Ain Shams University
Faculty of Engineering
Structural Engineering Department

STRUCTURALPERFORMANCE OF HIGH-RISE BUILDINGSWITH TRANSFER FLOORS

By

Amal Mohamed Kamel Elawady, B.Sc.
Structural Engineering Department
Faculty of Engineering
Ain Shams University

A Thesis

Submitted in Partial Fulfillment for the Requirements of the Master ofScience in Civil Engineering (Structural Engineering)

Supervisors

Prof. Ezzeldin Yazeed Sayed Ahmed
Professor of Steel Structures
Structural Engineering Department
Faculty of Engineering
Ain Shams University

Prof. Amr Ali Abdelrahman
Professor of Concrete Structures
Structural Engineering Department
Faculty of Engineering
Ain Shams University

Dr. Hussein Okail
Assistant Professor
Structural Engineering Department
Faculty of Engineering
Ain Shams University

©Cairo, Egypt 2012

STATEMENT

This thesis is submitted to Ain Shams University, Cairo, Egypt, on August 2012 for the degree of Master of Science in Civil Engineering (Structural Engineering).

No part of this thesis has been submitted for a degree or a qualification to any other University or Institute.

Date : 01/ 09/2012

Name : Amal Mohamed Kamel Elawady

Signature:

Ain Shams University
Faculty of Engineering
Structural Department

APPROVAL SHEET

Thesis : Master of Science in Civil Engineering (StructuralEngineering)

Student Name: Amal Mohamed Kamel Elawady

Thesis Title: Structural Performanceof High-Rise BuildingswithTransferFloors

Examiners Committee: Signature

Prof. Dr. MashhourAhmed Ghoneim
Professor of Structural Engineering Department,
Faculty of Engineering, Cairo University

Prof. Dr. Abdelraheem Khalil Dessouki
Professor of Structural Engineering Department,
Faculty of Engineering, Ain Shams University

Prof. Dr. Ezzeldin Yazeed Sayed Ahmed
Professor of Structural Engineering Department,
Faculty of Engineering, Ain Shams University

Prof. Dr. Amr Ali Abdelrahman
Professor of Structural Engineering Department,
Faculty of Engineering, Ain Shams University

Date: 01/ 09/2012

INFORMATION ABOUT THE RESEARCHER

Name : Amal Mohamed Kamel Elawady

Date of Birth :April16th, 1986

Place of Birth : Egypt

Qualifications :B.Sc. Degree in Civil Engineering (Structural Engineering) Faculty of Engineering, Ain Shams University (2008)

Present Job: Teaching Assistant, Ain Shams University

Signature :

ACKNOWLEDGMENT

First of all, I would like to praise Allah for every gift bestowed on me.

I would also like to extend my warmest heartfelt gratitude to all my family especially to the soul of my father who stood by me and supported me in every step of my life. I would like to deeply thank my mother and convey my sincere appreciation for her assistance, encouragement, support, understanding, and patience;may Allah please her.

I would like to express my sincerest gratitude to my advisors, Prof. Ezzeldin Yazeed, Prof. Amr Ali Abdelrahman and Dr. Hussein Okail, for their continuous valuable guidance, their constant encouragement, support, and friendship; whom without their tutelage I would have never completed this thesis. I would like to express my admiration and thanks for their loyalty, trustfulness, persistence, understanding and kindness.

I am greatly indebted to all my colleagues who supported me especially Eng. Mohamed Abdel Aziz, and Eng. Mohamed Fawzy for their precious help.

I would like to acknowledge Dar Al Handasah consultants for their support and for providing helpful sources of scientific data.

Finally, there are no words that can express my sincere gratitude to the love of my siblings, friends, andmy baby nephews;to them this thesis is dedicated.To my best friend who was always thereby my side, to Mary.

Amal Mohamed Kamel Elawady

My youngest brother Ibrahim,

We were dreaming together the best possible future for our country; but you left.

Completing this thesis prevented me from being by your side in your final days.

I hope your immaculate soul accept this apology:I hope you will forgive me.

To The Souls of My Father and My Brother Ibrahim

To My Patient Mother

Ain Shams University
Faculty of Engineering
Structural Engineering Department

Abstract of the M.Sc. Thesis Submitted by:
Eng. /Amal Mohamed Kamel Elawady

Title of the thesis:

STRUCTURAL PERFORMANCE OF HIGH RISE BUILDINGSWITH TRANSFER FLOORS

ABSTRACT

Structures with transfer floors redistribute the loads from the lateral resisting system above it to a wider-spaced system below. This system is widely used in many multi-purpose high-rise buildings which are constructed in densely populated areas.

