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SHEAR STRENGTH OF REINFORCED CONCRETE BEAMS–RELATIONAL DATA BASE*

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Abstract– Shear capacity of concrete (V_c) in reinforced concrete members depends on a number of influencing parameters including compressive strength of concrete (f'_c), ratio of tension reinforcement ($\boldsymbol{\rho}$), shear span to depth ratio ($\frac{a}{d}$), size effect or depth factor (ξ), size of the aggregate in relation to the minimum size of the member (aggregate interlock aspects). Over the last several decades, researchers have tested reinforced concrete beams (without web reinforcement) to study these parameters over a range limited by the breadth and depth of their experimental investigations and, on the basis of their experimental results, proposed empirical equations for predicting the shear capacity of concrete in reinforced concrete beams.

In this paper a relational database using ACCESS software is developed. The database contains experimental results of 2145 shear critical reinforced concrete beams without web reinforcement.

Using the ACCESS shear database developed in this study, an evaluation was conducted to assess the predictive accuracy of shear design equation of Euro Code EC2. The results indicate that the Euro Code EC2 design equations are found to be adequately conservative to predict the shear capacity of reinforced concrete beams over the range of variables considered in this study.

Keywords– Shear strength, concrete compressive strength, shear span to depth ratio empirical equations, database

1. INTRODUCTION

Extensive research has been carried out in the area of shear strength of reinforced concrete [1-19], however, there is no consensus among researchers regarding the relational theory for shear failure as in the case of flexure.

Over the years, researchers have selected different influencing parameters in their empirical expressions (on the basis of the variable considered in their experimental program) and also because there is no general theory or approach accepted for predicting the ultimate shear capacity of reinforced concrete beams without web reinforcement. This has been stated in the two state- of-the art reports published by joint ACI-ASCE Committee 445[20] and CEB Bulletin 237 [21]. These empirical equations are derived from set of reinforced concrete beams without web reinforcement and are limited by the range of variables considered in their respective experimental programs.

In this study a relational database is developed and populated with test data of shear critical reinforced concrete beams without web reinforcement. The database is populated with the experimental results of 157 [22-27] shear critical reinforced concrete beams (without web reinforcement) that were tested between 2002 and 2009. The database is further populated with experimental results of 439 reinforced concrete beams (without web reinforcement), tested prior to 2002, contained in the Database of Karl-Heinz Reineck et al [28] and 1849 reinforced concrete beams (without web reinforcement), tested prior to 2002, contained in the database of Michael P. Collins et al [29].

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Since there is no consensus regarding an accepted theory for predicting the shear failure of reinforced concrete beam as in case of flexural failure, Codes of practice provide empirical equations for estimating the shear strength of reinforced concrete. Euro Code of practice EC2 [30] also provides empirical equation to predict the shear capacity of reinforced concrete beams. Using the ACCESS shear database, an evaluation was conducted to assess the predictive accuracy of shear design equation of Euro Code EC2. The results indicate that equation in the Euro Code EC2 is adequately conservative to predict the shear capacity of reinforced concrete over the range of variables considered in this study.

2. CRITERIA FOR SETTING UP THE ACCESS SHEAR DATABASE

The shear capacity of concrete (V_c) in reinforced concrete beams without web reinforcement is influenced by number of parameters including the major influencing factors such as compressive strength of concrete (f'_c), shear span to depth ratio ($\frac{a}{d}$), ratio of tension reinforcement (ρ), size effect or depth factor (ξ), size of the aggregate in relation to the minimum size of the member (aggregate interlock aspects).

The purpose of developing the ACCESS shear database was to collect in one place the test results of reinforced concrete beams without web reinforcement, so that it can be used not only for evaluating the design equations in the Codes [30, 31], but could also be used for accessing the predictive index (V_{test} /V_{pre}) of proposed empirical equations for predicting the shear strength of reinforced concrete beams. The shear database can also be used for possible development of a comprehensive empirical equation for estimating the shear strength of reinforced concrete beams.

In the shear database, fields are allocated for storing the experimental information for 6 major influencing factors, concrete compressive strength f'_c, shear span to depth ratio ($\frac{a}{d}$), ratio of tension reinforcement (ρ), width (b) and depth of beam (d), and measured ultimate shear load (V_u). These six parameters also form the basis of the number of empirical equations proposed in the literature [32-36] since the 1960's for estimating the shear capacity of concrete (V_c). The information on the depth of the beam (d) could be used to study the size effect or the depth factor (ξ). Using the ACCESS shear database an empirical equation was proposed [37] to predict the shear capacity of deep beams.

3. DEVELOPMENT OF SHEAR DATABASE

The ACCESS data base developed has 8 fields, one field for authors name along with year of publication, one field for beam designation, and 6 fields for storing the experimental information for 6 major influencing factors. The factors used in the database are concrete compressive strength f'_c, shear span to depth ratio ($\frac{a}{d}$), ratio of tension reinforcement (ρ), width (b) and depth of beam (d), and measured ultimate shear load (V_u).

The database is populated with test data for reinforced concrete beams without web reinforcement and tested under the typical two point load arrangement. The data in the ACCESS Shear database is in SI units.

