A Plasticity Model to Predict the Effects of Confinement on Concrete

Thesis by

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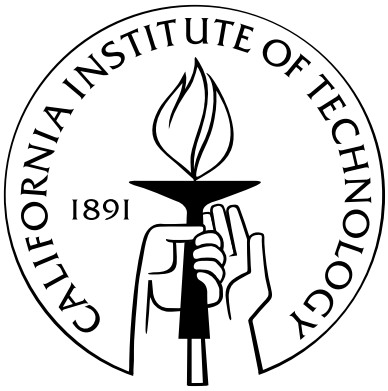

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Acknowledgements

I recall, while reading multiple other theses early in the course of my research, wondering why it was that people felt the need to lavishly thank all those around them at the completion of their thesis. I thought to myself, *it's a thesis, not an Academy Award!* But as I arrive (finally!) at the end of my own Ph.D., I now appreciate that this is not a journey one can complete on one's own. Without a strong network of support, I know I would never have finished. And so, I shall launch into my own 'acceptance' speech.

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Abstract

A plasticity model to predict the behavior of confined concrete is developed. The model is designed to implicitly account for the increase in strength and ductility due to confining a concrete member. The concrete model is implemented into a finite element (FE) model. By implicitly including the change in the strength and ductility in the material model, the confining material can be explicitly included in the FE model. Any confining material can be considered, and the effects on the concrete of failure in the confinement material can be modeled. Test data from a wide variety of different concretes utilizing different confinement methods are used to estimate the model parameters. This allows the FE model to capture the generalized behavior of concrete under multiaxial loading. The FE model is used to predict the results of tests on reinforced concrete members confined by steel hoops and fiber reinforced polymer (FRP) jackets. Loading includes pure axial load and axial load-moment combinations. Variability in the test data makes the model predictions difficult to compare but, overall, the FE model is able to capture the effects of confinement on concrete. Finally, the FE model is used to compare the performance of steel hoop to FRP confined sections, and of square to circular cross sections. As expected, circular sections are better able to engage the confining material, leading to higher strengths. However, higher strains are seen in the confining material for the circular sections. This leads to failure at lower axial strain levels in the case of the FRP confined sections. Significant differences are seen in the behavior of FRP confined members and steel hoop confined members. Failure in the FRP members is always determined by rupture in the composite jacket. As a result, the FRP members continue to take load up to failure. In contrast, the steel hoop confined sections exhibit extensive strain

softening before failure. This comparison illustrates the usefulness of the concrete model as a tool for designers. Overall, the concrete model provides a flexible and powerful method to predict the performance of confined concrete.

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Variable	Definition	Location
$a_{0,peak}$, $a_{1,peak}$, $a_{2,peak}$, $a_{3,peak}$	parameters defining the peak tensile meridian	Equation 3.1
$b_{0,peak}$, $b_{1,peak}$, $b_{2,peak}$, $b_{3,peak}$	parameters defining the peak compressive meridian	Equation 3.1
$a_{0,residual}$, $a_{1,residual}$, $a_{2,residual}$, $a_{3,residual}$	parameters defining the residual tensile meridian	Equation 3.1
$b_{0,residual}$, $b_{1,residual}$, $b_{2,residual}$, $b_{3,residual}$	parameters defining the residual compressive meridian	Equation 3.1
c	parameter defining the yield tensile meridian	Equation 3.2
D^e_{ijkl}	material elastic modulus tensor	Section 2.3
D^p_{ijkl}	material plastic modulus tensor	Equation 3.14
$D^{tangent}_{ijkl}$	material tangent modulus tensor	Equation 3.13
d	parameter defining the yield compressive meridian	Equation 3.2
$d\epsilon_{ij}$	total strain increment	Equation 2.14
$d\epsilon^p_{ij}$	plastic strain increment	Equation 2.14
$\overline{d\epsilon^p}$	effective plastic strain increment	Equation 2.17

$d\lambda$	positive scalar factor of proportionality, used for plastic flow definition	Equation 3.12
$d\sigma_{ij}$	elastic stress increment	Equation 3.10
$d\psi$	damage increment	Equation 3.5
E	modulus of elasticity	Section 3.4
F	failure surface	Section 2.2
F_{peak}	peak loading surface	Equation 3.4
$F_{residual}$	residual loading surface	Equation 3.4
F_{yield}	yield loading surface	Equation 3.4
f'_c	unconfined concrete compressive strength	Section 3.1.1
I_1, I_2, I_3	first, second, and third invariants of the stress tensor	Equations 2.5 through 2.7
J_2, J_3	second and third invariants of the deviatoric stress tensor	Equation 2.8 and 2.9
Q	potential surface	Section 3.3
$R_{peak}(\xi, \theta)$	cross section of the peak loading surface in the deviatoric plane	Equation 3.3
$R_{residual}(\xi, \theta)$	cross section of the residual loading surface in the deviatoric plane	Equation 3.3
$R_{yield}(\xi, \theta)$	cross section of the yield loading surface in the deviatoric plane	Equation 3.3
r	deviatoric length invariant	Equation 2.11
$r_{c,peak}$	compression meridian of the peak loading surface	Equation 3.1
$r_{c,residual}$	compression meridian of the residual loading surface	Equation 3.1
$r_{c,yield}$	compression meridian of the yield loading surface	Equation 3.2
$r_{t,peak}$	tensile meridian of the peak loading surface	Equation 3.1
$r_{t,residual}$	tensile meridian of the residual loading surface	Equation 3.1

$r_{t,yield}$	tensile meridian of the yield loading surface	Equation 3.2
s_{ij}	deviatoric stress tensor	Equation 2.3
α, γ	parameters controlling the effect of confinement on damage accumulation	Equation 3.5
β	defines the location of the failure surface relative to the loading surface	Equation 3.7
ϵ^e_{ij}	total elastic strain	Equation 2.16
ϵ_{ij}	total strain	Equation 2.15
ϵ^p_{ij}	total plastic strain	Section 2.3
θ	Lode angle or angle of similarity	Equation 2.12
κ	parameter controlling the rate of travel of the failure surface from one loading surface to the next	Equation 3.7
ν	Poisson's ratio	Section 3.4
ξ	hydrostatic length invariant	Equation 2.10
σ_{ij}	stress tensor	Equation 2.1
$\sigma_1, \sigma_2, \sigma_3$	principal stress invariants	Section 2.1
ϕ	parameter controlling damage accumulation at low stress levels	Equation 3.5
ψ	current damage level	Section 3.2
ψ_{peak}	damage level corresponding to the peak stress state	Section 3.2
ω	parameter controlling the amount of plastic volume change	Figure 3.6