© IJEDR 2018 | Volume 6, Issue 3 | ISSN: 2321-9939

Improvement of shear provision in ES EN 1992-1-1:2015 for members requiring design shear reinforcement

Teklewoine Haile Fitwi
[1]Lecturer,
[1]Civil Engineering
[1]Adigrat University, Adigrat, Ethiopia

***Abstract*— Shear failure is undesirable since it is a brittle mode of failure which occurs with little or no warning, unlike the flexural failure of under-reinforced concrete beams which deflect significantly prior to failure giving warning of impending failure. Recent studies by Kenneth Kwesi Mensah on reliability assessment of structural concrete with reference to stirrup design concluded that the existing provisions of EN 1992-1-1 for shear in beams are highly conservative and becomes un-conservative(unsafe) at low and high percentage of shear reinforcements respectively. Since the new Ethiopian building codes of standard is adopted from the European code EN 1992-1-1 and uses the concept of variable strut inclination method to design for members requiring shear reinforcement, consequently this study was carried on assessing and adjusting the shear design provisions of ES EN 1992-1-1:2015 with reference to finite element analysis software Abaqus CAE and Published Experimental tests. Model beams were analyzed using finite element computer software Abaqus CAE in addition to available experimental data's. Shear resistance of model beams is plotted against respective selected parameters. This study has provided ways of adjusting the current formulation to achieve sufficient consistency across the range of typical application by providing adjustment factor Ω to the shear provision specified in ES EN 1992-1-1:2015 for members requiring design shear reinforcement.**

Keywords: ES EN 1992-1-1:2015, EN 1992-1-1, Abaqus CAE, Shear,RC Beams.

I. INTRODUCTION

For reinforced concrete structures flexural resistances are predicted with a reasonable accuracy while accurate prediction of the shear resistances is difficult due to uncertainty in the shear transfer mechanism, particularly after initiation of cracks. A recent Ph.D. dissertation by Kenneth Kwesi Mensah on reliability assessment of structural concrete with special reference to stirrup design concluded that the existing provisions of Eurocode EN 1992-1-1 for shear in beams are markedly conservative at low percentage of shear reinforcement and becomes unsafe at high percentage of shear reinforcements. Taking into consideration of this study and since our code is also new one and adopted from the European codes it should be investigated to very such conditions, thus this work is intended to assess and recommend adjustment factor to correct the provision for members requiring design shear reinforcement provided in ES EN 1992-1-1:2015.

General Objective

Broadly the objective of this study is to assess and find methods of adjusting the current shear design provisions of ES EN 1992-1-1.2015 for members requiring design shear reinforcement.

Specific Objectives

- To verify available experimental results by finite element software Abaqus CAE.
- To critically compare the value of shear resistance for the selected parameters found from the calculations of the formula from ES EN 1992-1-1:2015 with that of the shear resistance found from Abaqus CAE results and available experimental data's.
- To examine selected parameters affecting shear resistance of a member at different proportions.
- To come up with an adjustment factor to correct the shear provision of ES EN 1992-1-1.2015 for members requiring design shear reinforcement.

II. : METHODLOGY

The study is based on available experimental data's and analysis of a number of beam models. These models are analyzed using computer software Abaqus CAE.

Flow Chart

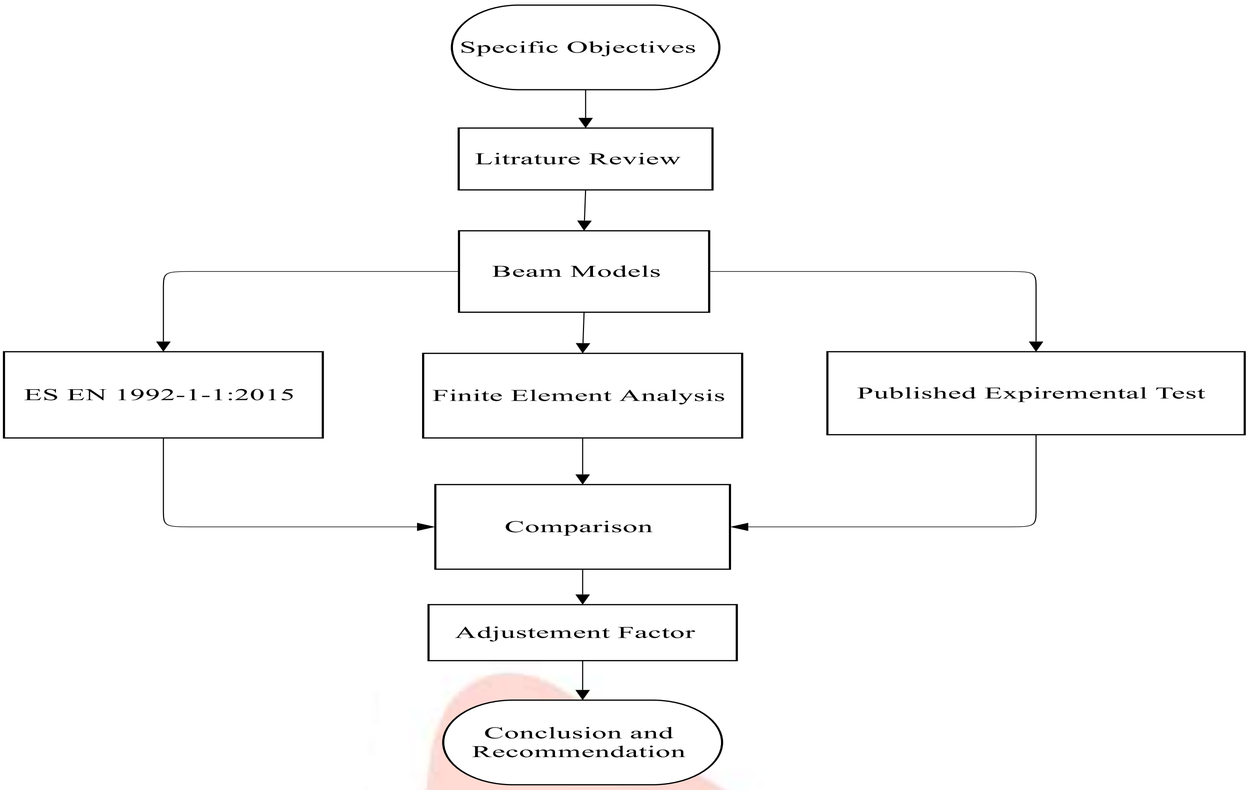


Figure 1 Flow chart

Material property

C-20 to C-53 characteristic mean compressive strength of concrete and S-400 to S-600 grade of steel is used for all beam models analyzed by Abaqus CAE.

C-12 to C-125.4 characteristic mean compressive strength of concrete and S-185.5 to S-820 mean yield strength of steel is used for the available experimental data's. Elastic material properties of these materials are taken as per the recommendations of ES EN 1992-1-1:2015.

Selected Parameters

The parameters chosen in this study are presented as follows

ρ_w	Shear reinforcement ratio
f_{ywk}	Characteristic yield strength of stirrups
f_{ck}	Characteristic compressive cylinder strength of concrete
b	Breadth of beam
d	Effective depth of beam
a/d	Shear span to depth ratio of beam

All of the parameters listed above are related to the shear resistance of a member. The Variations in values of each parameter considered is presented below, altogether there are around 321 model beams which have been analyzed with Abaqus CAE and available experimental data's.

Variation of each parameter analyzed by Abaqus CAE

Class limits in MPa	0-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.00-1.25	1.25-1.50	1.50-1.75
No. of Models	1	15	25	35	21	8	5

Table 1 Distribution of $\rho_w f_{ywk}$ [MPa] for the whole model analyzed by Abaqus CAE

Class limits in MPa	0.0-12.0	12.0-18.0	18.0-24.0	24.0-30.0	30.0-36.0	36.0-42.0	42.0-48.0
No. of Models	3	20	35	42	4	4	2

Table 2 Distribution of f_{ck} [MPa] for the whole model analyzed by Abaqus CAE

Class limits in mm	0-160	160-185	185-210	210-235	235-260	260-285	285-310	310-335	335-360	360-385	385-410
No. of models	1	3	18	11	42	11	17	2	2	1	2

Table 3 Distribution of b_w [mm] for the whole model analyzed by Abaqus CAE

Class limits in mm	0-366	366-416	416-466	466-516	516-566	616-666	716-766	915
No. of models	23	1	1	22	38	1	23	1

Table 4 Distribution of d [mm] for the whole model analyzed by Abaqus CAE

Class limits	0-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5
No. of models	1	23	38	1	22	1	24

Table 5 Distribution of a/d for the whole model analyzed by Abaqus CAE

Variation of each parameter for the available experimental data's

Class limits in MPa	0-0.21	0.21-0.71	0.71-1.21	1.21-1.71	1.71-2.21	2.21-2.71
No. of models	1	116	59	26	6	3

Table 6 Distribution of $\rho_w f_{ywk}$ [MPa] for the entire database of experimental data's