The ACCESS Shear database developed in this study is initially populated with test results of 157 [22-27] reinforced concrete beams without web reinforcement tested from 2002 to 2009. The 157 beams that were used initially in the development of the ACCESS shear database have an effective depth of 300 mm and have high strength concrete. Out of these 157 test beams, 35 beams have width of 230 mm and the rest have a width of 150mm. The ratio of tension reinforcement (ρ) is $\leq 2\%$ and the shear span to depth ratio (a/d) varies between 1 and 6. The database was further populated with published test results of 439 reinforced concrete beams without web reinforcement, contained in the database of Karl-Heinz Reineck et al [28] and 1849 reinforced concrete beams without web reinforcement contained in the database of Michael P. Collins et al [29]. Thus the experimental data and results of 2145 reinforced concrete beams without web reinforcement are contained in the ACCESS shear database.

Of the 2145 reinforced concrete beams without web reinforcement in the database, 1959 beams are simply supported rectangular reinforced concrete beams, 8 are continuous reinforced concrete beams and 178 are T- beams. The database contains test data of 1478 beams with $\frac{a}{d} < 2.5$, and 667 beams with $\frac{a}{d} \geq 2.5$. There are 629 beams with high strength concrete (f'_c > 40MPa) and 1516 beams with normal strength concrete ($f'_c \leq$ 40MPa).

Figures 1 to 4 show the number of beams included in the ACCESS shear database for each of the major influencing parameters, i.e. concrete compressive strength f'_c, shear span to depth ratio $\frac{a}{d}$, ratio of tension reinforcement ρ, and effective depth (d).

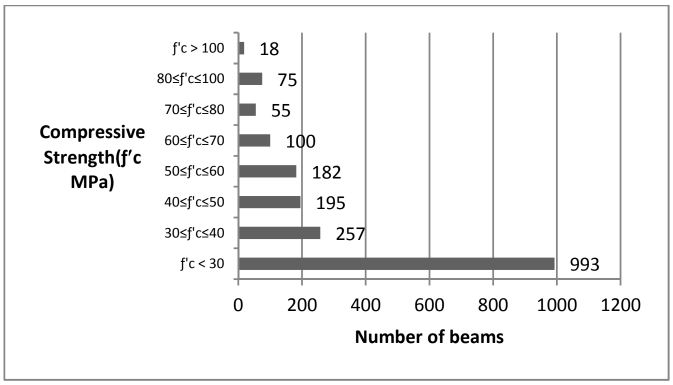

Fig. 1. Data of number of beams for various f'_c included in the ACCESS shear database

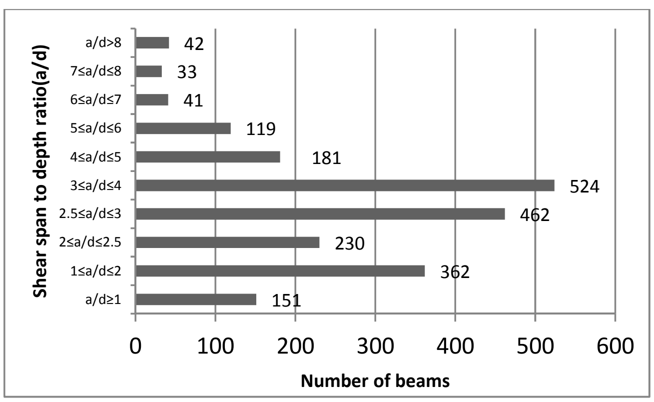

Fig. 2. Data of number of beams for various a/d included in the ACCESS shear database

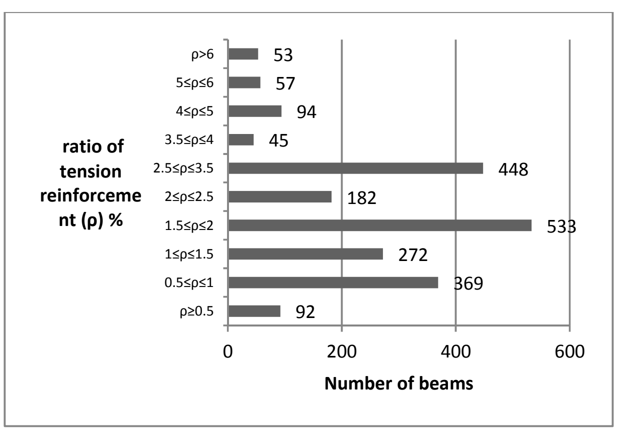

Fig. 3. Data of number of beams for various ρ included in the ACCESS shear database

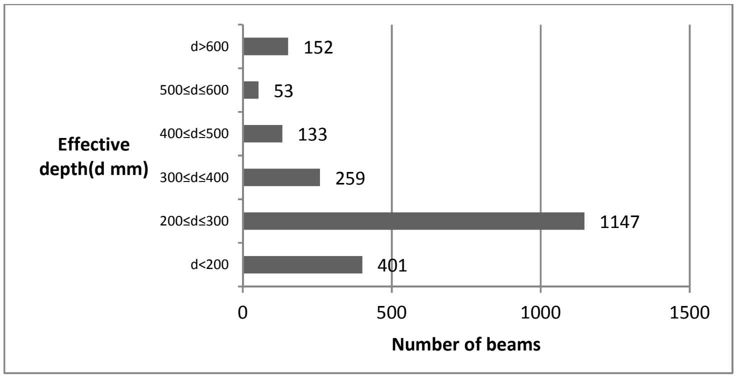

Fig. 4. Data of number of beams for various d included in the ACCESS shear database

4. MAJOR INFLUENCING PARAMETERS

In order to study the influence of major parameters on shear strength of reinforced concrete beams, a dimensionless factor termed (ESI), *experimental shear index* $\left(v = \frac{V}{bdf'_c}\right)$ is used. Figures 5 to 8 show the effect of concrete compressive strength f'_c, shear span to depth ratio $\frac{a}{d}$, ratio of tension reinforcement ρ and effective depth d on the *experimental shear index* (ESI).

