EFFECT OF SUPPORT CONDITIONS ON STRUCTURAL RESPONSE UNDER DYNAMIC LOADING

By

Wasim Khaliq

(2004 – NUST – MS PhD – STR – 02)

A thesis submitted in partial fulfillment of
the requirements for the degree of
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In

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Brigadier Dr. Tayyeb Akram, Ph.D (USA)

National Institute of Transportation, Risalpur

National University of Sciences and Technology, Rawalpindi, Pakistan

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DEDICATED TO

MY PARENTS AND FAMILY

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ABSTRACT

In design practice, dynamic structural analysis is carried out with base of structure considered as fixed; this means that foundation is placed on rock like soil material. While conducting this type of analyses the role of foundation and soil behavior is totally neglected. The actions in members and loads transferred at foundation level obtained in this manner do not depict the true structural behavior.

FEM analysis are proposed where both superstructure and foundation soil are coupled together. This type of FEM analysis is quite complicated and expensive for design environments. A simplified model is required to depict dynamic response of structures with foundations based on flexible soils.

The primary purpose of this research is to compare the superstructure dynamic responses of structural systems with fixed base to that of simple soil model base. The selected simple soil model is to be suitable for use in a design environment to give more realistic results. For this purpose building models are idealized with various heights and structural systems in both 2D and 3D space. These models are then provided with visco-elastic supports representing 3 soil bearing capacities and the analysis results are compared to that of fixed supports models.

The results indicate that fixed support system underestimates natural time period of the structures. Dynamic behavior and force response of visco-elastic support is different from fixed support model. Fixed support models result in over designed base columns and under designed beams.

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Chapter 1

INTRODUCTION

1.1 GENERAL

In conventional design practice structural engineers analyze building systems by modeling them as fixed or pin jointed support system. This means that the soil is considered totally rigid (like solid rock), which is not true. We know that the soil is flexible medium and even if the supports are considered pinned instead of fixed they do not truly depict the exact behavior of structure. After analysis the resulting forces acting to foundations like loads and moments are passed over to the geotechnical engineers, which are usually higher due to fixed support considerations. The geotechnical engineers usually take into account a simplified behavior of the superstructure, often by applying absolutely flexible loads to foundations with higher safety factors. As a result a contradiction remains about subsoil if it is absolutely rigid or ductile and the structure if it is absolutely flexible or of finite rigidity (Shashkin et al 2005).

The assumption of rigid supports (e.g. fixed column bases) results in column bending moments at the base larger than what may be the actual bending moments. The resulting foundation design to satisfy the strength of framing and soil bearing criteria is quite conservative. Under dynamic loads, the foundation has an ability to rotate with relatively small angle, this results in appreciable reduction of column base bending moment. The reduction of building framing force redistribution could present an opportunity for the engineer to perform an economical framing and foundation design and increase design loads on existing buildings without additional reinforcement (Milman 2000).

The best solution of the problem is to add response of soil to the structure. Especially when analyzing the building for dynamic loading, the dynamic behavior of soil against structure should be considered. The FEM modeling and analysis makes it possible to predict the behavior of the designed buildings and also allows conducting a back-analysis of main reasons of structural failures, if any. The coupled analysis of considering the properties of soil and structure together is quite complicated and becomes uneconomical and time consuming which renders it unsuitable in design environment. The purpose of this research is to propose a simple model that can be used in a design environment and give more realistic results.

1.2 PROBLEM STATEMENT

In practice, dynamic structural analysis is carried out with base of structure considered as fixed; this means that foundation is placed on rock like soil material. While conducting this type of analyses the role of foundation and soil behavior is totally neglected. The actions in members and loads transferred at foundation level obtained in this manner do not depict the true structural behavior.

FEM modeling and analysis are proposed where both superstructure and foundation soil are coupled together. However, FEM modeling and analysis is quite complicated and expensive for general design environments.

A simplified model is required to depict dynamic response of structures with foundations based on flexible soils.

1.3 SCOPE

The scope of research is to study the dynamic response of 5, 10 and 20 story framed structures based on four types of support conditions of varying stiffness. The framed structures will be analyzed with and without shear walls. Both 2 dimensional (2D) and 3 dimensional (3D) models are analyzed. The applied loading is ground accelerations of El Centro earthquake record (Earthquake Engineering Research Laboratory 1975).

1.4 OBJECTIVES

The objectives of the research are:

- To study the support deflection response of structures under the influence of dynamic loading.
- To study the structural member force envelope from dynamic analysis.

- To study influence of support type and soil stiffness on dynamic response of structures.
- To study the influence of shear walls on dynamic behavior of structures with flexible supports.

Chapter 2

LITERATURE REVIEW

2.1 GENERAL

In a design environment, analysis of structures is carried out using fixed base models as they are easy to develop and analyze. Fig. 2.1 illustrates examples of fixed base models. Fixed base models do not depict the true structural behavior they result in higher forces at base and lower forces at the beams and other members.

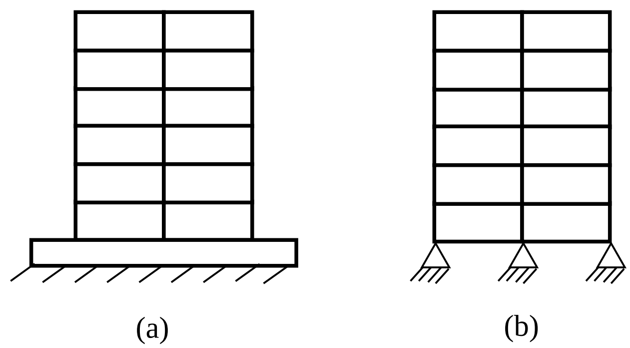

Fig. 2.1. Fixed base models (a) fixed support (b) pinned support

With development in FEM it is now possible to model foundation soil along with superstructure with specific properties assigned to them. However, these FEM solutions are complicated, time consuming and uneconomical for use in general design environments.

Therefore, simple analysis techniques based on simple material models are needed to determine the behavior of structures on soil in design environments. A convenient model substitution was presented by Winkler in 1867 by assigning spring stiffness value based on subgrade modulus of soil (Scott 1981, Bowles 1988).

The Winkler springs are perfectly elastic model and it does not exhibit the true soil behavior in dynamic analysis. Wu and Shen (1996) used the visco-elastic foundation model (Kelvin model) in their study on dynamic analysis of concrete pavements. They found that the model yields more realistic values, as the visco-elastic foundation model considers the spring stiffness along with soil damping as shown in Fig. 2.2.