Class limits in MPa	0-20.7	20.7-35.7	35.7-50.7	50.7-65.7	65.7-80.7	80.7-95.7	95.7-110.7	110.7-125.7
No. of models	1	79	43	27	41	15	2	3

Table 7 Distribution of f_{ck} [MPa] for the entire database of experimental data's

Class limits in mm	0-76	126-176	176-226	226-276	276-326	326-376	376-426	426-476
No. of models	9	65	46	47	25	10	3	6

Table 8 Distribution of b_w [mm] for the entire database of experimental data's

Class limits in mm	0-95	95-195	195-295	295-395	395-495	495-595	595-695	695-795	795-895	895-995	More
No. of models	3	6	93	43	33	7	10	4	2	9	1

Table 9 Distribution of d [mm] for the entire database of experimental data's

Class limits	0-2.49	2.49-2.99	2.99-3.49	3.49-3.99	3.99-4.49	4.49-5.49	5.49-5.99
No. of models	4	50	94	38	12	4	9

Table 10 Distribution of a/d for the entire database of experimental data's

Calibration of finite element analysis software Abaqus CAE

The classic series of beam test conducted by bressler and scordelis some years ago to investigate the behavior of reinforced concrete in shear, is commonly regarded as a benchmark against which finite element analysis models can be calibrated. Mean compressive strength of concrete for bressler-scordelis A1 beam series is 24.1MPa.

The nonlinear analysis of a reinforced concrete beam was conducted based on the finite element analysis software Abaqus CAE. In this simply supported beam analysis, the plasticity model of concrete damage in Abaqus CAE has been introduced thoroughly. Finally, the results of the experimentation and the Abaqus CAE analysis were compared in table.

Beam no.	b(mm)	h(mm)	d(mm)	L(mm)	Span(mm)	Bottom steel	Top steel	Stirrups
A1	307	561	466	4100	3660	4no.9	2no.4	No.2 at 210 mm

Table 11 Cross-section details of bressler-scordelis beam

Bar size	Diameter(mm)	Area(mm^2)	f_y(MPa)	f_u(MPa)	E_s(MPa)
No.2	6.4	32.2	325	430	190000
No.4	12.7	127	345	542	201000
No.9	28.7	645	555	933	218000

Table 12 Material details of bressler-scordelis beam

Test setup for Bressler-Scordelis beams

The test setup used to perform the experiment is shown below. The beams were subjected to monotonic center point loading with a force controlled loading procedure employed.

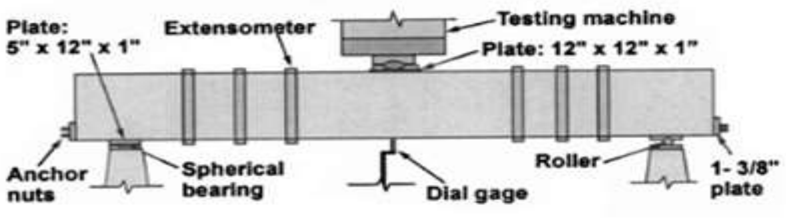


Figure 2 Test setup of bressler-scordelis beams

Finite Element Model

Using material and cross-section details of Bressler-Sordelis beam to model on finite element software Abaqus CAE. . The interaction between steel cage and the concrete is defined as embedded region constraint. This type of constraint allows you to embed a region of the model within a "host" region of the model or within the whole model, tying the displacements of each embedded node to the displacements of the surrounding nodes. Solution of the Finite Element equations is performed using the arc length convergence algorithm method (Static/Riks method).

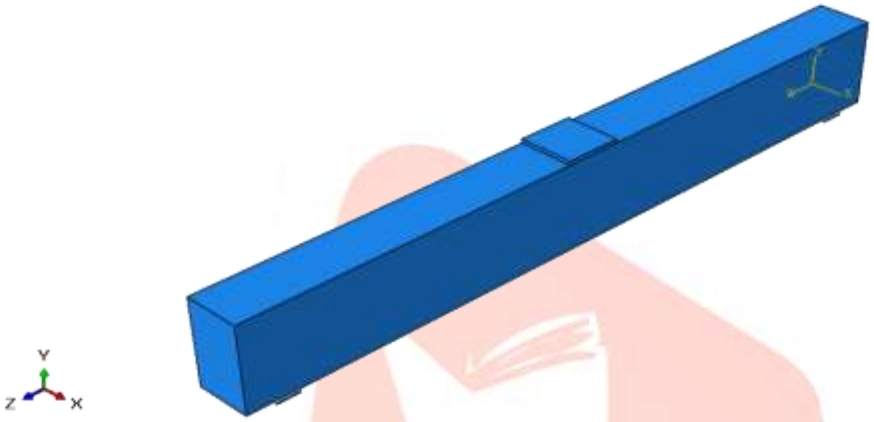


Figure 3 Finite Element Model

Simulation result

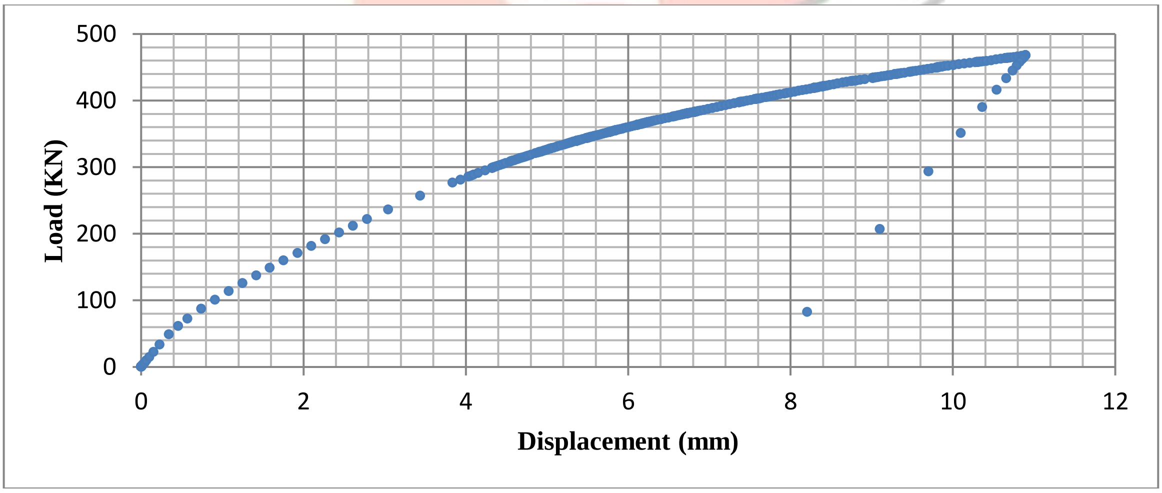


Figure 4 Load vs. Displacement (Abaqus CAE)

Comparison of experimental result with Abaqus CAE out puts

Type	Ultimate Load(KN)	Mid Span Deflection(mm)
Bressler-Scordelis A-1 beam Test	467	14.2
Simulation Result	467.76	10.90
P_S/P_{B-S}	1.002	0.767

Table 13 Comparison of experimental and simulation result

Shear Failure of Beam A1

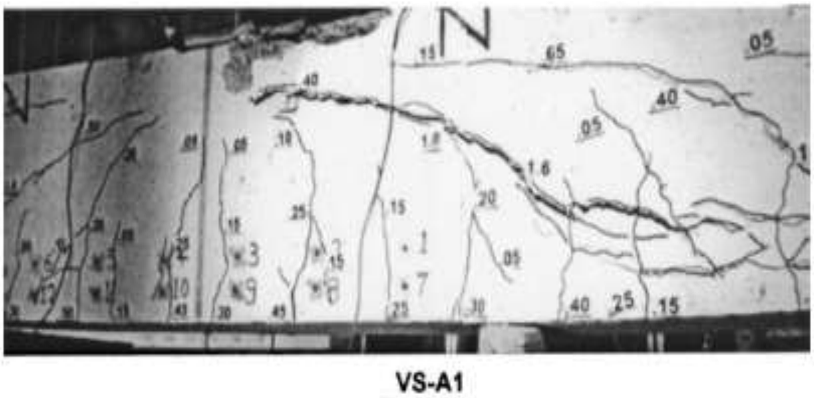


Figure 5 Bressler-Scordelis beam (A1)

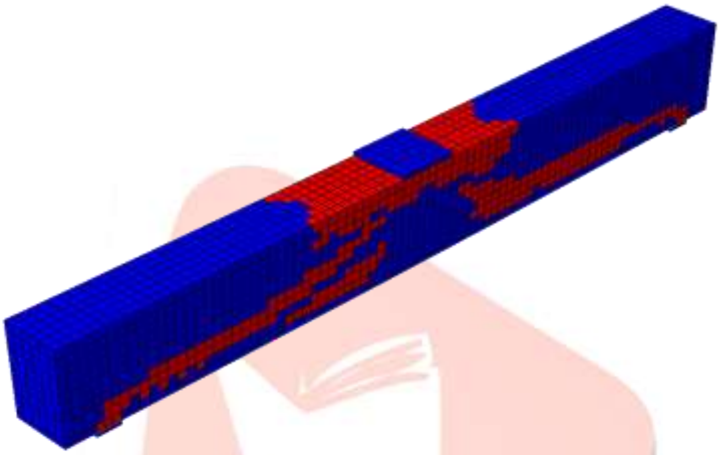


Figure 5 Finite element beam (A1)

III. RESULTS

Performance of Strut Inclination Method of ES EN 1992-1-1:2015

In ES EN 1992-1-1:2015, a variable strut inclination method is adopted to design the reinforced concrete beams with shear reinforcement. It assumes that the shear force is entirely resisted by a truss consisting of concrete struts equilibrated by shear reinforcements.