An analytical investigation for the seismic response of high-rise buildings with transfer floors is performed in this research. A number of prototype models are analyzed using elastic response spectrum and nonlinear time history analysis techniques. Three-dimensional finite element models are adopted in the analyses. The analyzed models compare two different transfer floor systems: transfer plates and transfer girders. The vertical position of each transfer system with respect to the building height,are varied in these models. Four different building heights are considered which cover the range of medium- to high-rise buildings. Global seismic response of the building such as story shear distribution, bending moment distribution, inter-story drift, floor displacements and accelerations are numerically scrutinized.

The results presented in the research show damage localization in the vicinity of the transfer floor. Furthermore, it is evident from these results that the location of the transfer floor influences the overall seismic response of the structure. The numerical analyses also reveal that the transfer girders system is a competitive alternative to the slab transfer system: reduced seismic weights at the transfer floor level as well as less material cost with slight change in the global seismic behavior of the building are obtained via transfer girder system. Transfer girder system is

more flexible than slab type and yields reduced straining actions on the structural vertical walls.

TABLE OF CONTENTS

ACKNOWLEDGE ..... **V**

ABSTRACT ..... **VIII**

TABLE OF CONTENTS ..... **X**

LIST OF FIGURES ..... **XII**

LIST OF TABLES ..... **XVIII**

TABLE of CONTENTS

Chapter 1

1.1. General 1
1.2. Research Objectives 2
1.3. Outline of the Thesis 3

Chapter 2

2.1 Introduction 5
2.2 Types of Transfer Floor Systems 5
2.3 Structural Irregularity Classification 6
2.4 Codes Limitations and Current Design Guidelines 8
2.4.1 Load Combinations 8
2.4.2 Static Lateral-Force Procedures 9
2.4.3 System Limitations 10
2.4.4 Height limitation 11
2.5 Structural System Choice 12
2.5.1 Plan Configuration of Transfer Structures 12
2.5.2 Vertical Positioning of Transfer structures 15
2.6 Transfer Structures' Local Deformation Effect 17
2.7 Transfer Structure-Resisting Elements Compatibility Effect 20
2.8 Stress Concentration in the building with transfer floors 20
2.9 Lateral Stiffness Degradation Measurement and Effect 23
2.9.1 Equivalent Stiffness Estimation 23
2.9.2 Acceptable Loss in Story Strength 25
2.9.3 Soft Story Formation 26
2.9.4 Lateral Deformation below the Transfer Structure 27
2.9.5 Effects of Lateral stiffness Variation of Structure above and below a Transfer Structure 30
2.10 Story Drifts 31
2.10.1 Drift demand 34
2.10.2 Ductility requirements 35
2.11 Three-Dimensional Finite Element Modeling of Buildings with Transfer Floors 36

Chapter 3

3.1 General 39

3.2 Outline of Analytical Programme 39
3.3 Seismic Input 40
3.4 Description of Prototype Building 41
3.5 Finite Element Simulation 46
3.6 Model Data 49
3.6.1 Reinforced Concrete 49
3.6.2 Steel Reinforcement 49
3.6.3 Elements Stiffness Modifiers 49
3.6.4 Loading Data 50
3.7 Building Weights Comparison 50
3.8 Numerical Analysis Results 52
3.8.1 50 Story Tower T-50 52
3.8.2 Seventy Five Story Tower T-75 73
3.8.3 Twenty Five Story Tower T-25 90
3.8.4 Ten Story Tower T-10 107
Chapter 4
4.1 General 127
4.2 Sources of Nonlinearities 128
4.2.1 Material Nonlinearity 128
4.3 Outline of Analytical Programme 130
4.4 Finite Element Simulation 130
4.4.1 Nonlinear Solution Procedure 131
4.4.2 Incremental Iterative Algorithm 132
4.4.3 Convergence Criteria 132
4.5 Description of the Building Model 132
4.5.1 Reinforced Concrete Model 132
4.5.2 Steel Reinforcement 134
4.5.3 Time History Record Scaling 135
4.5.4 Loading Data 137
4.6 Numerical Analysis Results 138
4.6.1 Story Shear and Story Moment Distribution 139
4.6.1 Story Drift and Story Displacement Distribution: 149
Chapter 5
5.1 Summary 159
5.2 Conclusions 160
5.3 Recommendations 162
5.4 Suggestions for Future Research Work 162
References 165