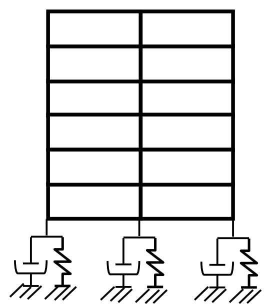

Fig. 2.2. Structural model showing visco-elastic support conditions

2.2 STRUCTURAL SYSTEMS

The International Building Code 2003 (IBC 2003) defines structural system in detail as per their load resisting mechanisms. The structural systems described in IBC 2003 that resist earthquake lateral loads are defined as under:

2.2.1 Moment-Resisting Frame System (MRF)

A structural system with an essentially complete space frame providing support for gravity loads. Moment-resisting frames provide resistance to lateral loads (earthquake loads) primarily by flexural action of members.

2.2.2 Dual system

It is a combination of moment-resisting frames and shear-walls or braced frames. Dual system is also known as Shear-Wall Frame (SWF) and has the following features:

- An essentially complete space frame that provides support for gravity loads.

- Resistance to lateral loads (earthquake loads) is provided by shear walls or braced frames and moment-resisting frames. The moment-resisting frames shall be designed to independently resist at least 25 per cent of the design base shear.
- The two systems shall be designed to resist the total design base shear in proportion to their relative rigidities considering the interaction of the dual system at all levels.

2.3 STRUCTURAL RESPONSE

Analysis for earthquakes differs from that for gravity loads, the earthquake-induces lateral forces to the geometry of the structure which are resisted by flexural actions in members or by members with great shear resistances such as shear-walls. Without realistic structural modeling, forces and displacements can be concentrated in portions of a structure that are not capable of providing adequate strength or ductility (Nilson et al. 2003). Following considerations are taken into account to develop realistic structural designs:

2.3.1 Structural Considerations

The earthquake response depends strongly on the geometric properties of a structure, especially height. Tall buildings respond more strongly to long-period (low frequency) ground motion, while short buildings respond more strongly to short-period (high-frequency) ground motion. Fig 2.3 shows the shapes for the principal mode of vibration of a three story frame structure. The first mode (Fig 2.3a) usually provides the greatest contribution to lateral displacement (Nilson et al. 2003).

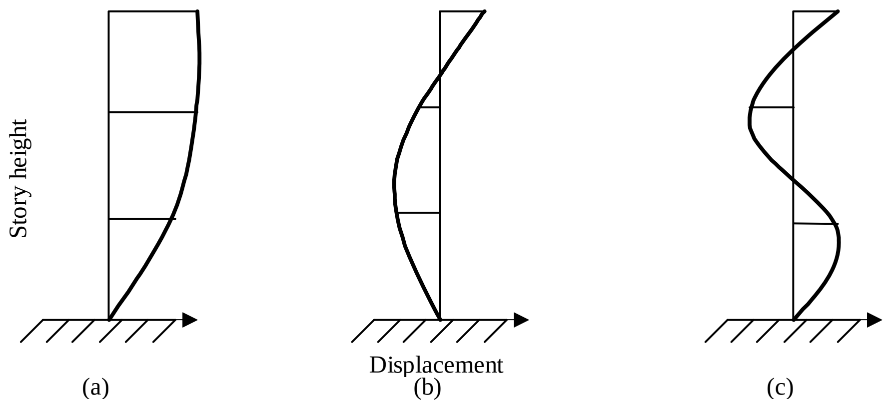

Fig. 2.3. Modal shapes of a three story building (a) first mode (b) second mode (c) third mode

2.3.2 Member Considerations

Members designed for seismic loading must perform in a ductile fashion and dissipate energy in a manner that does not compromise the strength of the structure. The method of ensuring ductility in members subject to shear and bending is to provide confinement for the concrete. When confinement is provided, beams and columns can undergo nonlinear cyclic bending while maintaining their flexural strength and without deteriorating due to diagonal tension cracking. The formation of ductile hinges allows reinforced concrete frames to dissipate energy (Nilson et al. 2003).

2.4 BOUNDARY CONDITIONS

Boundary conditions, also called support conditions in structural mechanics, are often misrepresented in the mathematical model or misstated as input data to Finite Element software. Care is needed because changes in support conditions that appear minor can have a major effect on computed results. Support conditions are not often obvious in a real world problem. To see that even a simple problem presents many choices and uncertainties, consider stress analysis of a table-top under uniform downward load. Let the tabletop be a flat rectangular plate supported by prismatic vertical legs at four corners. If the top is analyzed alone, simple supports at corners make the model too flexible, while fixity at corners makes it too stiff. If legs are included in the model, legs may be fixed at the floor, pinned, or free to slide. Connections between legs and the table top may be loose. A leg may be short or the floor uneven.

If the physical problem does not present a clear choice of appropriate boundary conditions, it may be possible to bind the correct result by two analyses, one with simple supports and other with fixed supports. These two analyses will respectively overestimate and underestimate the magnitude of the actual forces and reactions. (Cook et al. 2003)

2.5 DYNAMIC ANALYSIS PROCEDURES

The design of structure against seismic forces requires determining, the response of the structure during an earthquake. Three common ways to calculate the response of a structure during earthquake are (IBC 2003):

- Time history analysis.
- Response spectrum analysis.
- Equivalent static load method using certain codes.

2.5.1 Time History Analysis

The history analysis is dynamic analysis performed in the time domain. This type of analysis can be used in conjunction with modal analysis and direct integration analysis. The time history records represent quantities such as acceleration, velocity or displacement as function of time (Chopra 2003).

2.5.2 Response Spectrum Analysis (RSA)

Response spectrum is a plot of the maximum response (acceleration, velocity or displacement) of a family of idealized single degree of freedom damped oscillators as function of their natural frequencies, or periods, to a specific vibratory in put motion at their support. Elastic dynamic analyses of a structure utilize the peak dynamic response of all modes having a significant contribution to total structural response. Peak modal responses are calculated using the ordinates of the appropriate response spectrum curve which corresponds to the modal periods. Maximum modal contributions are combined in a statistical manner to obtain an approximate total structural response (ASCE 7-02).