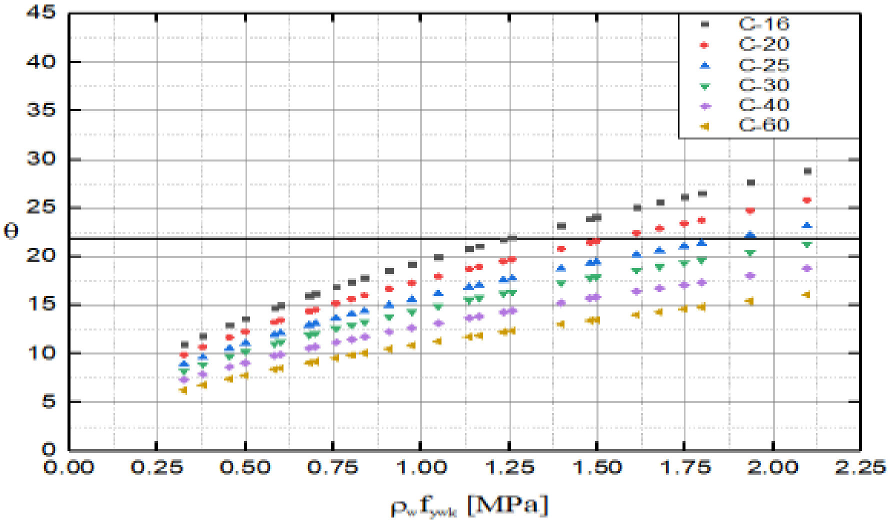


Figure 6 Strut angle θ vs. $\rho_w f_{ywk}$ for varying concrete grades

Fig 16 illustrates with 21.8^0 limit imposed to ensure $cot\theta$ doesn't exceed 2.5. It can be observed that θ only exceeds 21.8^0 at common situations of low f_{ck} and high $\rho_w f_{ywk}$. However, for situations when $\theta > 21.8^0$, $cot\theta$ assumes values less than 2.5.

Comparison of ES EN 1992-1-1:2015 with Abaqus CAE results

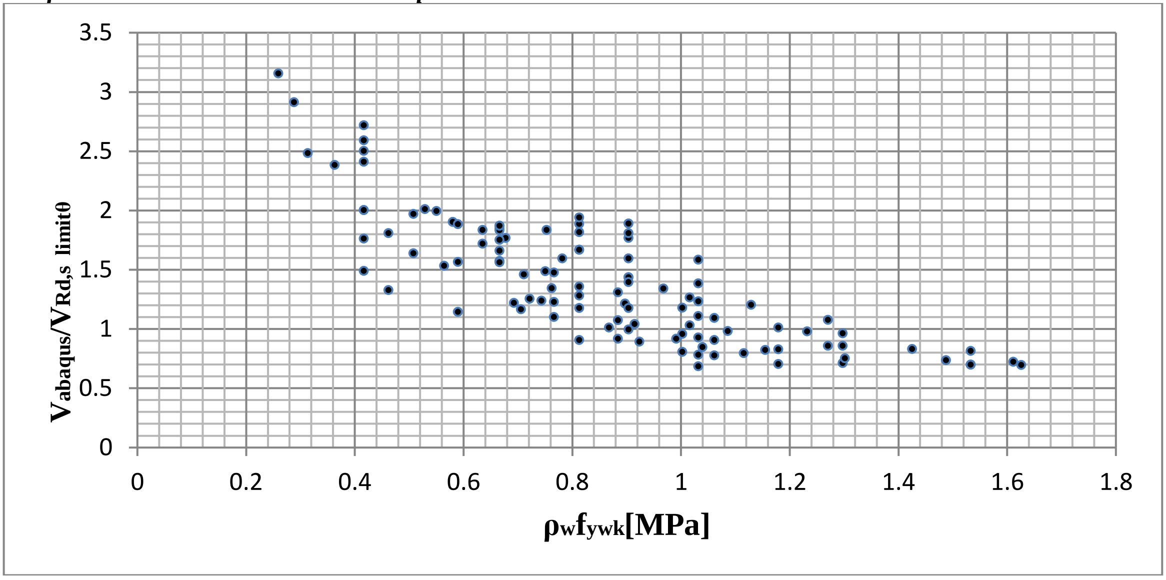


Figure 7 $V_a/V_{Rd,\ s\ limit\ \theta}$ vs. shear reinforcement parameter

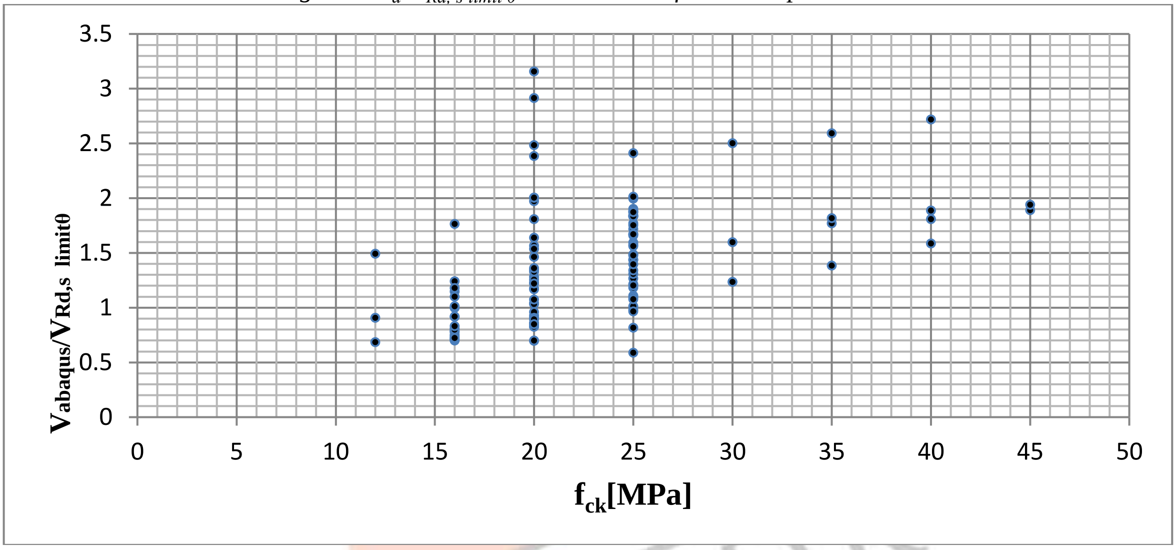


Figure 8 $V_a/V_{Rd,\ s\ limit\ \theta}$ vs. compressive cylinder strength of concrete

