7. MODIFICATION OF ULTIMATE SHEAR STRENGTH OF S N PATEL AND S K DAMLE INCORPORATING SIZE EFFECT PARAMETER

Moderate Deep beam is intermediate beam between Shallow beam and Deep beam. Shallow beam generally fails in Flexure mode while the Deep beam fails in shear mode. In Moderate deep beam Initially develop flexure crack in flexure zone. Afterward the shear crack develops in shear zone. Resulting Ultimately leading to Flexure shear failure in Moderate Deep beam. Many Researchers are presently in process of development of shear strength formula for Moderate deep beam.

Equation[12] (or Original Equation) for Ultimate load for Beams fails in shear given by S. N. Patel and S. K. Damle is:

$$Wu = 2Vu = \frac{3.ft.b.d}{\sqrt{1+0.75(\frac{a}{d})^2}} + \frac{fy}{\sqrt{1+(\frac{a}{d})^2}} \cdot \sum_0^i (\frac{yi}{d} + 0.4).Asi.\sin(\alpha 1 + \theta) \quad \ldots(7.1)$$

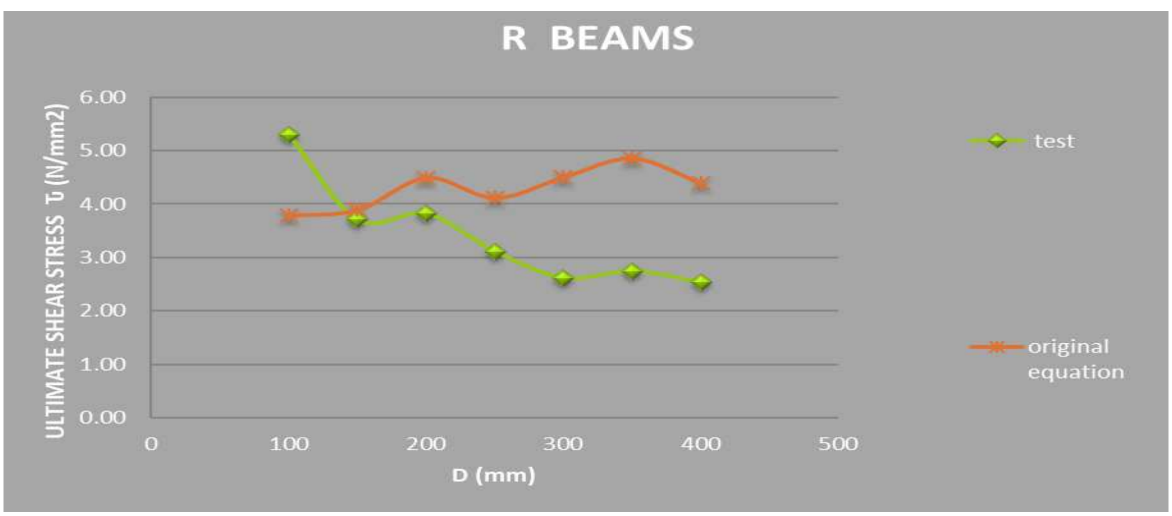
- f_t =Tensile strength of concrete
- b = Width of beam
- d = Effective depth of beam
- a = Shear span
- f_y = Yield strength of reinforcement
- y_i = Depth of reinforcement layer from top of beam
- A_{si} = Area of steel in i^{th} level
- $\propto 1 = \frac{3}{\sqrt{1+0.75(\frac{a}{d})^2}}, \theta = \tan^{-1}\frac{d}{a}$

7.1 INCORPORATING SIZE EFFECT FACTOR IN ORIGINAL EQUATION

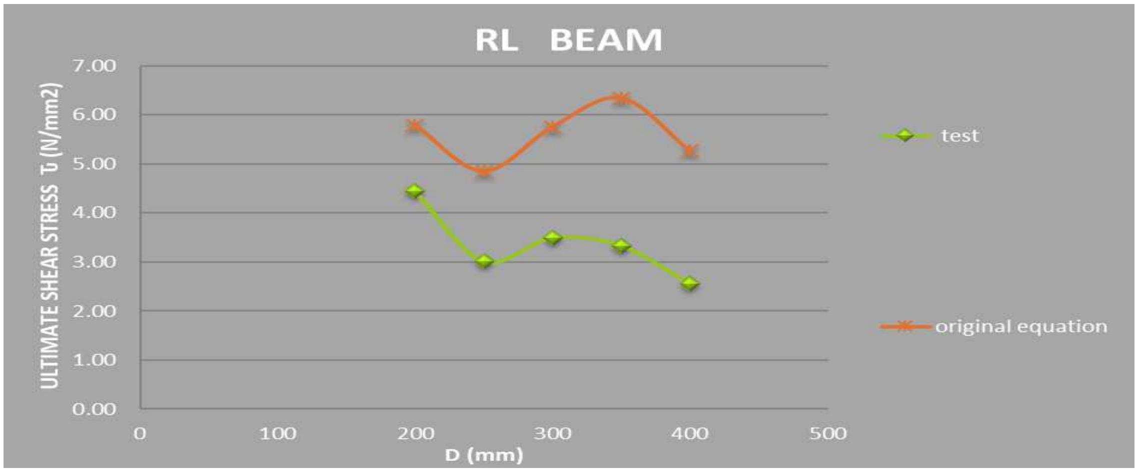
For every Physical theory an important part is scaling, to establish the size effect parameter. when geometrically similar structures are compared. The size effect in solid mechanics is understood by its characteristic structure size (dimension) D on the Nominal strength of structure. Generally, smaller size of specimens has observed higher strength. A number of factors influence the behaviour of material and its strength properties. The strength properties include compressive and tensile strength, bond and fatigue strength, creep, and various dimensional changes. Along with these properties, the nature of the material and the geometric configuration of specimens are also important. For geometrically similar RCC beam two main factors compressive strength of concrete and depth of beam are important.

Size effect is prone to decrease the average shear strength due to increasing depth of the member for concrete moderate deep beam. It has been confirmed that by increasing the depth of beams the shear strength decreases.

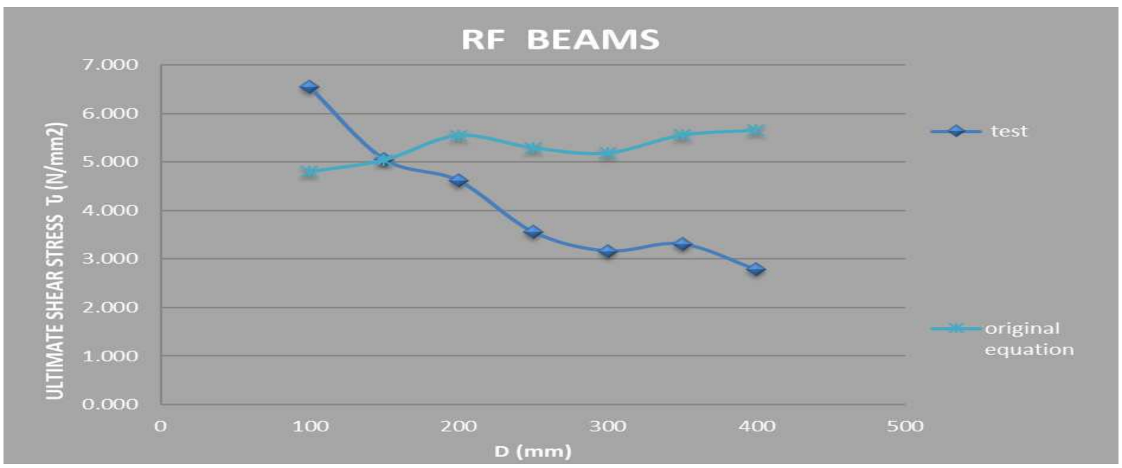
Here, the graph of Ultimate Shear Stress vs. Depth of Beam for 24 Experimental Results and Result predicted by above Original Equation. The graph of Depth v/s Ultimate shear stress is as follow:



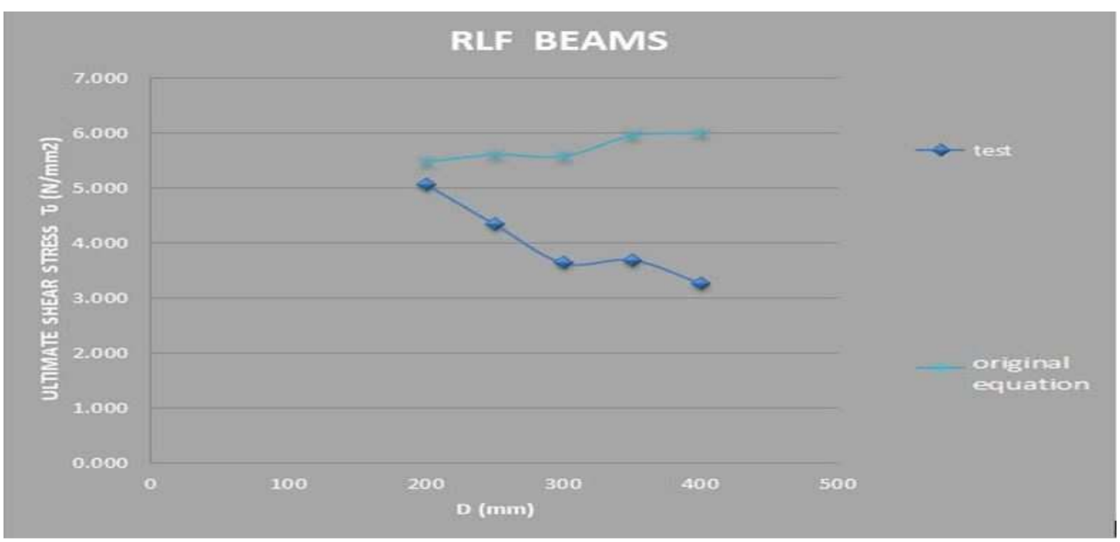
Graph 7-1 Ultimate Shear Stress vs. Depth for “R” beams



Graph 7-2 Ultimate Shear Stress vs. Depth for “RL” beams



Graph 7-3 Ultimate Shear Stress vs. Depth for “RF” beams



Graph 7-4 Ultimate Shear Stress vs. Depth for “RLF” beams

From Above graph it reveals that the Ultimate shear stress decrease with increase in Depth of beam. The shear stress decreases due to size effect parameter. The Ultimate shear stress calculated by original equation is not decrease with depth of beam. So, size effect parameter is necessary to incorporate in Original equation of Shear Strength of moderate deep beam.

From past Research [18], [53] it is suggested that shear strength of concrete beam is directly proportional to $d^{-1/3}$ and $fck^{1/3}$. So, we have to incorporate size effect parameter in terms of $d^{-1/3}$ and $fck^{1/3}$ in above equation.

