

CONNECTION SYSTEMS FOR BRACED AND UNBRACED PRECAST
STRUCTURE DUE TO LATERAL LOADINGS

QUEK KENG HUA

A project report submitted in partial fulfillment of the
requirement for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

OCTOBER 2009

UNIVERSITI TEKNOLOGI MALAYSIA

DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT

Author's full name : OUEK KENG HUA

Date of birth : 27-01-1982

Title : CONNECTION SYSTEMS FOR BRACED AND UNBRACED
 PRECAST STRUCTURE DUE TO LATERAL LOADINGS

Academic Session : SEMESTER 1 SESSION 09/10

I declare that this thesis is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)*
- OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledged that Universiti Teknologi Malaysia reserves the right as follows:

1. The thesis is the property of Universiti Teknologi Malaysia.
2. The Library of Universiti Teknologi Malaysia has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by :

SIGNATURE

820127-12-5139

(NEW IC NO. /PASSPORT NO.)

SIGNATURE OF SUPERVISOR

Assoc. Prof. Dr. Abd. Latif Saleh

NAME OF SUPERVISOR

Date : 20/11/09

Date : 20/11/09

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

“I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Master of Engineering (Civil – Structure)”

Signature :

Name of Supervisor : *ASSOC.PROF.DR.ABD.LATIF SALEH*

Date :

I declare that this thesis entitled '*CONNECTION SYSTEMS FOR BRACED AND UNBRACED PRECAST STRUCTURE DUE TO LATERAL LOADINGS*' is the result of my own research except as cited in references. This thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : QUEK KENG HUA

Date : 21 SEPTEMBER 2009

ACKNOWLEDGEMENT

I would like to thank all the parties who have given the co-operation to me in writing this project report. I am sincerely grateful to my supervisor, ASSOC.PROF.DR.ABD.LATIF SALEH for his continuous support and guidance in this project. He has set a high standard for the conduct of this study and his valuable suggestions and guidance have provided me the motivation needed to complete this project report.

I thank my family and friends for their supports and encouragement. Their encouragement provided the often-needed motivation and inspirations for me to push through the hard times. I would also like to acknowledge the contributions of those who have helped either directly or indirectly in the completion of this project.

ABSTRACT

The connections between precast concrete components play an important role in determining the stabilization of precast concrete framed structures. Despite numerous years of extensive research, no fully fixed design method exists. Many areas of connection behaviour still require investigation. Much of the research has been done, and approximate analytical methods are available for almost all the identifiable regular forms of tall structure. The main objective of this research is to investigate the moment of resistance and the behaviour of simple beam-to-column connections in precast concrete frames by using engineering software. This research methodology mainly consists of finite element static load analysis on braced and unbraced frame which with different connection types. From the analysis result, although the braced structure with fixed connection type is apparently posed the less displacement than other type of model in this analysis, but the value of displacement still not satisfied as a structural to resist all lateral especially seismic forces. Several unsatisfactorily connections, however, still show potentials of reaching the required loading capacity. Therefore, modification and improvement can be made to improve their performances.

ABSTRAK

Kaedah sambungan antara komponen dalam struktur konkrit pratuang memainkan peranan penting dalam menentukan kestabilan kerangka struktur tersebut. Walaupun banyak kajian telah dijalankan, tetapi masih tiada kaedah rekabentuk yang khusus dapat dihasilkan. Masih banyak lagi sifat kelakunan sambungan yang perlu dikaji. Banyak penelitian telah dilakukan, dan sudah tersedia anggaran kaedah analisis bagi hampir semua bentuk bangunan tinggi. Objektif yang utama untuk kajian ini adalah untuk menyiasat rintangan momen dan sifat-sifat sambungan rasuk-tiang di dalam struktur konkrit pratuang dengan menggunakan program komputer. Di dalam kajian ini, analisis beban statik dengan menggunakan kaedah unsur terhingga dikenakan kepada struktur yang dirembat dan tidak dirembat. Berdasarkan keputusan analisis yang dibuat, walaupun struktur yang mempunyai sambungan tegar adalah yang paling kurang anjakan daripada sambungan yang tidak tegar, tetapi nilai untuk anjakan masih tidak memuaskan untuk menahan beban terutamanya beban gempa bumi. Sesetengah sambungan tidak memuaskan, tetapi masih menunjukkan potensi mencapai beban kapasiti yang dikehendaki. Walau bagaimanapun, modifikasi dan pembaikan untuk sambungan masih boleh dilakukan untuk meningkatkan pretasinya.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	ACKNOWLEDGEMENT	iii
	ABSTRACT	iv
	ABSTRAK	v
	TABLE OF CONTENTS	vi
	LIST OF TABLES	ix
	LIST OF FIGURES	x
	LIST OF SYMBOLS	xiii
CHAPTER 1	INTRODUCTION	1
	1.1 General Introduction	1
	1.2 Problem Statement	2
	1.3 Aims and Objectives of Study	3
	1.4 Scope of Study	4
CHAPTER 2	LITERATURE REVIEW	5
	2.1 General Introduction	5
	2.2 Precast Concrete System	6