2.5.3 Equivalent Static Load Method (ESL)

During the earthquake, structures vibrate to and fro. There will be one maximum displacement value at which the structure may fall. If the structure is displaced the same amount (approximately) by applying set of static forces throughout the height of the structure, response close to the actual dynamic analysis can be obtained for some structures. The most common procedure is to determine base shear for the structure and then to distribute this base shear into the set of static forces along the height of the structure depending upon the stiffness and inertia of the storey of the structure (ASCE 7-02).

2.5.4 Modal Analysis

Modal analysis is used to determine the vibration modes of a structure. These modes are useful to understand the nonlinear dynamic behavior of the structure. Hence, the method is aimed at the estimation of fundamental frequencies and time periods at performance levels in which the building is expected to respond elastically, such as conventional buildings subjected to moderate earthquake ground motions or critical facilities during severe earthquake ground motions. Modal analysis is done in this study to get the natural time periods of the model structures.

2.6 FOUNDATION SOIL MODEL IDEALIZATION

Soil Structure Interaction (SSI) can affect the response of structures especially for those structures founded on relatively flexible soil. It is important to include the SSI effects particularly in the analysis of the structures located in seismic zones or prone to dynamic loading. However, in structural analyses mostly simplified models with fixed base are considered (Shen et al. 2002).

The coupled analysis considering the properties of soil and structure together is quite complicated and becomes uneconomical and time consuming which renders it unsuitable in design environment (Scott 1981). Researchers do address the SSI problem in dynamic analyses but the techniques are too complicated and are unsuitable for use in design office.

In the design environment the soil half space is modeled as spring support to incorporate the SSI effects and most common used spring constant is Winkler spring (Scott 1981, Bowles 1988). The dynamic behavior of soil is different as compared to its static behavior; therefore, the Winkler spring technique is not suitable for problems where dynamic behavior of soil is considered.

Models are proposed which take into account the response of soil under action of dynamic forces as Wu and Shen (1996) used the visco-elastic foundation model (Kelvin model) in their study on dynamic analysis of concrete pavements. This model was found to be giving more realistic values as the visco-elastic foundation model considers the spring stiffness along with the dampness coefficient depicting the stiffness and damping properties of soil. Present FEM programs utilize the visco-elastic spring element which is basically a spring damper that has spring stiffness and viscous damping lumped together. The model assigned with visco-elastic spring proves better in dynamic environment.

Chapter 3

METHODOLOGY

3.1 GENERAL

The primary purpose of this research is to compare the superstructure dynamic responses of structural systems with fixed base to that of simple soil model base. The selected simple soil model is to be suitable for use in a design environment and give more realistic results.

For this purpose building models are idealized with various heights and structural systems in both 2D and 3D space. These models are then provided with visco-elastic supports representing 3 soil bearing capacities and the analysis results are compared to that of fixed support models.

3.2 ESTABLISHMENT OF VARIABLES

To study the effect of support conditions on structural response under dynamic loading, the selected variables are support flexibility and structure height. The influence of these variables is studied on 2D and 3D models with two types of structural systems namely MRF and dual system.

3.3 PRELIMINARY STRUCTURAL DESIGN

The scheme adopted for developing the models used in dynamic analysis for this research is as under:

3.3.1 Preliminary Design and Analysis

In preliminary design, material properties are decided, then loads due to gravity and earthquake are ascertained, finally the structural models are idealized. Basic calculations carried out in the preliminary analysis and design stage are given in Appendix I.

3.3.2 Final Structural Models

From the preliminary analysis final member cross sections are selected and final analysis is done to confirm the structural design capacities. A summary of final design details of all the models used in this research is given in Table I.1 (Appendix I).

3.3.3 Structural Damping Property

Chopra (2003) suggests that the damping property for superstructure should be between 3 and 5 per cent for the structure under dynamic analysis. For the purpose of structural analysis the damping property of the structure is selected as 4 per cent in this study.

3.4 SUPERSTRUCTURE MODELS

For the purpose of FEM analysis, 5, 10 and 20 story framed structures are selected with two types of structural system namely MRF and SWF as described in Chapter 2. The models are created with SAP 2000 software (Computers and Structures, Inc. 2003) with different support properties in 2D and 3D space. Fig I.1 and Fig I.2 (Appendix I) illustrate the 5 story models with fixed supports, flexible supports and shear walls. Fig I.3 and Fig I.4 (Appendix I) depict same conditions for 10 story models and Fig I.5a and Fig I.5b (Appendix I) for 20 story models. Fig I.6 and Fig I.7 (Appendix I) illustrate the 3D models with different supports and structural systems. Models in this category are of regular shape all around with identical shear walls both in longitudinal and traverse direction.

3.5 IDEALIZED SOIL BEHAVIOR

3.5.1 Foundation Soil Model

The visco-elastic foundation model (Kelvin model) is found more suitable in dynamic analysis as in this model coupled stiffness and damping property makes it more realistic to depict the soil behavior. For dynamic analysis, such foundations at the base of structure can be modeled by using realistic spring stiffness properties selected from finite element properties based on classical half-space equations which consider damping lumped with stiffness of the springs (Wilson 2002). The classical damping of the superstructure ranges between 3 and 5 per cent but for the supporting soil it ranges from 15 to 20 per cent because of the inherent damping properties of the soil (Chopra 2003).

3.5.2 Soil Properties and Support Conditions

For the purpose of this research, three soil bearing capacities 0.5 TSF, 0.75 TSF and 1.0 TSF are considered. Based on the above, four types of support conditions were selected for research as follows:

- Fixed support type with infinite bearing capacity – S1
- Flexible support with bearing capacity of 1.0 TSF – S2
- Flexible support with bearing capacity of 0.75 TSF – S3
- Flexible support with bearing capacity of 0.5 TSF – S4

3.5.3 Properties of Visco-elastic Model used for Foundation

In this research a visco-elastic spring model is used to depict the dynamic behavior of structural model based on flexible soil medium. The model is simple to use in a design environment and gives reasonable results. The visco-elastic spring element is basically a spring that has spring stiffness and viscous damping lumped together.