LIST OF FIGURES

Figure 1.1 Saudi Arabia Embassy Tower in Egypt 1
Figure 2.1 Low-rise buildings with columns supporting transfer beams 13
Figure 2.2 Setback Structure 14
Figure 2.3 Framing System Irregularity 14
Figure 2.4 Desirable and undesirable story stiffness distribution 15
Figure 2.5 Geometry of prototype frames 17
Figure 2.6 Deformation of transfer structure and shear concentration at the transfer structure 19
Figure 2.7 Overstrength profiles of tested frames 23
Figure 2.8 Numerical models for calculating the equivalent stiffness below and above the transfer structure 24
Figure 2.9 Numerical models for calculating the equivalent stiffness below and above the transfer structure with consideration of the rotation above the transfer structure 24
Figure 2.10 Typical shear and flexural deformations of a substructure below a transfer structure 26
Figure 2.11 Estimation on Ru and RΔu 28
Figure 2.12 Variations of inter-storey drifts due to change in shear and flexural stiffness (the dotted lines represent the new inter-storey drift profiles after stiffness reductions) 29
Figure 2.13 Inter story Drifts 31
Figure 2.14 Illustration of the direction of force effect 32
Figure 2.15 Stiffness variation effect 34
Figure 3.1 Response Spectrum According to the UBC 97 code 40
Figure 3.2 Transfer Plate System-Vertical Section 43
Figure 3.3 Transfer Plate System-Plan 44
Figure 3.4 Transfer Girder System-Plan 44
Figure 3.5 Girder System- Vertical Section 45
Figure 3.6 3D View for Tower of 25 Stories with Transfer Plate at 50%H 46
Figure 3.7 Transfer Plate Model 47
Figure 3.8 3D View for Tower of 25 Stories with Transfer Girder System at 50%H 47
Figure 3.9 Transfer Girder System 48
Figure 3.10 T-50 Story Shear in X direction due to spectral analysis ... 51
Figure 3.11 T-50 Base Shear in X and Y directions due to spectral analysis and Structures periodic time 52
Figure 3.12 T-50 Story Shear around TF floor 53
Figure 3.13 T-50 Story Moment in X Direction due to spectral analysis 54
Figure 3.14 T-50 Story Drift in X Direction due to spectral analysis 55
Figure 3.15 T-50 Story Displacement in X direction due to spectral analysis 55
Figure 3.16 T-50 Modal Participation mass ratio 56

Figure 3.17 T-50-10 H% (Slab to Girder Solution) Story Shear due to spectral analysis 57
Figure 3.18 T-50-10% H (Slab to Girder Solution) Story Moment due to spectral analysis 58
Figure 3.19 T-50-10% H (Slab to Girder Solution) Story Drift due to spectral analysis 59
Figure 3.20 T-50-10% H (Slab to Girder Solution) Story Displacement due to spectral analysis 59
Figure 3.21 T-50-10% H (Slab to Girder Solution) Periodic Time 60
Figure 3.22 T-50-20% H (Slab to Girder Solution) Story Shear due to spectral analysis 61
Figure 3.23 T-50-20% H (Slab to Girder Solution) Story Moment due to spectral analysis 61
Figure 3.24 T-50-20% H (Slab to Girder Solution) Story Drift due to spectral analysis 62
Figure 3.25 T-50-20% H (Slab to Girder Solution) Story Displacement due to spectral analysis 62
Figure 3.26 T-50-20% H (Slab to Girder Solution) Periodic Time 63
Figure 3.27 T-50-30% H (Slab to Girder Solution) Story Shear due to spectral analysis 63
Figure 3.28 T-50-30% H (Slab to Girder Solution) Story Moment due to spectral analysis 64
Figure 3.29 T-50-30% H (Slab to Girder Solution) Story Drift due to spectral analysis 64
Figure 3.30 T-50-30% H (Slab to Girder Solution) Story Displacement due to spectral analysis 65
Figure 3.31 T-50-30% H (Slab to Girder Solution) Periodic Time 65
Figure 3.32 T-50-50% H (Slab to Girder Solution) Story Shear in X direction due to spectral analysis 66
Figure 3.33 T-50-50% H (Slab to Girder Solution) Story Moment due to spectral analysis 67
Figure 3.34 T-50-50% H (Slab to Girder Solution) Story Drift due to spectral analysis 67
Figure 3.35 T-50-50% H (Slab to Girder Solution) Story Displacement due to spectral analysis 68
Figure 3.36 T-50-50% H (Slab to Girder Solution) Periodic Time 68
Figure 3.37 T-75 Story Shear in X direction due to spectral analysis 69
Figure 3.38 Base Shear in X and Y directions due to spectral analysis (kN) 70
Figure 3.39 T-75 Story Shear around TF floor in X and Y direction (kN) 70
Figure 3.40 T-75 Story Moment in X direction due to spectral analysis 71
Figure 3.41 T-75 Story Drift in X direction due to spectral analysis 71