Figure 5 shows the effect of concrete compressive strength f'_c on the ESI. Out of 2145 beams, 1520 (71%) beams are with normal strength concrete ($f'_c \leq 40$ MPa) and 625 (29%) beams are with high strength concrete ($f'_c > 40$MPa). From Fig. 5 it can be seen that ESI decreases non-linearly with increase in concrete compressive strength f'_c thus indicating that the shear force V does not increase linearly with increase in concrete compressive strength f'_c.

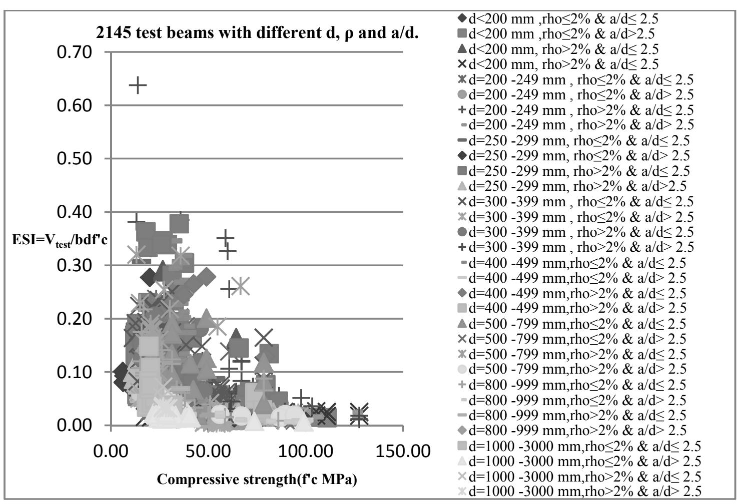

Fig. 5. Influence of f'_c on ESI for various d, ρ and a/d

Figure 6 shows the effect of shear span to depth ratio $\frac{a}{d}$ on the ESI. Out of 2145 beams, 743 (35%) beams are for shear span to depth ratio $\frac{a}{d} \leq 2.5$ and 1492 (65%) beams are for shear span to depth ratio $\frac{a}{d} > 2.5$. From Fig. 6 it can be seen that ESI decreases non-linearly with increase in shear span to depth ratio $\frac{a}{d}$, thus indicating that the shear force V does not increase linearly with increase in shear span to depth ratio $\frac{a}{d}$. The increase in ESI for beams with lower shear span to depth ratio $\frac{a}{d}$ may be attributed to the beneficial influence on the ultimate shear capacity due to direct compressive force path associated with arch action.

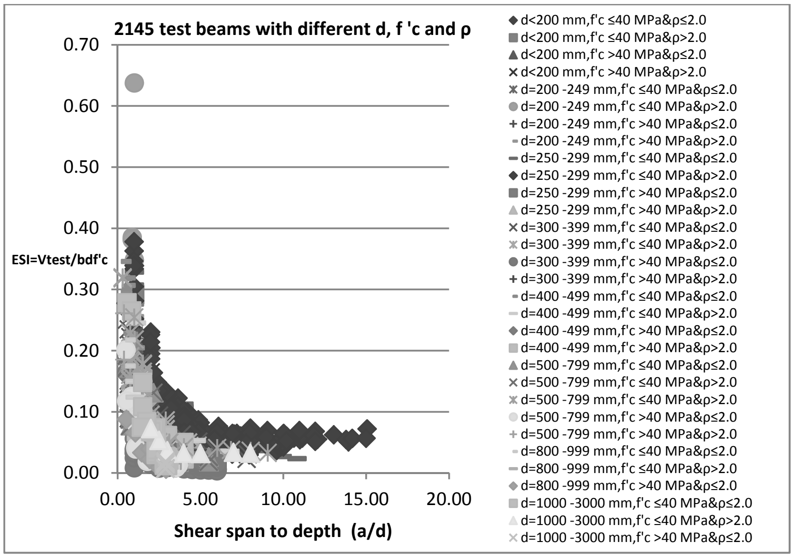

Fig. 6. Influence of a/d on ESI for various d, f'_c and ρ

Figure 7 shows the effect of ratio of tension reinforcement ρ on the ESI. Out of the 2145 beams, 1266 (59%) beams are with ρ ≤ 2%, and 879 (41%) beams are with ρ > 2%. From Fig. 7 it can be seen that there is no obvious trend in the variation of ESI with the change in the ratio of tension reinforcement ρ.