Size effect parameter multiply in concrete component in above equation. Non-Linear Regression Analysis is used to find size effect parameter S_f. So, the Modified Equation obtained is:

$$Wu = 2Vu = \frac{3.ft.b.d}{\sqrt{1+0.75(\frac{a}{d})^2}}.Sf + \frac{fy}{\sqrt{1+(\frac{a}{d})^2}}.\sum_0^i(\frac{yi}{d}+0.4).Asi.\sin(\alpha_1+\theta) \quad \ldots (2)$$

Where, Sf = Size effect factor

$= 3.38*(d)^{-1/3}*(fck)^{1/3} - 1.27$

(Obtained by Non-Linear Regression analysis) Appendix III

7.2 NON-LINEAR REGRESSION ANALYSIS PROCEDURE

Here, Modified Equation is given by,

$$Wu = 2Vu = \frac{3.ft.b.d}{\sqrt{1+0.75(\frac{a}{d})^2}}.S_f + \frac{fy}{\sqrt{1+(\frac{a}{d})^2}}.\sum_0^i(\frac{yi}{d}+0.4).Asi.\sin(\alpha 1+\theta)$$

Now if we have to equate this equation with experimental load values then one can quantify Size Effect parameter

$\therefore W_{ex} = W_u$ …… (3)

$$\therefore W_{ex} = \frac{3.ft.b.d}{\sqrt{1+0.75(\frac{a}{d})^2}} S_f + \frac{fy}{\sqrt{1+(\frac{a}{d})^2}}.\sum_0^i(\frac{yi}{d}+0.4).Asi.\sin(\alpha 1+\theta)$$

$$\therefore S_f . \frac{3.ft.b.d}{\sqrt{1+0.75\left(\frac{a}{d}\right)^2}} = W_{ex} - \frac{fy}{\sqrt{1+\left(\frac{a}{d}\right)^2}} . \sum_0^i\left(\frac{yi}{d} + 0.4\right).Asi.\sin(\propto 1 + \theta) \qquad \ldots\ldots(4)$$

$\therefore S_f$ x A = B

$$A = \frac{3.ft.b.d}{\sqrt{1+0.75\left(\frac{a}{d}\right)^2}}$$

$$B = W_{ex} - \frac{fy}{\sqrt{1+\left(\frac{a}{d}\right)^2}} . \sum_0^i\left(\frac{yi}{d} + 0.4\right).Asi.\sin(\propto 1 + \theta)$$

$$\therefore S_f = \frac{B}{A}$$

$$S_f = \frac{Wex - \frac{fy}{\sqrt{1+\left(\frac{a}{d}\right)^2}} . \sum_0^i\left(\frac{yi}{d}+0.4\right).Asi.\sin(\propto 1+\theta)}{\frac{3.ft.b.d}{\sqrt{1+0.75\left(\frac{a}{d}\right)^2}}} \qquad \ldots\ldots(1)$$

By using equation (5), we can find numerical value of S_f is as follow:

Table 7.1: Experimental size effect factor values for different series of beams

Sr. No.	Series	D in mm	D in mm	f_{ck} in N/mm^2	S_f	Mode of Failure
1	R	100	80	41.41	1.536872	Flexure-shear
2	R	150	130	41.41	0.942475	Flexure*
3	R	200	180	44.02	0.868932	Flexure-shear
4	R	250	230	41.41	0.636186	Flexure-shear
5	R	300	280	44.02	0.466848	Flexure-shear
6	R	350	330	44.02	0.426109	Flexure-shear
7	R	400	380	41.41	0.446227	Flexure-shear
1	RL	200	180	48.82	0.730993	Flexure-shear
2	RL	250	230	32.69	0.44994	Flexure-shear
3	RL	300	280	48.82	0.487137	Flexure-shear
4	RL	350	330	48.82	0.352183	Flexure-shear
5	RL	400	380	32.69	0.291694	Flexure-shear
1	RF	100	80	34.65	1.453176	Flexure*
2	RF	150	130	34.65	1.004278	Flexure-shear
3	RF	200	180	42.28	0.912275	Flexure-shear
4	RF	250	230	34.65	0.561471	Flexure-shear
5	RF	300	280	42.28	0.511446	Flexure*
6	RF	350	330	42.28	0.4785	Flexure-shear
7	RF	400	380	34.65	0.377392	Flexure-shear
1	RLF	200	180	42.71	0.839943	Flexure-shear
2	RLF	250	230	41.62	0.607412	Flexure-shear
3	RLF	300	280	42.71	0.504245	Flexure-shear
4	RLF	350	330	42.71	0.41491	Flexure-shear
5	RLF	400	380	41.62	0.358676	Flexure-shear
Note: * - beams fails in flexure, these results are not considered for regression analysis						

Here, Size Effect Factor should be in terms of $d^{-1/3}$ and $fck^{1/3}$. So, Dependent Variable is S_f and Independent Variable is $d^{-1/3}$ *$fck^{1/3}$ for Regression Analysis.

Table 7.2 : Experimental size effect factor value for Regression analysis

Sr. No.	Series	d in mm	f_{ck} in N/mm^2	Sf	$d^{-1/3} * fck^{1/3}$
1	R	80	41.41	1.536872	0.802919024
2	R	180	44.02	0.868932	0.625353874
3	R	230	41.41	0.636186	0.564667074
4	R	280	44.02	0.466848	0.539714396
5	R	330	44.02	0.426109	0.510950348
6	R	380	41.41	0.446227	0.477647173
7	RL	180	48.82	0.730993	0.647304198
8	RL	230	32.69	0.449940	0.521870036
9	RL	280	48.82	0.487137	0.558658719
10	RL	330	48.82	0.352183	0.528885035
11	RL	380	32.69	0.291694	0.441445514
12	RF	130	34.65	1.004278	0.643556423
13	RF	180	42.28	0.912275	0.617003306
14	RF	230	34.65	0.561471	0.532098214
15	RF	330	42.28	0.478500	0.504127451
16	RF	380	34.65	0.377392	0.450097445
17	RLF	180	42.71	0.839943	0.619087956
18	RLF	230	41.62	0.607412	0.565619986
19	RLF	280	42.71	0.504245	0.534306569
20	RLF	330	42.71	0.414910	0.505830731
21	RLF	380	41.62	0.358676	0.478453233

Results obtained from Regression Analysis (MS Excel) are as follow:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.95352
R Square	0.9092
Adjusted R Squ	0.90442
Standard Error	0.09058
Observations	21

ANOVA

	df	SS	MS	F	ignificance F
Regression	1	1.56092	1.56092	190.251	2.4E-11
Residual	19	0.15589	0.0082		
Total	20	1.7168			

	Coefficients	tandard Err	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	pper 95.0%
Intercept	-1.27127	0.13762	-9.23761	1.9E-08	-1.55931	-0.98323	-1.55931	-0.98323
$d^{-1/3} * fck^{1/3}$	3.38049	0.24508	13.7932	2.4E-11	2.86752	3.89345	2.86752	3.89345

So, Size Effect Factor $S_f = 3.38*(d)^{-1/3}*(fck)^{1/3} - 1.27$

7.3 COMPARISON OF ULTIMATE SHEAR STRENGTH TEST RESULTS WITH DIFFERENT EQUATIONS

7.3.1 RCC Series of Beams (R)

Table 7-3 : Comparison of Experimental Test Results for Ultimate Load with Various formula

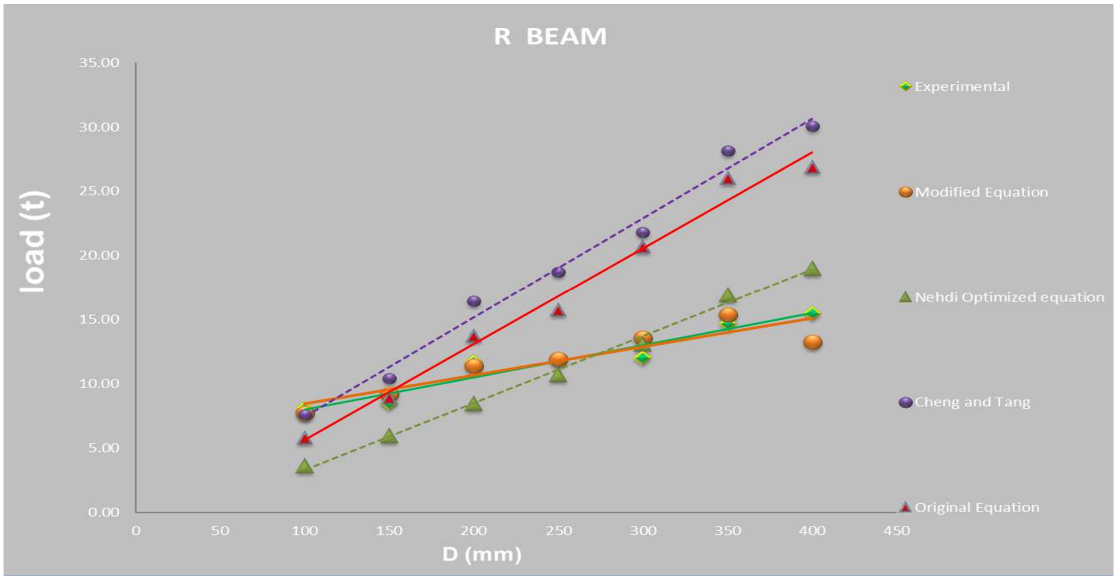
ULTIMATE LOAD (Wu theoretical) (Ton)						
BEAM		Experimental Test Value	Nehdi Optimized Equation(35)	Cheng and Tang(33)	Original Equation(12)	Modified Equation
R	D 10	8.10	3.64	7.63	5.78	7.70
	D 15	8.50	5.94	10.44	8.92	9.20
	D 20	11.70	8.44	16.42	13.75	11.41
	D 25	11.90	10.68	18.74	15.74	11.93
	D 30	12.00	13.10	21.81	20.68	13.60
	D 35	14.70	16.93	28.13	26.02	15.37
	D 40	15.50	18.99	30.05	26.87	13.23

Table 7-4 : Comparison of % difference For Ultimate Load with Various formula

% Difference ((Wu exp – Wu theo)/Wu exp) x 100					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
R	D 10	122.80	6.20	40.11	5.22
	D 15	43.13	-18.62	-4.72	-7.63
	D 20	38.60	-28.75	-14.92	2.55
	D 25	11.43	-36.50	-24.40	-0.27
	D 30	-8.42	-44.97	-41.98	-11.74
	D 35	-13.19	-47.75	-43.51	-4.35
	D 40	-18.39	-48.43	-42.32	17.20
Average		22.14	-33.37	-21.17	1.44

It reveals from Table 7-4 that the comparisons of test results and theoretical values for RCC series of beams. RCC Beams R(D10 to D40) were tested. Its Ultimate load were compared with Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation and Modified Equation. Average error between Experimental results and Modified Equation is 1.44%. While between Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation and Experimental results shows 22%, -33 % and -21% error respectively.

(Note: Here, Original Equation is given by S N Patel and Dr S K Damle)



Graph 7-5 : Graph of Ultimate Load vs. Depth for (R) beams

7.3.2 LAYERED RCC Series of Beams (RL)

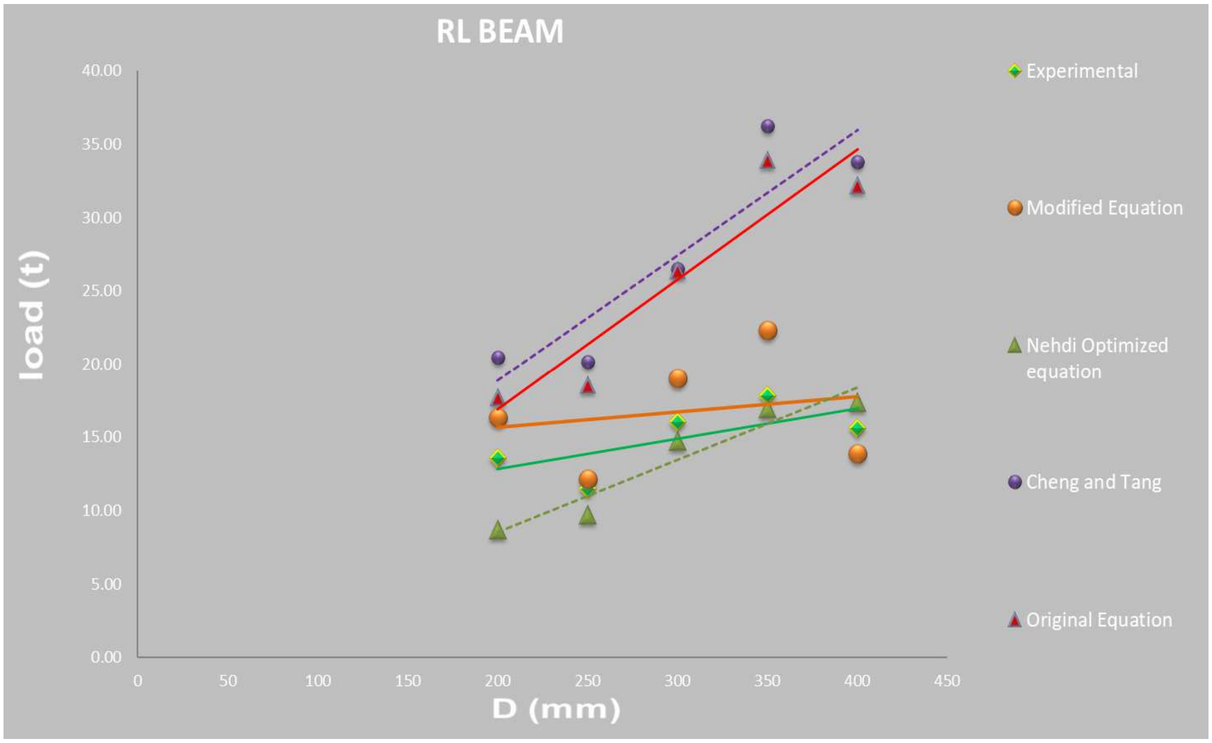
Table 7- 5 : Comparison of Experimental Test Results for Ultimate Load with Various formulas

ULTIMATE LOAD (Wu theoretical) (Ton)						
BEAM		Experimental Test value	Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RL	D 20	13.60	8.64	20.44	17.71	16.30
	D 25	11.50	9.70	20.18	18.55	12.16
	D 30	16.00	14.73	26.50	26.38	19.00
	D 35	17.80	16.91	36.22	33.93	22.28
	D 40	15.60	17.34	33.79	32.20	13.86

Table 7-6 : Comparison of % difference For Ultimate Load with Various formulas

Difference ((Wu exp – Wu theo)/Wu exp) x 100					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RL	D 20	57.32	-33.47	-23.20	-16.58
	D 25	18.57	-43.01	-38.01	-5.39
	D 30	8.62	-39.62	-39.35	-15.79
	D 35	5.27	-50.85	-47.54	-20.12
	D 40	-10.05	-53.83	-51.55	12.55
Average		15.95	-44.16	-39.93	-9.06

It reveals from Table 7-6 that the comparisons of test results and theoretical values for Layered RCC series of beams. Layered RCC Beams (D20 to D40) were tested and its Ultimate load were quantified with Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation and Modified Equation and compared with test results. Average error given by Modified Equation is -9 % to the test results. Whereas Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation shows 16 %, -44% and -40 % error respectively.