Figure 3.42 T-75 Story Displacement in X direction due to spectral analysis 72
Figure 3.43 T-75 Modal participation mass ratio 72
Figure 3.44 T-75-10% H (Slab to Girder Solution) Story Shear due to spectral analysis 73
Figure 3.45 T-75-10% H (Slab to Girder Solution) Story Moment due to spectral analysis 74
Figure 3.46 T-75-10% H (Slab to Girder Solution) Story Drift due to spectral analysis 74
Figure 3.47 T-75-10% H (Slab to Girder Solution) Story Displacement due to spectral analysis 75
Figure 3.48 T-75-10% H (Slab to Girder Solution) Periodic Time 75
Figure 3.49 T-75-20% H (Slab to Girder Solution) Story Shear due to spectral analysis 76
Figure 3.50 T-75-20% H (Slab to Girder Solution) Story Moment due to spectral analysis 76
Figure 3.51 T-75-20% H (Slab to Girder Solution) Story Drift in X direction due to spectral analysis 77
Figure 3.52 T-75-20% H (Slab to Girder Solution) Story Displacement due to spectral analysis 77
Figure 3.53 T-75-20% H (Slab to Girder Solution) Periodic Time 78
Figure 3.54 T-75-30% H (Slab to Girder Solution) Story Shear due to spectral analysis 78
Figure 3.55 T-75-30% H (Slab to Girder Solution) Story Moment due to spectral analysis 79
Figure 3.56 T-75-30% H (Slab to Girder Solution) Story Drift in X direction due to spectral analysis 79
Figure 3.57 T-75-30% H (Slab to Girder Solution) Story Displacement due to spectral analysis 80
Figure 3.58 T-75-30% H (Slab to Girder Solution) Periodic Time 80
Figure 3.59 T-75-50% H (Slab to Girder Solution) Story Shear due to spectral analysis 81
Figure 3.60 T-75-50% H (Slab to Girder Solution) Story Moment due to spectral analysis 81
Figure 3.61 T-75-50% H (Slab to Girder Solution) Story Drift due to spectral analysis 82
Figure 3.62 T-75-50% H (Slab to Girder Solution) Story Displacement due to spectral analysis 82
Figure 3.63 T-75-50% H (Slab to Girder Solution) Periodic Time 83
Figure 3.64 T-25 Story Shear in X direction due to spectral analysis 84
Figure 3.65 T-25 Base Shear in X and Y directions due to spectral analysis (kN) and Structures periodic time 84
Figure 3.66 T-25 Story Shear around TF floor in X and Y direction due to spectral analysis (kN) 85

Figure 3.67 T-25 Story Moment in X direction due to spectral analysis 85
Figure 3.68 T-25 Story Drift in X direction due to spectral analysis 86
Figure 3.69 T-25 Story Displacement in X direction due to spectral analysis.....86
Figure 3.70 T-25 Modal participation mass ratio.....87
Figure 3.71 T-25-10% H (Slab to Girder Solution) Story Shear due to spectral analysis 88
Figure 3.72 T-25-10% H (Slab to Girder Solution) Story Moment due to spectral analysis 88
Figure 3.73 T-25-10% H (Slab to Girder Solution) Story Drift due to spectral analysis 89
Figure 3.74 T-25-10% H (Slab to Girder Solution) Story Displacement due to spectral analysis 89
Figure 3.75 T-25-10% H (Slab to Girder Solution) Periodic Time.....90
Figure 3.76 T-25-20% H (Slab to Girder Solution) Story Shear due to spectral analysis 90
Figure 3.77 T-25-20% H (Slab to Girder Solution) Story Moment due to spectral analysis 91
Figure 3.78 T-25-20% H (Slab to Girder Solution) Story Drift due to spectral analysis 91
Figure 3.79 T-25-20% H (Slab to Girder Solution) Story Displacement due to spectral analysis 92
Figure 3.80 T-25-20% H (Slab to Girder Solution) Periodic Time.....92
Figure 3.81 T-25-30% H (Slab to Girder Solution) Story Shear due to spectral analysis 93
Figure 3.82 T-25-30% H (Slab to Girder Solution) Story Moment due to spectral analysis 93
Figure 3.83 T-25-30% H (Slab to Girder Solution) Story Drift due to spectral analysis 94
Figure 3.84 T-25-30% H (Slab to Girder Solution) Story Displacement due to spectral analysis 94
Figure 3.85 T-25-30% H (Slab to Girder Solution) Periodic Time.....95
Figure 3.86 T-25-50% H (Slab to Girder Solution) Story Shear due to spectral analysis 95
Figure 3.87 T-25-50% H (Slab to Girder Solution) Story Moment due to spectral analysis 96
Figure 3.88 T-25-50% H (Slab to Girder Solution) Story Drift due to spectral analysis 96
Figure 3.89 T-25-50% H (Slab to Girder Solution) Story Displacement due to spectral analysis 97
Figure 3.90 T-25-50% H (Slab to Girder Solution) Periodic Time.....97
Figure 3.91 T-10 Story Shear in X direction due to spectral analysis.....98
Figure 3.92 T-10 Base Shear in X and Y directions due to spectral analysis (kN) and Structures periodic time 99