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Research Article

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Shear Behaviour of RC Beams: A Numerical Study

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Abstract:

A two-dimensional (2D) nonlinear finite element (FE) model developed for reinforced concrete (RC) beams is presented in this paper. The FE model was validated in order to perform further parametric studies on RC beams with and without existing steel shear links. The parameters were tension reinforcement ratio, concrete compression strength, and beam size. Moreover, the accuracy of “Turkish Standards 500: Requirements for design and construction of reinforced concrete structures (TS500)” in terms of predicting the total shear force capacity of RC beams was examined. The FE model properly captured the experimental load capacity, with a mean value of 1.04. The increase in overall shear force capacity caused by the increasing tension reinforcement ratio from 1.79 to 3.33% was 18.3% for RC beams with existing steel shear links, whereas it was 10.6% for RC beams without existing steel shear links. The total shear force capacities of RC beams with and without steel shear links increased once concrete compression was increased from 30 to 70 MPa. An increasing beam size resulted in a reduction in shear stress at failure of 33.8% and 32.7% for RC beams with and without shear links, respectively. TS500 design code gave conservative results in calculating the overall shear force capacity of RC beams.

1. Introduction

There is absolutely no uncertainty that inappropriately designed RC beams against shear, as compared with inappropriately designed RC beams in flexural, have catastrophic effects since shear failure takes place in a brittle and immediate way. It is therefore crucial to understand the shear behaviour of RC beams and the parameters influencing the shear behaviour. However, research examining the effect of some of the most principal factors on the shear behaviour of RC beams has yet to be fully understood [1,2]. For example, when compared to large-scaled RC beams, a substantial number of experimental studies were carried out to physically test laboratory-scaled RC beams [3-6]. This is especially concerning since the size effect in RC beams causes a decrease in shear stress and a change from ductile to brittle behaviour once beam dimensions are increased [2,3,5,6]. This paper numerically investigates the shear behaviour of RC beams both with and without existing steel shear links. A two-dimensional (2D) nonlinear finite element (FE) model was created and verified against experimental results in the current literature. The effects of tension reinforcement ratio, concrete compression strength, and beam size on the shear behaviour of RC beams were investigated. Furthermore, the numerical results in terms of total shear capacity of RC beams were used to assess “Turkish Standards 500: Requirements for design and construction of reinforced concrete structures (TS500)” [7] for designing RC beams.

2. Material and Methods

VecTor2 software [8] established on Disturbed Stress Field Model (DSFM) [9] was used to create a 2D FE model. The summary of analysis and constitutive material models of the developed FE model, together with the main parameters, are shown in Table 1. The RC beam, which was included in the experimental study carried out by Elsanadedy et al. [10], was used to validate the FE model. As shown in Fig. 1, the RC beam was 200 mm wide and 450 mm deep and was tested in a four-point-bending configuration [10]. The beam was reinforced in tension and compression with three 16 mm and two 10 diameter steel bars, respectively. The shear reinforcement of the beam consisted of 8 mm-