The spring stiffness and damping properties of the visco-elastic model are determined as follows:

3.5.3.1 Spring Stiffness of Visco-elastic Model used for Foundation

In order to determine the modulus of subgrade reaction to be used for spring stiffness, approximate method proposed by Bowels (1988) has been used. This method is based on the bearing capacity ($q_a = q_u/FS$) and the value for subgrade reaction is given by equation:

$$k_s = 12(FS)q_a \qquad (3.1)$$

where: k_s = modulus of subgrade reaction (kcf)

q_a = allowable bearing capacity (ksf)

q_u = ultimate bearing capacity (ksf)

FS = factor of safety

With an assumed value of factor of safety as three and the allowable bearing capacity values of 0.5, 0.75 and 1.00 TSF, the modulus of subgrade reaction (k_s) values for raft footing used in this research are:

- For 1.0 TSF bearing capacity

  k_s = 12×3×2.24 = 80.64 k/ft3
- For 0.75 TSF bearing capacity

  k_s = 12×3×1.68 = 60.48 k/ft3
- For 0.5 TSF bearing capacity

  k_s = 12×3×1.12 = 40.32 k/ft3

Table 3.1 provides guidelines for estimation of modulus of subgrade reaction, k_s, for various types of soils (Bowles 1988). The above calculated values of modulus of subgrade reaction are within the range specified in Table 3.1.

Table 3.1. Range of Values of Modulus of Subgrade Reaction k_s

Soil	k_s, (kcf)
Loose sand	30-100
Medium dense sand	60-500
Dense sand	400-800
Clayey medium dense sand	200-500
Silty medium dense sand	150-300
Clayey soils	
q_u < 4 (ksf)	75-150
4 (ksf) < q_u < 8 (ksf)	150-300
q_u > 16 (ksf)	>300

3.5.3.2 Damping Property of Visco-elastic Model Used for Foundation

Chopra (2003) suggests that the damping property for soil should be between 15 to 20 per cent for soil region to depict the reasonable damping behavior. The damping property used for this research is selected as 18 per cent.

3.6 DYNAMIC STRUCTURAL ANALYSIS

Two types of analysis modal and time history analysis are carried out to determine the structural response of the models. Modal analysis determines natural dynamic behavior of structures where as time history analysis determines dynamic response of structures to earthquake loading.

3.6.1 Modal Analysis

To determine the vibration modes of the structures and find natural time periods modal analysis is carried out. These modes are used here to understand the nonlinear dynamic behavior of the structure.

3.6.2 Time History Analysis

Time history analysis procedure is utilized with direct integration method. Time-history analysis is a step-by-step analysis of the dynamical response of a structure subjected to El Centro earthquake loading record (Earthquake Engineering Research Laboratory 1975).

3.7 SOFTWARE USED

SAP 2000 software (Computers and Structures, Inc. 2003) is used for dynamic analysis for this research. Dynamic seismic analysis is a feature of SAP 2000 and it gives the desired results like modal response, displacements and member forces. SAP 2000 has the capability of carrying out step by step time history analysis using direct integration methods. SAP 2000 also has an element library containing damper elements that are capable of spring stiffness and damping. In the model developed in SAP 2000 the damping of the damper element is adjusted to 18 per cent and in the superstructure damping is kept as 4 per cent.

3.8 APPLIED LOADING

3.8.1 International Building Code (IBC 2003)

Several building codes are currently in use in different regions of the world. The international building code, published by the International Conference of building officials, is the building code most extensively used in the world. Following load combinations used for this research are based on IBC 2003 load combinations.

- D + L (designated as D+L combination)
- D + E + L (designated as D+L+E combination)
- El Centro time history load (designated as Time hist combination)

where: D = dead load

L = live load

E = earthquake load

3.8.2 Earthquake Loading

Fig. 3.2 shows the ground acceleration record of El Centro earthquake (Earthquake Engineering Research Laboratory 1975). The ground acceleration record of El Centro earthquake is used extensively in earthquake engineering investigations (Chopra 2003). This is one of the most precisely recorded and tested data in engineering and is used for dynamic response calculations (Chopra 2003). This ground motion record is available within SAP2000 software as time history function to analyze the structure against earthquake loads and its data is also available on the internet.

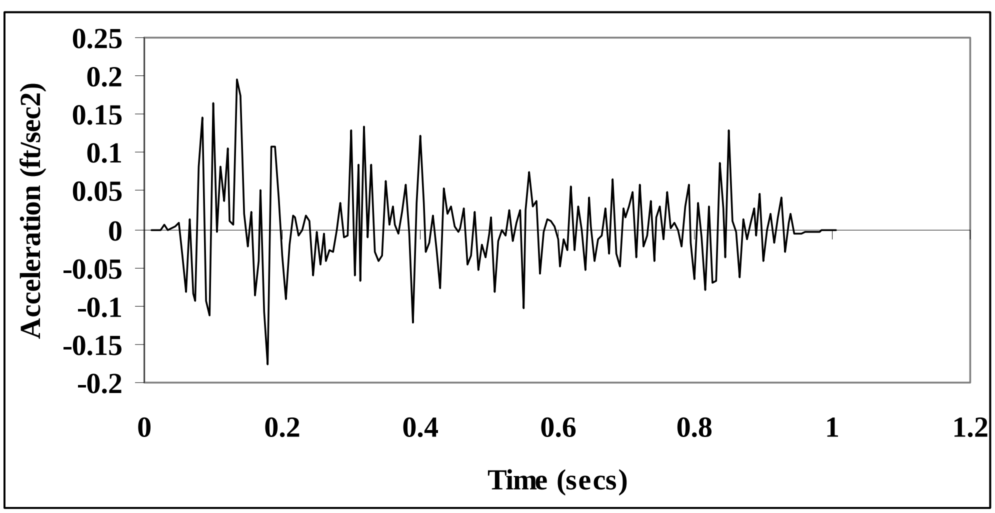

Fig. 3.1. El Centro, ground motion record (Earthquake Engineering Research Laboratory 1975)

3.9 MODEL DESIGNATION

The models used for dynamic analysis consist of 5, 10 and 20 story heights, four support conditions of varying stiffness designated as S1, S2, S3 and S4, constructed in both 2D and 3D space, and two structural systems MRF and dual system symbolized as MRF and SWF. The model designation symbols are tabulated in Table 3.2.

Table 3.2. Model Designation Symbols

Story height			Model type		Support conditions				Structural system	
05S	10S	20S	2D	3D	S1	S2	S3	S4	MRF	SWF

The model designated as 05S-2D-S1-MRF, describes story height - 5, model type - 2D, support condition - S1, and structural system - MRF. Similarly, the model designated 05S-2D-S2-SWF, describes story height – 5, model type – 2D, support condition – S2, and structural system - SWF.

3.10 STRUCTURAL RESPONSES STUDIED

From the FEM analysis, four types of results are obtained to study the effect of support conditions on structural response. These are:

- Natural time period - inherent dynamic property of a structural model and is evaluated by modal analysis.
- Top story displacement, support deflection and base shear - dynamic responses of a structure to applied earthquake loads, determined from time history analysis.

