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# High Strength Concrete Beams Subject to Axial Compressive Stress

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This paper forms part of a comprehensive investigation of the shear behaviour of high strength concrete beams submitted to axial compressive stress and attempts to search the basis for the development of simple design procedures for these structural elements, particularly the study of the shear force portion absorbed by the concrete, $V_C$.

Most current building codes express the shear strength of beams in terms of the shear force portion carried by transverse reinforcement, $V_S$, and the shear force portion "carried by the concrete", $V_c$. This "concrete contribution" can be assumed as:

$$V_{C,ACI} = \left(1.4\sqrt{f_c'} + 17.2\rho_w \frac{V_{ud}}{M_u - N_u \frac{(4h-d)}{8}}\right) b_w d \text{ [kN]}, \text{ to ACI 318-86(1)} \quad (1)$$

$$V_{C,NBR} = 0.15 * b_w * d * \sqrt{f_{ck}} * \left(1 + \frac{M_0}{M_{sd}}\right) \text{ [kN]}, \text{ according to NBR 6118(2).} \quad (2)$$

$$V_{C,REV} = 0.6 * f_{ctd} * b_w * d * \left(1 + \frac{M_0}{M_{sd}}\right) \text{[kN]}, \text{ according to NBR 6118 review.} \quad (3)$$

$$V_{C,CEB} = V_\theta - V_{45} \text{ [kN]}, \text{ according to CEB FIP-1990 (4)} \quad (4)$$

$$V_\theta = \left(\frac{A_{sw} * f_{yd}}{s}\right) * z * (\cot g\theta + \cot g90) * \operatorname{sen} 90 \quad (5)$$

considering $V_{45}$ and $V_\theta$ the total shear force ($V_c + V_s$) according to the "plasticity truss model" with the angle of inclination of the diagonal concrete struts, θ, equal to 45 degrees for $V_{45}$ and variable from 18.4 up to 45 degrees for $V_\theta$.

Based on the research's results herein presented, a new equation is proposed for predicting the ultimate shear force portion "carried by the concrete", $V_c$:

$$V_{C,PROP} = 0.6 * f_{ctd} * b_w * d * (1+\kappa)^2 \text{ [kN]}, \text{ with } (1 + \kappa)^2 \le 2 \quad (6)$$

with the compression degree, $k$, assumed as:

$$\kappa = \frac{N}{N_{nec}} \tag{7}$$

where $N$ is the compressive axial load applied in the beam and $N_{nec}$ is the service compressive axial load necessary to avoid tension stresses in required cross section of the beam, assumed as:

A total amount of seven beams, with a concrete compressive strength around 85 $N/mm^2$, were analysed. All of them had identical geometry and reinforcement, longitudinal and transversal. The only variables were the intensity of the compressive axial load applied and its application point through outs the beam's height.

The loading on the beams was made up of a concentrated load, applied at the midspan of the beams, and of a compressive axial load, applied at their external faces.

A web reinforcement ratio, $\rho_w$,of 0.252% was adopted for all the beams. Logically this value was chosen in order to be inferior to the web reinforcement ratio, which was calculated according to the classical truss model - $\rho_{w,45}$, once the shear failure by yielding of the web reinforcement was required. Strains in the longitudinal bars and shear reinforcement were measures by strain gages.

The intensity and position difference point application of the compressive axial load resulted in a variability of the compression degree, $k$, in the investigated beams.

All the tested beams have reached the ultimate shear capacity by the yielding of the web reinforcement as it was expected.

Failure was sudden and complete, particularly in beams with high compression degree, $\kappa$.

Results of the tests conducted here have shown that the truss model can be extended to high-strength concrete beams subjected to axial compressive stress, on the shear design. At least the ones which have been made of concrete with a compressive strength until 85 $N/mm^2$.

The shear force portion "absorbed by the concrete", $V_C$, calculated according ACI code equation, NBR code equation and CEB code equation, were compared with the experimental data obtained in this work and it could be noticed that the all code equations were very conservative for high strength concrete beams herein tested, underestimating the influence of shear force portion "absorbed by the concrete", $V_C$, at the shear strength design.

It was possible to notice for this research's beams, as it was already observed by Leonhardt for the usual strength concrete beams subject to axial compressive stress, the possibility of a bigger reduction shear load portion, $V_c$, due to the compression degree increased, $k$, within the beams ). This reduction possibility may be explained due to the fact that the longitudinal compression stresses delay the crack beginning of the beams and, therefore, they delay the mobilised of the web reinforcement too.

The new proposal, presented in this paper, **eq. (6)**, has provided satisfactory values of "shear force portion absorbed by the concrete", $V_c$, for high strength concrete beams submitted to axial compressive stress.