Graph 7-6 : Graph of Ultimate Load vs. Depth for (RL) beams

7.3.3 FIBEROUS RCC Series of Beams (RF)

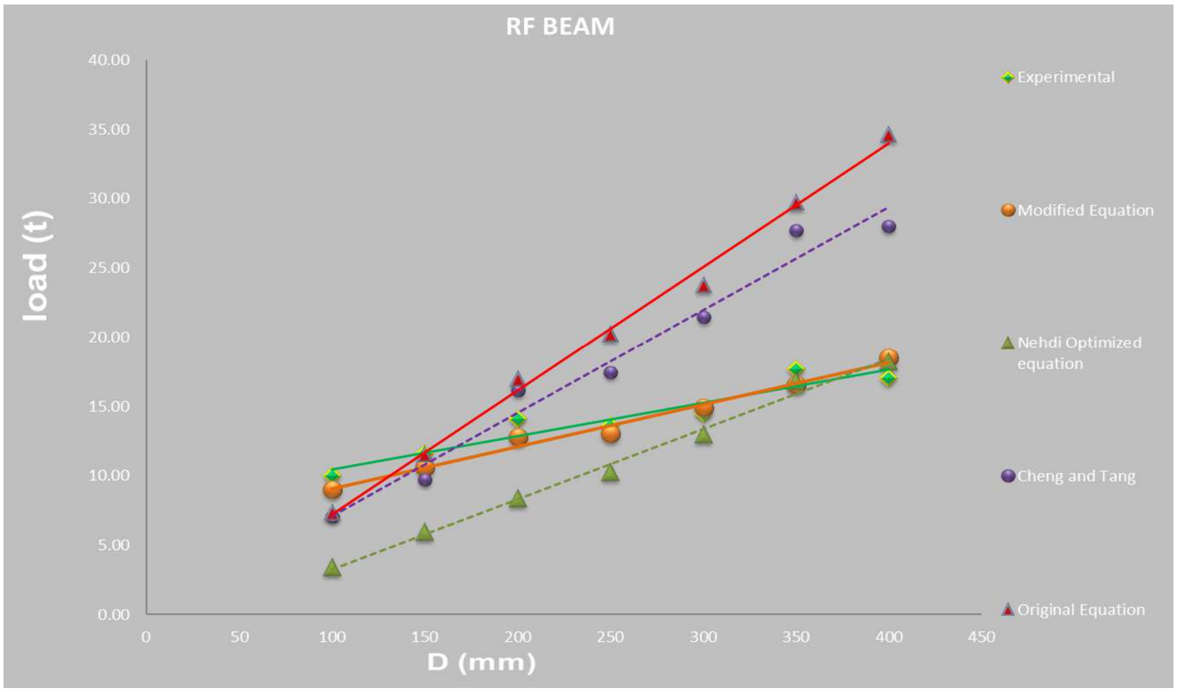
Table 7–7 : Comparison of Experimental Test Results for Ultimate Load with Various formulas

ULTIMATE LOAD (Wu theoretical) (Ton)						
BEAM		Experimental	Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RF	D 10	10.00	3.40	7.06	7.34	9.03
	D 15	11.60	5.91	9.70	11.56	10.61
	D 20	14.10	8.36	16.16	16.97	12.78
	D 25	13.60	10.25	17.46	20.23	13.00
	D 30	14.50	12.98	21.46	23.78	14.90
	D 35	17.70	16.78	27.70	29.72	16.56
	D 40	17.00	18.23	28.03	34.61	18.50

Table 7- 8 : Comparison of % difference For Ultimate Load with Various formulas

% Difference ((Wu exp – Wu theo)/Wu exp) x 100					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RF	D 10	194.13	41.61	36.31	10.80
	D 15	96.21	19.54	0.38	9.29
	D 20	68.59	-12.74	-16.90	10.32
	D 25	32.68	-22.10	-32.78	4.60
	D 30	11.69	-32.42	-39.02	-2.67
	D 35	5.50	-36.09	-40.44	6.87
	D 40	-6.75	-39.34	-50.88	-8.11
average		22.34	-28.54	-36.01	2.2

It reveals from Table 7-8 that the comparisons of test results and theoretical values for Fibrous RCC series of beams. Fibrous RCC Beams RF (D10 to D40) were tested and its Ultimate load were quantified with Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation and Modified Equation and compared with test results. Average error given by Modified equation is 2% to the test results. Where Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation shows 22 %, -29% and -36% error respectively.



Graph 7-7 : Graph of Ultimate Load vs. Depth for (RF) beams

7.3.4 FIBEROS LAYERED RCC Series of Beams (RLF)

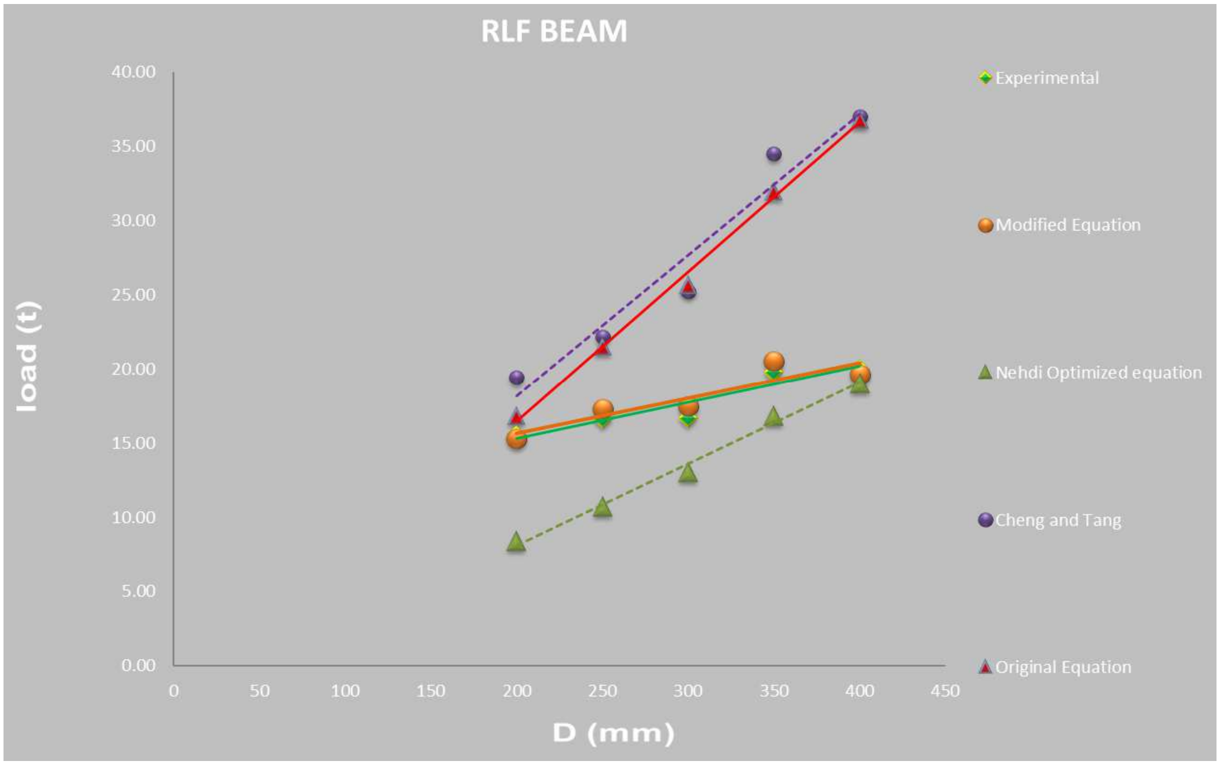
Table 7- 9 : Comparison of Experimental Test Results for Ultimate Load with Various formulas

ULTIMATE LOAD (Wu theoretical) (Ton)						
BEAM		Experimental	Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RLF	D 20	15.50	8.38	19.42	16.78	15.24
	D 25	16.60	10.69	22.14	21.48	17.27
	D 30	16.70	13.01	25.21	25.64	17.44
	D 35	19.80	16.82	34.49	31.94	20.49
	D 40	20.00	19.02	36.98	36.76	19.63

Table 7- 10 : Comparison of % difference For Ultimate Load with Various formulas

% Difference ((Wu exp – Wu theo)/Wu exp) x 100					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RLF	D 20	84.89	-20.20	-7.65	1.70
	D 25	55.26	-25.02	-22.72	-3.87
	D 30	28.34	-33.75	-34.86	-4.27
	D 35	17.74	-42.60	-38.00	-3.37
	D 40	5.18	-45.92	-45.59	1.91
average		38.28	-33.50	-29.76	-1.58

It reveals from Table 7-10 that the comparisons of test results and theoretical values for Fibrous Layerd RCC series of beams. Fibrous Layered RCC Beams RLF (D20 to D40) were tested and its Ultimate load were quantified with Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation and Modified Equation and compared with test results. Average error given by Modified Equation is -2 % to the test results. While Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation shows 38 %, -34 % and -30% error respectively.



Graph 7- 8 : Graph of Ultimate Load vs. Depth for (RLF) beam

7.4 COMPARISON OF ULTIMATE SHEAR STRENGTH RATIO ($W_{U\,TEST}$/ $W_{U\,THEO}$) FOR DIFFERENT EQUATION

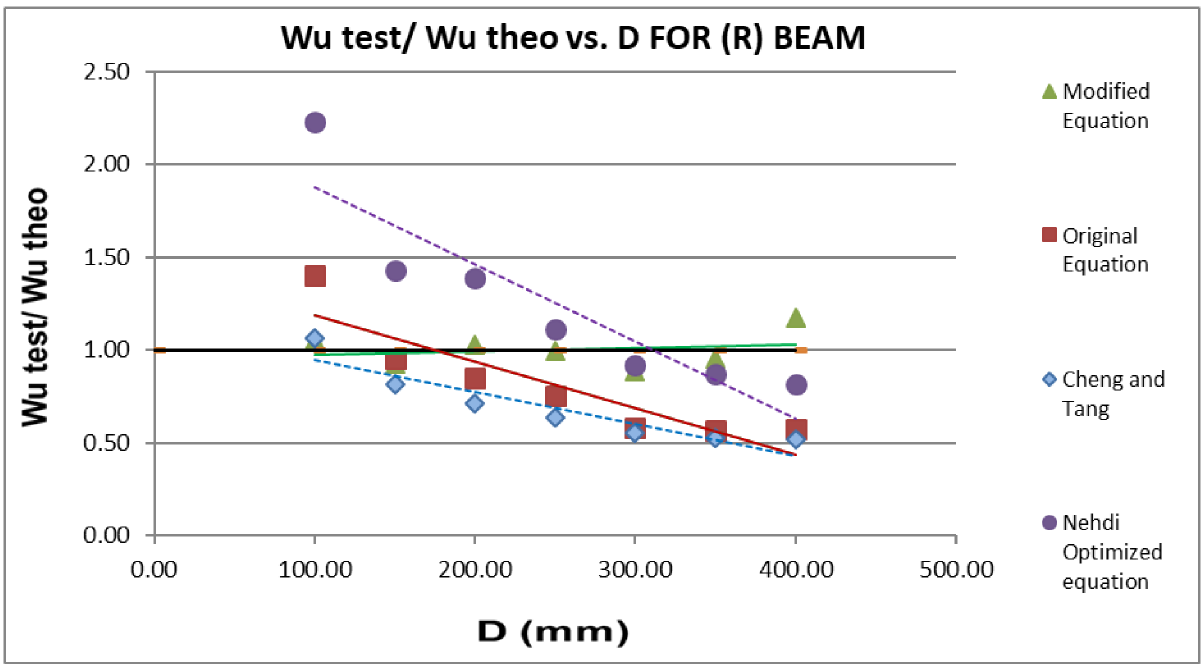
7.4.1 RCC Series of Beams (R)

Table 7- 11 : Comparison of Wu test/ Wu theo with Various formula for (R) beams

Wu test/ Wu theo					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
R	D 10	2.23	1.06	1.40	1.05
	D 15	1.43	0.81	0.95	0.92
	D 20	1.39	0.71	0.85	1.03
	D 25	1.11	0.63	0.76	1.00
	D 30	0.92	0.55	0.58	0.88
	D 35	0.87	0.52	0.56	0.96
	D 40	0.82	0.52	0.58	1.17
average of absolute deviation		0.37	0.15	0.22	0.07
average		1.25	0.69	0.81	1.00

It reveals from Table 7–11 that the comparisons for ratios of test results to theoretical values of Ultimate shear strength for RCC series of beams R (D10 to D40). Average of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 1.00. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 1.25, 0.69 and 0.81 respectively.