2.3	Stability	6
2.4	Lateral Stability	7
2.5	Unbraced Frame	8
2.6	Braced Frame	8
2.7	Shear Frame	10
2.8	Floor Diaphragms	11
2.9	Limiting Stresses	18
2.10	Diaphragms Action In Composite Floors With Structural Toppings	20
2.11	P-delta Effect	22
2.12	Pushover Analysis	25
2.13	Finite Element Analysis (FEA)	26
2.14	Linear Finite Element Analysis (LFEA)	27
2.15	3-Dimensional Frame Element	29
2.16	Stiffness Matrix In Local Direction	30
2.17	Static Analysis	32
2.18	Moment-rotation Relationships	33
2.19	Typical Connection For Precast Structure	34
CHAPTER 3	METHODOLOGY OF ANALYSIS	39
3.1	General Introduction	39
3.2	Method Of Analysis-ORION	41
3.3	Design Concept	42
3.4	Frame Geometry	43
3.5	Material Properties	46
3.6	Structural Details	46
3.7	Boundary Conditions and Loadings	47
3.8	Load Combination	49
3.9	Sway Effect	51
3.10	Definition Of Bracing For Columns And Walls	52
3.11	Meshing	52
CHAPTER 4	RESULTS AND DISCUSSIONS	55

4.1	Verifications Of Finite Element Model	55
4.2	Load-Deflection Of The Frame Structure	64
4.3	Connections	66
CHAPTER 5	CONCLUSIONS AND RECOMMENDATIONS	75
5.1	Conclusions	75
5.2	Factors Affecting Structure Behaviour	76
5.3	Recommendation For Further Investigation	77
REFERENCES		78
APPENDIX A		80

LIST OF TABLES

TABLES	TITLE	PAGE
Table 3.1	Reinforced concrete properties	46
Table 3.2	Loadings	47
Table 4.1:	Comparison of frame deflections -10 storey (cast in-situ, flexural stiffness of slab included)	61
Table 4.2	Comparison of frame deflections -20 storey (cast in-situ, flexural stiffness of slab included)	62
Table 4.3	Comparison of frame deflections -30 storey (cast in-situ, flexural stiffness of slab included)	63
Table 4.4	Analysis results for unbraced frame	67
Table 4.5	Analysis results for braced frame	67

LIST OF FIGURES

FIGURES	TITLE	PAGE
Figure 2.1	Unbraced frame	8
Figure 2.2	Braced frame	9
Figure 2.3	Collapse patterns	9
Figure 2.4	Sway deflection under wind pressure (Bungale S. Taranath, 1988)	10
Figure 2.5	(a) Plan geometry of floor diaphragms (b) Floor diaphragm shear force and bending moments diagrams.	12
Figure 2.6	Analysis of multi-wall (more than 2) system of shear wall bracing. (a) Definitions, (b) Floor deflections due to rotations caused by eccentric loading.	13
Figure 2.7	Shear stresses in floor diaphragms. (a) Floor span parallel to load, (b) Floor span perpendicular to load.	16
Figure 2.8	Forces acting in a precise concrete floor diaphragm. (according to deep beam theory)	17
Figure 2.9	Collapse patterns for P-delta effect	24
Figure 2.10	Displacement under lateral load	25
Figure 2.11	Divided member forces	29
Figure 2.12	Divided member forces	30
Figure 2.13	Typical moment-rotation curve (Park and Paulay, 1975).	33