Chapter 4

COMPUTATIONAL MODELING RESULTS AND ANALYSIS

4.1 GENERAL

The FEM analyses are performed using software SAP 2000 according to IBC 2003. This chapter presents analysis, of FEM analyses results, conducted on structural models finalized in Chapter 3. The FEM analyses results are tabulated in Tables II.1 to II.12 (Appendix II) and graphically illustrated in Figs. II.1 to II.48 (Appendix II).

4.2 ANALYSIS OF STRUCTURAL RESPONSES FROM FEM ANALYSES RESULTS

The following sections present analysis and discussion on the FEM analyses results. To compare the responses of the different models, the FEM analyses results are normalized to one, except for the natural time periods as they can be readily compared.

4.2.1 Effect of Support Conditions on Structural Response

Analysis of results shows that, the dynamic behavior of the structure changes with the decrease in stiffness of supports.

The results also indicate that that earthquake response of a visco-elastic support coupled is significantly different from that calculated with fixed base model. Similar phenomenon is observed by Celebi (2005).

The response of structure in dynamic modal analysis indicates that first mode of the building is more critical and it contributes maximum to the member force envelopes. Same is reported by Taghavi (2005). The results for dynamic response of structures appear to be identical in mode shapes especially in first three modes which are expected (Taghavi 2005).

4.2.1.1 Natural Time Period

The results for all the models indicate that the natural time period increases with decrease in stiffness of supports. Fig 4.1 illustrates the natural time periods for 10S-2D-MRF model. The increase in time period for supports S2, S3, and S4 compared to S1 are 26, 28 and 35 per cent respectively for MRF system.

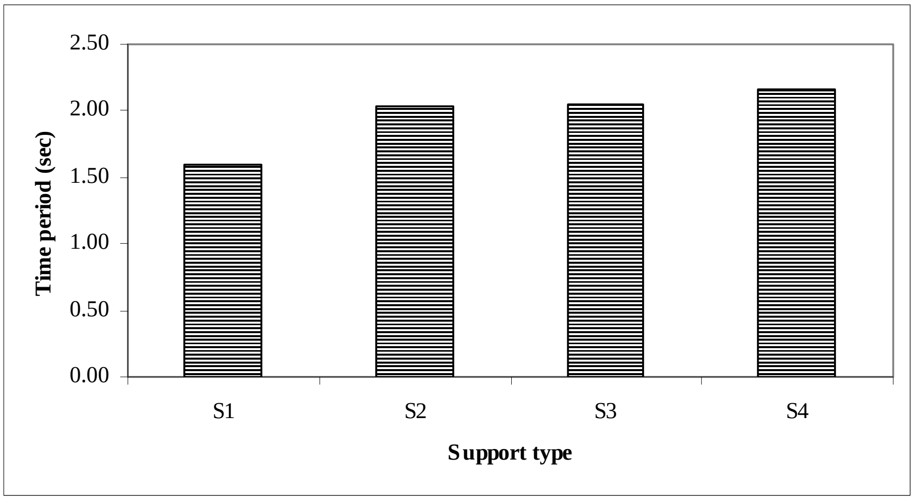

Fig. 4.1. Effect of support conditions on time period of 10S-2D-MRF model

4.2.1.2 Top Story Displacements

In all models, increase in top story displacement is observed with decrease in support stiffness. Top story displacement of 10S-2D-MRF model is illustrated in Fig. 4.2. The increase in top story displacement for supports S2, S3, and S4 to that of S1 is 7, 8 and 16 per cent respectively for this model.

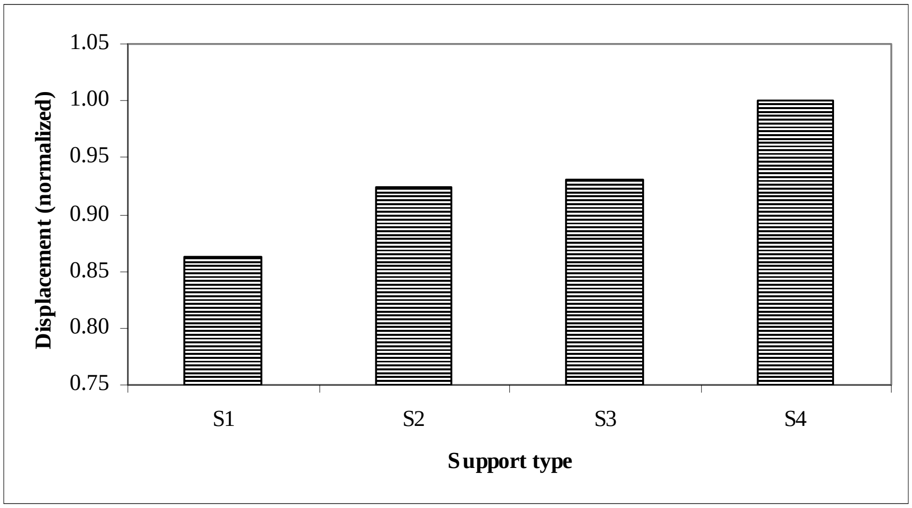

Fig. 4.2. Effect of support conditions on displacement response of 10S-2D-MRF model

4.2.1.3 Support Deflection

The support deflection increases with decrease in support stiffness, in all the models. Support deflection of 10S-2D-MRF model is illustrated in Fig. 4.3. The increase in support deflection for 10S-2D-MRF model is 73 per cent between support type S2 and S4. Support deflection for support type S1 is zero as it is considered as fixed base. Similar trend, of increase in support deflection is observed in all the models.

