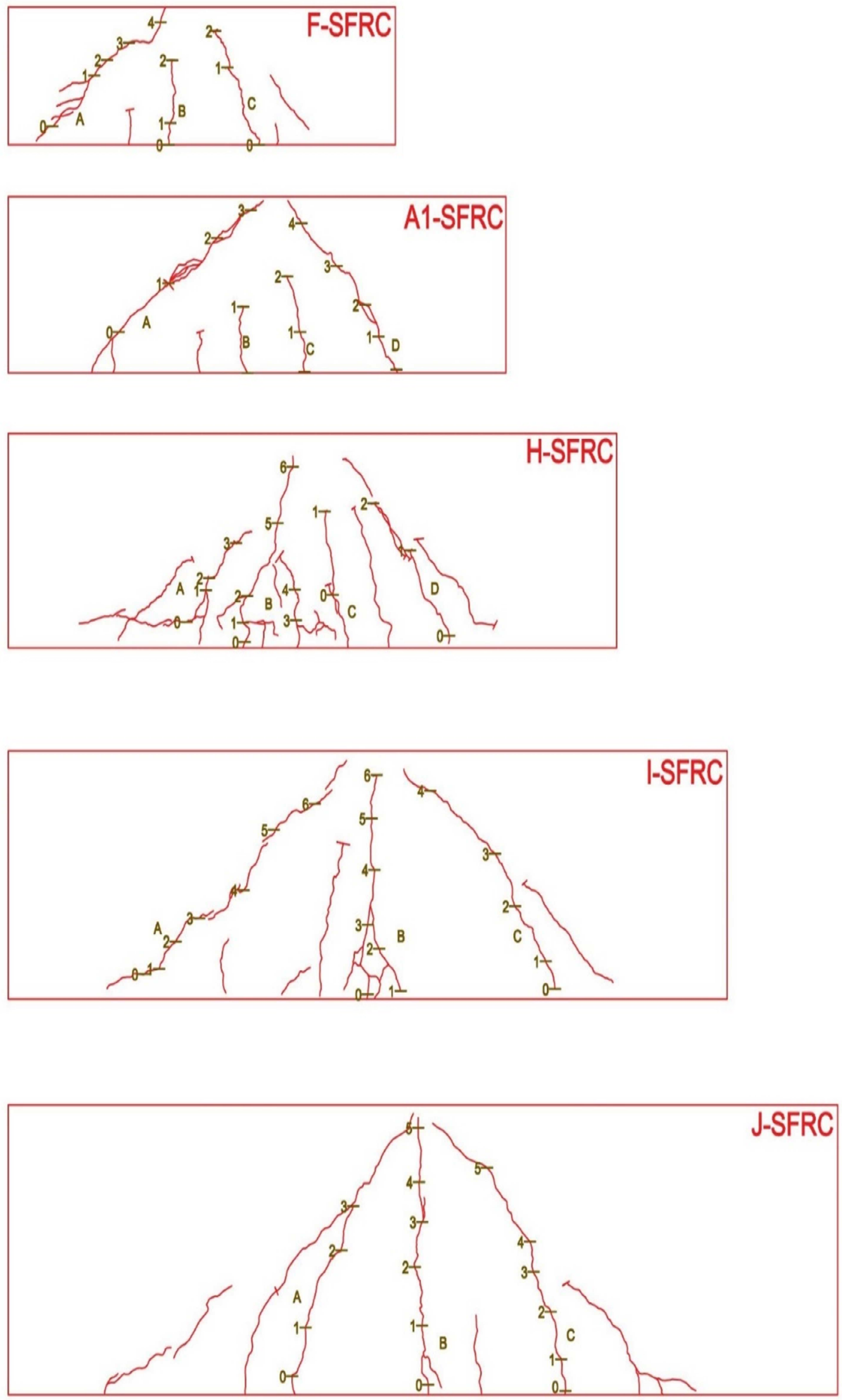


Figure 11-3 Crack Pattern Of F To J SFRC/1P

11.11. CRACK PATTERN CRACK DEVELOPMENT IN SPECIMENS WITH a/d=1 (TWO POINT LOADING)

In Moderate Deep Beams Flexure and diagonal shear cracks were developed in specimens. Previously It was observed in many researchers' papers. In A2 size specimens, First measurable crack develops in flexure zone at 8 ton (RCC) , 5.1 ton (PFRC) and 5.2 ton (SFRC) specimens. as shown below in Figure 11-4.