Average of absolute Deviation of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 0.07. While The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 0.37, 0.15 and 0.22 respectively.



Graph 7-9 : Graph of Wu test / W theo. vs. Depth for (R) beams

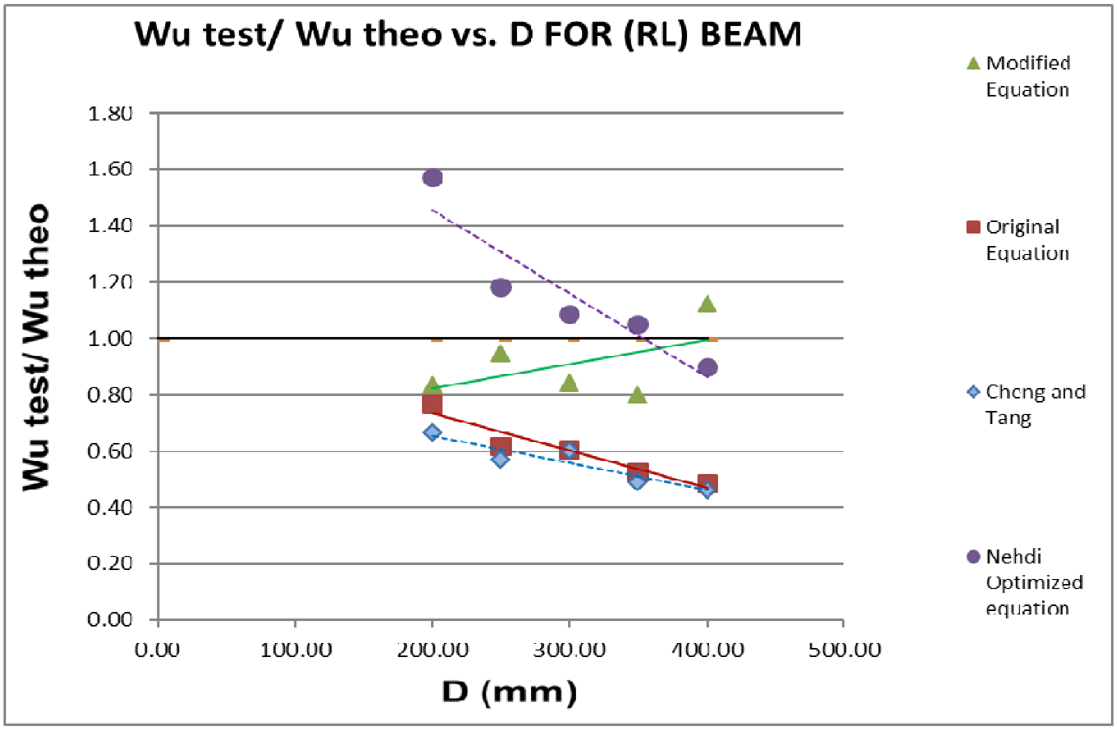
7.4.2 LAYERED RCC Series of Beams (RL)

Table 7-12: Comparison of Wu test/ Wu theo with Various formula for (RL) beams

Wu test/ Wu theo					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RL	D 20	1.57	0.67	0.77	0.83
	D 25	1.19	0.57	0.62	0.95
	D 30	1.09	0.60	0.61	0.84
	D 35	1.05	0.49	0.52	0.80
	D 40	0.90	0.46	0.48	1.13
average of absolute deviation		0.18	0.07	0.08	0.10
average		1.16	0.56	0.60	0.91

It reveals from Table 7-12 that the comparisons for ratios of test results to theoretical values of Ultimate shear strength for Layerd RCC series of beams RL (D20 to D40). Average of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 0.91. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 1.16, 0.56 and 0.60 respectively.

Average of absolute deviation of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 0.10. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 0.18, 0.07 and 0.08 respectively.



Graph 7-10 : Graph of Wu test / W theo. vs. Depth for (RL) beams

7.4.3 FIBEROUS RCC Series of Beams (RF)

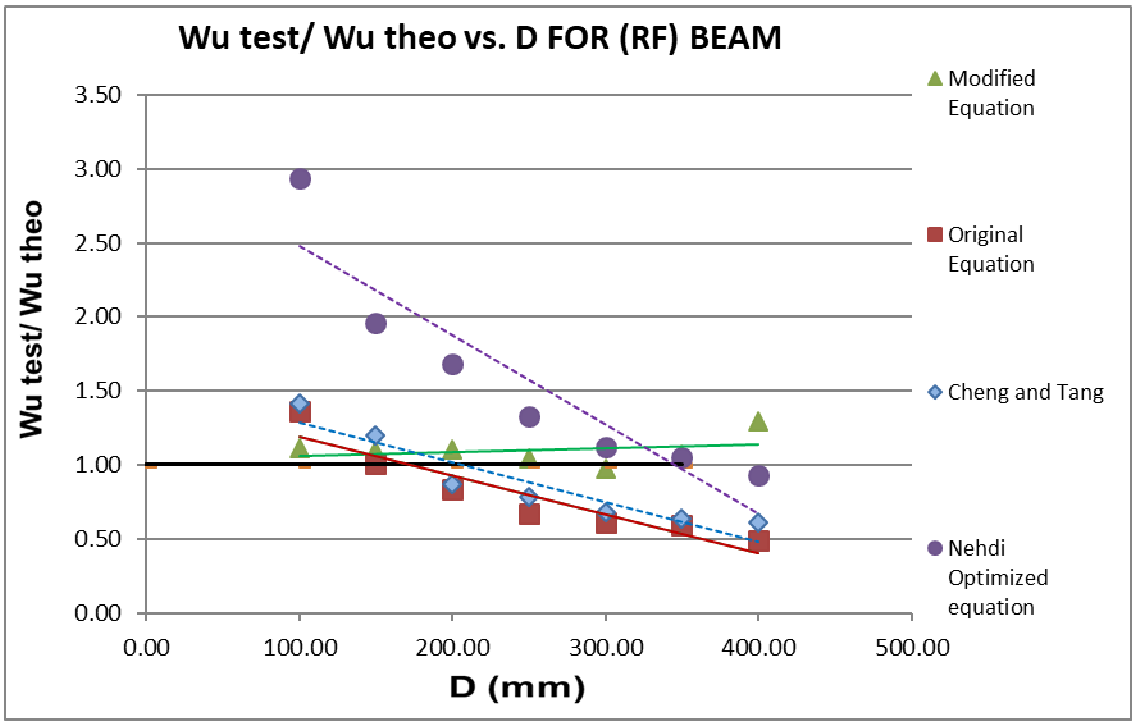
Table 7- 13 : Comparison of Wu test/ Wu theo with Various formula for (RF) beams

Wu test/ Wu theo					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RF	D 10	2.94	1.42	1.36	1.11
	D 15	1.96	1.20	1.00	1.09
	D 20	1.69	0.87	0.83	1.10
	D 25	1.33	0.78	0.67	1.05
	D 30	1.12	0.68	0.61	0.97
	D 35	1.05	0.64	0.60	1.07
	D 40	0.93	0.61	0.49	1.29
average of absolute deviation		0.53	0.24	0.23	0.06
average		1.57	0.88	0.80	1.10

It reveals from Table 7-13 that the comparisons for ratios of test results to theoretical values of ultimate shear strength for

FIBEROUS RCC series of beams RF (D10 to D40). Average of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 1.10. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 1.57, 0.88 and 0.80 respectively.

Average of Absolute Deviation of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 0.06. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 0.53, 0.24 and 0.23 respectively.



Graph 7- 11 : Graph of Wu test / W theo. vs. Depth for (RF) beams

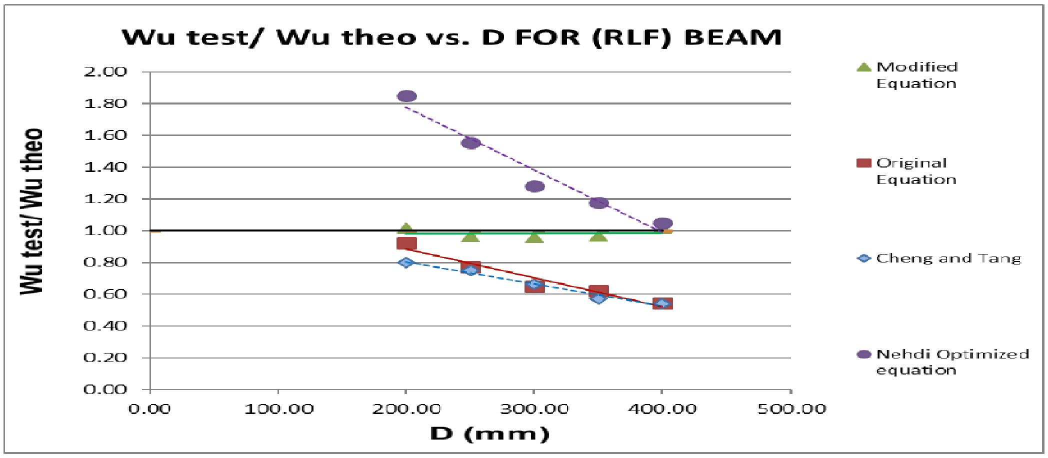
7.4.4 FIBEROUS LAYERED RCC Series of Beams (RLF)

Table 7-14 : Comparison of Wu test/ Wu theo with Various formula for (RLF) beams

Wu test/ Wu theo					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RLF	D 20	1.85	0.80	0.92	1.02
	D 25	1.55	0.75	0.77	0.96
	D 30	1.28	0.66	0.65	0.96
	D 35	1.18	0.57	0.62	0.97
	D 40	1.05	0.54	0.54	1.02
average of Absolute deviation		0.25	0.09	0.12	0.03
average		1.38	0.67	0.70	0.98

It reveals from Table 7-13 that the comparisons for ratios of test results to theoretical values of ultimate shear strength for FIBEROUS RCC series of beams RF (D10 to D40). Average of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 1.10. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 1.57, 0.88 and 0.80 respectively.

Average of Absolute Deviation of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 0.06. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 0.53, 0.24 and 0.23 respectively.



Graph 7-12 : Graph of Wu test / W theo. vs. Depth for (RLF) beams

7.4.5 Overall Comparison of Ultimate Shear Strength Ratio (Wu test/ Wu theo) for Different Equations

Table 7-15 : Overall comparison of Ultimate shear strength ratio with various formulas

Wu test/ Wu theo					
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
R	D 10	2.23	1.06	1.40	1.05
	D 15	1.43	0.81	0.95	0.92
	D 20	1.39	0.71	0.85	1.03
	D 25	1.11	0.63	0.76	1.00
	D 30	0.92	0.55	0.58	0.88
	D 35	0.87	0.52	0.56	0.96
	D 40	0.82	0.52	0.58	1.17
RL	D 20	1.57	0.67	0.77	0.83
	D 25	1.19	0.57	0.62	0.95
	D 30	1.09	0.60	0.61	0.84
	D 35	1.05	0.49	0.52	0.80
	D 40	0.90	0.46	0.48	1.13
RF	D 10	2.94	1.42	1.36	1.11
	D 15	1.96	1.20	1.00	1.09
	D 20	1.69	0.87	0.83	1.10
	D 25	1.33	0.78	0.67	1.05
	D 30	1.12	0.68	0.61	0.97
	D 35	1.05	0.64	0.60	1.07
	D 40	0.93	0.61	0.49	1.29
RLF	D 20	1.85	0.80	0.92	1.02
	D 25	1.55	0.75	0.77	0.96
	D 30	1.28	0.66	0.65	0.96
	D 35	1.18	0.57	0.62	0.97
	D 40	1.05	0.54	0.54	1.02
average of absolute deviation		0.37	0.17	0.19	0.09
average		1.35	0.71	0.74	1.01

It reveals from Table (7-15) that the comparisons for ratios of test results to theoretical values of Ultimate shear strength for All series of beams i.e. RCC Beam, RL RCC Layered Beam, RF RCC Fibrous Beam and RLF RCC Layered Fibrous Beams. Average of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 1.01. The values obtained form Nehdi-

Optimized Equation, Cheng and Tang Equation and Original Equation are 1.35, 0.71 and 0.74 respectively.