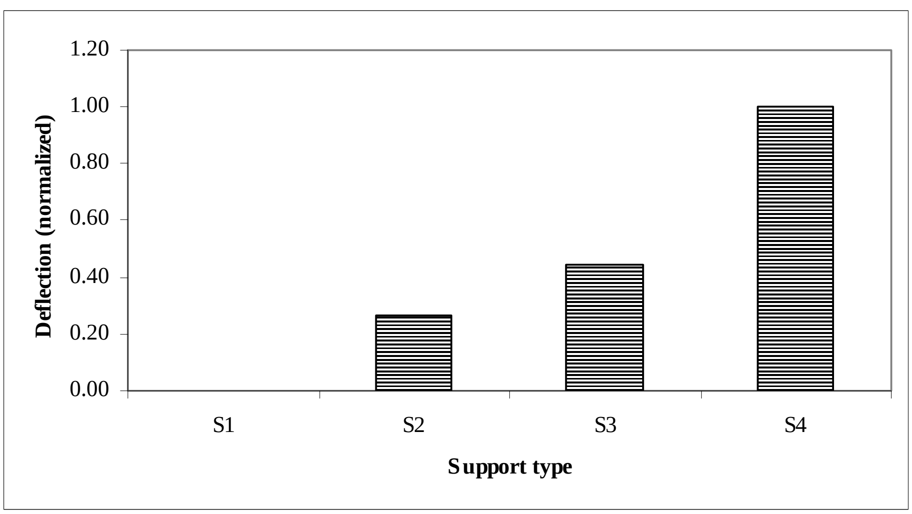

Fig. 4.3. Effect of support conditions on support deflection of 10S-2D-MRF model

4.2.1.4 Base Shear

Generally the base shear is found to be decreasing in all the models as the support stiffness is decreased. Base shear for 10S-2D-MRF model is illustrated in Fig. 4.4. The decrease in base shear is 30 per cent when support type is changed from S1 to S4. This indicates that fixed support models yield high base shears that result in heavy column designs.

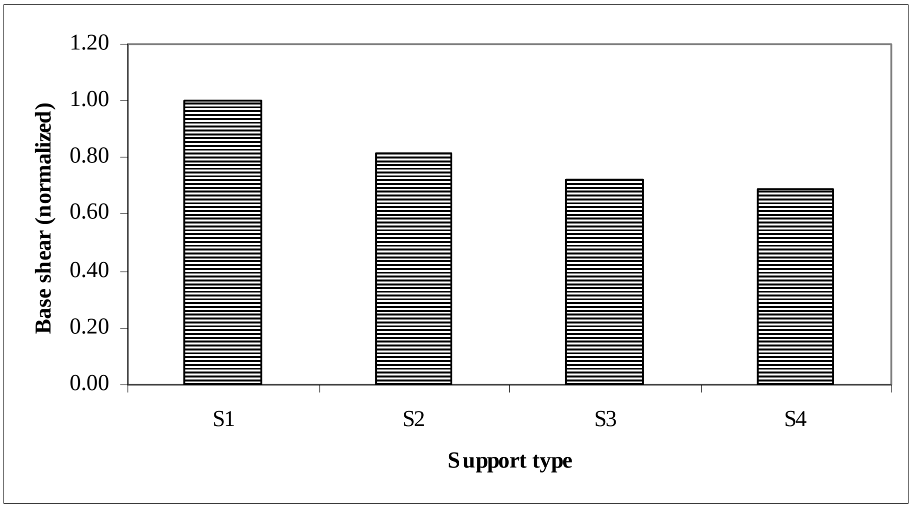

Fig. 4.4. Effect of support conditions on base shear of 10S-2D-MRF model

4.2.2 Effect of Story Heights with Varying Support Conditions on Structural Response

The dynamic behavior of the structural system is ascertained by its natural time period, whereas, the base shear gives a measure of its earthquake response. The effects of varying heights and support conditions on natural time period and base shear are discussed in succeeding paragraphs.

4.2.2.1 Natural Time Period

Fig. 4.5 illustrates the trend of increase of time period with the change in height of the structure. The values of time periods for 5S-2D-MRF, 10S-2D-MRF, and 20S-2D-MRF models are tabulated in Table 4.1.

For 2D-MRF with support type S1, the increase in time period is 107 and 71 per cent for increase in height from 5S to 10S and 10S to 20S respectively. Similarly, for 2D-MRF with support type S3, the increase in time period is 120 and

72 per cent for increase in height from 5S to 10S and 10S to 20S respectively. These values indicate that the increase in time period with respect to change in height is independent of support conditions.

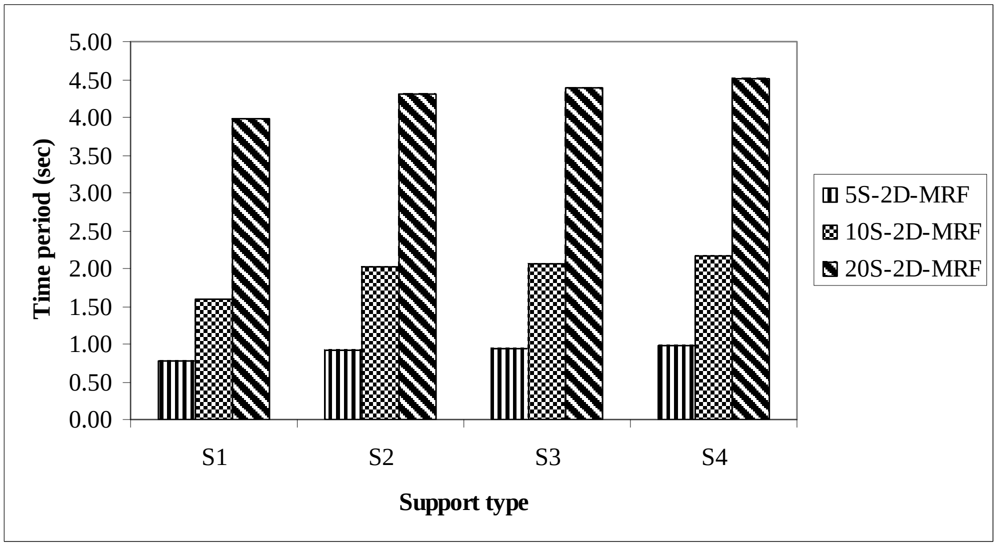

Fig. 4.5. Effect of story height on time period of 2D-MRF models

Table 4.1. Time Period of Models with Different Heights

Support types	Model types		
	5S-2D-MRF	10S-2D-MRF	20S-2D-MRF
S1	0.77	1.6	2.74
S2	0.92	2.03	3.25
S3	0.93	2.05	3.52
S4	0.99	2.16	3.63

4.2.2.2 Base Shear

Fig. 4.6 illustrates the trend of decrease in base shear with the change in height of the structure. The values of normalized base shear for 5S-2D-MRF, 10S-2D-MRF, and 20S-2D-MRF models are tabulated in Table 4.2.

For 2D MRF models, the decrease in base shear from support type S1 to S4 is 55, 31, and 22 per cent for height 5S, 10S, and 20S respectively. This indicates that change in base shear with respect to change in support condition is dependent on structural height.