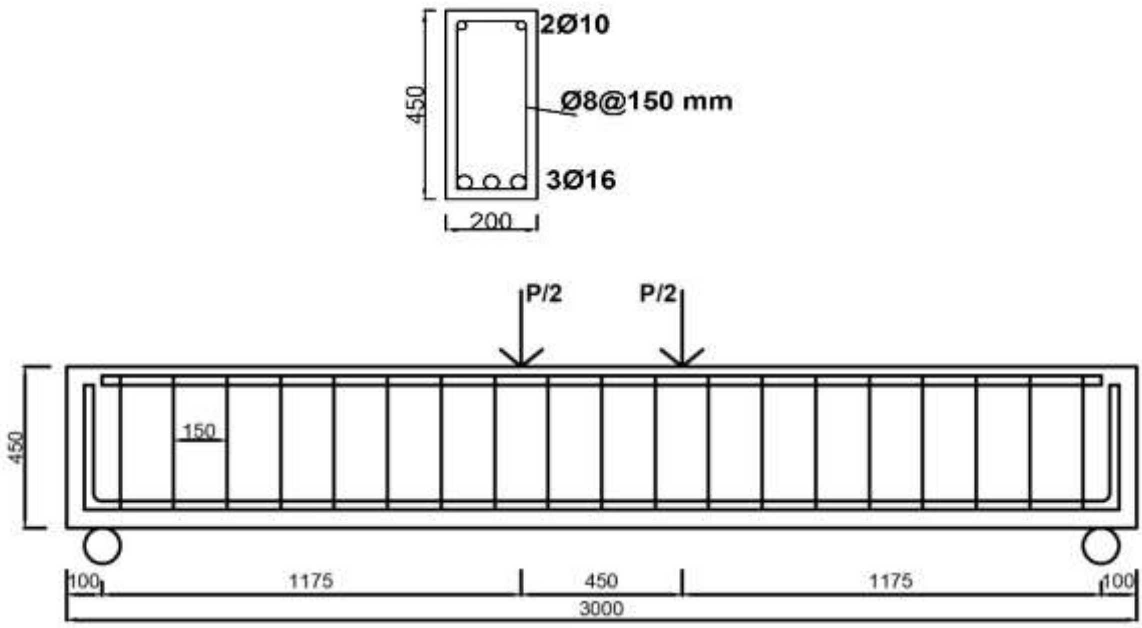

Figure 1. *Details of RC beam tested by Elsanadedy et al. [10] (all dimensions in millimeters)*

Table 1. *FE modelling* [8]

<table>
<tr><th colspan="2">Concrete Models</th><th colspan="6">Reinforcement Models</th></tr>
<tr><td>Concrete Pre- and Post-Peak</td><td>Popovics (HSC) Base Curve</td><td colspan="3">Hysteretic Response*</td><td colspan="3">Bauschinger Effect (Seckin)</td></tr>
<tr><td>Compression Softening</td><td>Vecchio 1992-B (e1-e0-Form)</td><td colspan="3">Dowel Action*</td><td colspan="3">Tassios (crack slip)</td></tr>
<tr><td>Tension Stiffening*</td><td>Modified Bentz 2003</td><td colspan="3">Buckling*</td><td colspan="3">Akkaya 2012 (Modified Dhakal-Maekawa)</td></tr>
<tr><td>Tension Softening*</td><td>Bilinear</td><th colspan="6">Main Input Parameters</th></tr>
<tr><td>Confined Strength*</td><td>Kupfer/Richart</td><th>f_c (MPa)</th><th>f_t* (MPa)</th><th colspan="2">E_c* (MPa)</th><th>Mesh Size (mm)</th><th>Poisson's ratio*</th></tr>
<tr><td>Dilation*</td><td>Variable-Isotropic</td><td>50</td><td>$0.33\sqrt{f_c}$ (VecTor2)</td><td colspan="2">$3320\sqrt{f_c}+6900$ (VecTor2)</td><td>25</td><td>0.15</td></tr>
<tr><td>Cracking Criterion*</td><td>Mohr-Coulomb (Stress)</td><th colspan="6">Analysis Models</th></tr>
<tr><td>Crack Stress Calculation*</td><td>Basic (DSFM/MCFT)</td><td colspan="3">Strain History*</td><td colspan="3">Previous Loading Considered</td></tr>
<tr><td>Crack Width Check*</td><td>Agg. / 2.5</td><td colspan="3">Cracking Spacing*</td><td colspan="3">CEB-FIP 1978-Deformed</td></tr>
<tr><td>Crack Slip Calculation*</td><td>Walraven</td><td colspan="3">Max. No. of Iterations</td><td colspan="3">100</td></tr>
<tr><td>Creep and Relaxation*</td><td>Not Considered</td><td colspan="3">Convergence Limit*</td><td colspan="3">1.00001</td></tr>
<tr><td>Hysteretic Response*</td><td>Nonlinear/w-Plastic Offsets</td><td colspan="3">Structural Damping*</td><td colspan="3">Not Considered</td></tr>
<tr><td colspan="2" rowspan="2">*Default models (VecTor2)</td><td colspan="3">Geometric Nonlinearity*</td><td colspan="3">Considered</td></tr>
<tr><td colspan="3">Convergence Criteria*</td><td colspan="3">Displacements-Weighted Average</td></tr>
</table>

diameter steel bars. The spacing between these shear links was 150 mm centre-to-centre (c/c). The concrete compression strength was 50 MPa. The yield strengths of 8-, 10-, and 16-mm steel bars were 570, 575, and 575 MPa, respectively.