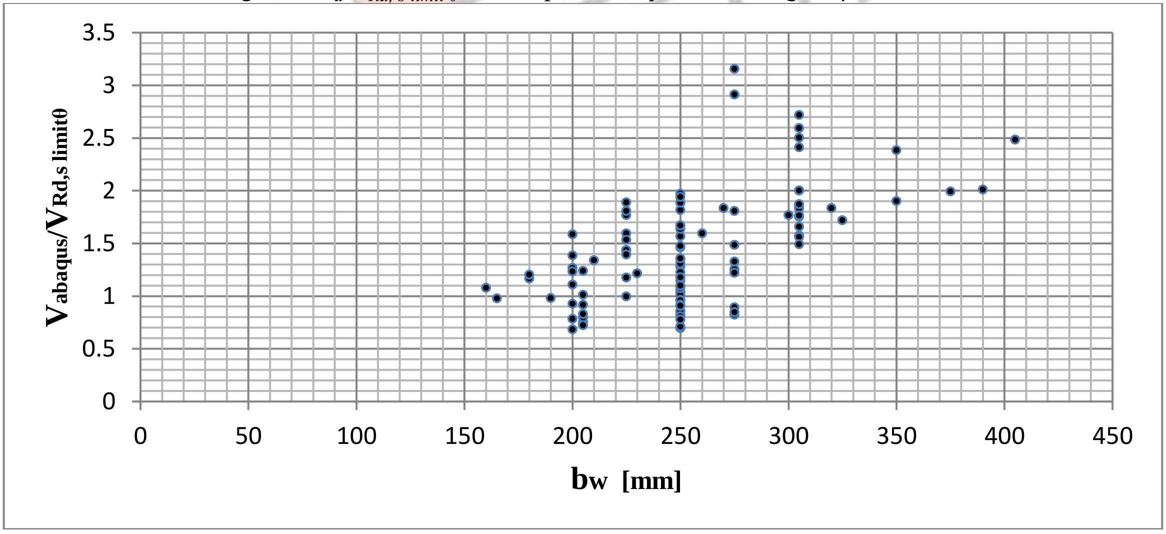


Figure 9 $V_a/V_{Rd,\ s\ limit\ \theta}$ vs. breadth of beams

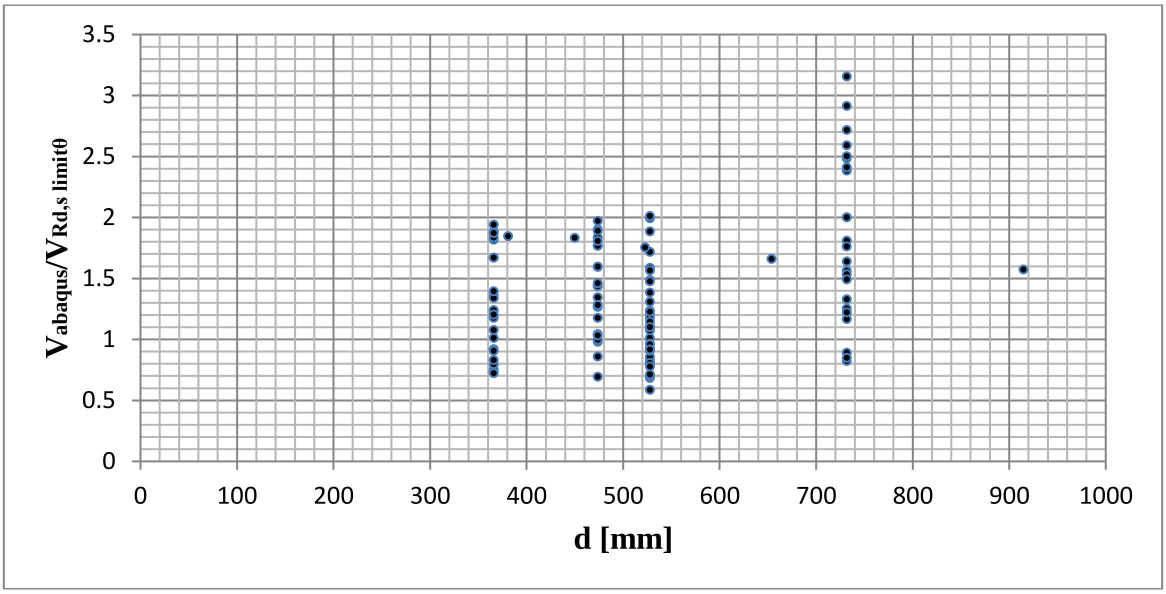


Figure 10 $V_a/V_{Rd,\,s\ limit\ \theta}$ vs. depth of beams

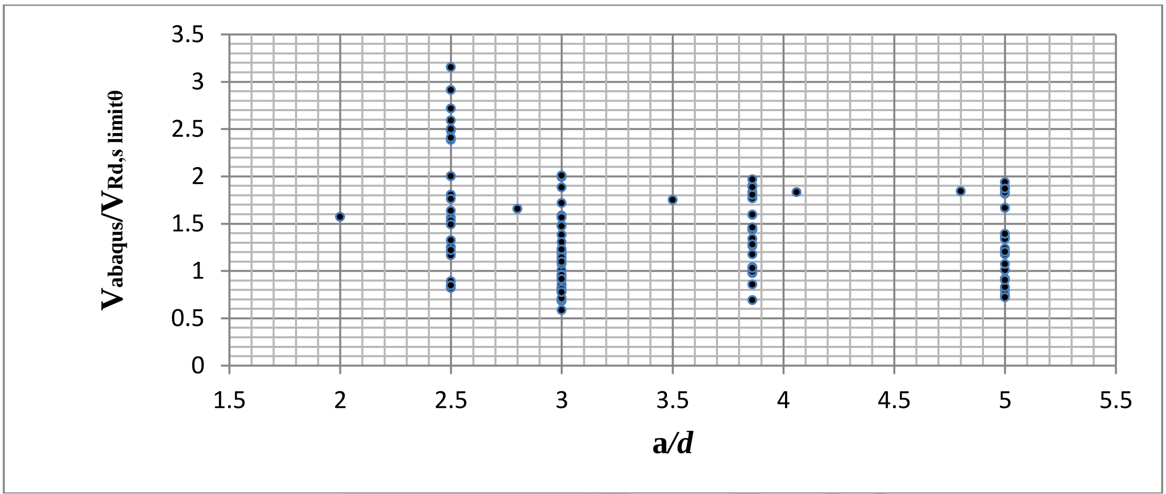


Figure 11 $V_a/V_{Rd,\,s\ limit\ \theta}$ vs. shear span to depth ratio

Comparison of ES EN 1992-1-1:2015 with Published experimental Tests

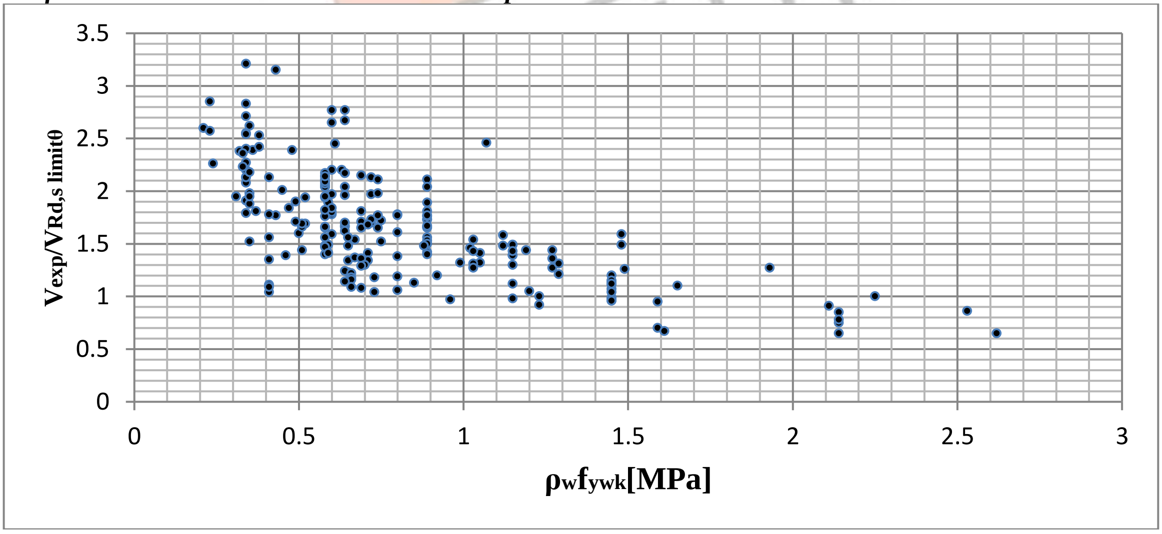


Figure12 $V_{exp}/V_{Rd,s\ limit\ \theta}$ vs. shear reinforcement parameter

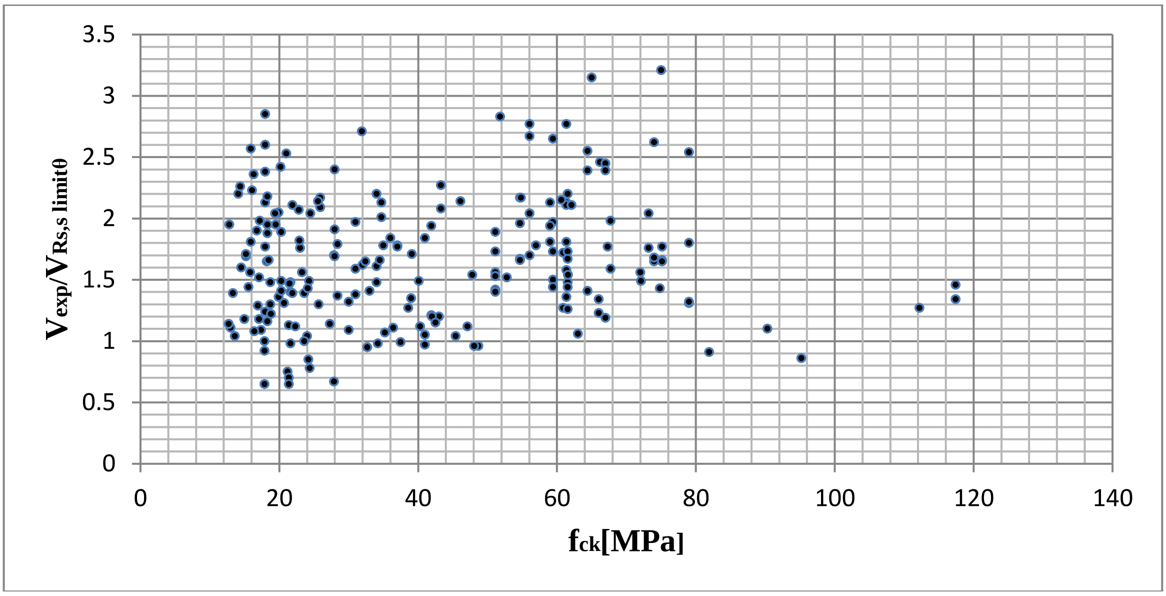


Figure 13 $V_{exp}/V_{Rd,s\ limit\ \theta}$ *vs. compressive cylinder strength of concrete*