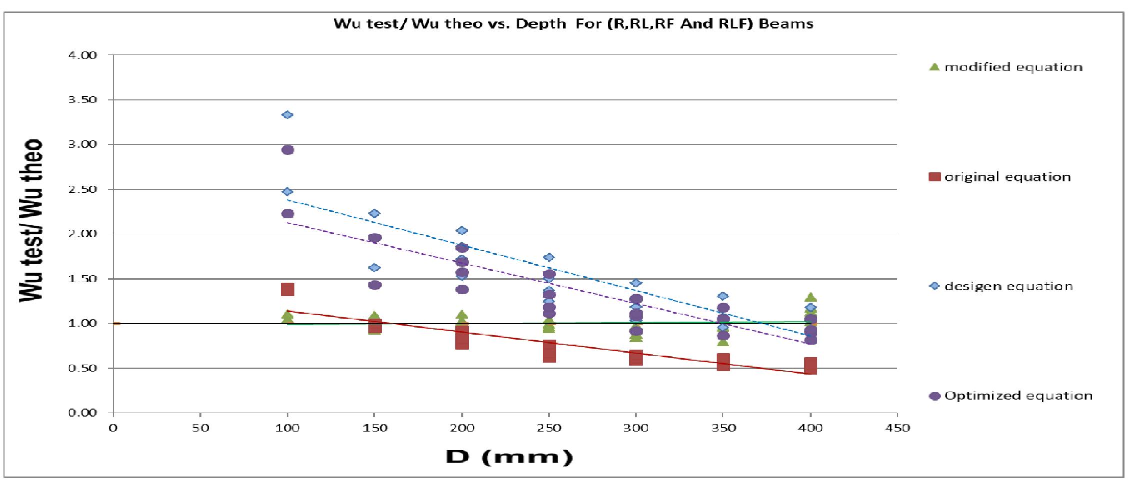
Average of absolute deviation of Ultimate shear strength ratio (Wu test/ Wu theo) for Modified Equation is 0.09. The values obtained for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation are 0.37, 0.17 and 0.19 respectively.

7.4.6 Overall Comparison of % Difference for Ultimate Load with Various Formula

Table 7-16 : Overall comparison of % difference with various formulas

Overall average % Difference ((Wu exp – Wu theo)/Wu exp) x 100				
Beam series	Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
R	28.25	-31.04	-17.01	4.07
RL	15.95	-44.16	-39.93	-9.06
RF	25.00	-27.57	-35.25	3.42
RLF	38.28	-33.50	-29.76	-1.58
average	26.87	-34.07	-30.49	-0.79

It reveals from Table 7-16 that the comparisons of test results and theoretical values for All series of beams i.e. RCC Beam, RL RCC Layered Beam , RF RCC Fibrous Beam and RLF RCC Layered Fibrous Beams. Overall average of average error given by Modified Equation is -0.79% to the test results. While for Nehdi-Optimized Equation, Cheng and Tang Equation, Original Equation show 26.87%, -34.07% and -30.49% error respectively.



Graph 7-13 : Graphical Overall Comparison of Ultimate Shear Strength Ratio of Test Result with Different Equations

7.5 SIZE EFFECT

Size effect means when shear stress decrease with increasing the depth of the member. It can easily understand by plotting graph of Shear Stress vs. Depth of beam.

The shear stress criteria in terms of Nominal shear stress and Ultimate shear stress. The Nominal shear stress and Ultimate shear stress used to find the Crack width of the section.

Nominal shear stress typically calculated by = $Wu/(bD\sqrt{(fck)})$

Ultimate shear stress typically calculated by = Wu/bD

Nominal shear stress considering crack length = $Wu/(bLc\sqrt{(fck)})$

Ultimate shear stress considering crack length by = Wu/bLc

Where,

Wu = Ultimate load (N)

fck = Characteristic compressive strength of concrete after 28 days (N/mm^2)

b = Width of specimen (mm)

D = Overall depth of specimen (mm)

Lc = Ultimate shear crack length (mm)

Nominal shear stress at failure was calculated using above formula for RCC, LAYERED RCC, FIBEROUS RCC, FIBEROUS LAYERED RCC and graphs are plotted with respect to beam depth.

7.5.1 Size Effect (Shear Stress) of Tested Beams

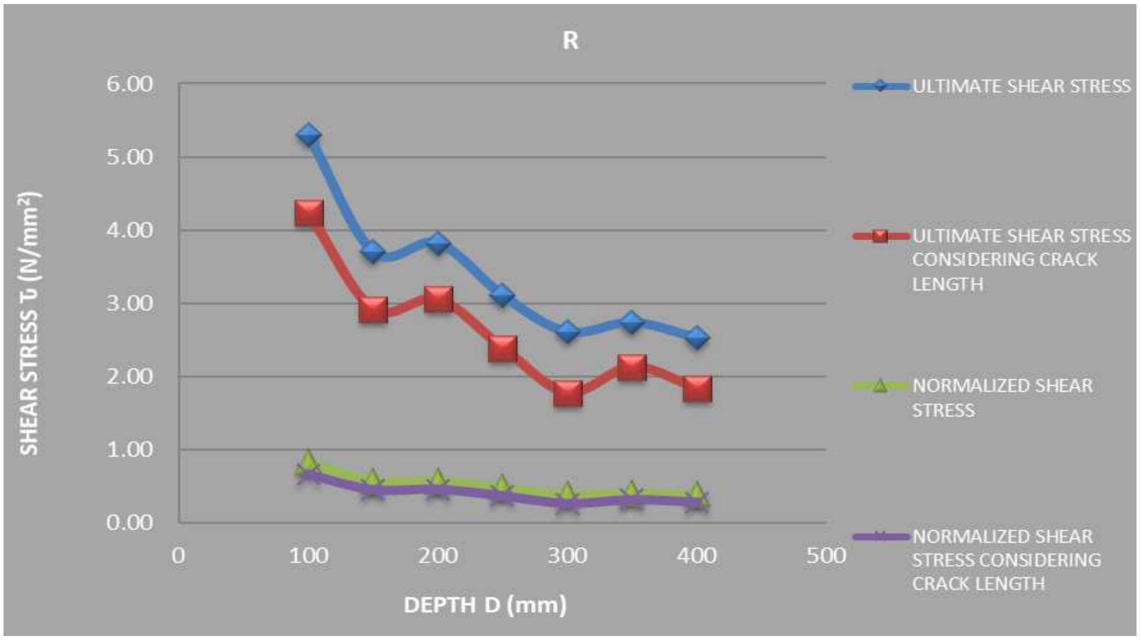
Table 7 – 17 : Size effect of tested beams with different parameters

BEAM		B (mm)	D (mm)	fck (N/mm²)	Lc (mm)	Test (Ton)	SHEAR STRESS OF TESTED BEAMS (N/mm²)			
							US	USCC	NS	NSCC
R	D 10	75	100	41.41	125	8.1	5.30	4.24	0.82	0.66
	D 15	75	150	41.41	190	8.5	3.70	2.92	0.58	0.45
	D 20	75	200	44.02	250	11.7	3.82	3.06	0.58	0.46
	D 25	75	250	41.41	325	11.9	3.11	2.39	0.48	0.37
	D 30	75	300	44.02	440	12	2.62	1.78	0.39	0.27
	D 35	75	350	44.02	450	14.69	2.75	2.14	0.41	0.32
	D 40	75	400	41.41	550	15.5	2.53	1.84	0.39	0.29
RL	D 20	75	200	48.82	270	13.6	4.45	3.29	0.64	0.47
	D 25	75	250	32.69	330	11.5	3.01	2.28	0.53	0.40
	D 30	75	300	48.82	385	16	3.49	2.72	0.50	0.39
	D 35	75	350	48.82	490	17.8	3.32	2.37	0.48	0.34
	D 40	75	400	32.69	500	15.6	2.55	2.04	0.45	0.36
RF	D 10	75	100	34.65	110	10	6.54	5.94	1.11	1.01
	D 15	75	150	34.65	152	11.6	5.06	4.99	0.86	0.85
	D 20	75	200	42.28	250	14.1	4.61	3.69	0.71	0.57
	D 25	75	250	34.65	300	13.6	3.56	2.96	0.60	0.50
	D 30	75	300	42.28	253	14.5	3.16	3.75	0.49	0.58
	D 35	75	350	42.28	490	17.7	3.31	2.36	0.51	0.36
	D 40	75	400	34.65	515	17	2.78	2.16	0.47	0.37
RLF	D 20	75	200	42.71	245	15.5	5.07	4.14	0.78	0.63
	D 25	75	250	41.62	325	16.6	4.34	3.34	0.67	0.52
	D 30	75	300	42.71	400	16.7	3.64	2.73	0.56	0.42
	D 35	75	350	42.71	460	19.8	3.70	2.81	0.57	0.43
	D 40	75	400	41.62	545	20	3.27	2.40	0.51	0.37

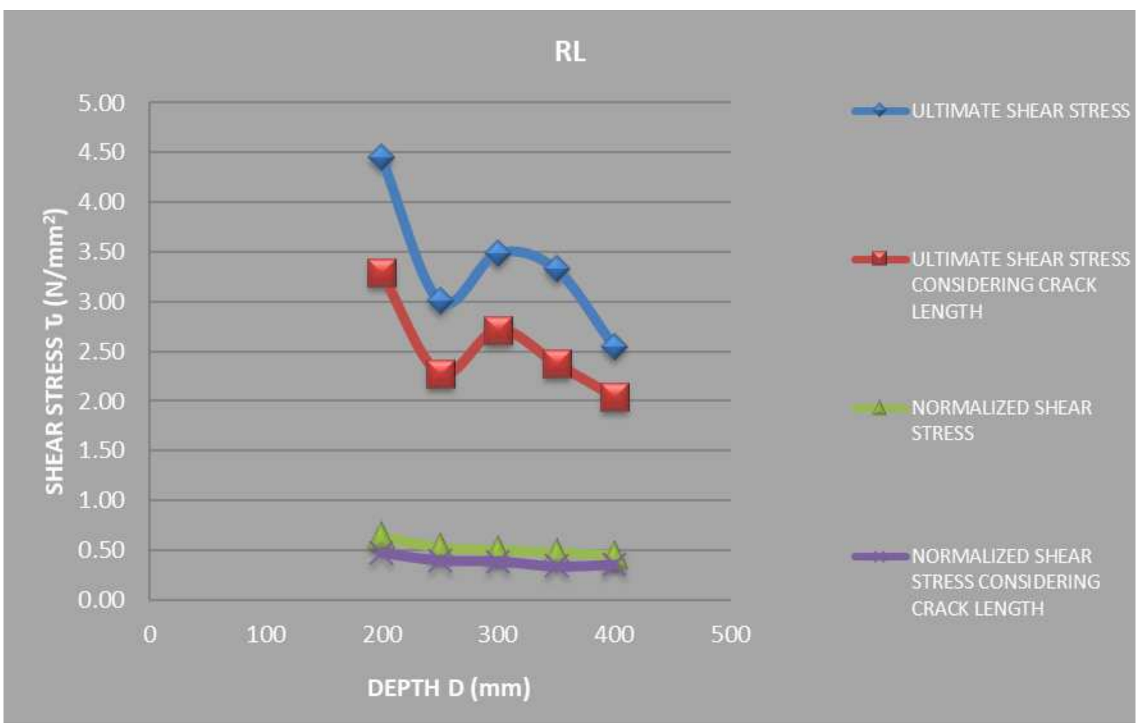
(Here, US = Ultimate Shear Stress, USCC = Ultimate Shear Stress Considering Crack Length,

NS = Normalized Shear Stress, NSCC = Normalized Shear Stress Considering Crack Length

