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Seismic evolution of soft storeyed buildings when subjected to real time earthquake and how it can be strengthen

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***Abstract -** Generally RC framed structures are designed without regards to structural action of masonry infill walls present. Masonry infill walls are widely used as partitions. These buildings are generally designed as framed structures without regard to structural action of masonry infill walls. They are considered as non- structural elements. RC frame building with open first storey is known as soft storey, which performs poorly during strong earthquake shaking. Past earthquakes are evident that collapses due to soft storeys are most often in RC buildings. In the soft storey, columns are severely stressed and unable to provide adequate shear resistance during the earthquake. Hence a combination of two structural system components i.e. Rigid frames and RC shear walls or Rigid frames and Bracings leads to a highly efficient system in which shear wall and bracings resist the majority of the lateral loads and the frame supports majority of the gravity loads.*

1. INTRODUCTION

The capacity of structural members to undergo inelastic deformations governs the structural behaviour and damageability of multi-storey buildings during earthquake ground motions. From this point of view, the evaluation and design of buildings should be based on the inelastic deformations demanded by earthquakes, besides the stresses induced by the equivalent static forces as specified in several seismic regulations and codes. Although, the current practice for earthquake-resistant design is mainly governed by the principles of force-based seismic design, there have been significant attempts to incorporate the concepts of deformation-based seismic design and evaluation into the earthquake engineering practice. In general, the study of the inelastic seismic responses of buildings is not only useful to improve the guidelines and code provisions for minimizing the potential damage of buildings, but also important to provide economical design by making use of the reserved strength of the building as it experiences inelastic deformations. In recent seismic guidelines and codes in Europe and USA, the inelastic responses of the building are determined using nonlinear static methods of analysis known as the pushover methods.

Thus the impact of wind and seismic forces acting on them becomes an important aspect of the design. Improving the structural systems of Multi-Storeyed buildings can control their dynamic response. With more appropriate structural forms such as shear walls, tube structures and braced structures, and improved material properties, the maximum height of concrete buildings has soared in recent decades. Therefore; the time dependency of concrete has become another important factor that should be considered in analyses to have a more reasonable and economical design.

A large portion of India is susceptible to damaging levels of seismic hazards. Hence, it is necessary to take in to account the seismic load for the design of Multi-Storeyed Structures. The different lateral load resisting systems used in Multi-Storeyed building are: 1.Bare frame 2.Brace frame 3.Shear wall frame. Due to Industrial revolution, availability of jobs and facilities, population from rural area is migrating towards cities. Because of this metro cities are very thickly populated. Availability of land goes on decreasing and land cost also increases. To overcome this problem the use of multi-storeyed buildings is must. But such provisions increases self weight and live load along with earthquake forces. With in-crease in height stress, strain, deformation and displacement in the structure increases; which ultimately increases the cost of construction due to increased cross-sections of the elements. Bracing systems provide lateral stability to the overall frame-work.

Nonlinear static (pushover) analysis can provide an insight into the structural aspects, which control performance during severe earthquakes. The analysis provides data on the strength and ductility of the structure. Which cannot to be obtained by elastic analysis. By pushover analysis, the base shear versus top displacement curve of the structure, usually called capacity curve, is obtained.

Two key elements of performance based design procedure are demand and capacity. Demand is a representation of the earthquake ground motion. Capacity is a representation the structure's ability to resist the seismic demand. The performance is dependent on manner that the capacity is able to handle the demand. In other words, the structure must have the capacity to resist the demands of the earthquake such that the performance of the structure is compatible with the objectives of the design. .

Capacity:

The overall capacity of a structure depends on the strength and deformation capacities of the individual components of the structure. In order to determine capacities beyond the elastic limits, some form of non linear analysis, such as pushover procedure is required .This procedure uses a series of sequential elastic analyses, superimposed to approximate a force-displacement capacity diagram of the overall structure. The mathematical model of structure is modified to account for reduced resistance of yielding components. A lateral force distribution is again applied until additional components yield. This process is continued until the structure becomes unstable or until a predetermined limit is reached.

Methodology

The analysis procedures can be divided into linear procedures (linear static & linear dynamic) and nonlinear procedures (nonlinear static and nonlinear dynamic).The analysis procedures considered in this study are discussed below.