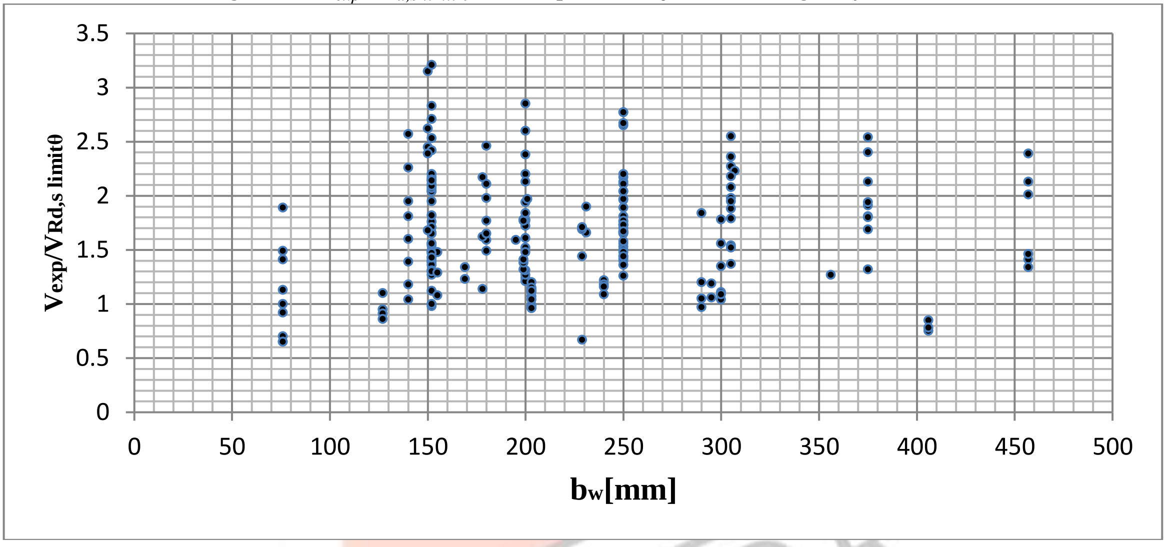


Figure 6 $V_{exp}/V_{Rd,s\ limit\ \theta}$ *vs. breadth of beams*

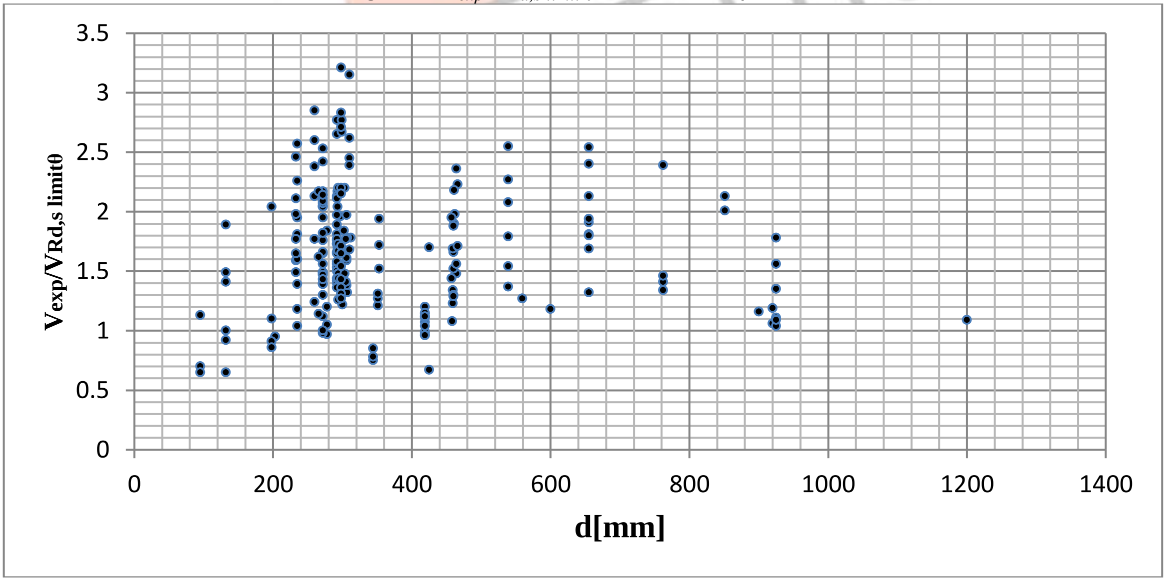


Figure 15 $V_{exp}/V_{Rd,s\ limit\ \theta}$ *vs. depth of beams*

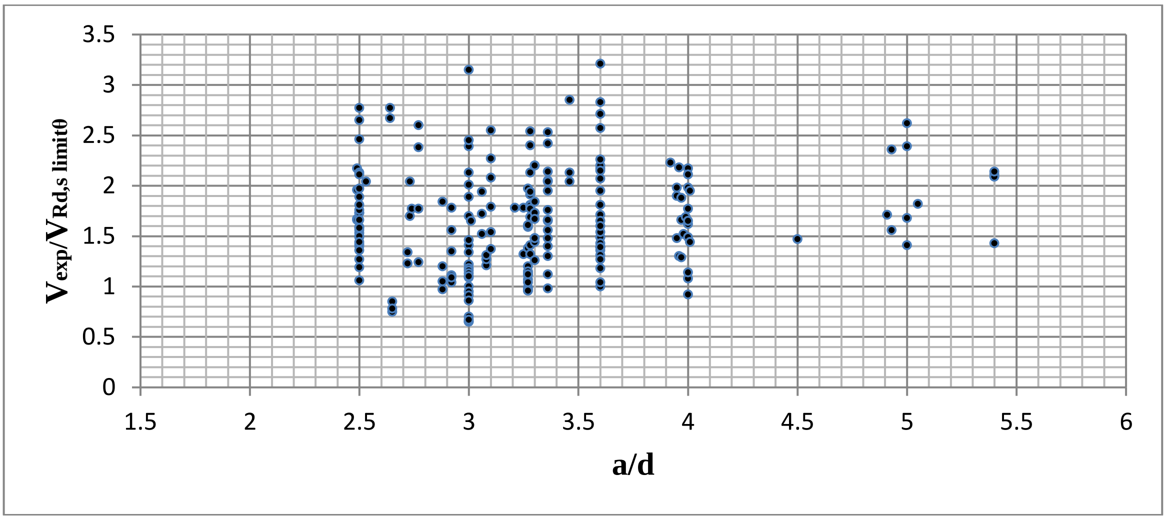


Figure 16 $V_{exp}/V_{Rd,s\ limit\ \theta}$ vs. shear span to depth ratio

Formulation of Adjustment factor

Grouping of shear strength parameters

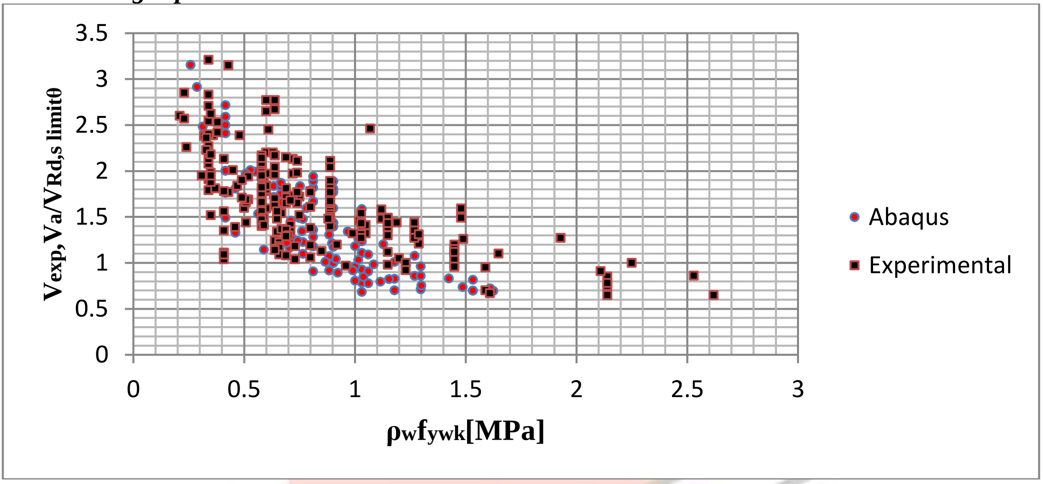


Figure 17 V_{exp}, $V_a/V_{Rd,\ s\ limit\ \theta}$ vs. shear reinforcement parameters