3. Results and Discussions

The RC beam physically tested by Elsanadedy et al. [10] was numerically validated in terms of ultimate load capacity and corresponding deflection at ultimate load capacity. Fig. 2 compares the experimental results with the FE results. The developed FE model captured the experimental load capacity with a mean value of 1.04 (see Table 2). As shown in Fig. 2, both physically and numerically tested beams failed in flexure. The uncracked stiffness of the numerically tested beam was in good correlation with that of the experimentally tested beam. This can be attributable to the fact that elastic constants and boundary conditions were accurately modelled. Similar to the experimental load-displacement curve, the load-displacement curve of the numerically modelled beam turned from a linear to a nonlinear response after the formation of cracks. Finally, the numerically modelled beam had a ductile failure with a plateau.

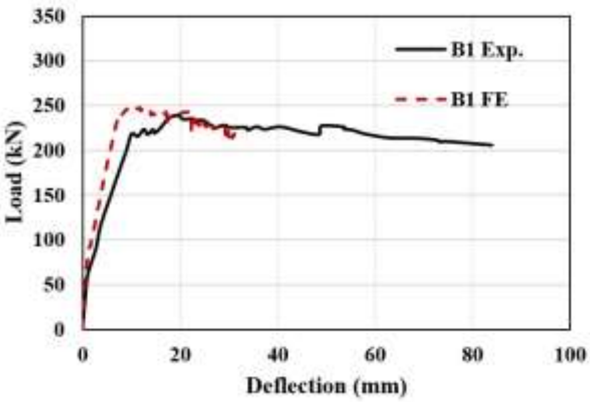

Figure 2. *Experimental* [10] *and FE-predicted load-deflection curves*

Table 2. *Comparison between experimental and FE results*

Load at failure (kN)			
Beam	**Exp.**	**FE**	**FE/Exp.**
B1	239	247.7	1.04

After obtaining validated results, it was conducted to examine the parameters influencing the structural behaviour of RC beams. To examine the shear behaviour of RC beams, shear-deficient beams taken into account in parametric studies were identical to RC beam tested by Elsanadedy et al. [10] but had a tension and compression reinforcement of 25 mm diameter steel bars and a shear reinforcement of 6 mm diameter steel bars. This ensured that numerically modelled beams had brittle behaviour and thus failed in shear. The investigated parameters were tension reinforcement ratio, concrete compression strength, and beam size. It should be noted that all numerical investigations were performed on RC beams with and without existing steel shear links. Moreover, all results were compared to TS500 [7] predictions. Of note is that the material safety factors of concrete and steel have been set to 1. TS500 [7] considers the overall shear resistance capacity (V_r) of a RC beam as the sum of the contributions of concrete (V_c) and steel shear links (V_w) as given in equation 1.

$$V_r = V_c + V_w \quad (1)$$

V_c can be calculated as follows;

$$V_c = 0.8 * V_{cr} \quad (2)$$

Where V_{cr} is shear cracking strength of a RC section and is calculated as given in equation 3.

$$V_{cr} = 0.65 * f_{ctk} * b_w * d \quad (3)$$

Where b_w and d are the width and effective depth of the RC beam, respectively. TS500 [7] recommends calculating f_{ctk} as follows;

$$f_{ctk} = 0.35 * \sqrt{f_{ck}} \quad (4)$$

Where f_{ck} is the compressive strength of concrete.

The contribution of steel shear links to shear strength is given by equation 5.

$$V_w = \frac{A_{sw}}{s} * f_{yw} * d \quad (5)$$

Where A_{sw} is the area of steel shear reinforcement, s is the spacing of steel shear links, and f_{yw} is the yield strength of steel shear reinforcement.

The impact of tension reinforcement ratio on the total shear force capacity of RC beams both with and without existing steel shear links was studied by modelling shear-deficient beams identical to the beam hereinabove mentioned but with tension reinforcement ratios ranging from 1.79 to 3.33%. Fig. 3 shows the effect of tension reinforcement ratio on total shear force capacity. An increase in the tension reinforcement ratio instigated an increase in total shear force capacity for RC beams both with and without steel shear links. This increase caused by the rising tension reinforcement ratio from 1.79 to 3.33% was 18.3% for RC beams with existing steel shear links, whereas it was 10.6% for RC beams without existing steel shear links. This can be attributable to confinement. The confined tension reinforcement increased the total shear strength capacity more than that of unconfined tension reinforcement. Moreover, TS50 [7] gave conservative predictions in terms of total shear force capacity for RC beams both with and without shear links. The reason for the constant predictions of TS500 [7] can be explained by the fact that the effect of tension reinforcement on the shear force capacity of RC beams is not considered. As can be seen in Fig. 3, the effect of tension reinforcement on RC beams, especially with existing shear reinforcement, linearly increased the total shear force capacity.