- **LINEAR STATIC ANALYSIS**

This method is perhaps the simplest procedure at disposal for a structural engineer to perform an earthquake analysis and achieve reasonable results. It is prescribed in any relevant code for earthquake analysis and is widely used especially for building and other common structures meeting certain regularity conditions. The method is also called "The Lateral Forced Method" as the effects of n earthquake are assumed to be the same as the once resulting from the statically transverse loadings. If the structural response is not significantly affected by contributions from higher modes of vibration it is reasonable to assume that with an appropriate set of inertia forces one may achieve a good approximation for the response. This is the basic concept of the "Equivalent Static Method".

- **LINEAR DYNAMIC ANALYSIS**

As a result of recent developments in desktop computing capabilities and seismic analysis software, there has been a shift among practicing engineers toward the routine application of linear dynamic analysis rather than linear static analysis for multistoried buildings. The application of linear dynamic analysis is favored due to its ability to explicitly account for the effects of multiple modes of vibration. Furthermore, the results of linear dynamic analysis can be used to determine whether significant inelastic behavior is likely to occur and thus can be used to determine whether more complex static or dynamic nonlinear analysis is warranted.

In general, for a multistory building it is necessary to take into account contribution from more than one mode. Each mode has its own particular pattern of deformation. For building applications, the dominant first mode shape resembles flexural deformation of a cantilever beam. The contribution of higher modes diminishes very quickly, and it is nearly always sufficient to consider the first three modes of vibration to obtain reasonably accurate result for most short – to medium – rise buildings. For high rise buildings, it may be necessary to consider more than three modes. The significant modes that contribute to response may be determined by selecting the number of modes such that their combined participating mass is at least 90% of the total effective mass in the structure.

NONLINEAR STATIC PUSHOVER ANALYSIS

Pushover analysis is a nonlinear static method of analysis. This analysis technique, also known as sequential yield analysis or simply "Pushover" analysis has gained significant popularity during past few years. It is one of the three analysis techniques recommended by FEMA 273/274 and a main component of Capacity Spectrum Analysis method (ATC-40). The static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The expectation is that the pushover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components.

ANALYTICAL MODELLING

DESCRIPTION OF THE SAMPLE BUILDING

The description of each building model is given below as fallows.

Model 1:Building modeled as bare frame. However, masses of the walls are included.

Model 2: Full infill masonry model, building has one full brick masonry wall of 230mm thick in all the storey including the ground storey.

Model 3: Building has one full brick infill masonry wall in all storeys except ground storey

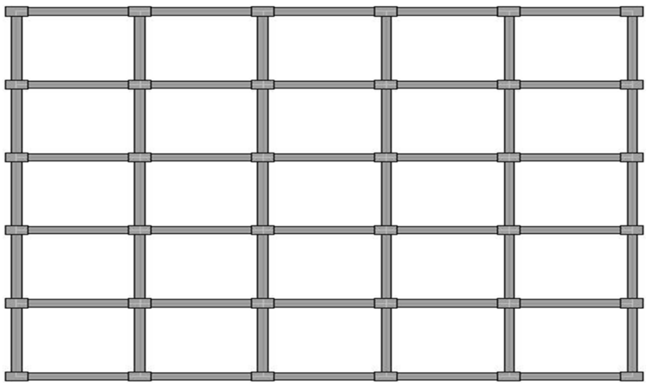
Model 4: Building model is as same as model 3, Further L type R.C shear walls (200mm thick) is provided at the corners in X and Y direction and a core wall at centre.

Model 5: Building model is as same as model 3, Further C type R.C shear walls (200mm thick) is provided in mid bay in longitudinal and transverse direction with central core wall.

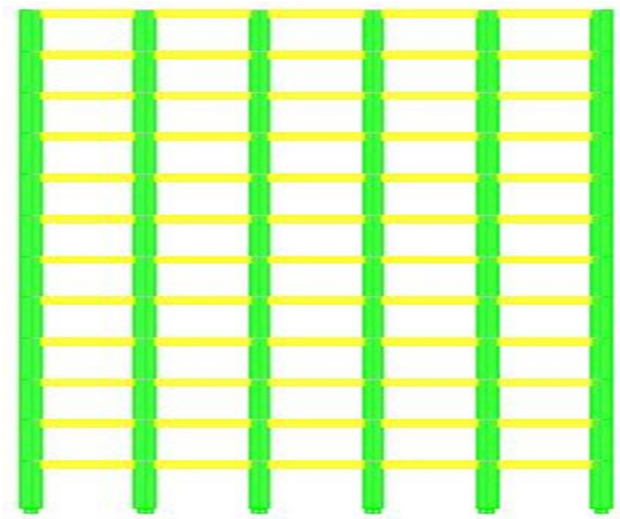
Model 6: Building model is as same as model 3, Further Planar R.C shear walls (200mm thick) is provided in mid bay in longitudinal and transverse direction with central core wall.