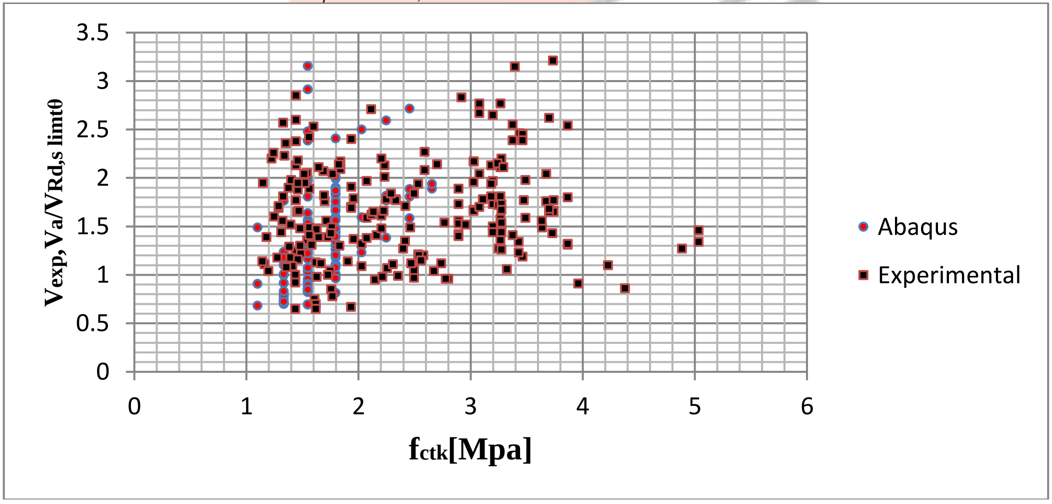
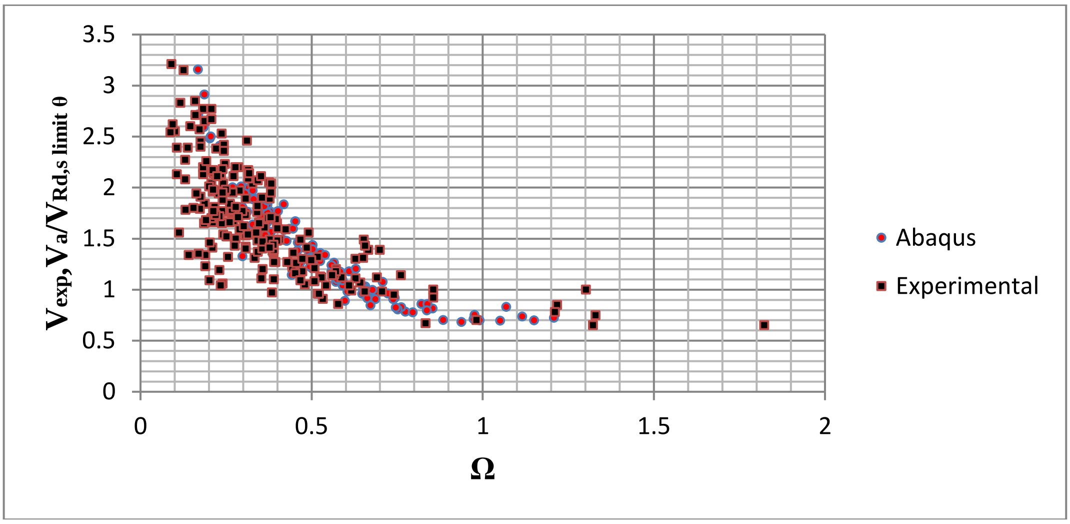


Figure 18 V_{exp}, $V_a/V_{Rd,\ s\ limit\ \theta}$vs. characteristic tensile strength of concrete



Where Ω is an adjustment factor quantified by $\Omega = \frac{\rho_w f_{ywk}}{f_{ctk}} = \frac{A_{sw} f_{ywk}}{b\, s\, f_{ctk}}$

Figure 19 V_{exp}, $V_a/V_{Rd,\,s\ limit\ \theta}$ vs. dimensionless parameter Ω

Non-linear regression

Non-linear regression is employed to develop an adjustment factor for shear reinforcement design in ES EN 1992-1-1:2015 by considering models analyzed by Abaqus CAE and published experimental tests.

Equation: Power, two Parameters

$f = ax^b$

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.8059	0.6495	0.6484	0.3140

Table a

	Coefficient	Std. Error	t	P
a	0.9451	0.0264	35.8212	<0.0001
b	-0.4744	0.0201	-23.6208	<0.0001

Table b

	DF	SS	MS
Regression	2	848.5796	424.2898
Residual	319	31.4456	0.0986
Total	321	880.0252	2.7415

Table c Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	58.2744	58.2744	591.1654	<0.0001
Residual	319	31.4456	0.0986		
Total	320	89.7200	0.2804		

Table d Corrected for the mean of the observations:

Table 14 Summary of nonlinear regression

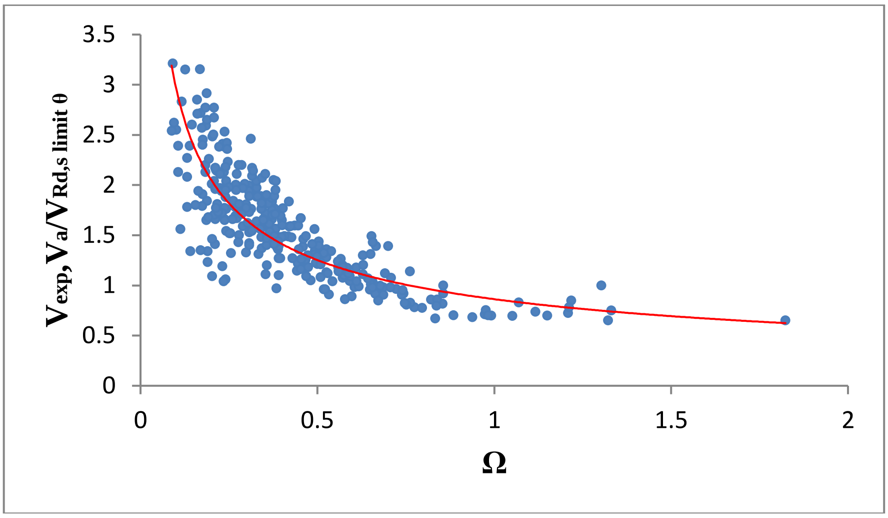


Figure 20 Curve fit

The existing $V_{Rd,s}$

$$V_{Rd,s} = V_{Ed} = \frac{A_{sw}}{s} z f_{ywk} cot\theta$$

[1]

ES EN 1992-1-1:2015 recommended limits for $cot\theta$ as

$$1 \leq cot\theta \leq 2.5$$

The new $V_{Rd,s}$ from this study

$$V_{Rd,s} = \Omega(\frac{A_{sw}}{s} z f_{ywk} cot\theta)$$

$$\Omega = 0.9451(\frac{\rho_w f_{ywk}}{f_{ctk}})^{-0.4744}$$

[2]

Equation 4.6 is an adjustment factor from the curve fitting, therefore

$$V_{Rd,s} = 0.9451\left(\frac{\rho_w f_{ywk}}{f_{ctk}}\right)^{-0.4744} (\frac{A_{sw}}{s} z f_{ywk} cot\theta)$$

Where $z = 0.9d$ (from ES EN 1992-1-1:2015), simplifying and approximating the above equation yields new adjusted expression

$$V_e = 0.945\left(\frac{A_{sw}}{s} f_{ywk}\right)^{0.52} z\,(f_{ctk} b)^{0.47}\, cot\theta$$

[3]

Where f_{ctk} characteristic tensile strength of concrete

$f_{ctk} = 0.21(f_{ck})^{2/3}$

A_{sw}	Area of the 2-legs of stirrups
s	Spacing of stirrups
f_{ywk}	Characteristic yield strength of stirrups
z	Internal lever arm
b	Breadth of beams
θ	Compressive strut angle

With ES EN 1992-1-1:2015 recommendation of limits for cotθ as

$$1 \leq cot\theta \leq 2.5$$

Validation of adjusted equation (equation 3)

