SEISMIC DESIGN OF THE MASONRY INFILL RC FRAME BUILDINGS WITH FIRST SOFT STOREY

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ABSTRACT

The main aim of this study was to investigate the seismic performance and design of the masonry infill Reinforced Concrete (R/C) frame buildings with the soft first storey under a strong ground motion. The study also highlighted the error involved in modeling of the infill RC frame building as completely bare frame neglecting stiffness and strength of the masonry infill wall in the upper floors. The envelope curve for representing non-linear behaviors of masonry infill wall was determined for numerical analysis. The attempt was made to determine the strength increasing factor (η) to account the effect of the soft storey through various 2D analytical models using Capacity Spectrum Method (CSM) and established its relationship with initial stiffness ratio (K_o2/K_o1). In this study, the non-linear dynamic time history analysis was also carried out with a three dimensional practical model in order to verify the proposed strength increasing factor (η).

Key words: First soft storey, Capacity Spectrum Method, Strength increasing factor, Storey drifts

INTRODUCTION

In urban and semi-urban areas of Nepal, like several other developing countries around the world, reinforced concrete frame structure is very popular for the building construction. Usually, the RC frame is filled with burnt clay bricks masonry as non-structural wall for partition of rooms in the floors which is called infill wall. The reason behind the popularity of using brick masonry in developing countries may be due to economy, architecture; aesthetic, locally available skill and material, good for water proofing, heat and sound insulation, and better security. Similarly, open first storey is nowadays as unavoidable features for the most of urban multistory buildings for vehicles parking, shop, reception, and lobby etc. In building with the first soft story, the upper storey being stiff undergoes less inter-storey drift, while the displacement will be concentrated at the first storey during seismic events. Hence, an abrupt change in the stiffness in first storey have adverse effect on the performance of the building during ground shaking which is known as first soft storey effect.

Problem statement

In current practice of structural design of the buildings in Nepal, masonry infills are treated as non-structural element and the frame is modeled as a bare frame. The strength and stiffness contribution of infill walls are often neglected and self weight of infill wall is modeled as uniformly distributed load. The entire lateral load is assumed to be resisted only by the moment resisting frame. In reality, the presence of the infill wall in the frame changes the lateral load transfer mechanism into truss actions leading to stress concentration in the ground floor. Hence, the effect of the first soft storey is failed to capture in the analysis. This error in modeling may lead to damage in the first soft storey during a strong earthquake.

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Macro modeling for brick infill masonry wall

The contribution of the masonry infill wall to represent the infill frame can be modeled by replacing the panel by a system of equivalent horizontal shear spring connected to the main frame vertically. The non-linear properties of the equivalent shear spring can be determined by the envelope curve. It can be represented by poly-linear strength envelop with initial elastic stiffness until the cracking force Q_c , post cracking degraded stiffness until the maximum force Q_y and post peak residual force Q_u. The corresponding lateral displacements are γ_c, γ_y and γ_υ respectively (Ref. Figure 1).

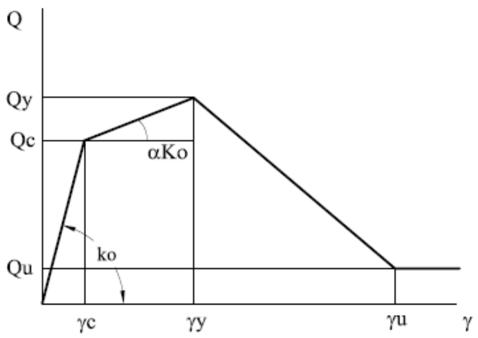


Figure 1 Skeleton for masonry infill wall context.

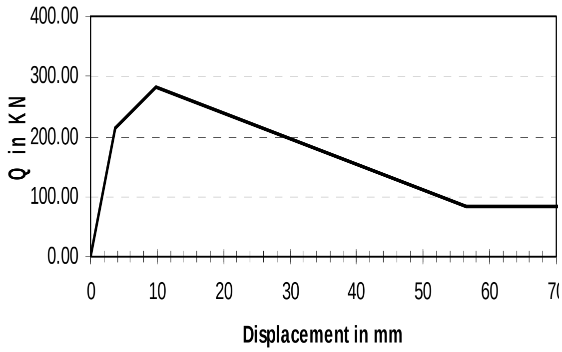


Figure 2 Skeleton curve for masonry wall in Nepalese

In this study, the brick masonry wall in Nepalese context was considered to determine the skeleton curves with the given parameters: Size of brick = 230x110x57mm, thickness of mortar= 10mm and mortar ratio 1:5. The compressive strength of the burnt brick, f_{cb}= 7.5 N/mm^2, compressive strength of mortar , f_j= 5.0 N/mm^2 and tensile strength of brick, $f_{tb} = 0.1f_{cb}$ = 0.75 N/mm$^{2.}$ The computer program was written in FORTRAN to obtain strength envelope (Skeleton) curve as shown in figure 2.