Model 7: Building model is as same as model 3, further concrete X bracings (230mm X 230mm thick) is provided at corners in longitudinal and transverse direction with central core wall.

Model 8: Building model is as same as model 3, further concrete X bracings (230mmX230mm thick) in C shaped is provided in mid bay in longitudinal and transverse direction along with central core wall.



Plan Layout



Elevation

Example building models studied

The plan layout of the reinforced concrete moment revisiting frame building is shown in figure 5.1. The elevation and 3D views of different building models are also shown above. For the study, the plan layout is kept the same for all the models. Each building model is of 21 storeys. The height of each storey is 3.5m except 11thstorey , height of 11th storey is 2m for all the different building models. The building is considered to be located in seismic zone V .In seismic weight calculations,50% of floor live load is considered. The input data given for all the different building models is listed below.

Design Data

Material Properties:

Young's modulus of (M30) concrete, E= 27.386x106kN/m^2

Density of Reinforced Concrete = 25kN/m^3

Modulus of elasticity of brick masonry= 3500x10^{3}kN/m^2

Density of brick masonry = 20kN/m^3

Assumed Dead load intensities:

Floor finishes = 1.5kN/m^2

Live load intensities:

Imposed loads = 3.5KN/ m^2

Member properties:

Thickness of Slab = 0.125m

Column size = (0.5m x 0.9m)

Beam size = (0.4m x 0.6m)

Thickness of wall = 0.23m

Thickness of concrete wall = 0.20m

Load Calculations:

Wall load on roof =1x0.23x20 = 4.6 KN/m

Wall load on each storey =2.9x0.23x20 = 13.34KN/m

Earthquake Live Load on Slab as per clause 7.3.1 and 7.3.2 of IS 1893 (Part-I) - 2002 is calculated as:

Roof (clause 7.3.2) = 0

Floor (clause 7.3.1) = 0.5x3.5 = 1.75kN/m2

IS: 1893-2002 Equivalent Static method

Seismic Data:

Zone factor as per (table 2 of IS 1893-2002)
= 0.36(Zone –V)

Importance factor I from (Table 6 of IS 1893-2002)
= 1.5(Important office building)

Response reduction factor R from

(Table 7 of IS1893-2002 =5.00(SMRF)

Soil type (Figure 2 of IS1893-2002) =Type II (Medium soil)

Equivalent static analysis procedure based on IS1893-2002

5.3.1 Fundamental time period (T)

Fundamental natural time period in seconds for moment resisting frame building without brick panels:

T = 0.075 h0.75

Fundamental natural time period in seconds for moment resisting frame building with brick infill panels:

$$T = \frac{0.09\,h}{\sqrt{d}}$$

For 21 storied frame building:

Time period in both longitudinal and transverse directions:

T = 0.075 x 42.50.75 = 1.248 sec

For 21 storied brick infill building:

Time period in longitudinal directions:

$$T = \frac{0.09 \times 42.5}{\sqrt{25}} = 0.765 \text{ se}$$

Time period in longitudinal directions:

$$T = \frac{0.09 \times 42.5}{\sqrt{20}} = 0.855 \text{ sec}$$

Spectral acceleration co-efficient (Sa/g)

For medium soil sites

$$\frac{sa}{g} = \begin{cases} 1 + 15\,T \\ 2.5 \\ 1.00/T \end{cases}$$

For 12 storied frame building:

$$\frac{sa}{g} = \frac{1.36}{T} = \frac{1.36}{1.248} = 1.089$$

For 12 storied brick infill frame building:

In longitudinal direction

$$\frac{sa}{g} = \frac{1.36}{T} = \frac{1.36}{0.765} = 1.777$$

In transverse direction

$$\frac{sa}{g} = \frac{1.36}{T} = \frac{1.36}{0.855} = 1.590$$

Design horizontal seismic coefficient (A_h)

$$A_h = \frac{Z}{2} * \frac{I}{R} * \frac{Sa}{g}$$

For 21 storied frame building:

$$A_h = \frac{0.36}{2} * \frac{1.5}{5} * 1.089 = 0.058$$

For 21 storied brick infill frame building:

In longitudinal direction

$$A_h = \frac{0.36}{2} * \frac{1.5}{5} * 1.777 = 0.096$$

In transverse direction

$$A_h = \frac{0.36}{2} * \frac{1.5}{5} * 1.590 = 0.058$$

Design Seismic Base Shear

Model No	Seismic Weight in KN	Design Seismic Base shear in KN(longitudinal dir.)	Design Seismic Base shear in KN(transverse dir.)
1	116237.7	6823.153	6823.153
2	116237.7	11158.82	9996.442
3	114126.3	10956.12	9814.862
4	113408.5	10887.21	9753.128
5	113236.2	10870.68	9738.313
6	111553.7	10709.16	9593.622
7	110865.3	10643.07	9534.417
8	111561.5	10709.9	9594.286

Design Seismic Base Shear for various models in longitudinal and transverse directions.

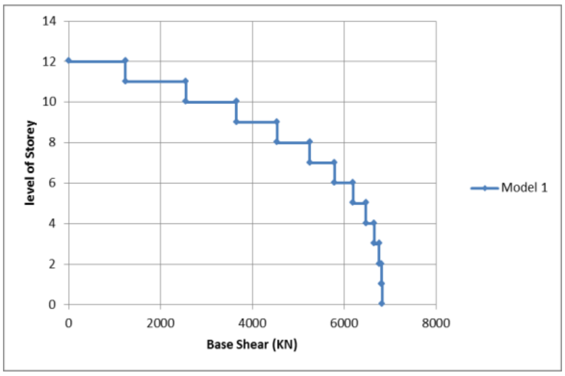
Distribution of lateral Design forces:

The lateral loads are distributed along the height of the building as per the fallowing expression

$$Q_i = V_B \frac{w_i\, h_i^{\,2}}{\sum_{j=1}^{n} w_j\, h_j\, 2}$$

Distribution of lateral design force for model 1

No. of Storey	Lateral load at Storey level Qx (KN)	Lateral load at Storey level Qy(KN)	Storey Shear Vbx(KN)	Storey Shear Vby(KN)
12	1234.541	1234.541	1234.541	1234.541
11	1321.372	1321.372	2555.913	2555.913
10	1094.845	1094.845	3650.757	3650.757
9	889.6019	889.6019	4540.359	4540.359
8	705.6437	705.6437	5246.003	5246.003
7	542.9699	542.9699	5788.973	5788.973
6	401.5806	401.5806	6190.554	6190.554
5	281.4756	281.4756	6472.029	6472.029
4	182.6551	182.6551	6654.684	6654.684
3	105.119	105.119	6759.803	6759.803
2	48.86729	48.86729	6808.671	6808.671
1	14.48245	14.48245	6823.153	6823.153



Base Shear diagram for model 1 along longitudinal direction.

RESULTS AND DISCUSSIONS

Most of the past studies on different buildings and unsymmetrical buildings have adopted idealized structural systems without considering the effect of masonry infill and concrete shear walls. Although these systems are sufficient to understand the general behaviour and dynamic characteristics of unsymmetrical buildings, it would be interesting to know how real buildings will respond to earthquake forces. For this reason hypothetical buildings, located on level ground having similar ground floor plan have been taken as structural systems for the study.

NATURAL PERIODS

All objects (including buildings and the ground) have a "natural period," or the time it takes to swing back and forth, from point A to point B and back again. As seismic waves move through the ground, the ground also moves at its natural period. When a building and the ground sway or vibrate at the same rate, they are said to resonate. When a building and the ground resonate it can mean disaster. This is because, as the building and ground resonate.

	IS CODE Method		ETABS Analysis	
Model No	Longitudinal	Transverse	Longitudinal	Transverse
1	1.25	1.25	1.6541	1.6541
2	0.765	0.855	0.5482	0.5482
3	0.765	0.855	0.7610	0.7610
4	0.765	0.855	0.4684	0.4684
5	0.765	0.855	0.4493	0.4493
6	0.765	0.855	0.4925	0.4925
7	0.765	0.855	0.5537	0.5537
8	0.765	0.855	0.5412	0.5412

Comparison of time period between IS code method and using ETABS for various building models

CONCLUSIONS

Fundamental natural period decreases when effect of infill wall, concrete shear wall and concrete bracings are considered.

As the soft stories Exist at Ground storey, the fundamental time period of the structure is increases; hence existence soft storey can make the structure to be Bare frame structures are having highest response reduction factor as compared to infill frame structures. It indicates that bare frame structures are capable

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