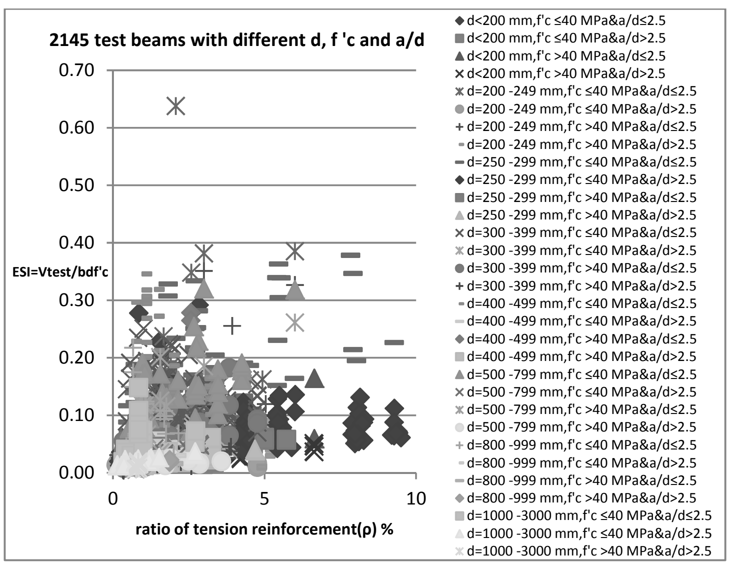

Fig. 7. Influence of ρ on ESI for various d, f'_c and a/d

Figure 8 shows the effect of effective depth of beam (d) on the ESI. Out of 2145 beams, 1548 (72%) beams are with effective depth (d) ≤ 300mm, 597 (28%) beams are with effective depth (d) > 300mm. From Fig. 8 it can be seen that the ESI decreases with the increase in the effective depth (d) of beam. This indirectly shows the size effect on the shear capacity of reinforced concrete beams. The larger the depth of the beam, the smaller the value of ESI, indicating a relative reduction in the shear capacity of concrete with increase in the depth of the member. It is also noted that for beams with concrete compressive strength $f'_c \geq 40$ MPa, the values of ESI are relatively smaller as compared to ESI values for beams with concrete compressive strength f'_c <40 MPa.

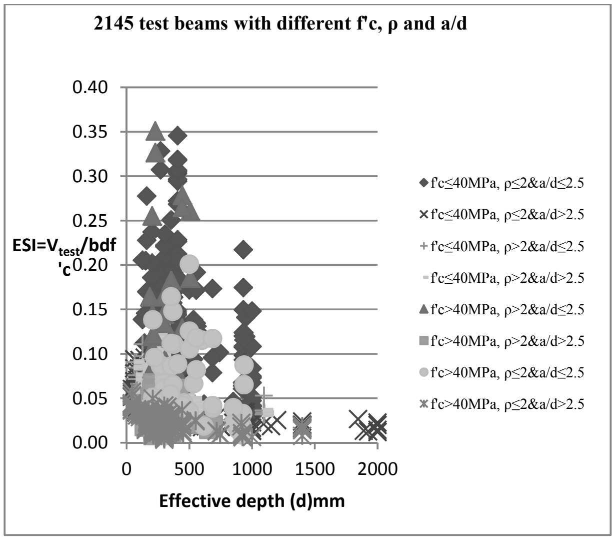

Fig. 8. Influence of d on ESI for various f'_c, ρ and a/d

5. COMPARISON WITH DESIGN EQUATION

a) Euro code EC2

The design equation in Euro Code EC2 (Eq.6.2a) for predicting the shear capacity of reinforced concrete beams without web reinforcement is:

$$V=\left(\frac{0.18}{\gamma_c}\,K(100\rho_l f_{ck})^{1/3}+0.15\sigma_{cp}\right)\text{bd} \qquad \text{SI units} \qquad \text{(EC2 Eq.6.2.a)}$$

$$V_{\min}=\left(0.035\text{k}^{3/2}f_{\text{ck}}^{\;1/2}\right)\text{bd}$$

Where

γ_c = material constant,

$k=1+\sqrt{\frac{200}{d}}\leq 2,$

ρ_l= longitudinal steel ratio

σ_{cp} = Axial stress in case of pre-stressed members.

f_{ck} = Concrete characteristic strength

b= width of beam

d= depth of beam

In order to evaluate the predictive accuracy of Euro Code EC2 Eq. (6.2.a), 1034 test beams with effective depth d ≥ 200 mm, concrete compressive strength f'_c< 106 MPa and ratio of tension reinforcement $\rho \leq 0.02$ were selected from ACCESS shear database. The variable k and f_{ck} in Euro Code EC2 Eq. (6.2.a) must satisfy the relations $k=1+\sqrt{\frac{200}{d}}\leq 2$ and $f_{ck}\leq 100\,MPa$ respectively. For the Euro Code EC2 Eq. (6.2.a), material constant γ_c has been taken as 1.40 [38] characteristic cylinder strength f_{ck} as per Reineck [28] is taken equivalent to concrete cylindrical strength as f_{ck}=f'_c-1.60 MPa, and the term $0.15\sigma_{cp}$ is taken as zero because all the beams that were used for evaluation are non-prestressed reinforced concrete beams.

