



COLLAPSE BEHAVIOUR OF
NON-DUCTILE PARTIALLY
PRESTRESSED CONCRETE BRIDGE
GIRDERS

By

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TO MY MOTHER

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Summary

Design procedures for indeterminate concrete structures rely on the ability of structural concrete to undergo large ductile deformations as the ultimate load is approached. Ductility limits have to be satisfied if the design procedures are to give safe results.

In order to study ductility limits, it is necessary to consider the overall behaviour of statically indeterminate structures. The behaviour of concrete sections alone is not sufficient for the determination of these limits. However, to model the behaviour of indeterminate structural members undergoing large deformations, a comprehensive understanding of the behaviour of concrete sections is pre-requisite. The model should accurately simulate material nonlinearities that take place throughout this behaviour.

This thesis describes a computer program which has been developed, using a *segmental, nonlinear method* of structural analysis, to simulate the behaviour of concrete structures as they are progressively loaded up to and beyond collapse. This computer program has been used in a parametric study of ductility requirements for indeterminate partially prestressed concrete bridge girders. The program has the following characteristics:

1. It is able to calculate the initial parasitic effects (i.e hyperstatic reactions and secondary moments) that may result from the prestressing forces. The parasitic effects are taken into account in the subsequent analysis of non-linear behaviour.
2. It takes into account material nonlinearity in the form of the moment curvature relations.
3. It is able to analyse the behaviour of concrete structures, under progressive load increments, to the point of collapse and beyond. The

program allows for local softening in the peak moment regions either before or after the structure as a whole attains its loading capacity. In this way the program makes it possible to analyse both ductile and non-ductile structures.

4. A whole range of possible loading patterns can be considered in the program, such as; prestressing loads, dead loads, point loads and uniformly distributed loads.
5. The program is able to analyse reinforced, fully prestressed and partially prestressed concrete structures, hence making it possible to analyse a structure with varying level of prestress within its members.

The program does not take into account the effect of axial thrust on moment-curvature relations. Also second-order geometric effects are not considered in the program. The program concerns itself with the instantaneous behaviour of structures and therefore does not take into account the effects of temperature, creep, shrinkage, support settlement and loading history.

Using this computer program, analytical studies on ductility limits were undertaken on fully designed continuous prestressed bridge girders. Based on these results a recommendation is made regarding ductility limits for use in design of prestressed concrete bridges.

STATEMENT OF ORIGINALITY

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university and, to my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made in the text. I consent to the thesis being made available for photocopying and loan if accepted for the award of the degree.

Kobamelo Kgoboko

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Principal Notation

A_g	= the gross cross-sectional area
A_p	= the cross-sectional area of prestressing steel
A_s	= the cross-sectional area of reinforcement
A'_s	= the cross-sectional area of compression steel
b	= the width of a cross-section
b_w	= the width of the web
C	= the compressive force
$CRTCVT$	= curvature of the critical segment
c	= the depth from extreme compressive fibers to the neutral axis at ultimate
D	= the overall depth of a cross-section in the plane of bending
d	= the effective depth of a cross-section
d_n	= the depth of the neutral axis = c
d_p	= the depth of prestressing steel from the top fibre
d_s	= the depth of reinforcing steel from the top fibre
dx	= length of the cross-section
EA	= axial stiffness of a section
EI	= flexural bending stiffness of a section
E_{cm}	= the mean value of the modulus of elasticity of concrete
E_p	= the mean value of the modulus of elasticity of tendons
E_s	= the mean value of the modulus of elasticity of reinforcement
e	= eccentricity of axial force
F	= ductility factor
F_{min}	= minimum ductility required for full moment redistribution to take place
f_c	= the stress of concrete at any given strain
f'_c	= the characteristic compressive cylinder strength of

	concrete at 28 days
f_c''	= the mean strength of concrete, often taken as $0.85f_c'$
f_{cm}	= the mean value of the compressive strength of concrete at any age
f_{cu}'	= the characteristic compressive cube strength at 28 days
f_{pe}	= effective prestress in a tendon
f_{ps}	= the stress in the prestressing steel at a given strain
f_{psu}	= the average stress in the prestressing steel at ultimate
f_{pu}	= the ultimate strength of a prestressing tendon
f_{py}	= the yield strength of the tendon
f_s	= the stress in a reinforcing steel at a given strain
f_{sy}	= yield stress of reinforcing steel
f_y'	= yield stress of compression steel
h_f	= flange thickness
j_{crt}	= the number designated to the critical segment
K	= curvature
K_o	= initial curvature due to prestress
K_u	= neutral axis-depth ratio = $\frac{d_n}{d}$
K_{unit}	= curvature due to a unit load
L	= length of a member
L_{si}	= length of a segment
l_a	= lever arm
M	= moment
M_{cr}	= bending moment causing cracking of a section
M_G	= moment due to dead load
M_o	= moment required to restore a section to zero curvature
M_{Q+I}	= moment due to live load and impact
M_u	= ultimate strength in bending
M_p	= plastic moment
M_y	= yield moment
M^*	= the bending moment of a section calculated using design loads

M_1	= primary moment due to prestress
M_2	= secondary moment due to prestress
M_3	= actual moment caused by prestressing
$NEW EI$	= new secant stiffness in an iteration step
NS	= total number of segments in a member
$ncrt$	= the number of a member that is housing a critical segment
$OLD EI$	= secant stiffness from the previous iteration step
P	= axial force
PAR	= plastic adaptation ratio
P_{eff}	= effective prestressing force in a tendon
P_j	= jacking force in a tendon
PPR	= partial prestressing ratio
p	= ratio of steel to area of a section
p_{ps}	= the prestressing index
q, q_m	= the reinforcing index
R	= radius or axial force
SF	= scale factor
T	= tensile force
U	= axial deformation
V	= shear force
W	= load on a structure
W_{max}	= maximum live load
W_1	= live load at formation of first hinge
W_2	= live load at formation of second hinge
\bar{w}	= global reinforcing index
y	= distance
γ	= safety factor
Δ	= deflection
δ	= displacements
ϵ	= a strain

ϵ_o	= extreme fibre strain
ϵ_p	= strain in the prestressing steel
ϵ_s	= strain in the reinforcing steel
ϵ_{sy}	= strain of the reinforcing steel at the yield point
ϵ_u	= ultimate strain
σ	= stress in a section
σ_o	= extreme fibre stress
σ_t	= tensile stress
θ	= rotation
ϕ	= curvature of a section
ϕ_o	= initial curvature due to prestressing
ϕ_u	= curvature at the end of the plastic plateau
ϕ_y	= curvature at the beginning of the plastic plateau
ϕ_{12}	= curvature of the first hinging segment at the formation of the second hinge