FIGURES	TITLE	PAGE
Figure 2.14	Connection failing in compression (Park and Paulay, 1975).	33
Figure 2.15	Screed Geometry	34
Figure 2.16	Construction Joint	34
Figure 2.17	Hollow core slab	35
Figure 2.18	Corbel	35
Figure 2.19	Slab-beam connection	36
Figure 2.20	Beam- column connections	36
Figure 2.21	Column -base connection	37
Figure 2.22	Column to foundation connection-pocket Foundation	37
Figure 2.23	Hollow core to wall connections	38
Figure 2.24	Hollow core to beam	38
Figure 3.1	Procedure flow chart	40
Figure 3.2	Analysis steps using orion	41
Figure 3.3	10-stories building (without braced) to be analyzed by orion	43
Figure 3.4	10-stories building (with braced) to be analyzed by orion	44
Figure 3.5	Plan view of the structures with a rigid slab diaphragm	45
Figure 3.6	Schematic representation of the equivalent dynamic load (Spathelf, 1989)	48
Figure 3.7	Schematic representation of the equivalent static load (Spathelf, 1989)	49
Figure 3.8	Load combinations	50
Figure 3.9	Definition of lateral loading in ORION	51
Figure 3.10	Definition of braced/unbraced iIn ORION	52
Figure 3.11	Meshing process in ORION	53
Figure 3.12	3D view of the model after meshing	53
Figure 3.13	3D view of the model after meshing	54

FIGURES	TITLE	PAGE
Figure 4.1	Comparison of the deformed shape for the global frame model: (a) unbraced frame; (b) braced frame	56
Figure 4.2	(a) Shear force diagram-unbraced frame; (b) Bending moment diagram-unbraced frame;	57
Figure 4.3	Axial force diagram-unbraced frame.	58
Figure 4.4	(a) Shear force diagram-braced frame; (b) Bending moment diagram-braced frame.	59
Figure 4.5	Contour plot for shearwall-braced frame.	60
Figure 4.6	Comparison of displacement results between unbraced frame and braced frame for 10 Storey.	64
Figure 4.7	Comparison of displacement results between unbraced frame and braced frame for 20 Storey.	65
Figure 4.8	Comparison of displacement results between unbraced frame and braced frame for 30 Storey.	66
Figure 4.9	Moment at column base versus connection fixity (10 storey)	68
Figure 4.10	Moment at column base versus connection fixity (20 storey)	69
Figure 4.11	Moment at column base versus connection fixity (30 storey)	69
Figure 4.12	Horizontal displacement versus connection fixity (10 storey)	71
Figure 4.13	Horizontal displacement versus connection fixity (20 storey)	72
Figure 4.14	Horizontal displacement versus connection fixity (30 storey)	73

LIST OF SYMBOLS

A_g	-	Gross cross-sectional area of concrete (mm ²)
A_e	-	Effective confined area (mm ²)
B	-	Cross-sectional width of concrete(mm)
E	-	Elasticity modulus
E_c	-	Elastic modulus of concrete (MPa)
f_c	-	Axial compressive strength of concrete (MPa)
f_o	-	The intercept stress (MPa)
f_{yt}	-	Yield stress of transverse slope (MPa)
H_n	-	Reaction in bracing
h_i	-	Height of floor i measured from base
K	-	Load factor
k_c	-	Concrete material efficiency coefficient
k_{sl}	-	Shape factor for lateral pressure distribution

k_{s2}	-	Shape factor for strain capacity reduction
M_R	-	Moment Resistant
P_c	-	Axial load (kN)
P_{cc}	-	Axial load at the end of first branch of confined concrete (kN)
P_{cu}	-	Ultimate axial load of confined concrete (kN)
Q	-	Design lateral force at floor
W_i	-	Seismic weight of floor
Z	-	Level arm
ε_c	-	Axial strain of concrete member
ε_{cc}	-	Axial strain of confined concrete
ε_l	-	Lateral concrete strain
ε_t	-	Transverse strain
μ'	-	Effective coefficient of shear friction
Δ	-	Displacement (mm)

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In the last decade, significant developments in architectural expression and in increasing demand for lighter, economical and taller buildings resulted in a systematical evolution of structural systems. The main design criteria for tall buildings are governed by the lateral stiffness in order to resist wind and earthquake forces.