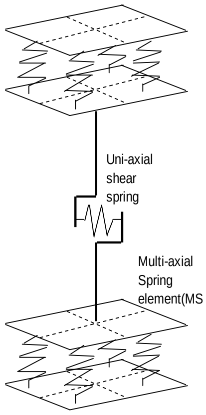
NUMERICAL MODLING FOR THE STRUCTURAL ELEMENTS

The structural elements were modeled by STERA3D (Dr. Taiki Saito, the chief researcher of IISEE, BRI) for non-linear structural analysis. All the structural members were considered as line elements with non linear springs to represent the non-linear behavior of the structure. The cross sections were considered to be rigid. The details of modeling are discussed below.

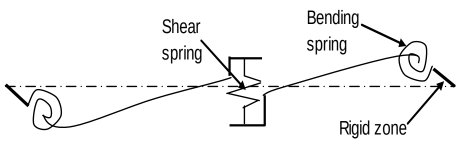
Column: The structure to be analyzed being first soft storey and often subjected to large fluctuating axial load due to overturning moment, the fiber model (multi spring model) was used for the column element to take into account the interaction between bending moment and axial force. Column element was idealized with the line element with fiber slice model at each ends consisting of steel and concrete multi axial springs elements in order to represent flexural and axial deformation to take account of the interaction between bi-directional bending moments and axial load. The bi- axial shear springs were also considered to represent the non linear shear deformation of the column. An origin-oriented poly-linear hysteresis model was used for representing non-linear shear spring.

Beam: The beam elements were represented as a uni-axial model with non-linear rotational spring at two critical ends and non-linear shear spring at the middle of the beam for shear deformation. The hysteresis tri-linear degradation modified Takeda model was applied for non-linear rotational spring model

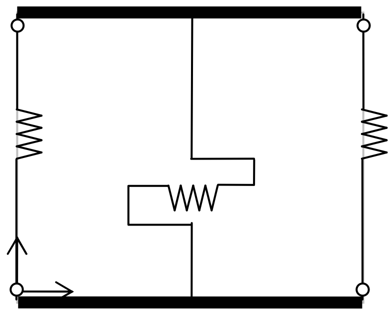
Masonry infill wall: Masonry walls were represented with a line element with non-linear shear spring at the mid of element. The poly-linear slip model was used as the hysteresis model.



a)Ms column model



b) Non-linear beam model



c) Infill masonry model

Figure 3 Structural Elements Models

DETERMINATION OF STRENGTH INCREASING FACTOR (η) FOR FIRST SOFT STOREY BY CAPACITY SPECTRUM METHOD

It was already discussed about soft storey effect in first storey due to presence of infill wall in the upper floors. However, the designers do not consider the strength and stiffness of the masonry wall in their analysis due to limitation in their knowledge. The performing the non-linear analysis is also very difficult for many engineers. Hence, the attempt was made to determine the strength increasing factor (η) to account for the soft storey effect due to infill wall and tried to establish its relationship with initial stiffness ratio between two floors and height of the structure so that designer can increase the lateral strength of the columns subjected to first soft storey to meet the drift demand due to the soft storey.

Model studied:

A prototype apartment building with typical floor plan was considered. The building was symmetrical in plan and the plan dimension of the building was 20m x 12m. The span length along both the axis was 4m c/c and floor height 3m c/c. The structural frame elements were designed for six storeys according to current practice with critical load combination prescribed in the prevailing code.

Capacity Spectrum Method:

Capacity Spectrum Method (referred as to CSM hereafter) can provide the realistic representation of the structure subjected to a severe earthquake and can be established as a rational alternative to nonlinear analysis for assessing seismic demands of the MDOF structure. The seismic demand in form of response spectrum and capacity in form of pushover analysis is plotted in ADRS format. The point of the intersection of two curves is the response of structure for the demand and is called the performance point.