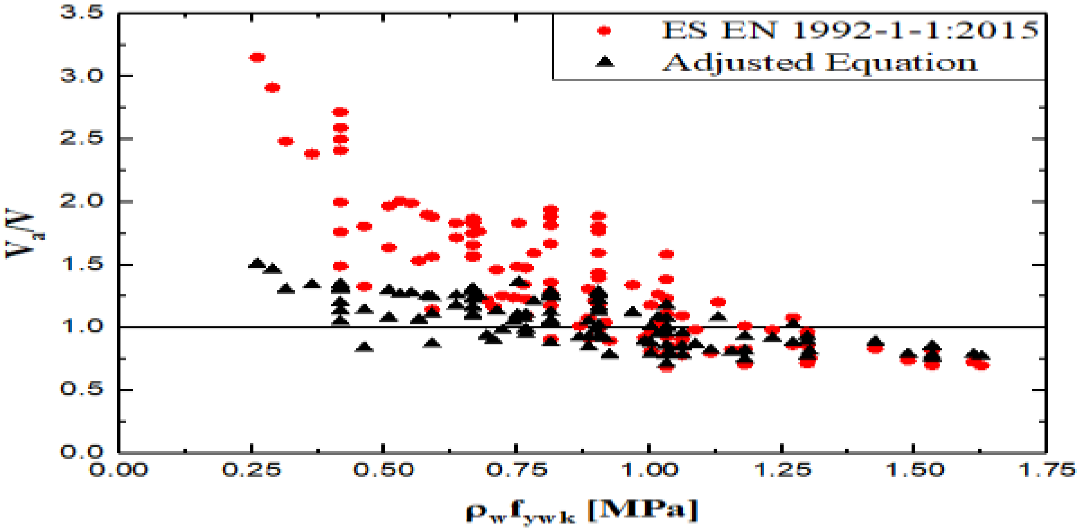


Figure 21 $V_a/V_{Rd,s\ limit\ \theta}$ *and* V_a/V_e *vs. shear reinforcement parameters*

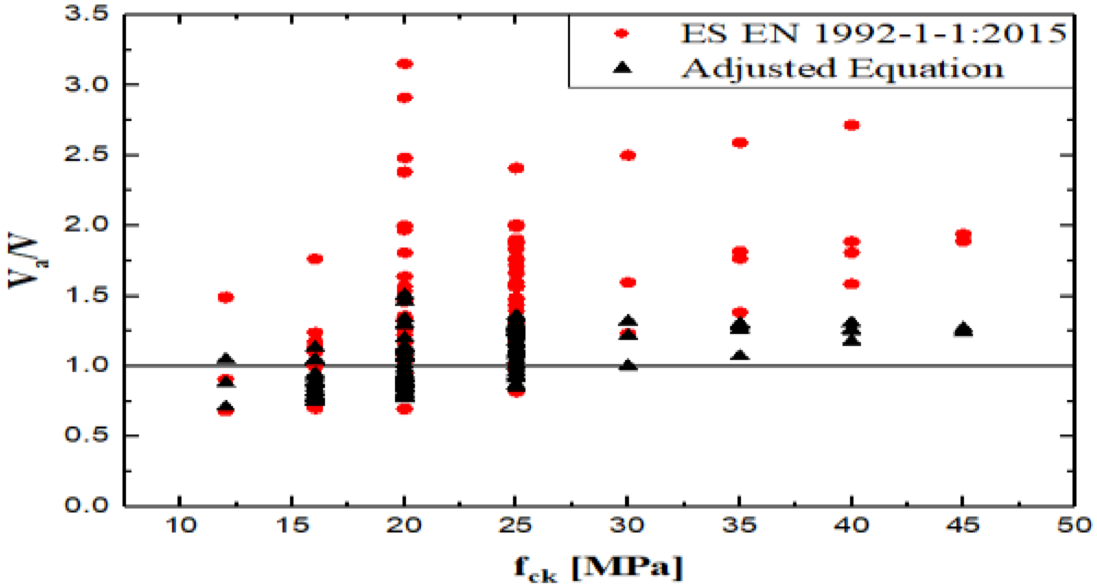


Figure 22 $V_a/V_{Rd,s\ limit\ \theta}$ *and* V_a/V_e *vs. compressive strength of concrete*

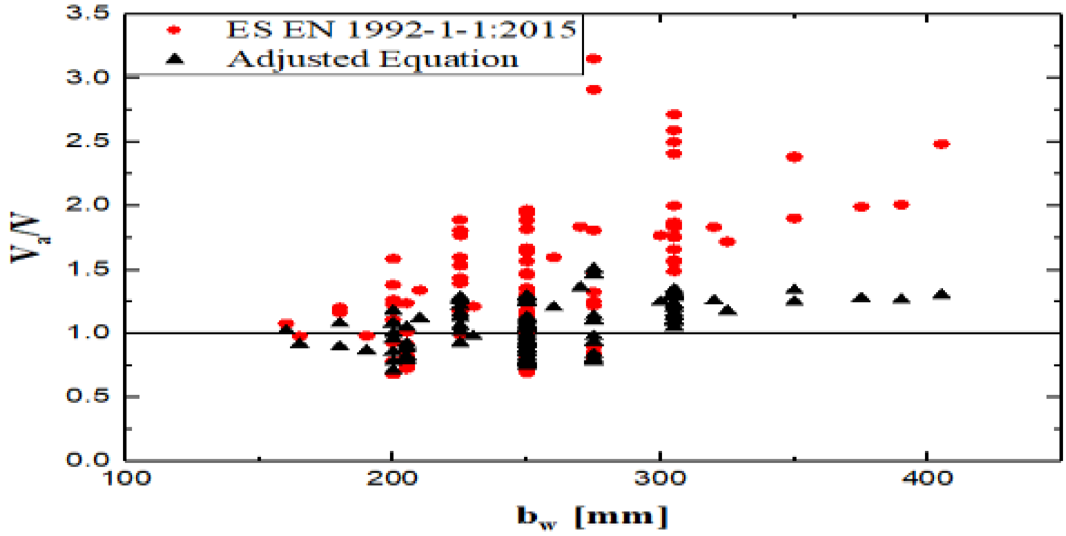


Figure 23 $V_a/V_{Rd,s\ limit\ \theta}$ *and* V_a/V_e *vs. breadth of beams*

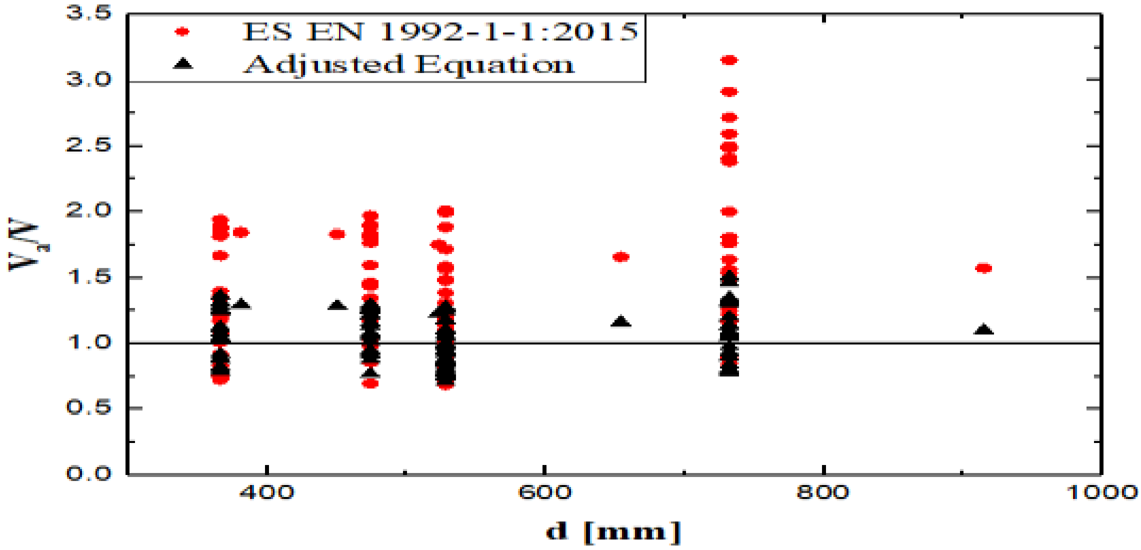


Figure 24 $V_a/V_{Rd,s\ limit\ \theta}$ *and* V_a/V_e *vs. depth of beams*

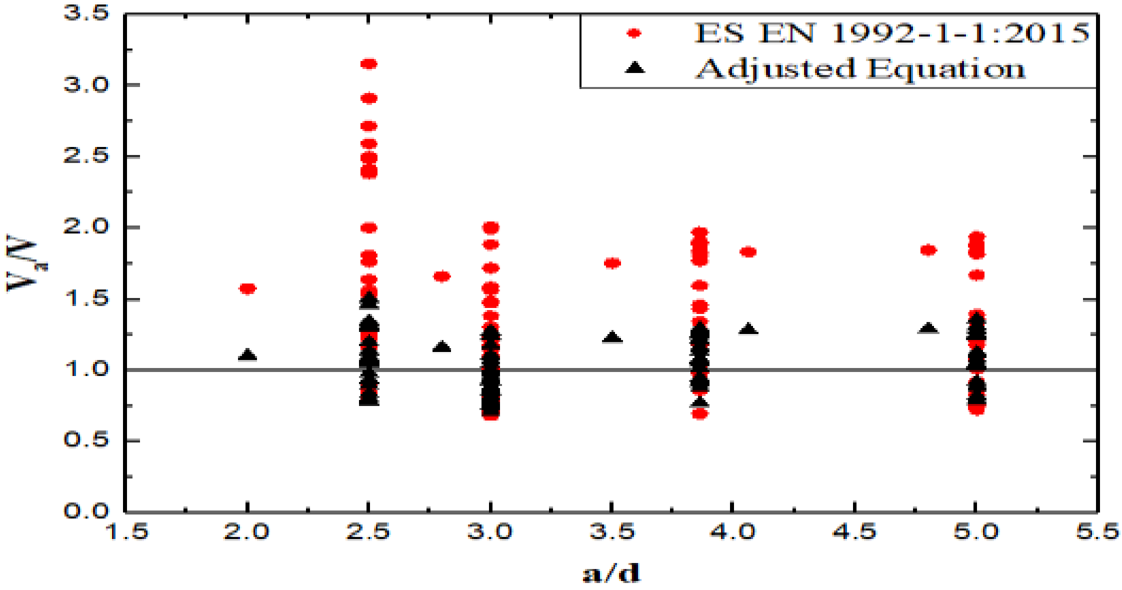


Figure 25 $V_a/V_{Rd,s\ limit\ \theta}$ *and* V_a/V_e *vs. shear span to depth ratio*