In order to evaluate the predictive accuracy of Euro Code EC2 Eq. (6.2.a), 928 reinforced concrete beams with shear span to depth ratio ($\frac{a}{d}$> 1.0) and 108 reinforced concrete beams having shear span to depth ratio ($\frac{a}{d}$≤ 1.0) were selected from ACCESS shear database. Figure 9 shows the plot of the measured ultimate shear force (V_{exp}) and predicted ultimate shear force $(V_{pre})_{EC2}$, along with the threshold line (V_{exp}/V_{pre} = 1). Out of 928 test reinforced concrete beams, 840 (90.5%) test results were above this threshold line and 88 (9.5%) of the results were below this threshold line. The average $\left(\frac{v_{exp}}{v_{pre}}\right)_{EC2}$ termed Margin of Safety for all the 928 reinforced concrete beams without web reinforcement having shear span to depth ratio $\frac{a}{d} > 1.0$ comes out to be 1.77 as shown in Table 1 which shows the summary of the results. Thus the Euro Code EC2 Eq. (6.2.a) is conservative for the test data of 928 beams with shear span to depth ratio $\frac{a}{d} > 1.0$ and with different concrete compressive strength f'_c and ratio of tension reinforcement ρ.

Out of 108 reinforced concrete beams having shear span to depth ratio ($\frac{a}{d} \leq 1.0$), test results of 107 beams were above this threshold line and 1 beam was below this threshold line. The average $\left(\frac{v_{exp}}{v_{pre}}\right)_{EC2}$ termed Margin of Safety for all the 108 reinforced concrete beams without web reinforcement having shear span to depth ratio $\frac{a}{d} \leq 1.0$ comes out to be 6.65 (Table 1). Thus the Euro Code EC2 Eq. (6.2.a) is conservative for the test data of 108 beams with shear span to depth ratio $\frac{a}{d} \leq 1.0$ and with different concrete compressive strength f'_c and ratio of tension steel ρ.

Table 1. Summary of results

			Strength of concrete		Size Effect			
Shear span to depth ratio ($\frac{a}{d}$)	No. of Beams used for Evaluation	Average Margin of Safety $\left(\frac{v_{exp}}{v_{pre}}\right)$	Normal Strength Concrete (NSC) / High Strength Concrete (HSC)	Average Margin of Safety $\left(\frac{v_{exp}}{v_{pre}}\right)$	No. of Beams used for Evaluation d<300mm / No. of Beams used for Evaluation d≥300mm	Average Margin of Safety $\left(\frac{v_{exp}}{v_{pre}}\right)$	No. of Beams used for Evaluation d <1200 mm	Average Margin of Safety $\left(\frac{v_{exp}}{v_{pre}}\right)$
$\left(\frac{a}{d}\right) > 1$	928	1.77	623	1.89	423	1.56	19	1.08
			305	1.50	505	1.85		
$\left(\frac{a}{d}\right) \leq 1$	108	6.65	87	6.94	21	4.91		
			21	5.45	87	7.07		

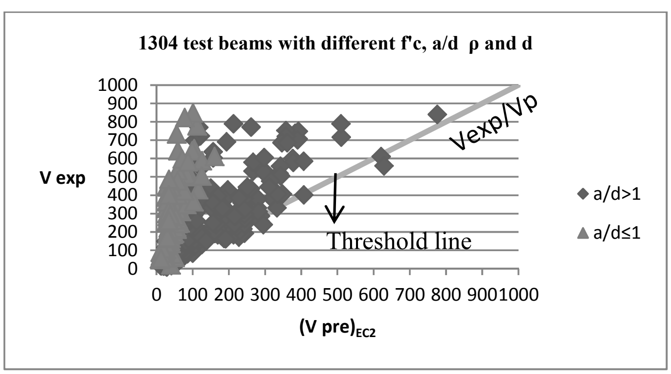

Fig. 9. Comparison of prediction of Euro Code EC2 Eq.6.2.a with experimental results

b) Influencing Parameters

1. Concrete strength: Figure 10 shows the effect of concrete compressive strength f'_c on the Margin of Safety $\left(\frac{v_{exp}}{v_{pre}}\right)_{EC2}$. Figure 10 contains data of 928 reinforced concrete beams with shear span to depth ratio ($\frac{a}{d} > 1.0$) and 108 reinforced concrete beams having shear span to depth ratio ($\frac{a}{d} \leq 1.0$). Out of 928 reinforced concrete beams, 623 (67%) beams were with concrete compressive strength f'_c≤40MPa and 305 (33%) beams were with concrete compressive strength f'_c >40 Mpa. Out of 623 normal strength concrete (NSC) beams (f'_c≤40MPa), test results of 600 were above the threshold line (V_{exp}/V_{pre} = 1) and test results of 23 beams were below the threshold line (V_{exp}/V_{pre} = 1). For NSC Beams, with shear span to depth ratio $\frac{a}{d}$> 1.0, the average margin of Safety when using Euro Code Eq. 6.2.a is 1.89 (Table 1). For the 305 high strength concrete (HSC) beams (f'_c >40 Mpa), test results of 240 beams were above the threshold line (V_{exp}/V_{pre} = 1) and test results of 65 beams were below the threshold line. For HSC beams, with shear span to depth ratio $\frac{a}{d}$> 1.0, when using Euro Code Eq. (6.2.a), the average Margin of Safety for Euro Code is 1.50 (Table 1).