Ultimate failure of A2 beams were observed in shear with the maximum crack width of 3.12mm (RCC), 3.17mm (PFRC) and 3.54mm (SFRC). These maximum widths were observed at middle one third portion of beam depth.

In RCC specimen, number of minor cracks were comparatively more than the PFRC and SFRC specimens. Looking towards B size specimens, it shows higher initial and Ultimate cracking load than A2. Major three cracks were easily visible in B size specimens of RCC and PFRC. The crack width was 2.52mm (RCC), 2.49mm (PFRC) and 2.50 mm (SFRC) specimens.

B type SFRC specimen reveals that steel fibers bridges arrest the minor cracks and improves control on cracking phenomenon. Similar pattern was also observed in B PFRC specimens but with a negligible width of hair cracks in flexure zone exist in it. Crack C as shown in Figure 11-4as a major one to cause failure in beam B. Propagation of crack starts at 11ton load and it extends up to mid depth of beam. The maximum crack width observed at 12 ton load.

In case of C and D size beams, Ultimate and Initial load carrying capacity increases compared to A2 and B. Shear failure was predominant in case of C size beam specimens even though flexure cracks were present at its initial stage of loading. The flexure cracks were propagating quickly in D size specimens.

PFRC beams shows largest crack spacing than RCC and SFRC specimens. From crack patten It is clearly visible that the crack width depends on the diameter of bar and its spacing inside the specimen. The reinforcement and fiber cover the cement mortar at peripheral surface so crack propagation reduces in specimen. In Two-point loading Crack widths decreases and Ultimate load carrying capacity increases compare one-point loading system.

E size specimens shows closer spacing cracks in RCC. Initially Flexure cracks and hair cracks were developed in specimens. Hair cracks remains on specimens till the failure of beam. (B, C and D cracks in Figure 11-4) In E type Specimen maximum crack width is 1.8 mm (RCC), 1.91mm (PFRC) and 2.14mm (SFRC) specimen.

Two-point loading system with a/d = 1, Declining trend of crack width was observed. As size of beam increases (Le/D), Ultimate load carrying capacity increases and widths of crack decreases. Closer spacing of cracks were observed in when depth of beam increases. Considering effect of polypropylene and steel fibers, it reduces crack width, crack spacing and number of hair cracks.

In E size of beams, corner support failure was also observed. A vertical crack gets developed inside cover region. It was not a major crack in failure of beams. Cluster of cracks initially develops at soffit of beam then get merged at middle one third portion of beam. Finally, the cracks were propagating towards loading point.