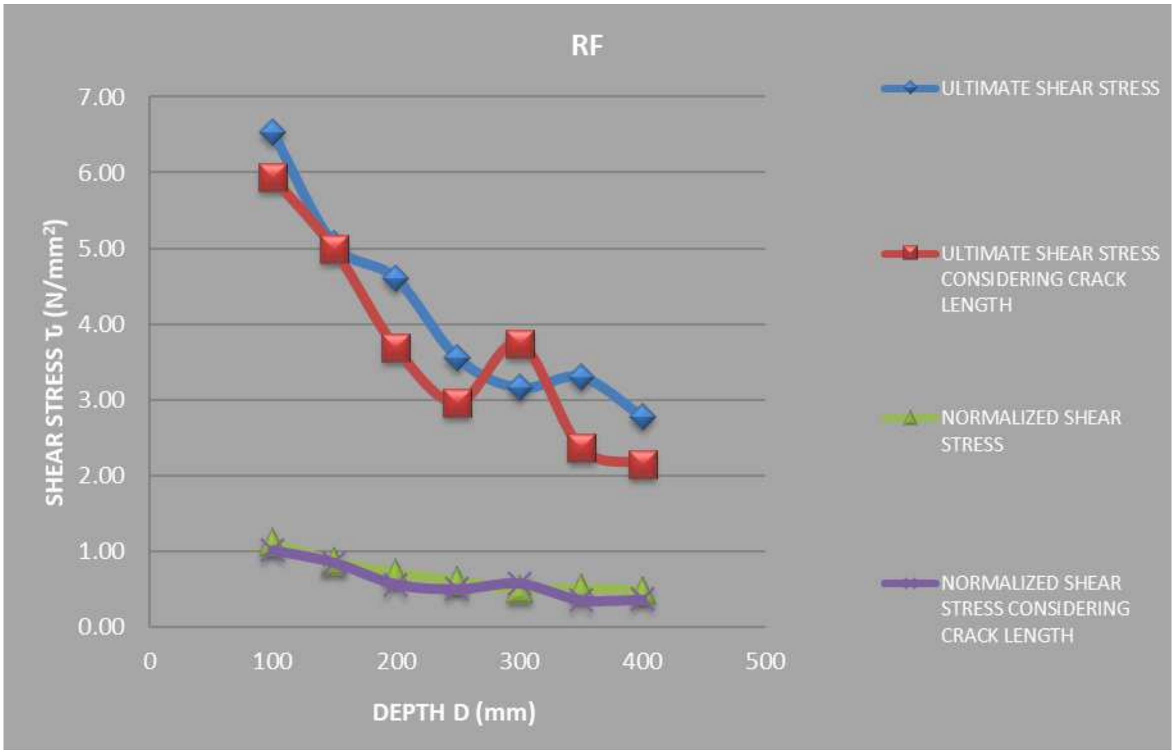
7.5.2 Graphical Representation of Size Effect for Tested Beams



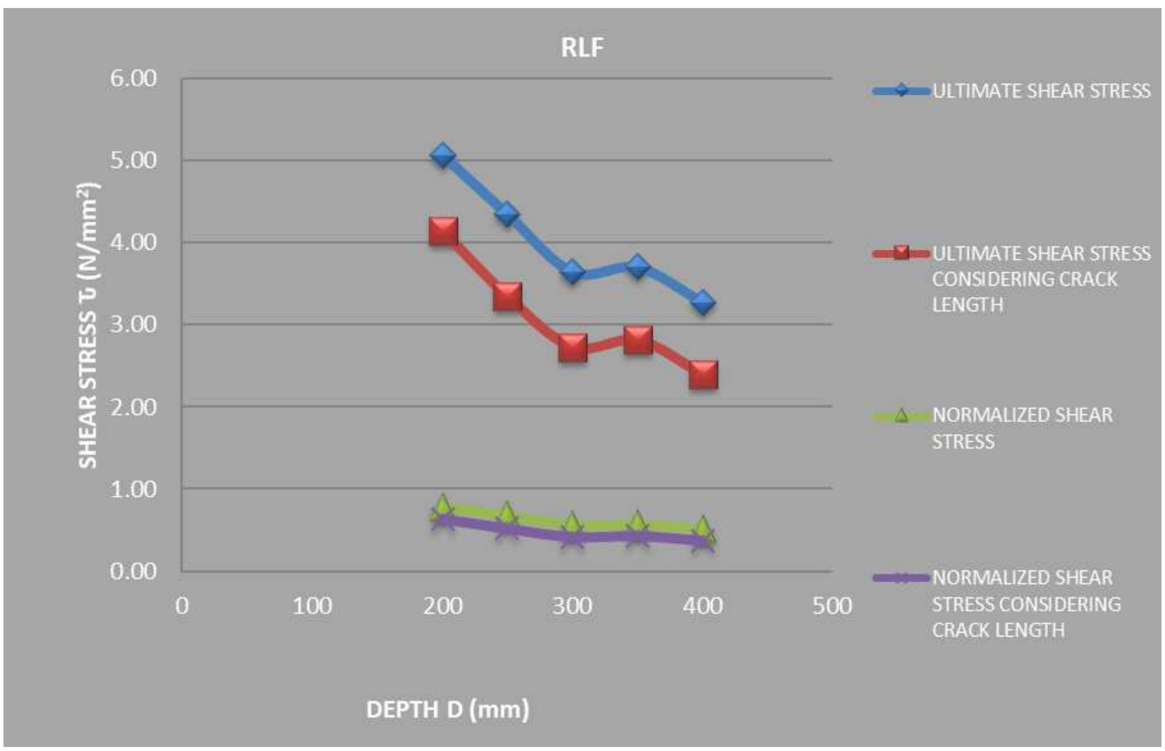
Graph 7- 14 : Size effect for RCC Series of Beams



Graph 7- 15 : Size effect for LAYERED RCC Series of Beams



Graph 7- 16 : Size effect for FIBEROUS RCC Series of Beams

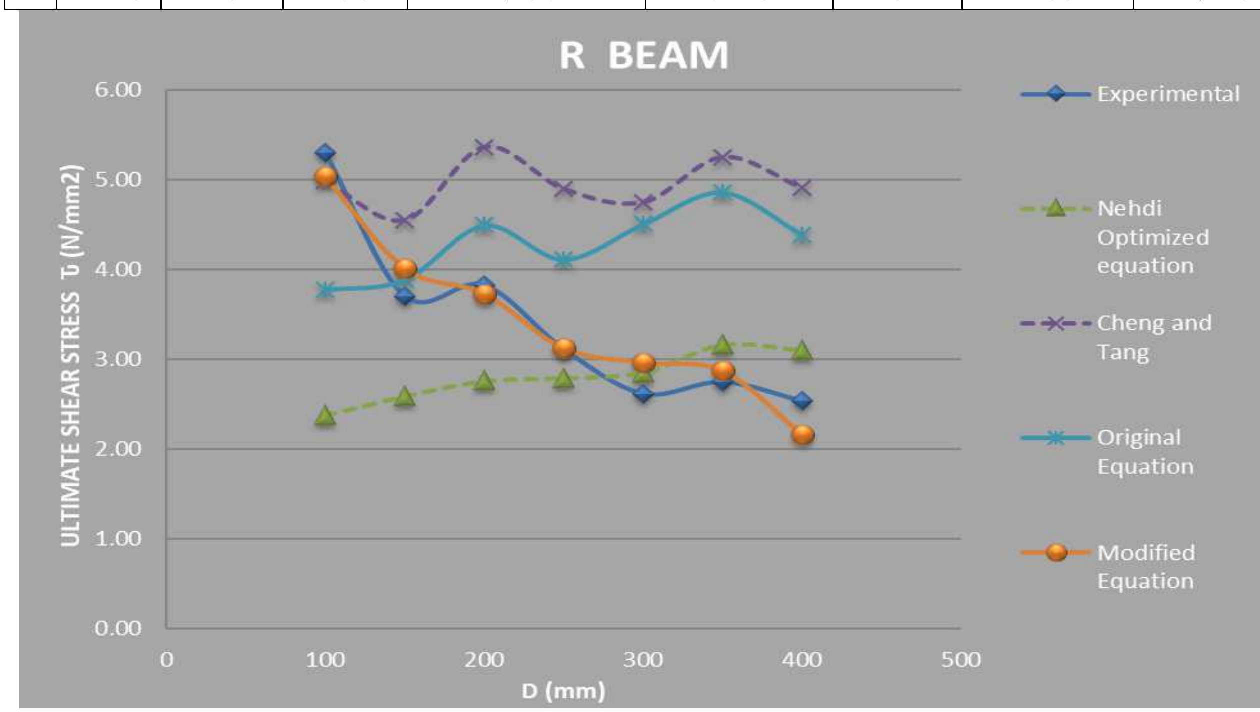


Graph 7- 17 : Size effect for FIBEROUS LAYERED RCC Series of Beams

7.6 COMPARISON OF SIZE EFFECT (ULTIMATE SHEAR STRESS VS. DEPTH) FOR "R" BEAM SERIES WITH ORIGINAL FORMULA AND MODIFIED FORMULA

Table 7- 18 : Comparison of Size Effect for "R" Beam Series

ULTIMATE SHEAR STRESS (N/mm2)								
BEAM		Width (mm)	Depth (mm)	Experimental	Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
R	D 10	75	100	5.30	2.38	4.99	3.78	5.03
	D 15	75	150	3.70	2.59	4.55	3.89	4.01
	D 20	75	200	3.82	2.76	5.37	4.50	3.73
	D 25	75	250	3.11	2.79	4.90	4.12	3.12
	D 30	75	300	2.62	2.86	4.75	4.51	2.96
	D 35	75	350	2.75	3.16	5.25	4.86	2.87
	D 40	75	400	2.53	3.10	4.91	4.39	2.16

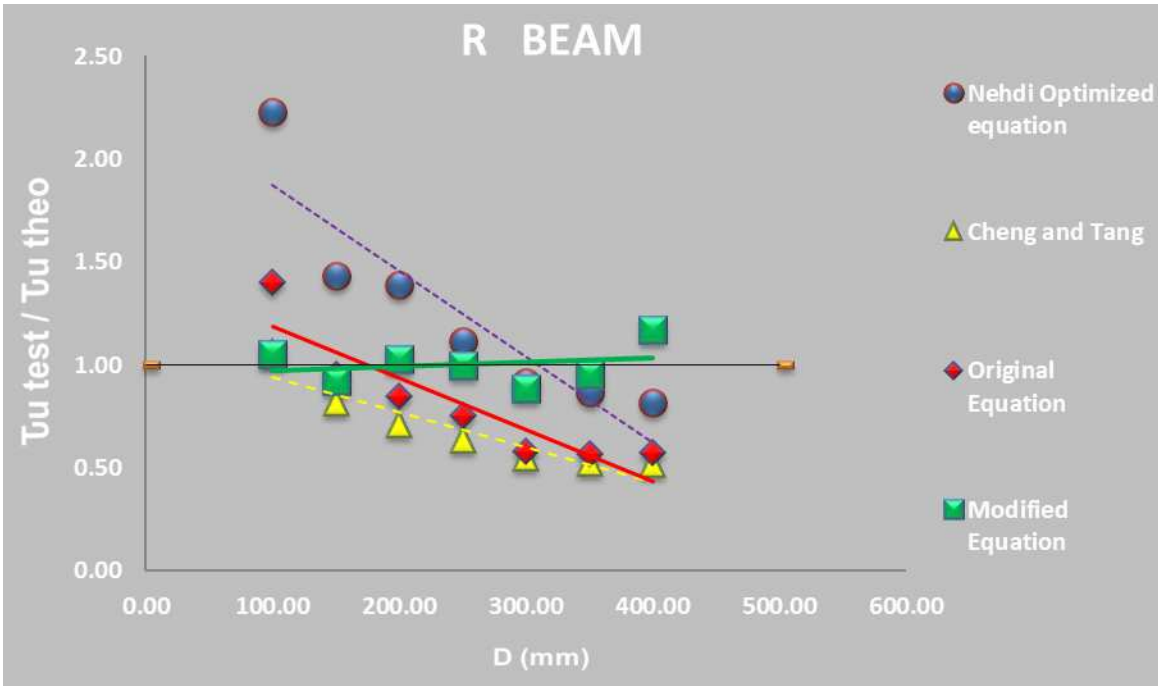


Graph 7- 18 : Graphical Representation of Size Effect for R Beam Series

7.6.1 Comparison and Graphical Representation of Ultimate Shear Stress Ratio for "R" Beam Series with Original Formula and Modified Formula

