Cairo University

LONG-TERM DEFLECTION OF REINFORCED CONCRETE BEAMS WITH EMBEDDED STEEL SECTION

By

Ahmed Fawzi Ahmed Ali Abd El-Monem

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

LONG-TERM DEFLECTION OF REINFORCED CONCRETE BEAMS WITH EMBEDDED STEEL SECTION

By
Ahmed Fawzi Ahmed Ali Abd El-Monem

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Structural Engineering

Under the Supervision of

Prof. Dr.
Ashraf Hassan El- Zanaty
Professor of RC Structures
Structural Department
Faculty of Engineering, Cairo University

Prof. Dr.
Hassan Mohammed Hassan Allam
Professor of RC Structures
Concrete Structures Research Institute
Housing and Building National Research Center

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

LONG-TERM DEFLECTION OF REINFORCED CONCRETE BEAMS WITH EMBEDDED STEEL SECTION

By
Ahmed Fawzi Ahmed Ali Abd El-Monem

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Structural Engineering

Approved by the
Examining Committee

____
Prof. Dr. Ashraf Hassan El-Zanaty, Thesis Main Advisor

____
Prof. Dr. Hassan Mohammed Hassan Allam, Member
Professor of RC Structures, Housing and Building National Research Center

____
Prof. Dr. Mohamed Rabie Mahmoud, Internal Examiner

____
Prof. Dr. Amr Ali Abd El-Rahman, External Examiner
Professor of RC Structures, Faculty of Engineering, Ain Shams University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

Engineer: Ahmed Fawzi Ahmed Ali
Date of Birth: 15/09/1981
Nationality: Egyptian
E-mail: ahmed_fawzi_2003@yahoo.co.uk
Phone. : 01223772782
Address: 111C, Al-Ahram Gardens, Giza, Egypt

Registration Date: 01/10/2010
Awarding Date: / /
Degree Doctor of Philosophy
Department: Structural Engineering

Supervisors: **Prof. Dr. Ashraf Hassan El-Zanaty**
Prof. Dr. Hassan Mohammed Hassan Allam (Concrete Structures Research Institute - Housing and Building National Research Center)

Examiners: **Prof. Dr. Amr Ali Abd El-Rahman** (Faculty of Engineering – Ain Shams University)
Prof. Dr. Mohammed Rabie Mahmoud
Prof. Dr. Ashraf Hassan El-Zanaty
Prof. Dr. Hassan Mohammed Hassan Allam (Concrete Structures Research Institute - Housing and Building National Research Center)

Title of Thesis:

Long-Term Deflection of Reinforced Concrete Beams with Embedded Steel Section

Key Words: Composite; creep; embedded; long-term

Summary:

This research investigates the long-term deflection of reinforced concrete beams with embedded steel section which is referred to as ‘composite beams’. An experimental program was carried out to record the long-term deflections and the creep factor of the composite beams and to compare it with that of the reinforced concrete beams. A nonlinear analysis program was used to validate the results of the experimental data, and then, a calibrated model was used to perform a parametric study to predict the creep behavior as well as the ultimate capacity of the composite beams. It was found that, to improve the creep factor, the embedded steel section could be in the compression side of the concrete section. On the other hand, to obtain good and optimum results for overall behavior of the composite beam, the embedded steel section could be in the middle of the cross-section of the beam.

Acknowledgement

The author wishes to express his sincere appreciation and gratitude to **Dr. Ashraf Hassan El- Zanaty**, Professor of RC Structures, Cairo University, for his continuous supervision of this work, help, advice and guidance through the research program.

The author is also indebted with great favor to **Dr. Hassan Mohammed Allam**, Professor of RC Structures, Housing and Building National Research Center, for his continuous guidance, valuable discussion, and cooperation throughout this research.

Special thanks are due to **Dr. Mohamed Morsy Abd El-Ghaffar Salem**, Teacher of RC Structures, Housing and Building National Research Center, for his great help and technical support in analyzing the experimental data and in the conduction of the analytical work. Moreover, gratitude is due to **Dr. Mohammed Gomaa**, Teacher of RC Structures, Fayoum University, for his helpfulness and self-denial.

Last, but not least, the author thanks his family for their encouragement and prayers, and dedicates his work to the soul of his father.

Table of Contents

List of Tables

List of Figures

List of Symbols

A_{steel}	Area of the embedded steel section.
$A_s{}'$	Area of compression reinforcement.
a	Load arm.
b	Width of the section.
b_f	Flange width.
c_1	The specific creep under 1 psi at the appropriate time.
d	Effective depth of the section.
d_{max}	Maximum aggregate size.
d_w	Web height.
E_c	Modulus of elasticity of concrete.
E_c'	Effective modulus of concrete.
E_{co}	Modulus of elasticity of concrete at the time of load application.
E_{ct}	Modulus of elasticity of concrete at time t.
E_o	The initial (undamaged) elastic stiffness of the material.
E_s	Modulus of elasticity of steel.
f_c'	The compressive strength of concrete.
$\bar{f}_c$	The compression equivalent effective cohesion stresses which determine the size of the yield (or failure) surface.
f_{co}	The critical stress that may be associated with the stress at which the volumetric strain reaches its maximum.
f_{ct}	Tensile strength of concrete.
f_{cu}	Characteristic compressive strength of concrete.
f_{sy}	The steel yield stress.
f_t	The tensile stress.
$\bar{f}_t$	The tension equivalent effective cohesion stresses which determine the size of the yield (or failure) surface.
G_F	The fracture energy.
G_{FO}	The base value of fracture energy that depends on maximum aggregate size.
L	Overall beam length.
M	Unfactored bending moment.
N_u	Factored axial load.

n_o	The modular ratio of steel to concrete.
P	The applied concentrated vertical load.
P_u	The ultimate concentrated vertical load.
q	Intensity of distributed load.
$\tilde{q}$	The uniaxial equivalent deviatoric stress.
S	Clear span of the beam.
s	Time-dependent factor for sustained loads.
t_f	Flange thickness
V_u	Factored concentrated vertical load.
w	Crack opening.
w_1	Crack opening for $f_t = 0.15 f_{ct}$
w_c	Crack opening for $f_t = 0$.
x_i	The initial ratio of the neutral axis depth to the effective depth of the section calculated using the modular ratio method for the completely cracked section.
x_{pc}	Distance between longitudinal reinforcement and the neutral axis.
x_t	The ratio of the neutral axis depth to the effective depth of the section calculated using the modular ratio method for the completely cracked section at time t.
α	Ratio of the compression reinforcement to the tension reinforcement.
α′	Deflection.
α_F	A coefficient depending on the maximum aggregate size.
α_I	The calculated deflection values for the uncracked condition.
α_{II}	The calculated deflection values for the fully cracked condition.
β_1	A coefficient which takes account of the bond properties of the bars.
β_2	A coefficient which takes account of the duration of the loading or of repeated loading.
θ	The temperature.
ε	The elastic strain due to stresses of 1 psi.
δ_u	Mid-span deflection corresponding to the ultimate load, P_u.
$\bar{\varepsilon}_{cr}$	The equivalent creep strain.
$\dot{\bar{\varepsilon}}^{cr}$	The uniaxial equivalent creep strain rate.
$\tilde{\varepsilon}_c^{pl}$	The compression equivalent plastic strain.