Demand Spectrum Curve: Unfortunately, in Nepalese code, only design spectra are given. Hence, based on Indian code IS1893:2002, The demand spectrum curve for Nepal was plotted for different damping factor considering 0.36g PGA as maximum considered earthquake(MCE) of return period 500 years.

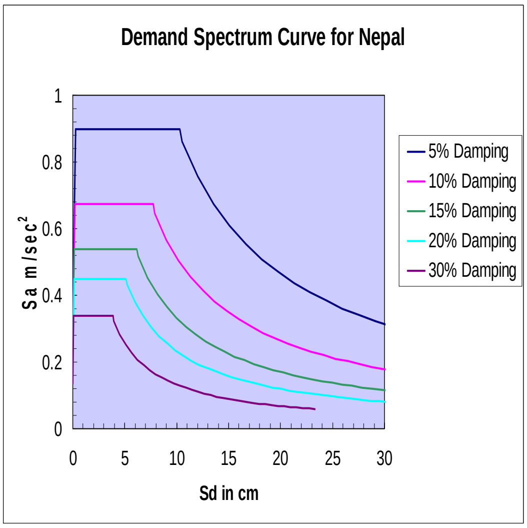


Figure 4 Demand Spectrum Curve

This simple static non-linear analysis method was used to determine the strength increasing factor (η). Firstly, the pushover analysis was carried out for the bare frame by applying incremental lateral loading according to the Ai distribution up to drift angle of 1/50 as the life safety limit. Similarly, analysis of the models by considering infill wall with first soft storey was carried out and it could not meet the demand. Then, the lateral strength of column in terms of size and reinforcement were increased gradually so that the strength could meet the demand. Therefore the strength increasing factor (η) is the ratio of the lateral strength of the strengthened frame structure subjected to soft storey to the lateral strength of the bare frame structure. Strength increasing factor (η) is function of initial storey stiffness ratio (Ko2/Ko1).

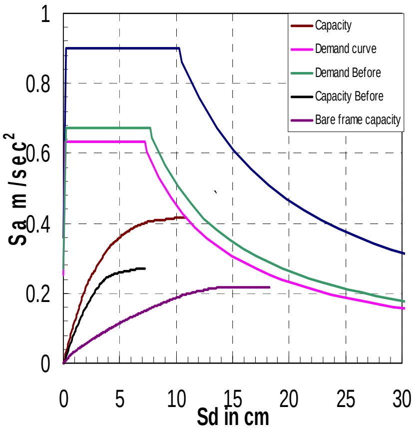


Figure 5 Capacity Spectrum Curves

Strength Increasing Factor (η) Vs Storey Stiffness Ratio

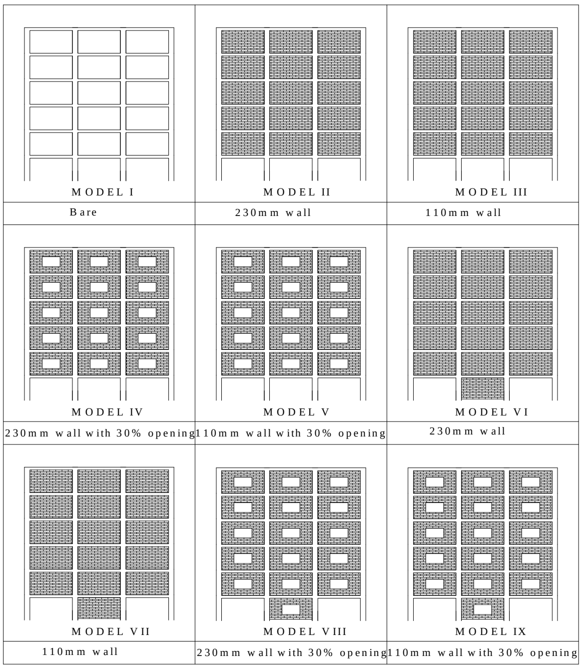


Figure 5 First soft storey models

As the soft storey means the abrupt change in stiffness along height of the building, the strength increasing factors depends upon storey initial stiffness ratio of the soft storey to the adjacent storey above it is a called initial stiffness ratio (Ko2/Ko1). Therefore, 2D models of six storied building with the most practical configurations of infill walls as shown in figure 5 were considered so that rational relationship could be established between Strength increasing factor (η) and initial stiffness ratio (Ko2/Ko1).