Table 7 – 19 : Comparison of Ultimate Shear Stress ratio For "R" Beam Series

BEAM		ULTIMATE SHEAR STRESS RATIO			
		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
R	D 10	2.23	1.06	1.40	1.05
	D 15	1.43	0.81	0.95	0.92
	D 20	1.39	0.71	0.85	1.03
	D 25	1.11	0.63	0.76	1.00
	D 30	0.92	0.55	0.58	0.88
	D 35	0.87	0.52	0.56	0.96
	D 40	0.82	0.52	0.58	1.17
average of absolute deviation		0.37	0.15	0.22	0.07
average		1.25	0.69	0.81	1.00

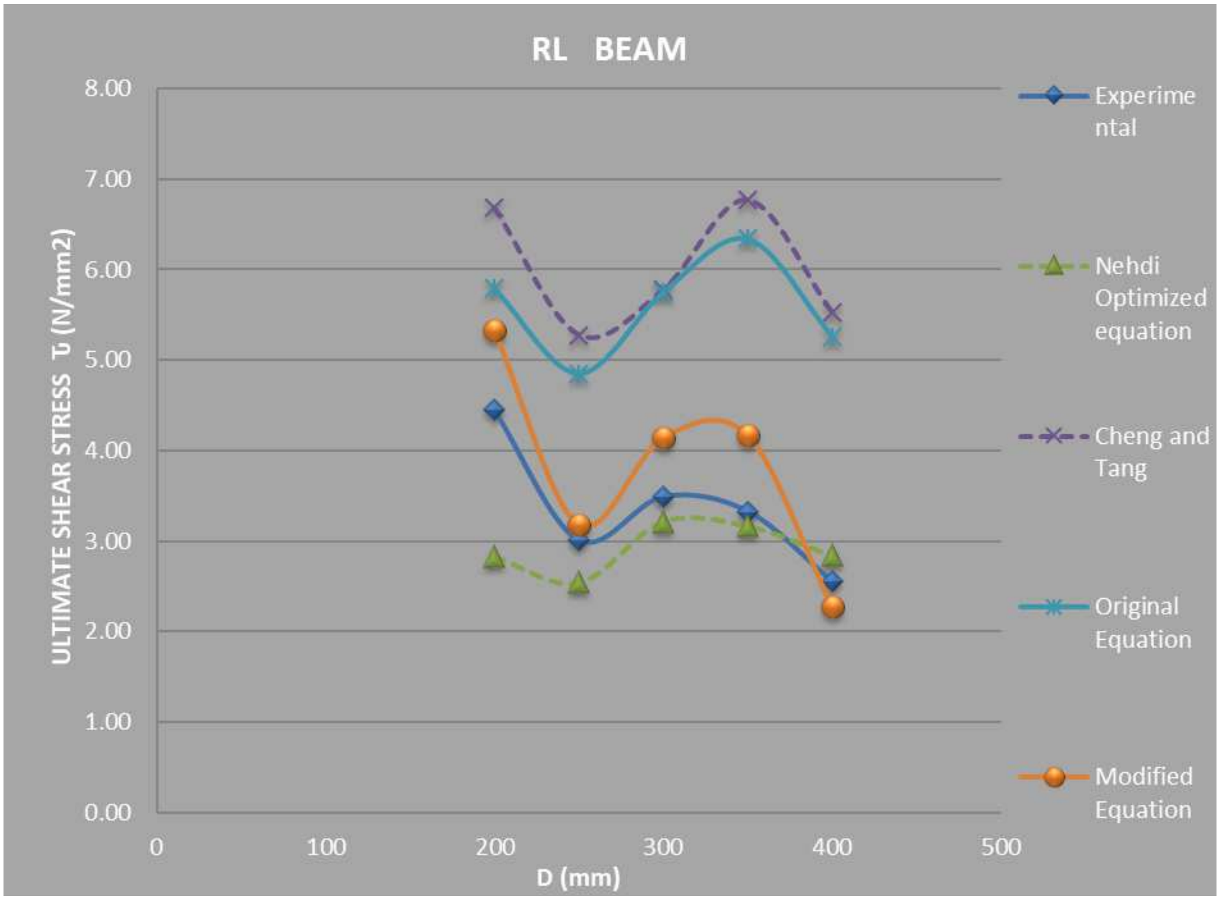


Graph 7-19 : Graphical Representation of Ultimate Shear Stress Ratio for "R" Beam Series

7.6.2 Comparison of Size Effect (Ultimate Shear Stress vs. Depth) For "RL" Beam Series with Original Formula and Modified Formula

Table 7 – 20: Comparison of Size Effect for "RL" Beam Series

ULTIMATE SHEAR STRESS (N/mm²)								
BEAM		Width (mm)	Depth (mm)	Experimental	Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RL	D 20	75	200	4.45	2.83	6.68	5.79	5.33
	D 25	75	250	3.01	2.54	5.28	4.85	3.18
	D 30	75	300	3.49	3.21	5.77	5.75	4.14
	D 35	75	350	3.32	3.16	6.76	6.34	4.16
	D 40	75	400	2.55	2.83	5.52	5.26	2.27

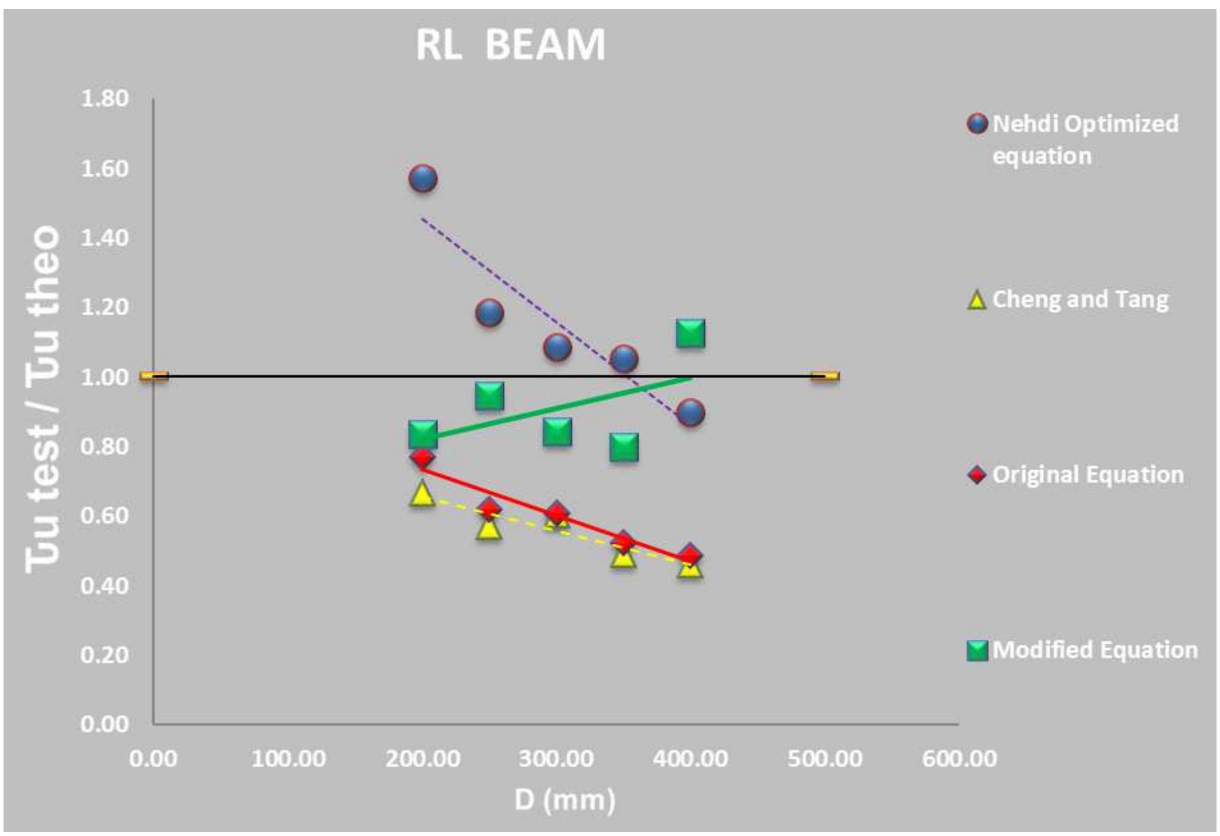


Graph 7-20 : Graphical Representation of Size Effect for RL Beam Series

7.6.3 Comparison and Graphical Representation of Ultimate Shear Stress Ratio for "RL" Beam Series with Original Formula and Modified Formula

Table 7- 21: Comparison of Ultimate Shear Stress Ratio for "RL" Beam Series

		ULTIMATE SHEAR STRESS RATIO			
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RL	D 20	1.57	0.67	0.77	0.83
	D 25	1.19	0.57	0.62	0.95
	D 30	1.09	0.60	0.61	0.84
	D 35	1.05	0.49	0.52	0.80
	D 40	0.90	0.46	0.48	1.13
average of absolute deviation		0.18	0.07	0.08	0.10
average		1.16	0.56	0.60	0.91

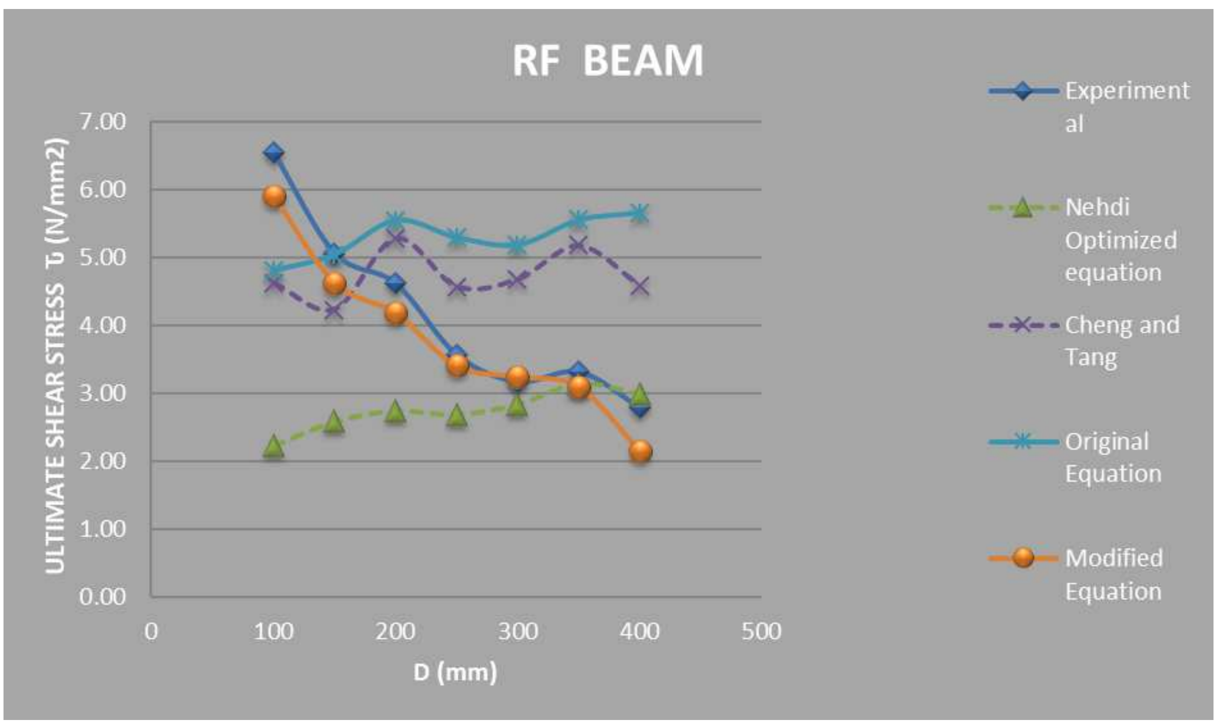


Graph 7-21 : Graphical Representation of Ultimate Shear Stress Ratio for "RL" Beam Series

7.6.4 Comparison of Size Effect (Ultimate Shear Stress vs. Depth) For "RF" Beam Series with Original Formula and Modified Formula

Table 7-22 : Comparison of Size Effect for "RF" Beam Series

ULTIMATE SHEAR STRESS (N/mm2)								
BEAM		Width (mm)	Depth (mm)	Experimental test value	Nehdi Optimized equation	Cheng and Tang	Original Equation	Modified Equation
RF	D 10	75	100	6.54	2.22	4.62	4.80	5.90
	D 15	75	150	5.06	2.58	4.23	5.04	4.63
	D 20	75	200	4.61	2.73	5.28	5.55	4.18
	D 25	75	250	3.56	2.68	4.57	5.29	3.40
	D 30	75	300	3.16	2.83	4.68	5.18	3.25
	D 35	75	350	3.31	3.13	5.17	5.55	3.09
	D 40	75	400	2.78	2.98	4.58	5.66	2.15