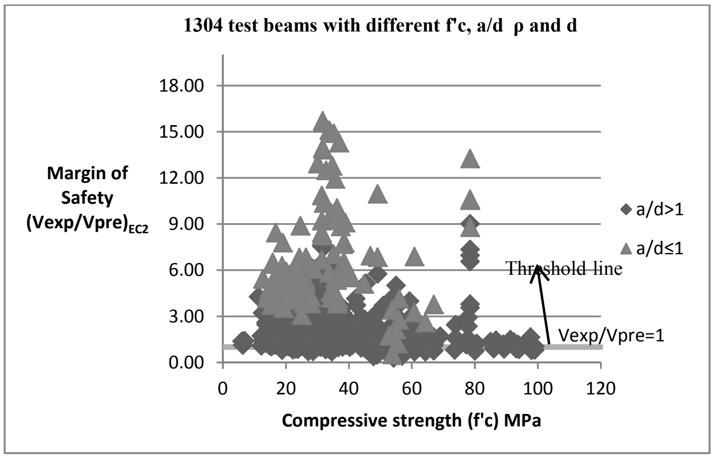

Fig. 10. Influence of f'_c on $\left(\frac{V_{exp}}{V_{pre}}\right)_{EC2}$

Out of 108 reinforced concrete beams having shear span to depth ratio ($\frac{a}{d}$≤ 1.0), 87 (81%) beams were with concrete compressive strength f'_c≤40 MPa and 21 (19%) beams were with concrete compressive strength f'_c >40 MPa. Out of 87 normal strength reinforced concrete beams (f'_c≤ 40 MPa), all the test results of 87 beams were above the threshold line (V_{exp}/V_{pre} = 1). For NSC Beams with $\frac{a}{d}$≤ 1.0, the average Margin of Safety when using Euro Code Eq. (6.2.a) is 6.94 (Table 1). For the 21 reinforced beams of high strength concrete (f'_c ≥40 MPa), the test results of 20 beams were above the threshold line (V_{exp}/V_{pre} = 1) and test result of 1 beam was below the threshold line. For HSC beams with $\frac{a}{d}$≤ 1.0, when using Euro Code Eq. (6.2.a), the average Margin of Safety is 5.45 (Table 1).

2. Effective depth: Figure 11 shows the effect of effective depth (d) on the Margin of Safety $\left(\frac{v_{exp}}{v_{pre}}\right)_{EC2}$. Figure 11 contains test data of 928 reinforced concrete beams with shear span to depth ratio ($\frac{a}{d}$> 1.0) and 108 reinforced concrete beams having shear span to depth ratio ($\frac{a}{d}$≤ 1.0). Out of 928 reinforced concrete beams with $\frac{a}{d}$> 1.0, 423 (46%) beams were with effective depth (d) < 300 mm and 505 (54%) beams were with effective depth (d) ≥ 300mm. Out of the 423 beams (with d <300 mm), test results of 401 beams were above the threshold line (V_{exp}/V_{pre} = 1) and test results of 22 beams were below the threshold line (V_{exp}/V_{pre} = 1). For beams with $\frac{a}{d}$> 1.0 and effective depth (d) < 300 , the average Margin of Safety when using Euro Code Eq. (6.2.a) is 1.56 (Table 1). Out of the 505 beams with d ≥ 300 mm, test results of 439 beams were above the threshold line (V_{exp}/V_{pre} = 1) and test results of 66 beams were below the threshold line. For beams with $\frac{a}{d}$> 1.0 and effective depth (d) ≥ 300, the average Margin of Safety when using Euro Code Eq. (6.2.a) is 1.85 (Table 1).

