UNIVERSITY OF MORATUWA

DEVELOPMENT OF A RATIONAL PROCEDURE FOR SHEAR DESIGN IN STRUCTURAL CONCRETE

By

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DECLARATION

I hereby, declare, that the work included in this thesis in part or whole, has not been submitted for any other academic qualification at any institution.

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ABSTRACT

Over the last century, the design for shear in reinforced concrete beams has been uncertain. The reason for this uncertainty is the lack of clear understanding of the true nature of load carrying mechanism. Researchers around the world have developed several shear design procedure as a remedy to this uncertainty. Most of them are empirical and some are rational which use various mathematical representations of load carrying mechanism. Almost all of these mathematical models are complicated and accuracy of is rather low compared to empirical methods.

With the advancement of concrete technology and introduction of new methods, the improvement of accuracy of shear design methods is rather unmatchable when compared with flexural design. However, some of the new shear design methods were adopted by codes of practice and the design formulae were modified by introducing various empirical factors based on test. So the shear design has now become very much empirical.

Some of the developed rational methods give good representation of the load carrying mechanism of beams. The method proposed here with the objective of developing a rational yet simple method, also assumes the load carrying mechanism of a beam as a truss. The tension carrying member represents the stirrups and the concrete portion is represented by compression member.

For this proposed method, the compression carrying concrete member is idealized as a cylindrical element applied with axial compression. The behavior of this idealized cylinder is modeled by using mathematical techniques like Isotropic and Anisotropic analysis. This developed method is compared with several key codes of practice using available test data for accuracy.

It is found that the proposed method is giving sound representation of the test results compared with most other codes of practice. According to the comparison, it is clear that this method is only second to Japanese code of practice.

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DEDICATION

To

my parents

and

all those who are interested and committed in advancement of science

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ABBRIVIATIONS

A	Cross sectional area
A_v	Cross sectional area of a stirrup
A_{sx}	Cross sectional area of longitudinal reinforcement
c	Radius of concrete cylinder
D	Compressive force acting on the cylinder
d_θ	Expansion in circumferential direction
$d_{\theta max}$	Maximum allowable expansion in circumferential direction
d	Depth of beam
d_{st}	Diameter of one leg of stirrup
E	Modulus of elasticity
E_c	Modulus of elasticity of concrete
E_{cr}	Reduced circumferential modulus of elasticity at the outer surface of cracked zone
E_θ	Circumferential modulus of elasticity of cracked concrete
f_c^*	Reduced concrete compressive strength
f_b	Stirrup-concrete bond stress
f_c'	Cubic compressive strength of concrete
f_c	Cylinder compressive strength of concrete
f_y	Yield strength of stirrup steel
f_{sx}	Yield strength of longitudinal reinforcement
f_t	Tensile strength of concrete
f_{tr}	Reduced tensile strength of concrete at the outer surface
f_θ	Stress in circumferential direction

h	Constant in hyperbolic stress-crack width equation for cracked concrete
k	Constant in hyperbolic stress-crack width equation for cracked concrete
L	Gauge length
Lc	Extent of radial cracking
m	Constant in hyperbolic stress-crack width equation for cracked concrete
N	Number of radial cracks
N^*	Axial forces in inclined bands
n	Number of stirrups crossing the crack plane
r	Radial distance
R	Radial distance to the inner boundary of elastic uncracked section
s	Stirrup spacing
t	Step size
u	Radial displacement
V^*	Shear forces in inclined bands
V	Shear capacity of beam
V_c	Shear forces carried by concrete
V_s	Shear forces carried by steel
V_t	Shear capacity of beam from test results
V_f	Calculated shear force from SFD
w	Crack width of radial crack
x'	Eccentricity of axial force in inclined band of concrete web
z	Lever arm of internal moment
θ	Inclination of crack with respect to the longitudinal axis

ε	Concrete strain
ε_r	Strain in the radial direction
ε_θ	Strain in the circumferential direction
$\varepsilon_{\theta \max}$	Maximum allowable tensile strain in the circumferential direction
ε_z	Strain in the *z* direction
ε_c	Concrete strain
ε_{sc}	Strain in solid concrete
ε_{2sc}	Principal compressive strain in solid concrete
ε_{xcr}	Longitudinal strain due to crack
ε_c	Longitudinal strain in solid concrete
ε''	Smeared strain due to crack slip
ε^*	Strain due to load
ε_x^*	Longitudinal strain due to load
ε_{sh}	Concrete shrinkage strain
ε_{cu}^*	Concrete strain at maximum compressive stress
ε_s	Stirrup strain
ε_{sy}	Yield strain of stirrups
$\Delta\varepsilon_s$	Anchorage slip of stirrup
σ_{nt}	Shear stress on crack faces
σ_{nn}	Normal stress on crack faces (compressive)
σ_2	Principal compressive stress in concrete strut
τ_u	Ultimate shear stress
$\Delta\tau$	Aggregate interlock contribution to the ultimate shear stress
φ	Crack inclination with respect to the longitudinal axis

ρ_{st}	Shear reinforcement ratio
ν	Poisson's ratio
ν_c	Poisson's ratio for concrete
σ_r	Normal stress in radial direction
σ_z	Normal stress in axial direction
σ_θ	Hoop stress acting in the circumferential direction
σ_{cr}	Reduced stress in the circumferential direction due to cracking
$\Delta\tau_{BND}$	Shear stress due to bending stiffness of band
$\Delta\tau_{INT}$	Shear stress due to aggregate interlock
Δ	A very small value for radius close to centre (to avoid ∞ stresses)
β	Crack angle
δ	Length between points where stresses are calculated
μ	Concrete - concrete friction coefficient
ψ	Friction angle ($\mu = \cot \psi$),
σ_f	Compressive stress normal to crack face
σ_{sw}	Stress in web reinforcement
τ_f	Shear friction across cracks
$\tau_{f\sigma}$	Friction term proportional to normal stress
τ_{fo}	Cohesion term of friction
$'$, $''$	First, Second derivative