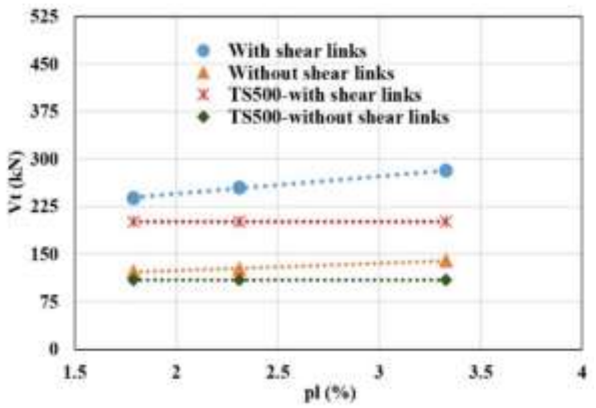

Figure 3. *Impact of tension reinforcement ratio*

The effect of concrete compression strength was examined by modelling RC beams with concrete compression strengths ranging from 30 to 70 MPa. Fig. 4 demonstrates the impact of concrete compression strength on the shear behaviour of RC beams both with and without steel shear links. The total shear force capacities of RC beams with and without steel shear links increased from 226.4 to 277.2 kN and from 105 to 144 kN, respectively, once concrete compression was increased from 30 to 70 MPa. As can be seen in Fig. 4, TS500 [7] predictions especially gave conservative predictions for RC beams with steel shear links. However, TS500 [7] predictions for total shear force capacities of RC beams both with and without steel shear links were in an increasing trend once concrete compression strength was enhanced from 30 to 70 MPa. The size effect in RC beams is one of the significant parameters influencing shear behaviour [1, 11-13]. In this study, the validated FE model was used to produce RC beams to assess the size effect. The numerically modelled beams were also identical to the shear-deficient beams hereinabove mentioned. All dimensions were scaled by a scale factor that varied between 0.667

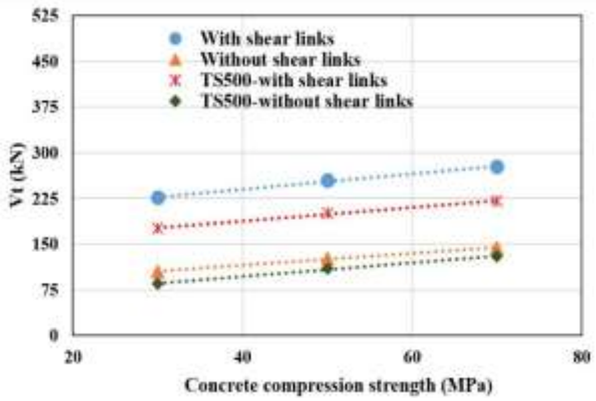

Figure 4. *Effect of concrete compression strength*

and 1.33. Of note is that reinforcement ratios were also kept constant. Fig. 5 demonstrates a variation in shear stress with effective beam depth for RC beams both with and without shear links. An increasing effective depth from 275 to 550 mm caused a reduction in shear stress at failure of 33.8% and 32.7% for RC beams with and without shear links, respectively. However, shear stress predictions of TS500 [7] were constant for RC beams both with and without shear links once the beam dimensions were increased or decreased. This proved that TS500 [7] does not consider the size effect.

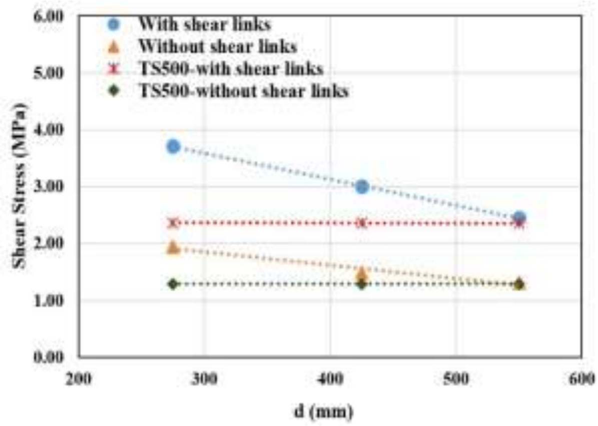

Figure 5. *Size effect*

4. Conclusions

A two-dimensional FE model was created and verified against the experimental results of Elsanadedy et al. [10]. The impacts of tension reinforcement ratio, concrete compression strength, and beam size on the shear behaviour of RC beams both with and without existing steel shear links. Moreover, the accuracy of TS500 [7] in terms of calculating the overall shear strength capacity of RC beams was examined. According to the numerical research, the following results were obtained:

➢ The enhancement in total shear force capacity caused by the increasing tension reinforcement ratio from 1.79 to 3.33% was 18.3% for RC beams with steel shear links, whereas it was 10.6% for RC beams without existing steel shear links. The impact of tension reinforcement on the shear force capacity of RC beams is not considered by TS500 [7]. Thus, it gave constant predictions for the overall shear force capacity of RC beams.