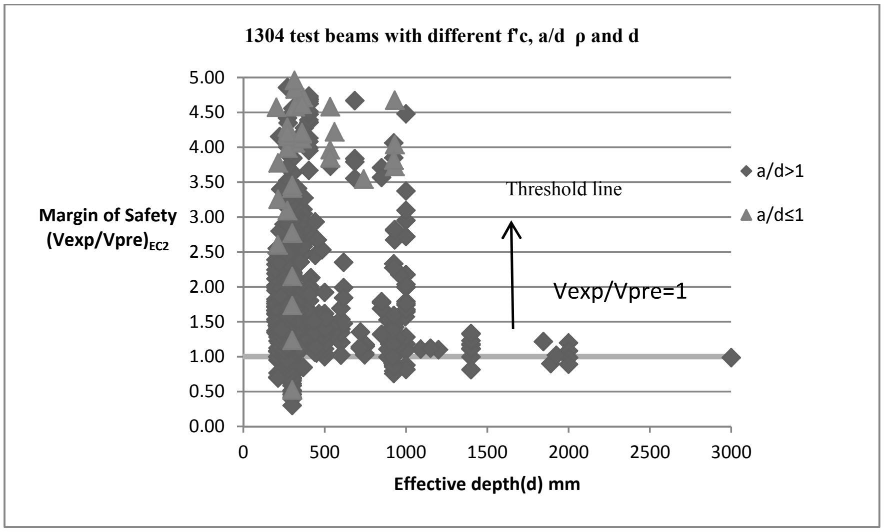

Fig. 11. Influence of d on $\left(\frac{V_{exp}}{V_{pre}}\right)_{EC2}$

Out of 108 reinforced concrete beams having shear span to depth ratio ($\frac{a}{d}\leq 1.0$) , 21(20%) beams were with effective depth (d) < 300mm and 87 (80%) beams were with effective depth (d) ≥ 300mm.). Out of the 21 beams (with d <300 mm), test results of all 21 beams were above the threshold line. For beams with $\frac{a}{d}\leq 1.0$ and effective depth (d) < 300 , the average Margin of Safety when using Euro Code Eq. (6.2.a) is 4.91 (Table 1). Out of the 87 beams with d ≥ 300 mm, the 86 test results were above the threshold line and test result of 1beam was below the threshold line. For beams with $\frac{a}{d}\leq$ 1.0 and effective depth (d) ≥ 300 , the average Margin of Safety when using Euro Code Eq. (6.2.a) is 7.07 (Table 1).

It can also be seen from Fig. 11 that, irrespective of ratio of tension reinforcement ρ, shear span to depth ratio $\frac{a}{d}$ and concrete compressive strengthf'_c, Euro Code Eq. (6.2.a) is conservative (with reduced margin of safety) for shear capacity of reinforced concrete beams having effective depth (d) > 1200 mm without web reinforcement and hence safe (with reduced margin of safety) for reinforced concrete beams with d > 1200 mm. For beams with effective depth (d) >1200, the average Margin of Safety when using Euro Code Eq. 6.2.a is 1.08 (Table 1).

6. SUMMARY AND CONCLUSION

In this study an ACESS data base containing the experimental results for shear capacity of 2145 reinforced concrete beams has been developed.

From the study of the influence of major parameters on shear strength of reinforced concrete beams, the following conclusions can be drawn;

1. The shear capacity of concrete (V_c) does not increase linearly with concrete compressive strength and does not increase linearly with shear span to depth ratio. (Figs. 5 and 6)
2. The shear capacity of concrete (V_c) reduces with increase in the depth (size) of the member, thus indicating a size effect.

From the evaluation study of design equation in Euro Code EC2 (Eq.6.2a) for predicting the shear capacity of reinforced concrete beams without web reinforcement, it was found that the Euro Code EC2 design equations are found to be adequately conservative as:

1. For NSC Beams, with shear span to depth ratio $\frac{a}{d}>1.0$, the average Margin of Safety when using Euro Code Eq. (6.2.a) is about 1.89 and for beams with a/d $\frac{a}{d}\leq 1.0$, the average Margin of Safety is about 6.94. (Table 1)

For HSC beams, with shear span to depth ratio $\frac{a}{d} > 1.0$, when using Euro Code Eq. (6.2.a), the average Margin of Safety for Euro Code is about 1.50 and for beams with $\frac{a}{d} \leq 1.0$, the average Margin of Safety is about 5.45. (Table 1)

LIST OF ABBREVIATIONS

V_c	shear capacity of concrete
f'_c	concrete compressive strength
ρ	ratio of tension reinforcement
$\frac{a}{d}$	shear span to depth ratio
ξ	size effect or depth factor
b	width of beam
d	effective depth
V_u	ultimate load
V_{exp}	shear force observed
V_{pre}	shear force predicted
ESI	experimental shear index

REFERENCES

1. ACI-ASCE Committee 326 (1962). Shear and diagonal tension. *ACI Journal, Proceedings*, Vol. 59, January, February, and March, pp. 1-30, pp. 277-344 and pp. 352-396.
2. Bentz, E. C., Vecchio, F. J. & Collins, M. P. (2006). Simplified modified compression field theory for calculating shear strength of reinforced concrete elements. *ACI Structural Journal*, Vol. 103, No. 4, Jul–Aug, pp.614-624.
3. Vecchio, F. J. & Collins, M. P. (1988). Predicting the response of reinforced concrete beams subjected to shear using modified compression field theory. *ACI Structural Journal*, May-Jun, pp. 258-268.
4. Vecchio, F. J. & Collins, M. P. (1986). The modified compression- field theory for reinforced concrete elements subjected to shear. *ACI Journal*, March-April, pp. 219-231.
5. Kani, G. N. J. (1966). Basic factors concerning shear failure. *ACI Journal, Proceedings*, Vol. 63, No. 6, pp. 441-467.
6. Kotsovos, M. D. & Bobrowski, J. (1993). Design model for structural concrete based on the concept of the compressive force path. *ACI Structural Journal*, Vol. 90, No.1 Jan-Feb, pp. 12-20.
7. Kotsovos, M. D. & Lefas, L. D. (1990). Behavior of reinforced concrete beams designed in compliance with the concept of compressive. *Force Path ACI Structural Journal*, Vol. 87, No. 2, Mar-Apr, pp. 127-139.
8. Kotsovos, M. D. (1983). Mechanism of shear failure magazine of concrete research. Vol. 35, No. 123, pp.99-106.
9. Kotsovos, M. D. (1984). Behavior of reinforced concrete beams with a shear span to depth ratio between 1.0 and 2.5, *ACI Journal*, June, pp. 279-286.
10. Kotsovos, M. D. (1986). Behavior of reinforced concrete beams with a shear span to depth ratio greater then 2.5. *ACI Journal*, pp.1026-1034.
11. Kotsovos, M. D. (1987). Behaviour of reinforced concrete t- beams in shear. *The Structural Engineer*, Vol. 65B, No.1, pp. 1-10.
12. Kotsovos, M. D. (1988). Compressive force path: basis for reinforced concrete ultimate limit state design. *ACI Structural Journal*, pp. 68-75.
13. Collins, M. P & Mitchell, D. (1986). A rational approach to shear design-The 1984 Canadian code provisions. *ACI Journal*, pp.925-933.
14. Collins, M. P. & Kuchma, D. (1999). How safe are our large, lightly reinforced concrete beams, slabs and footing? *ACI Structural Journal*, Vol. 96, No. 4, pp. 482-490.
15. Collins, M. P., Mitchell, D., Adebar, P. & Vecchio, F. J. (1996). A general shear design method. *ACI Structural Journal*, Vol. 93, No. 1, pp. 36-45.