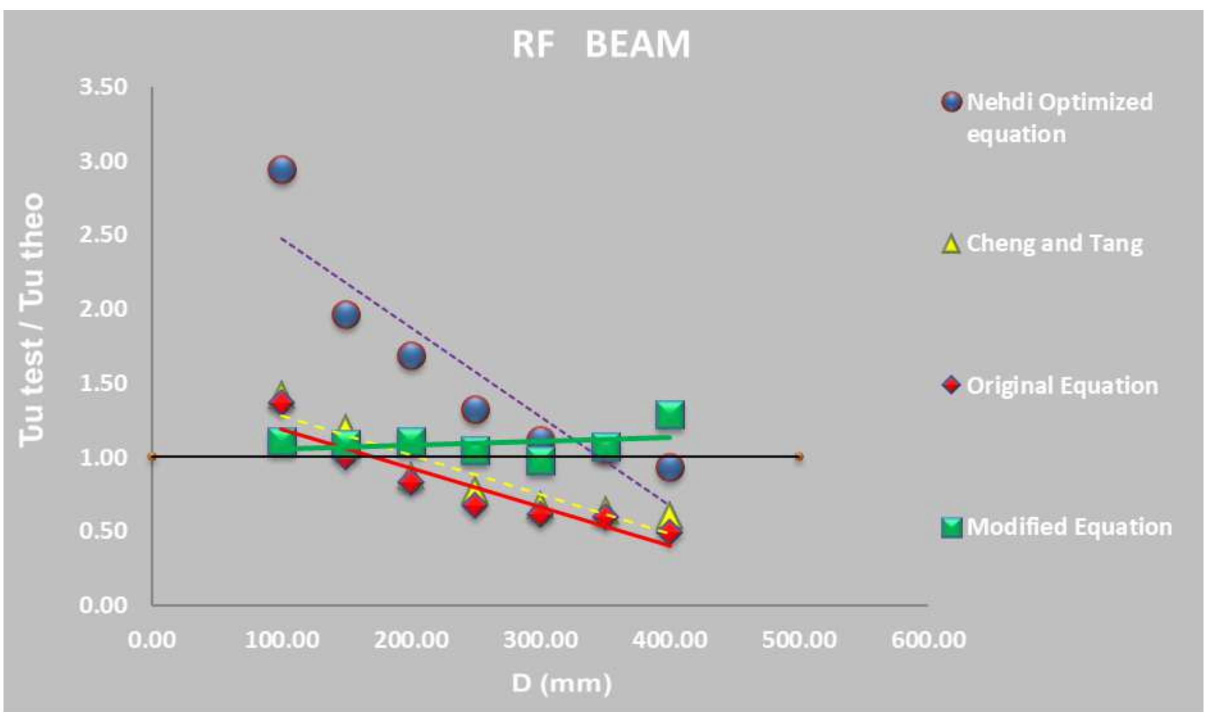


Graph 7-22 : Graphical Representation of Size Effect for "RF" Beam Series

7.6.5 Comparison and Graphical Representation of Ultimate Shear Stress Ratio for "RF" Beam Series with Original Formula and Modified Formula

Table 7-23 : Comparison of Ultimate Shear Stress ratio For "RF" Beam Series

		ULTIMATE SHEAR STRESS RATIO			
BEAM		Nehdi Optimized Equation	Cheng and Tang	Original Equation	Modified Equation
RF	D 10	2.94	1.42	1.36	1.11
	D 15	1.96	1.20	1.00	1.09
	D 20	1.69	0.87	0.83	1.10
	D 25	1.33	0.78	0.67	1.05
	D 30	1.12	0.68	0.61	0.97
	D 35	1.05	0.64	0.60	1.07
	D 40	0.93	0.61	0.49	1.29
average of absolute deviation		0.53	0.24	0.23	0.06
average		1.57	0.88	0.80	1.10

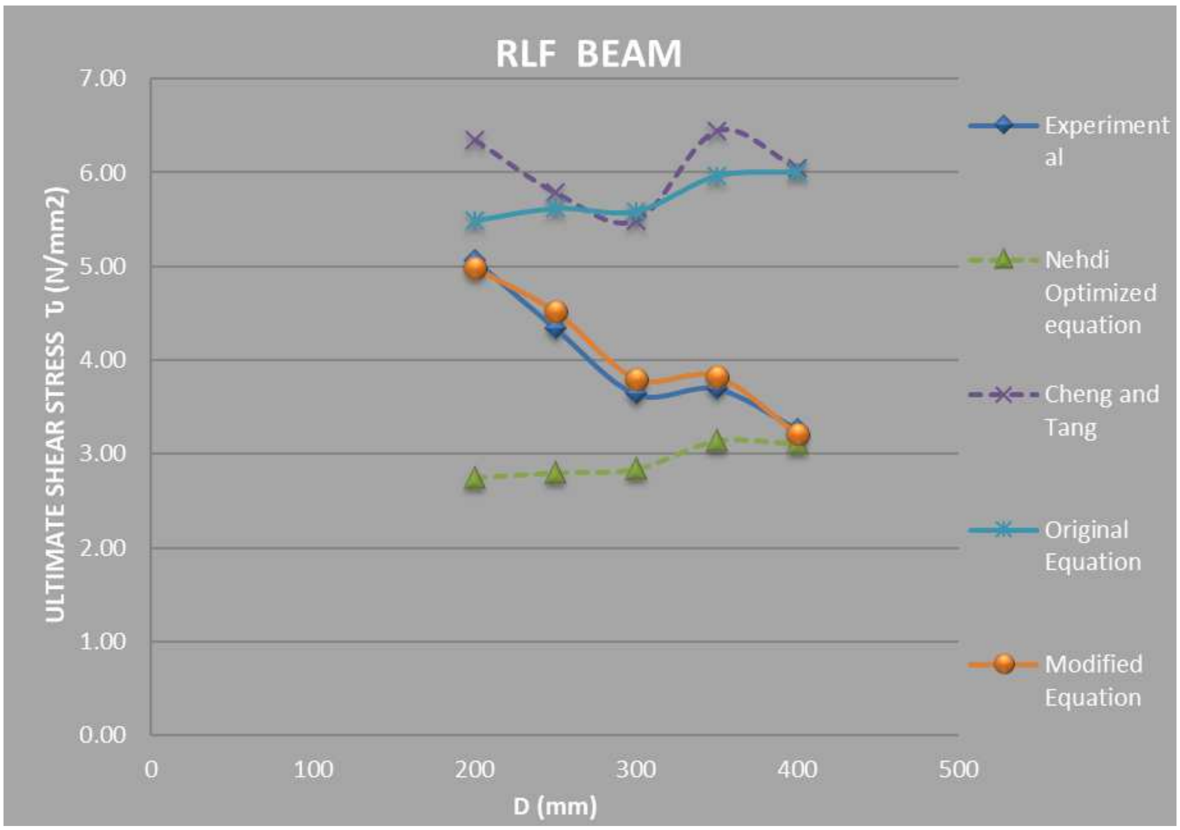


Graph 7-23 : Graphical Representation of Ultimate Shear Stress Ratio for "RF" Beam Series

7.6.6 Comparison of Size Effect (Ultimate Shear Stress vs. Depth) For "RLF" Beam Series with Original Formula and Modified Formula

Table 7-24 : Comparison of Size Effect for "RLF" Beam Series

ULTIMATE SHEAR STRESS (N/mm^2)								
BEAM		Width (mm)	Depth (mm)	Experimental	Nehdi Optimized equation	Cheng and Tang	Original Equation	Modified Equation
RLF	D 20	75	200	5.07	2.74	6.35	5.49	4.98
	D 25	75	250	4.34	2.80	5.79	5.62	4.52
	D 30	75	300	3.64	2.84	5.49	5.59	3.80
	D 35	75	350	3.70	3.14	6.44	5.97	3.83
	D 40	75	400	3.27	3.11	6.04	6.01	3.21

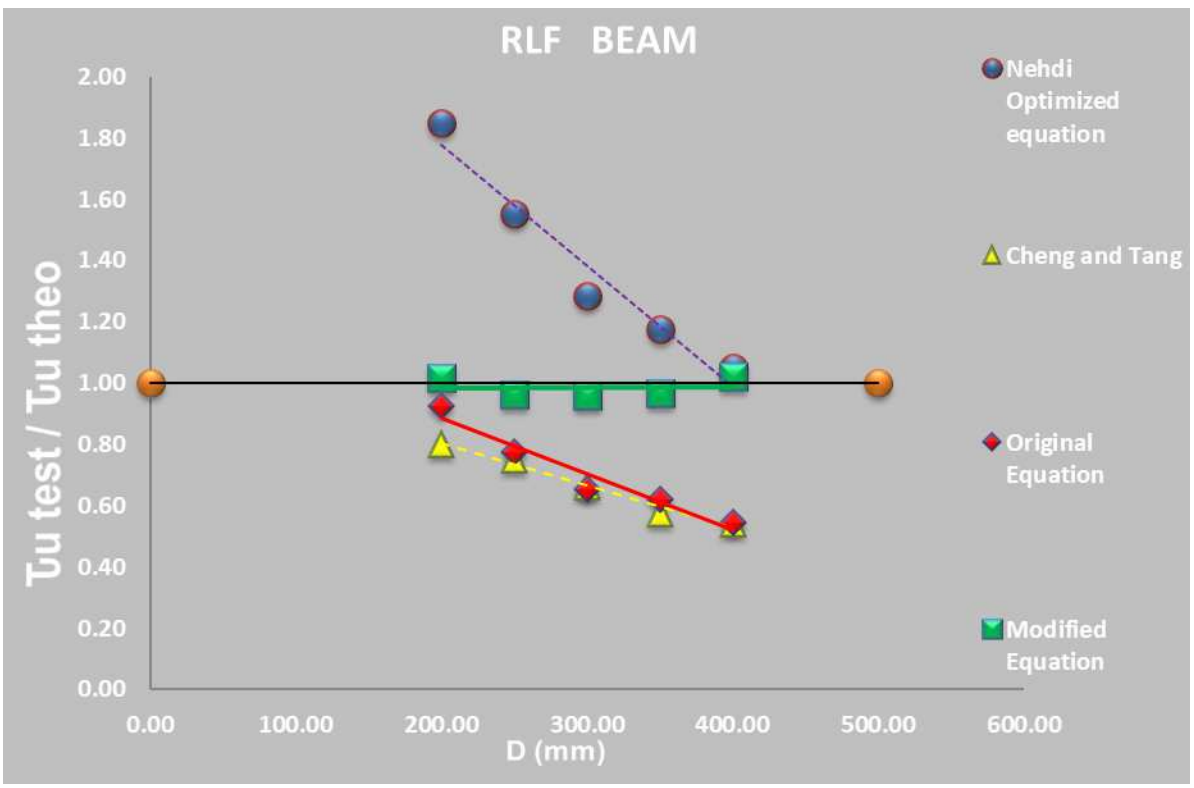


Graph 7-24 : Graphical Representation of Size Effect for "RLF" Beam Series

7.6.7 Comparison and Graphical Representation of Ultimate Shear Stress Ratio for "RLF" Beam Series with Original Formula and Modified Formula

Table 7-25 : Comparison of Ultimate Shear Stress Ratio for "RLF" Beam Series

BEAM		ULTIMATE SHEAR STRESS RATIO			
		Nehdi Optimized equation	Cheng and Tang	Original Equation	Modified Equation
RLF	D 20	1.85	0.80	0.92	1.02
	D 25	1.55	0.75	0.77	0.96
	D 30	1.28	0.66	0.65	0.96
	D 35	1.18	0.57	0.62	0.97
	D 40	1.05	0.54	0.54	1.02
average of absolute deviation		0.25	0.09	0.12	0.03
average		1.38	0.67	0.70	0.98



Graph 7-25 : Graphical Representation of Ultimate Shear Stress Ratio for "RLF" Beam Series

Graphs (7-18 to 7-25) shows that the Ultimate Shear Stress decreases with the increase in beam depth, which indicate incorporate of the size effect parameter in present Shear Strength Equation. The shear stress calculated by Original S. N. Patel and S. K. Damle's Equation is not decrease with increase in beam depth. It means size effect parameter required to be incorporate in original equation. Nature of graph for Modified S. N. Patel and S.K. Damle's Equation is similar to nature of graph for Experimental results. While graph for Nehdi-Optimized Equation, Cheng and Tang Equation and Original Equation does not give good agreement with experimental results.