The pushover analysis for each of the models by considering the stiffness and strength of the infill wall (except Model I) was carried out in such a way that capacity curve of the all models would meet the demand by increasing its lateral capacity. The strength increasing factors were calculated for each model as a ratio of the lateral capacity of the strengthened to bare (ref figure.6). The strength increasing factor (η) with initial stiffness ratio (Ko2/Ko1) is tabulated in the table1

Table 1 Table 1 Initial Stiffness Ratio

Model	Stiffness Ratio (K_1/K2)	Strength Increasing Factor
Model I	1	1.1
Model II	2.8	2.0
Model III	2.0	1.56
Model IV	1.8	1.5
Model V	1.4	1.4
Model VI	1.75	1.75
Model VII	1.5	1.44
Model VIII	1.4	1.42
Model IX	1.25	1.36

Figure 7 Storey drift angle

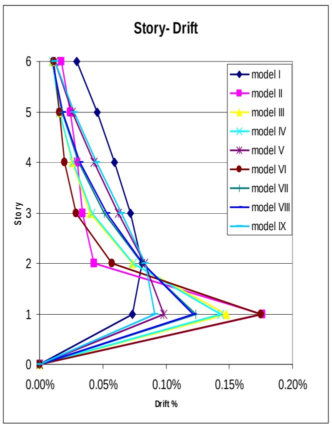
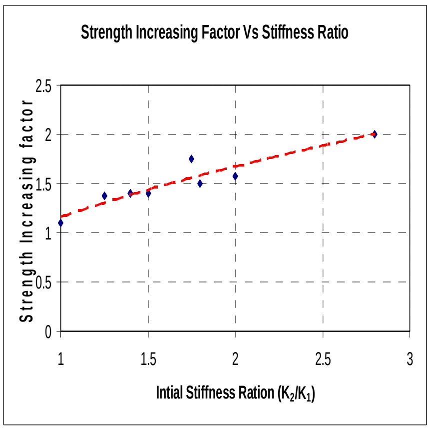


Figure 8 ƒÅ ? ko2/ko1 curve



Result and Discussion:

The storey drift ratio for each models showed that the storey drift demand increased with the increase in the stiffness ratio (Ko2/Ko1). Hence, the relationship between strength increasing factor (η) and Initial stiffness ratio (Ko2/Ko1) could be established and plotted in the figure 7.

CASE STUDY: PRACTICAL VERIFICATION OF STRENGTH INCREASING FACTOR (η)

A typical six story high apartment typed building with masonry infill wall with open soft first storey was considered which is very common in the urban areas of Nepal as shown in figure 8. The plan of the building is symmetrical with both directions and grid of the column layout is 5m c/c in each direction and the storey height of the building is 3m.

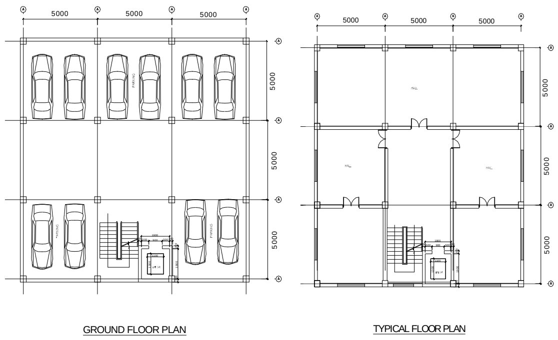


Figure 8 floor plans

Design of the Structural Elements

The structural design of the building was carried out to resist the seismic load as prescribed in Nepalese code and designed .
Detailing of the members was done according to the Indian building code. The size of the columns were calculated as two type, peripheral columns were 500X500mm with 8# 20ϕ + 4# 25ϕ and similarly, inner columns were 500X500mm with 8# 25ϕ +4# 20ϕ. The 8ϕ ties were provided as 100c/c. Grade of concrete and reinforcement were 16MPa and 415Mpa respectively.