➢ The total shear force capacities of RC beams with and without steel shear links increased from 226.4 to 277.2 kN and from 105 to 144 kN, respectively, once concrete compression was increased from 30 to 70 MPa. Although TS500's [7] predictions for total shear force capacities of RC beams both with and without steel shear links were in an increasing trend, their predictions were conservative.

➢ An increasing effective depth from 275 to 550 mm caused a reduction in shear stress at failure of 33.8% and 32.7% for RC beams with and without shear links, respectively. However, shear stress predictions of TS500 [7] were constant for RC beams both with and without shear links once the beam dimensions were increased or decreased.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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- **Author contributions:** The authors declare that they have equal right on this paper.

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] ACI Committee 445 on Shear and Torsion (1998). Recent approaches to shear design of structural concrete. *Journal of Structural Engineering*. 124(12):1375-1417. https://doi.org/10.1061/(ASCE)0733-9445(1998)124:12(1375)

[2] Bažant, Z. P. (1997). Fracturing truss model: size effect in shear failure of reinforced concrete. *Journal of Engineering Mechanics*. 123 (12): 1276-1288. https://doi.org/10.1061/(ASCE)0733-9399(1997)123:12(1276)

[3] Sogut, K., Dirar, S., Theofanous, M., Faramarzi, A. (2019, June 4-7). *Size effect in shear-deficient reinforced concrete T-beams strengthened with embedded FRP bars.* The 14th International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures, (FRPRCS-14), Belfast, UK.

[4] Söğüt, K. (2022). Numerical investigation on DE-strengthened-RC beams without steel shear reinforcement. *Journal of Structural Engineering & AppliedMechanics*.5(4):238-248. https://doi.org/10.31462/jseam.2022.04238248

[5] Bažant, Z.P., Kim J.K. (1984). Size effect in shear failure of longitudinally reinforced beams. *ACI Journal Proceedings.* 81 (5): 456-468.

[6] Benzeguir, Z.E.A., El-Saikaly, G., Chaallal, O. (2019). Size effect in RC T-beams strengthened in shear with externally bonded CFRP sheets: experimental study. *ASCE Journal of Composites for Construction*.23(6):04019048. https://doi.org/10.1061/(ASCE)CC.1943-5614.0001045

[7] TS 500: Requirements for design and construction of reinforced concrete structures, TSE (Turkish Standards Institute), Ankara, Turkey, 2014.

[8] Wong, P.S., Vecchio, F.J., Trommels, H. (2013). *VecTor2 & FormWorks User's Manual (2nd edition).* The University of Toronto.

[9] Vecchio, F.J. (2020). Disturbed stress field model for reinforced concrete: formulation. *ASCE Journal of Structural Engineering*. 126(9):1070-1077. https://doi.org/10.1061/(ASCE)0733-9445(2000)126:9(1070)

[10] Elsanadedy, H.M., Al-Salloum, Y.A., Almusallam, T.H., Alshenawy, A.O., Abbas, H. (2019). Experimental and numerical study on FRP-upgraded RC beams with large rectangular web openings in shear zones, *Construction and Building Materials*. 194:322-343. https://doi.org/10.1016/j.conbuildmat.2018.10.238

[11] Jeong, C.Y., Kim, H.G., Kim, S.W., Lee, K.S., Kim, K.H. (2017). Size effect on shear strength of reinforced concrete beams with tension reinforcement ratio. *Advances in Structural Engineering*.20(4):582-594. https://doi.org/10.1177/1369433216658486

[12] Syroka-Korol, E., Tejchman, J. (2014). Experimental investigations of size effect in reinforced concrete beams failing by shear. *EngineeringStructures*.58:63–78. https://doi.org/10.1016/j.engstruct.2013.10.012

[13] El-Sayed, A. K., Shuraim, A. B. (2016). Size effect on shear resistanceof high strength concrete deep beams. *Materials and Structures*. 49 (5): 1871–1882. https://doi.org/10.1617/s11527-015-0619-1