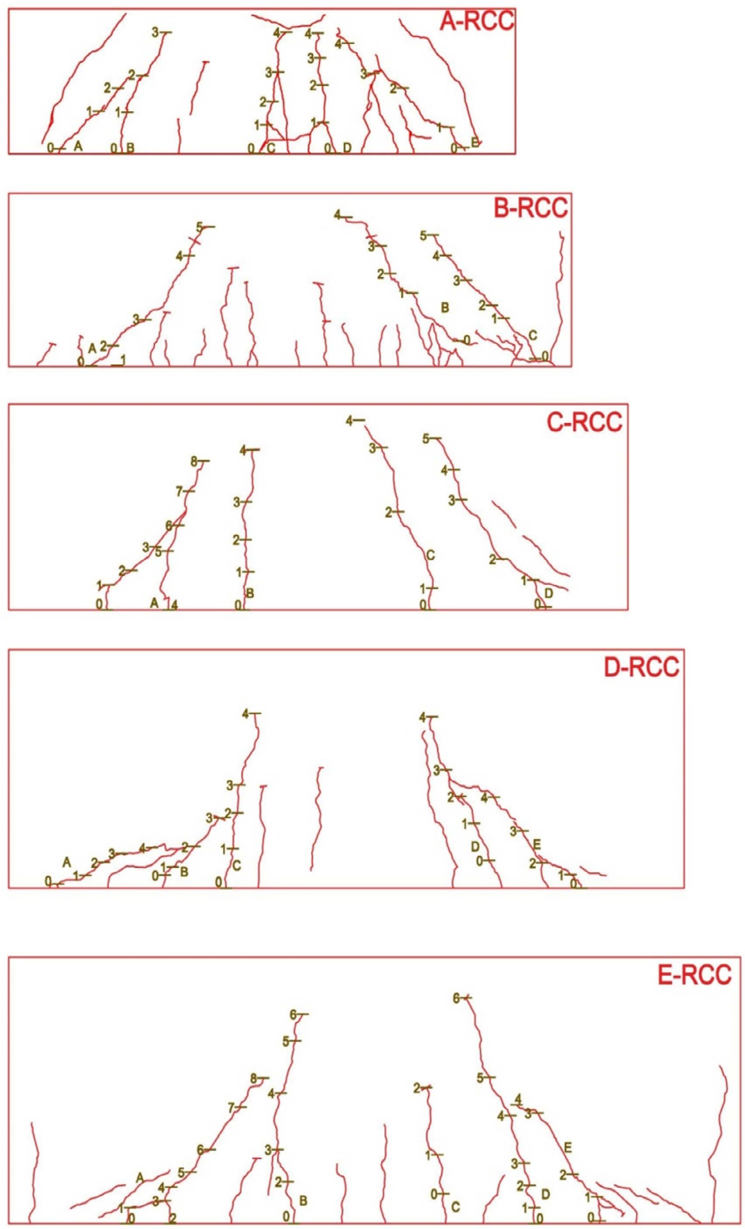


Figure 11-4 Crack Pattern of A2 To E RCC/2P

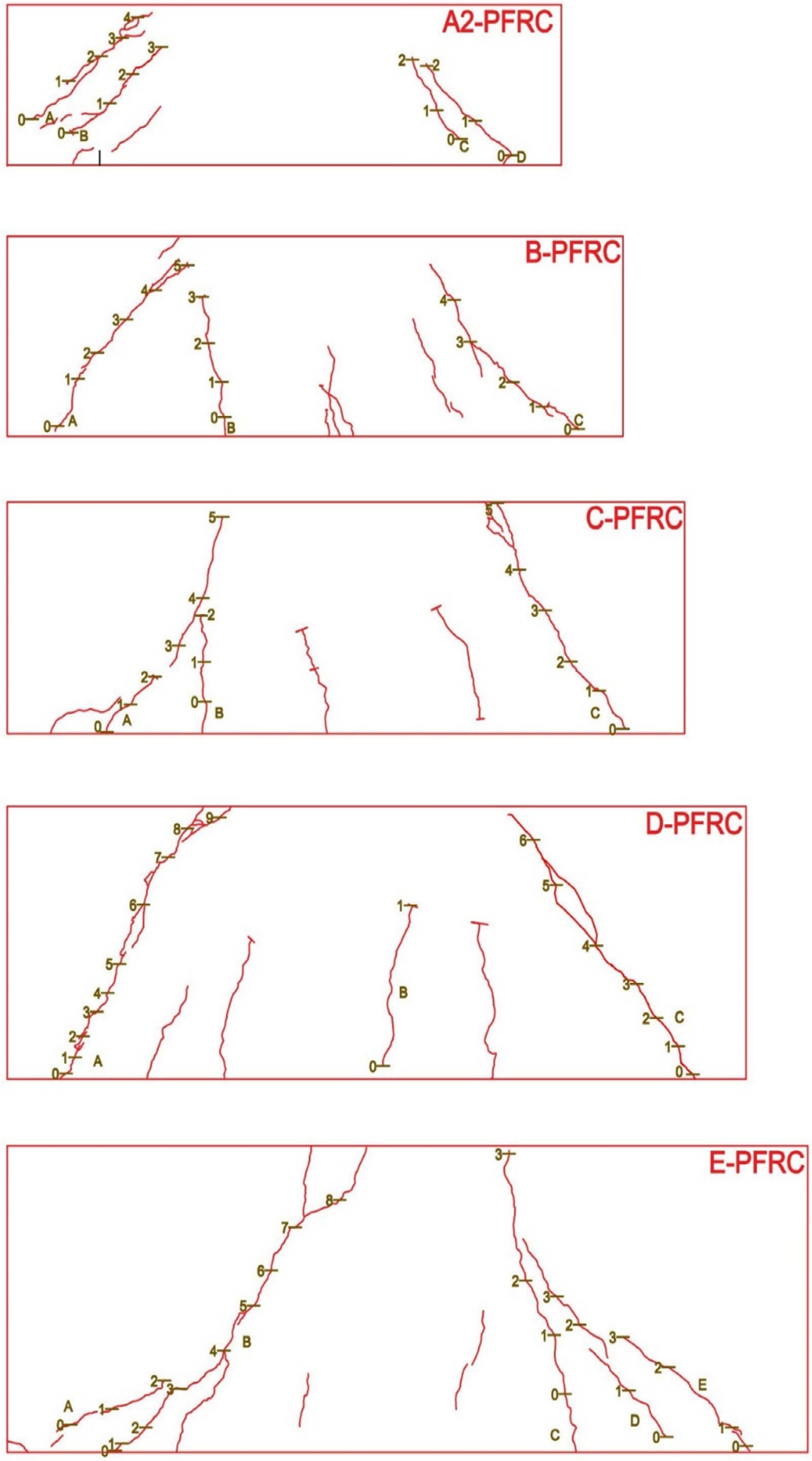