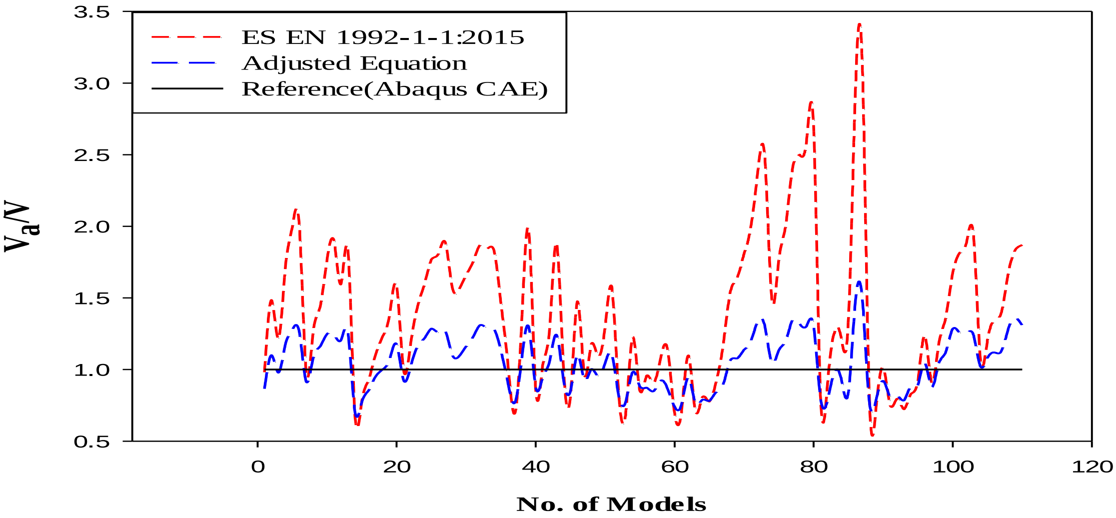


Figure 26 Comparison of $V_{Rd,\ s\ limit\ \theta}$ *and* V_e *with reference to* V_a

Figure 26 above shows the variations in shear resistance calculated using finite element software Abaqus CAE, ES EN 1992-1-1:2015 and new formula (EQ 3) with varying number of models. It can be seen in fig 36 the new formula (EQ 3) presents closer values to the finite element software Abaqus CAE than ES EN 1992-1-1:2015 with similar pattern of variation.

IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

ES EN 1992-1-1:2015 implemented the concept of variable strut inclination method to design for shear reinforcement by neglecting the contribution of concrete to shear resistance of the section $V_{Rd,c} = 0$ and by considering that the entire acting shear will be resisted by the provision of shear reinforcements. Where $V_{Rd,s}$ is shear resistance of stirrups and $V_{Rd,max}$ is the upper limit of design shear resistance set to avoid premature web crushing failures.

Concrete compressive strut angle θ generally increases with decreasing characteristic compressive strength of concrete.it only exceeds lower limit of strut angle θ (21.8^0) at a common situation of low characteristic compressive strength of concrete and high shear reinforcement parameter$(\rho_w f_{ywk})$.

Variable strut inclination method of capacity predictions in ES EN 1992-1-1:2015 generally give highly conservative capacity predictions at low $\rho_w f_{ywk}$ (shear reinforcement parameter) continuing to become slightly conservative and finally un-conservative (unsafe) as $\rho_w f_{ywk}$ increases.

It is concluded that the variable strut inclination method of capacity predictions in ES EN 1992-1-1:2015 markedly increases with increasing breadth and characteristic compressive strength of concrete.

Taking into consideration of published experimental data's and model analyzed by finite element software Abaqus CAE, An alternative expression for $V_{Rd,s}$ which is the ultimate shear resistance of stirrup reinforced section is provided taking in to account under and over estimation of variable strut inclination method capacity prediction of ES EN 1992-1-1:2015 shear provisions at low and high percentage of shear reinforcement respectively. And by adding a concrete contribution term (f_{ctk}) which can adjust the existing formulation of ES EN 1992-1-1:2015 shear design provisions for members requiring shear reinforcement.

Recommendation

The adjusted equation (equation 3) is more recommended to apply at low percentage of shear reinforcement ($\rho_w f_{ywk} \leq 0.5\ MPa$) and at high percentage of shear reinforcement ($\rho_w f_{ywk} \geq 1.5\ MPa$)

V. ACKNOWLEDGEMENTS

First of all, I thank the almighty God for providing me the peace and the health I utilized for conducting this research. Next I would like to express my sincere gratitude and appreciation to my advisor Dr.techn.Medhanye Beidebrhan for his invaluable guidance, consultation and insight provided throughout the research. And I would like to thank the Ethiopian Road Authority (ERA) for providing this chance.

REFERENCES

[1] An adequate theory for the shear strength of reinforced concrete structures. Collins, m. p., bentz, e. c., sherwood, e. g. & xie. 2008, Magazine of concrete research, p. 60.

[2] Mensah, Kenneth Kwesi. Reliability Assessment of Structural Concrete with Special Reference to stirrup Design (PhD dissertation). Stellenbosch : s.n., 2015.

[3] Walraven, j. c. & reinhardt, h. w. Theory and Experiments on the Mechanical Behaviour of Cracks in Plain and Reinforced Concrete Subjected to Shear Loading. s.l. : Delft University of Technology, 1981.

[4]. a new approach to the analysis of the confinement role in regularly cracking concrete elements. Gambarova, p. & karakoc, c. Chicago : s.n., 1983. Proceedings of 7th International Conference on Structural Mechanics in Reactor Technology. pp. 251–261.

[5] Analysis of shear- transfer actions on one-way RC members based on measured cracking pattern and failure kinematics. Campana, s., ruiz, m. f., anastasi, a. & muttoni, a. 2013, Magazine of Concrete Research, p. 65.

[6] Shear transfer in cracked reinforced concrete. Millard, S. G. & Johnson,R.P. 1985, Magazine of Concrete Research, p. 37.

[7] Mechanisms of shear resistance of concrete beams. Fenwick, r. c. & paulay, t. 1968, Journal of the Structural Division, ASCE, 94(ST10), pp. 2235-2350.

[8] Taylor, H. P.J. Investigation of the forces carried across cracks in reinforced concrete beams in shear by interlock of aggregate. London : s.n., 1970.

[9] Sigrist, V. Deformability of reinforced concrete beams. Zurich : s.n., 1995.

[10] Concrete Shear Strength: Another Perspective. Tureyen, a. k. & frosch, r. j. 2004, ACI Structural Journal, pp. 101-104.

[11] Contact density model for stress transfer across cracks in concrete. Li, N., Maekawa, L. & Okamura,H. 1989, Journal of the Faculty of Engineering, University of Tokyo, pp. 9-52.

[12] Soltani, M. Micro computational approach to post cracking constitutive laws of reinforced concrete and applications to nonlinear finite element analysis. University of Tokyo : s.n., 2002.

[13] Eleiott, A.F. An experimental investigation of shear transfer across cracks in reinforced concrete (PhD dissertation). Cornell University : s.n., 1974.

[14] Strain-based strength model for direct punching shear of interior slab–column connections. Park, H.G., Choi,K.K.& Chung, L. 2011, Engineering Structures, pp. 1062-1073.

[15] Mosley, B., Bungey, J., & Hulse, R. Reinforced Concrete Design to Eurocode 2(6thed.). New York : Palgrave Macmillan, 2007.

[16] 1992-1-1., ES EN. Design of concrete structures – Part 1-1:General rules and rules for Buildings. 2015.

[17] BSI. Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings. 2004.

[18] fib. fib Model Code for Concrete Structures. 7.3 Verification of structural safety (ULS) for predominantly static loading, 7.3.3 Shear. 2010.

[19] Shear Strength of Reinforced Concrete Beams. Bressler, B., & Scordelis, A.C. 1963, ACI Structural Journal, pp. 51-74.