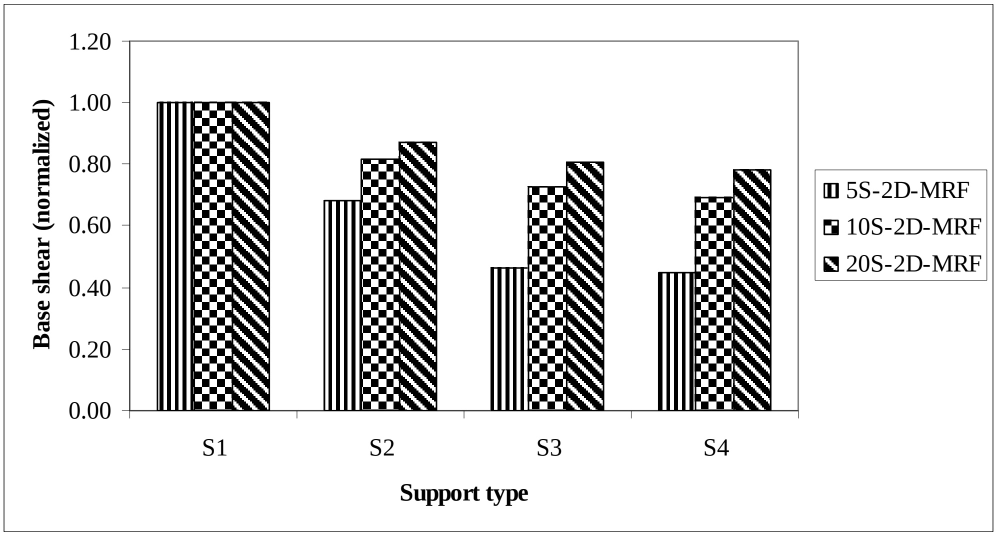

Fig. 4.6. Effect of story height and support type on base shear of 2D-MRF models

Table 4.2. Normalized Base Shear Values for MRF Models with Different Heights

Support types	Model types		
	5S-2D-MRF	10S-2D-MRF	20S-2D-MRF
S1	1.00	1.00	1.00
S2	0.68	0.82	0.87
S3	0.46	0.73	0.81
S4	0.45	0.69	0.78

4.2.3 Effects of Structural System with Varying Support Conditions on Structural Response

4.2.3.1 Natural Time Period

Fig 4.7 illustrates effect of support condition and structural system on time period. For change in model type from MRF to SWF, the decrease in time period for support type S1, S2, S3 and S4 is 30, 27, 24 and 25 per cent respectively. This indicates that the effect of structural system is not sensitive to support conditions.

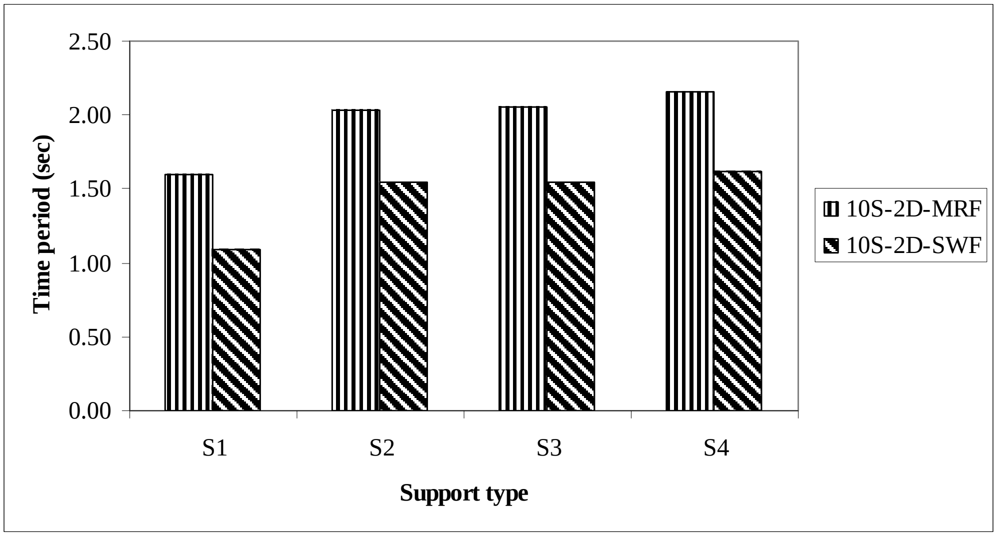

Fig. 4.7. Effect of structural system on time period of 10S-2D models

4.2.3.2 Base Shear

Fig. 4.8 illustrates the trend of decrease in base shear with the change in structural system. The values of normalized base shear for MRF and SWF models are tabulated in Table 4.3.

For 20S-2D models, the decrease in base shear from support type S1 to S4 is 22, and 48 per cent for MRF and SWF systems respectively. This indicates that change in base shear with respect to change in support condition is dependent on structural system.

Table 4.3. Normalized Base Shear Values for 20S-2D-MRF and 20S-2D-SWF Models

Support type	Structural system	
	MRF	SWF
S1	1.00	1.00
S2	0.87	0.74
S3	0.81	0.61
S4	0.78	0.52

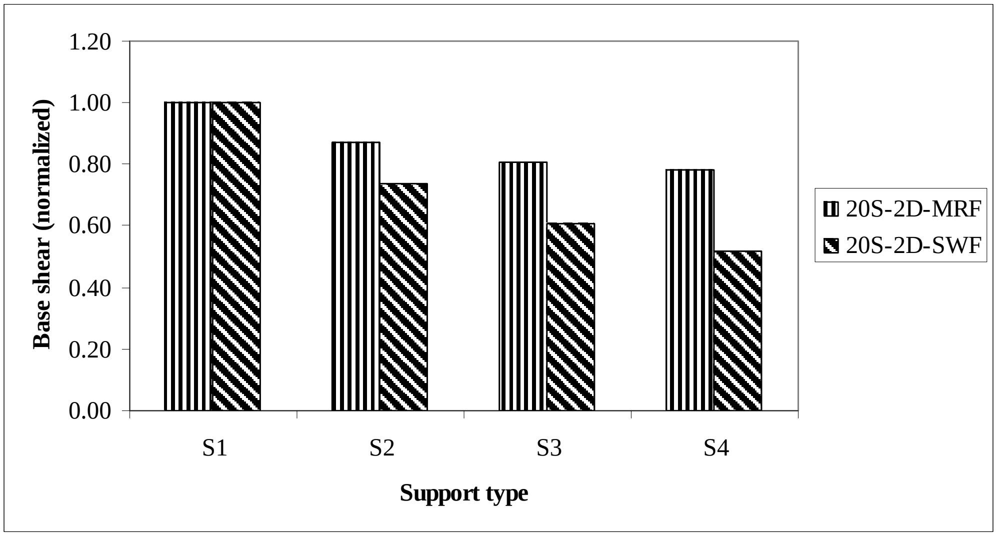

Fig. 4.8. Effect of structural system on base shear of 20S-2D-MRF and 20S-2D-SWF models