The structural system of precast concrete frames in multi-storey buildings consists of main components beams and columns and connections. The latter play an important role in joining the beams and columns and it is well known that connections show a variation of behaviour in terms of stiffness and strength. This in turn affects the frames behaviour and the way in which the frames are designed.

In traditional methods of design, the connections are normally assumed as either

perfectly pinned or perfectly rigid. The assumption of pinned connections implies no rotation continuity within the frame, in other words, no moment is transmitted from the beam to the column. The assumption of perfectly pinned connections as normally adopted in non-sway frames may lead to over-estimated of beam moments, over-estimated of services deflections in beams and under-estimated of column end moments.

On the other hand, the assumption of perfectly rigid connection implies full moment continuity. The assumption of perfectly rigid connections may lead to over-estimated of column end moment and over-estimated of connection moments.

1.2 Problem statement

Lack of experimental data and analytical proof accounts for the ductile connection details for beam-to-column connection in precast structure. In addition, reliable connection behaviour can only be properly assessed by laboratory testing or proven performance.

For most design, the connections are normally assumed as either perfectly pinned or perfectly rigid. In real a situation, a connection behaves in between the two cases above which is call semi-rigid. The most accurate method to study the non-linear behaviour of a connection is to fabricate the full-scale connection and test these to fail. Unfortunately, this is time consuming, expensive to undertake and has the disadvantage of only recording strain readings at pre-defined gauge locations on the test connection.

In this research, the understanding of the actual connection behaviour is very important, especially designed and constructed for resisting lateral load such as wind, seismic loads.

1.3 Aim and Objectives

The objectives of this study are as follows:

- i) To study the behaviour of beam-to-column connections in precast concrete frames by using computer software.
- ii) To present finite element analysis and analytical results for structural frames that include the material, geometry and connection nonlinearities.
- iii) To investigate the bending moment at the base of the frames at ultimate loads with fully fixed ,semi-rigid and flexible connection.
- iv) To demonstrate, through a series of analysis under different structural frame configurations, loads and joint conditions, the influence of the connections to the load carrying capacity and stability of the frames.

1.4 Scope and Limitation

The scopes of this research are:

- i. The scope of this study is limited to beam-to-column connections in precast concrete frames.
- ii. The precast beams, corbels and columns for this research were designed using BS 8110:1997.
- iii. The frame is subjected to static lateral loads.
- iv. The stiffness of the connection from the finite element analysis is input in 3D frame for modal and simulation of linear time history analysis (seismic load) under 0.15g and 0.50g intensity (Elcentro).
- v. Types of connection for this study are rigid connection, semi-rigid connection and flexible connection.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

In Malaysia, precast concrete structure is relatively new but the Malaysia Government is currently encouraging the construction industry to venture in this technology. Precast concrete means concrete which has been prepared for casting and the concrete either is statically reinforced or prestressed. Meanwhile a precast concrete element is of a finite size and must therefore connect with other elements to form a complete structure.

2.2 Precast Concrete System

There are three types of precast building system. The most common is the skeletal structure. The skeletal structure is the combination of beams and columns which are able and strong enough to resist vertical and horizontal loads. Sometimes, this system needs vertical wall (shear wall) to sustain horizontal load. The second type is precast wall system or known as panel system. This system is normally built on ground and depends on load bearing wall to resist vertical and horizontal loads.

The last system is portal frame. This type of system normally used in industrial building and warehouse.

2.3 Stability

It is essential that the building and its various component elements are stable and the candidate is likely to fail if the stability of the structure is not adequately demonstrated. There are two stability criteria to consider; lateral stability and uplift due to wind pressure.

2.4 Lateral Stability

The following are examples of loads that may impose lateral forces on the structure:

- a) Wind loads.
- b) Earthquakes.
- c) Lateral loads due to geometric imperfections.
- d) Horizontal component of soil loads.
- e) Accidental loads.

The structure should be designed to resist these loads in two orthogonal directions. For a multistorey building this can be achieved by using:

- a) Shear walls (braced)or;
- b) Moment-resisting frames (i.e. sway frame or unbraced).