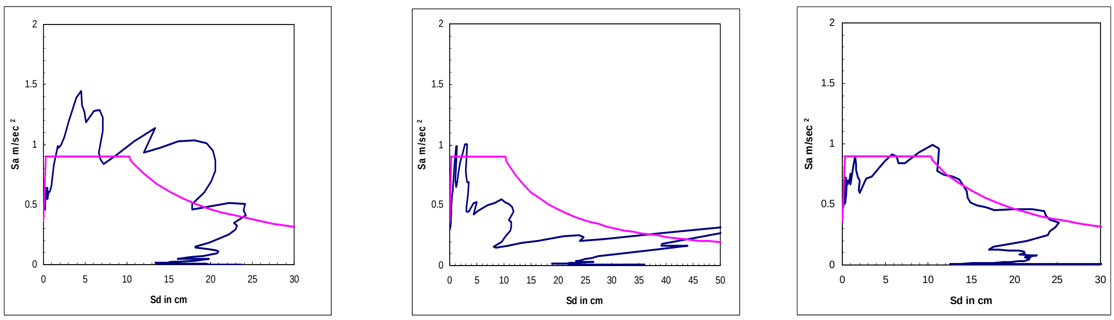
According to the graph of figure 8, the strength increasing factor (η) corresponding to Initial stiffness ratio 1.73 is 1.53. Hence, the columns of the building were redesigned for the base shear 1.53 times than that of the previous calculated base shear. The size and the reinforcement were calculated as 575 X 575mm and 12# 25ϕ respectively.

Table 2: Determination of η

Initial stiffness ratio		**Strength increasing factor**	
In X Dir.	In Y Dir.	In X Dir.	In Y Dir.
1.73	1.65	1.53	1.5

Non-linear Time History Dynamic Analysis

Non-linear dynamic time history analyses were carried out separately for bare, infill and strengthened infill frame with Kobe, Hachinohe and Chamauli (India).All the earthquakes were normalized to their maximum velocity of 50cm/sec. The Demand Spectrum for the response of all three normalized input ground motion were plotted in ADRS format. Similarly, the demand required by elastic response spectra was also plotted. Then, comparisons were done among them for all the three cases.

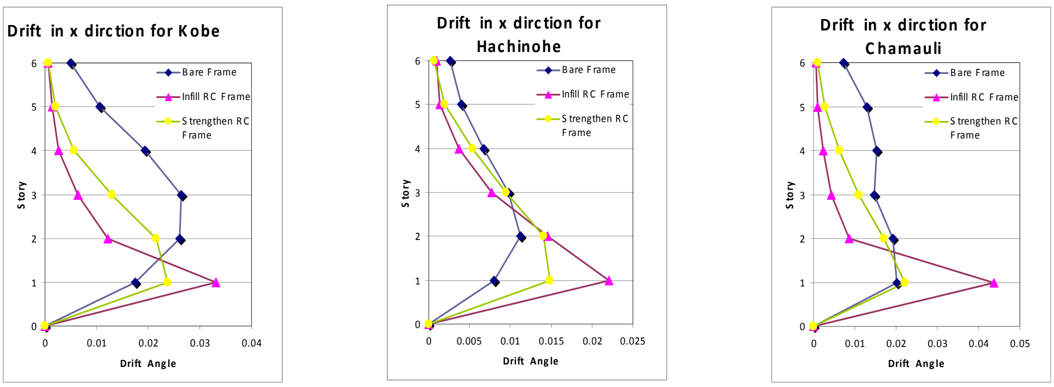


a) Kobe b) Hachinohe c) Chamauli (India)

Figure 9 Demand Spectrum Curves

Result and Discussion

All the three non linear dynamic time history analysis showed the development of soft storey in the first floor . By strengthening columns with the strength increasing factor (η), drift demand at first floor were considerably decreased. The result obtained from Chamauli earthquake which agrees with the demand spectrum showed that the drift ratio obtained after the strengthening the columns with strength increasing factor were almost 2% (Ultimate drift ratio). Hence, the proposed strength increased factor was well agreed.



a) Kobe b) Hachinohe c) Chamauli (India)

Figure 10 Max storey drift ratio

CONCLUSIONS

- The effect of infill wall predominately changes the behavior of the structure and it is essential to consider infill walls for seismic evaluation of the structure.
- NBC105 underestimates the base shear by around 10%. Hence, the immediate review of the code is required.
- Arrangement of infill wall in the frame affects the behavior of the structure. A relationship can be established between strength increasing factor(η) and initial stiffness ratio. Designer can use strength increasing factor (η) to take care of soft storey effect without carrying out non-linear analysis
- The non-linear dynamic time history analysis for 3d models proved that the demand of the soft first storey can be met by application of strength increasing factor (η).

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