4.2.4 2D Versus 3D Analysis

Fig. 4.9 illustrates the effect of support type on time period for 2D versus 3D models. In 2D model, the increase in time period with respect to S1 is 27, 28, and 35 per cent for S2, S3 and S4 respectively. Similarly, in 3D model, increase in time period with respect to S1 is 20, 26, and 33 per cent for S2, S3 and S4 respectively. This indicates that the effect of support conditions on 2D and 3D models is similar.

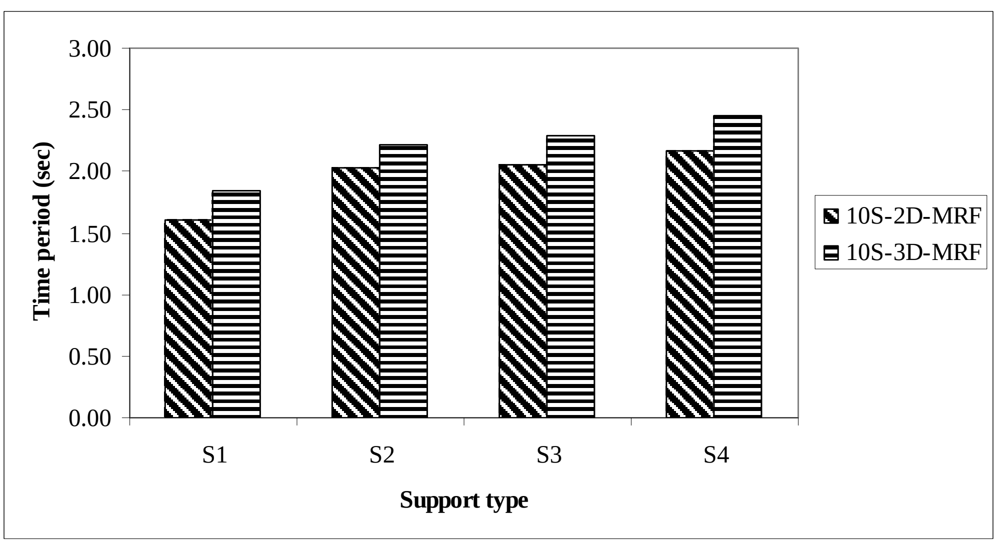

Fig. 4.9. Effect of support conditions on time period of 10S-MRF, 2D and 3D models

4.2.5 Effect of Support Conditions on Member Forces

Bending moments of first floor beams increase as the support stiffness is reduced.

The beam bending moments for first floor beams in 10S-2D-MRF model are illustrated in Fig. 4.10. Centre beam bending moment is 5.91 k-ft for support S1 and 8.00 k-ft for support S4. This increase in bending moments is 35 per cent. The results indicate that there is significant increase in beam bending moments when the support conditions are changed from fixed to flexible. Therefore, a fixed support model results in under designed beams.

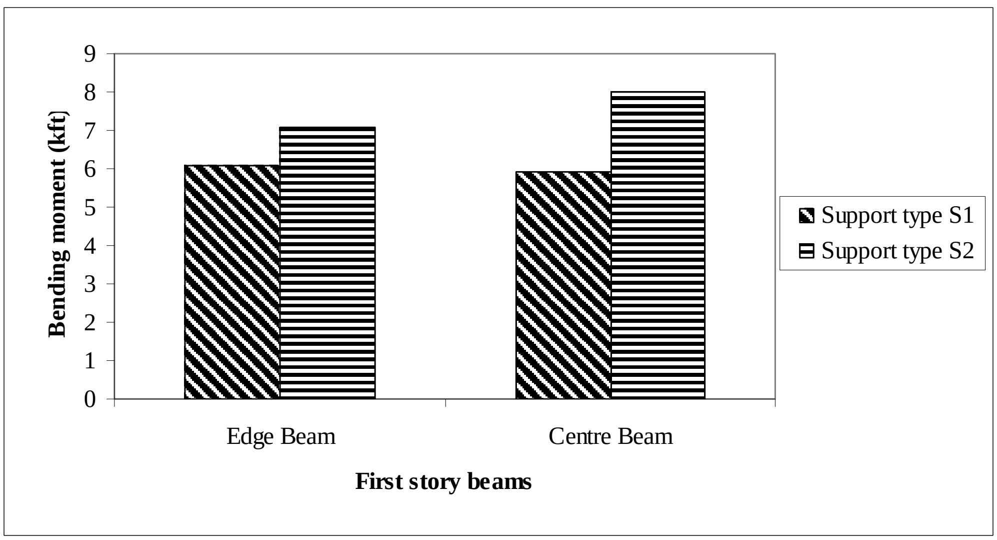

Fig. 4.10. Increase of first story beam moments in 10S-2D-MRF model with change in support conditions between S1 and S4

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the modeling and analysis in this research study, following conclusions are drawn:

- Fixed story models yield reduced natural time periods. Natural time period of structures increases with decrease in the support stiffness.
- Top story displacement and base deflection increases with decrease in support stiffness.
- Base shear decreases with decrease in support stiffness.
- Increase in structural height enhances the effect of support stiffness on earthquake response.
- Effect of support stiffness on earthquake response is also dependent on structural system.
- 2D models give conservative results as compared to 3D models, but the dynamic behavior remains similar in both cases.
- Fixed support models yield higher base shear forces but the beam forces are under estimated.

5.2 RECOMMENDATIONS

Following is recommended for future studies and research in this area;

- Analysis with soil models other than visco-elastic spring model needs to be done in future studies.
- Irregular building models analyses should also be studied to see the effects of discontinuity in stiffness or geometry.
- Earthquake response exciting the lateral modes is studied in this research. Response of models with critical torsional modes should be incorporated in future studies.

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