Figure 11-5 Crack Pattern of A2 To E PFRC/2P

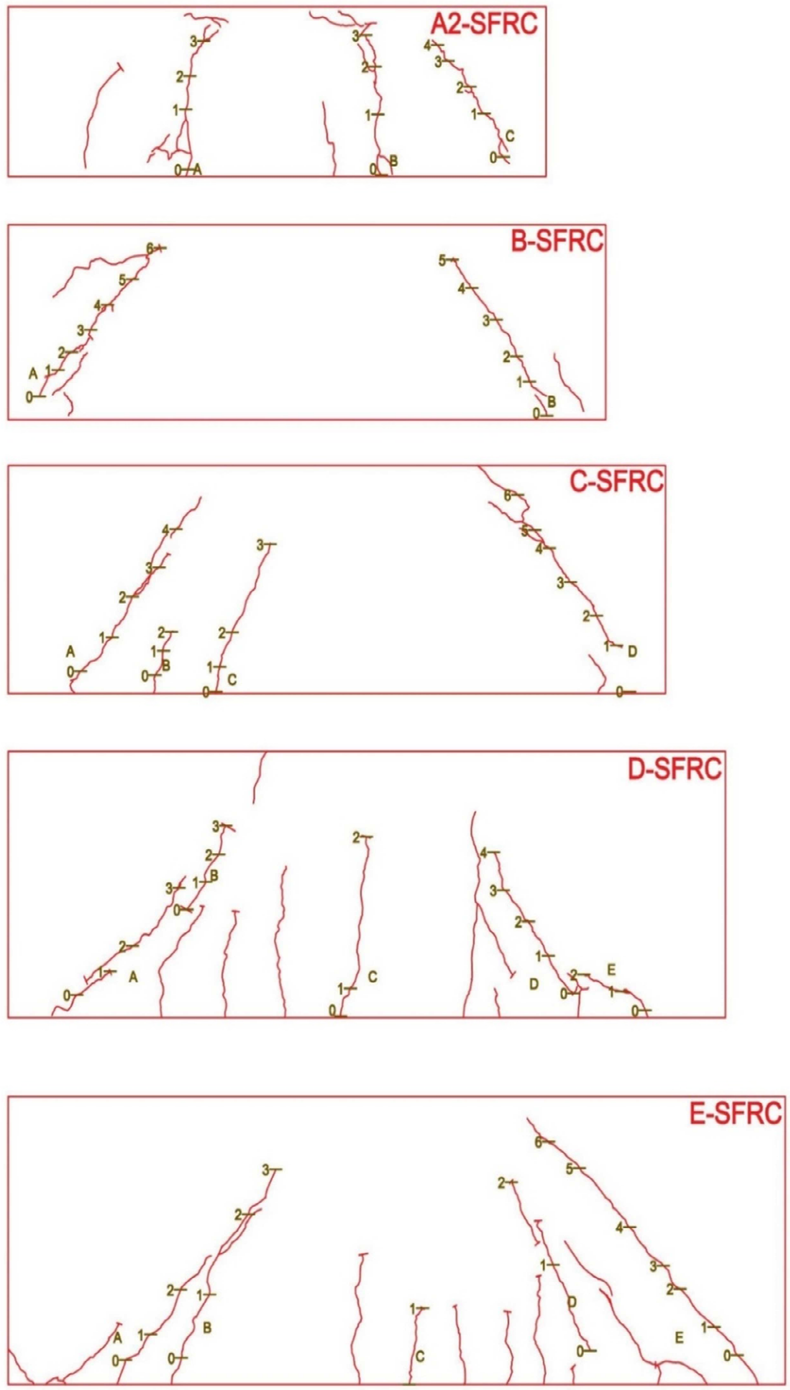


Figure 11-6 Crack Pattern of A2 To E SFRC/2P