2.5 Unbraced Frame

The unbraced frame is normally for frame up to three storeys and it is uneconomical for frame above three storeys. The reason is columns in unbraced frame act as cantilever beam to sustain the horizontal load as shown in Figure 2.1.

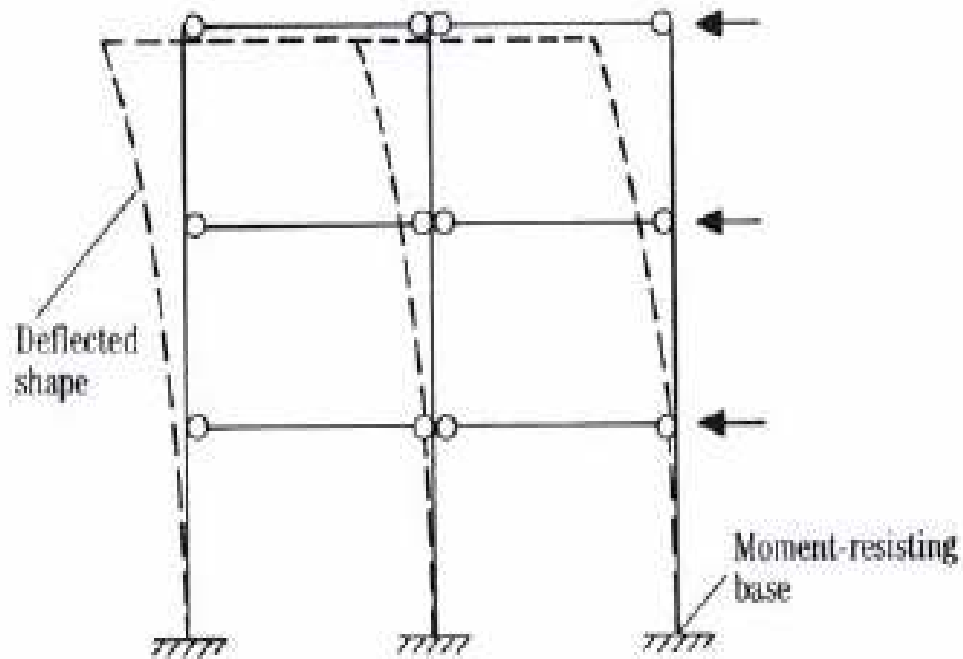


Figure 2.1 Unbraced Frame

2.6 Braced Frame

Braced frame is introduced for highrise building. For medium rise building, partially braced could be the suitable option as shown in Figure 2.2.