16. Collins, M. P., Bentz, E. C. & Sherwood, E. G. (2008). Where is shear reinforcement required? Review of research results and design procedures. *ACI Structural Journal*, Vol. 105, No. 5, pp. 590-600.
17. Zararis, P. D. & Papadakis, G. Ch. (2001). Diagonal shear failure and size effect in RC beams without web reinforcement. *Journal of Structural Engineering*, pp.733-742.
18. Arabzadeh, A. (2001). Analysis of some experimental results of simple supported deep beams using truss analogy method. *Iranian Journal of Science and Technology, Transaction of Civil Engineering*, Vol. 25, No. 1, pp. 115-128.
19. Ahmad, S., Shah, A., Zaman, N. & Salimullah, K. (2011). Design and evaluation of the shear strength of deep beams by strut and tie model (STM). *Iranian Journal of Science and Technology, Transaction of Civil Engineering*, Vol. 35, No. 1, pp. 1-13.
20. Joint ACI-ASCE Committee 445 Report, (1998).Recent approaches to shear design of structural concrete, ACI 445R-99.
21. ENV 1992-1-1 Comite Europeen de normalisation CEN, (1992). 'Eurocode 2- Design of concrete Structures - Part 1-1: General rules and rules for Buildings'.
22. Ali, S. (2001). *Flexural and shear behaviour of high strength concrete beams*. MSc thesis, Taxila University.
23. Shah, A. (2009). Evaluation of shear strength of high strength concrete beams. PhD Thesis, University of Engineering & Technology Taxila-Pakistan.
24. Bukhari I. A. (2002). Shear behaviour of high strength concrete beams without stirrups. MSc thesis, Taxila University.
25. Bukhari, I. A. & Ahmad, S. (2008). Evaluation of shear of high strength concrete beams without stirrups. *Arabian Journal for Science and Engineering*, Vol. 33, No. 2B.
26. Elahi, A. (2003). Effect of reinforcement ratio and shear span on shear strength of high strength concrete beams. MSc thesis, Taxila University.
27. Yaqub, M. (2002). Shear behaviour of high strength concrete beams without shear reinforcement. MSc thesis, Taxila University.
28. Reineck, K. H., Kuchma, D. A., Kim, K. S. & Marx, S. (2003). Shear database for reinforced concrete members without shear reinforcement. *ACI Structural Journal*, Vol. 100, No. 2.
29. Collins, M. P., Bentz, E. C. & Sherwood, E. G. (2008). Where is shear reinforcement required? Review of research results and design procedures. *ACI Structural Journal*, Vol. 105, No. 5, pp. 590-600.
30. European Committee for Standardization, (2002). Eurocode 2: Design of Concrete Structures - Part 1-1: General rules and rules for Buildings, Revised Final Draft, April 2002, p. 226.
31. Building code requirement for structural concrete (ACI 318-95) and commentary (ACI 318R-95).
32. Kani, G. N. J. (1967). How safe are our large reinforced concrete beams? *ACI Journal*, pp.128-141.
33. Mörsch, E. (1922). *Der eisenbetonbau-seine theorie und anwendung*. 5th Edition, Wittwer, Stuttgart, Vol. 1, Part 2.
34. Reinhardt, H. W., Cornelissen, H. A. W. & Hordijk, D. A. (1986). Tensile tests and failure analysis of concrete. *Journal of Structural Enginering*, ASCE, Vol. 112, No. 11, pp. 2462-2477.
35. Ahmad, S. H., Khaloo, A. R. & Poveda, A. (1986). Shear capacity of reinforced high- strength concrete beams. *ACI Journal*, Mar-Apr, pp. 297-305.
36. Zsutty, T. C. (1968). Beam shear strength prediction by analysis of existing data. *ACI Journal Proceedings*, Vol. 65, No. 11, pp. 763-773.
37. Ahmad, S. H., Rafeeqi, S. F. A. & Fareed, S. (2012). Shear capacity of normal and light weight reinforced concrete deep and short beams without web reinforcement. *International Journal of civil, structural, environmental and infra-structure Engineering research and development*, Vol. 2, Issue 1, 73-81.
38. NS 3473E-1992, (1992). *Concrete structures design rules*. Norwegian Council for Building Standardization, Norway.