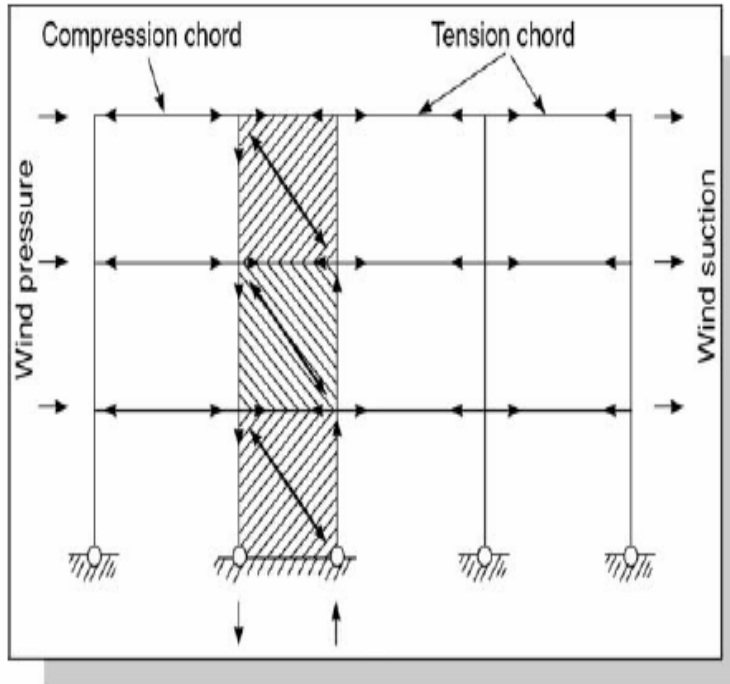


Figure 2.2 Braced Frame

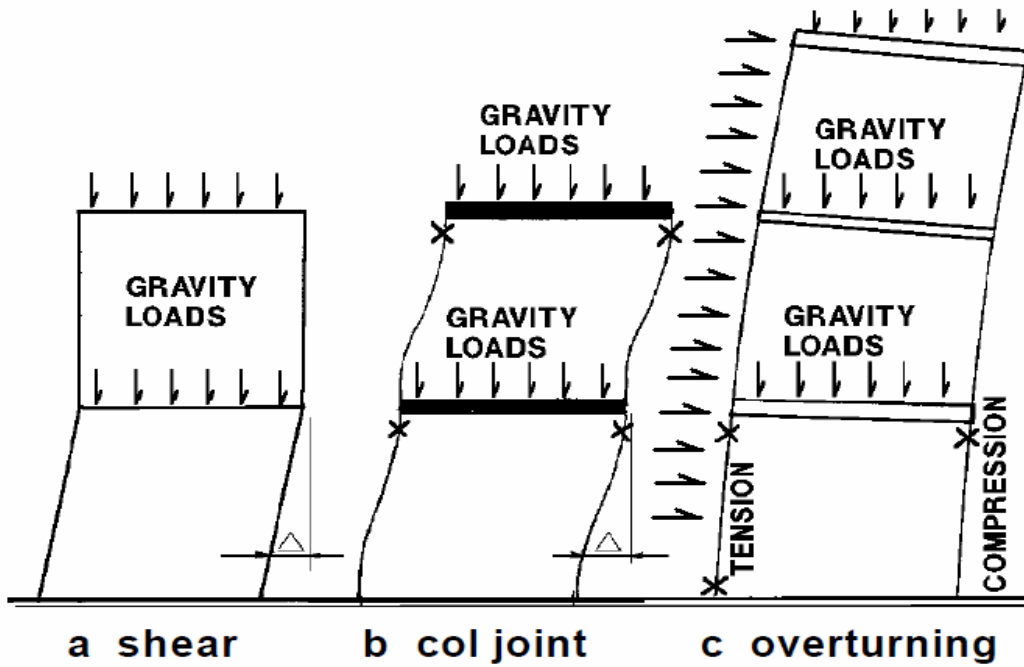


Figure 2.3 Collapse Patterns

2.7 Shear Frame

Moment resistant beam to column connections create shear frames or Vierendeel frames which provide lateral stiffness in both orthogonal directions. The efficiency towards lateral stiffness is controlled by the individual stiffness of the members depending on the section and the length of girders and columns. The resistance to sway deflection is mainly governed by the bending of beams and columns due to wind forces and less from column shortening or cantilever action. The figure below shows the theoretical sway deflection of this framing system under the action of wind forces.

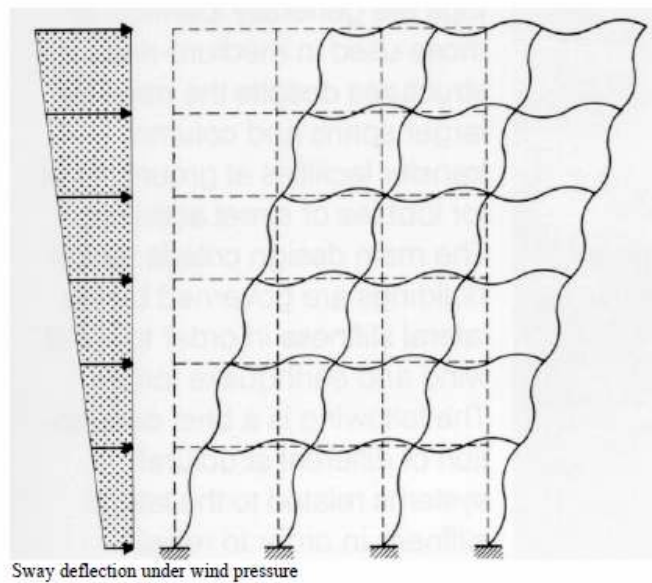


Figure 2.4 Sway deflection under wind pressure (Taranath, 1988)