Evaluation of Lateral Load Pattern for RCC Irregular Building in Pushover Analysis

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ABSTRACT

Nonlinear static analysis using pushover procedures are becoming increasingly common in engineering practice for seismic evaluation of building structures. Various distributions of lateral forces are recommended in FEMA-356 (2000) to perform a pushover analysis. However, the use of these force distributions does not adequately represent the effects of varying dynamic characteristics during the inelastic response or the influence of higher modes. In this paper, four lateral load patterns are evaluated by comparison of the pushover response of two twelve storey (i.e., L-Shape & C-Shape) RCC moment frame buildings.

1. INTRODUCTION

Nowadays design for seismic forces is still governed by force-based design principles, to evaluate the inelastic deformation demand in structural members in structural earthquake engineering practice is to use performance-based seismic evaluation methods. A most commonly used and popular approach to evaluate these inelastic demands is a "pushover" analysis in which a model of the building is subjected to an inverted variant distribution of lateral forces.

2. NON-LINEAR STATIC ANALYSIS

In this analysis, the static loads are applied in an incremental order until it reaches to the ultimate state of the structure. The non-linearity in the analysis comes from the various components of the structure, are modeled using a non-linear mathematical model.

This section describes the main steps of this analysis in a general manner. The application of the non-linear static procedure involves four distinct stages as described below and illustrated in Figures:
1. Define the mathematical model with the non-linear force deformation relationships for the various components/elements.
2. Define a suitable lateral load pattern.
3. Idealize the force-displacement curve.
4. Calculate the performance of the building.

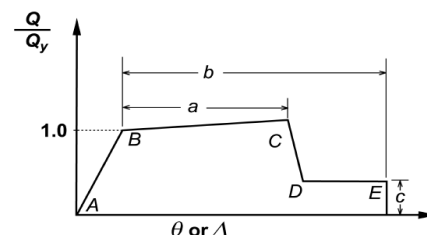### 2.1 NON-LINEAR FORCE DEFORMATION RELATIONSHIP

Figure 1. The generalized force deformation relation while exhibiting nonlinear behavior of a structural member

Figure 1 represents ductile behavior of a typical component, characterized by an elastic range (point A to point B on the curve). Followed by a plastic range (points B to E) it includes strain hardening (points B to C) and a strength-degraded range (points C to D) in which the residual force that can be resisted is significantly less than the peak strength, but still substantial. The residual resistance is observed until point E, where the final loss of resistance takes place. The performance of a structure is defined by the acceptance criteria to provide desirable information for evaluation or retrofit. Acceptance criteria for primary elements, that are required to have a ductile behavior, are typically within the elastic or plastic ranges between points B and C, depending on the performance level.
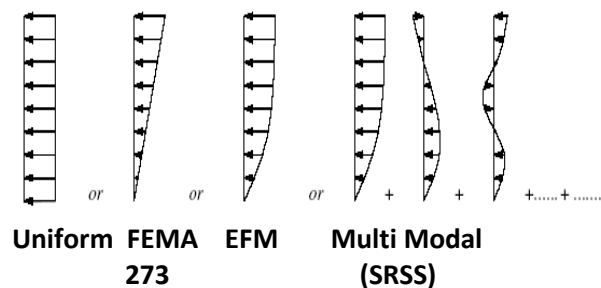

Uniform   FEMA   EFM   Multi Modal
        273   (SRSS)

Figure 2. Typical Load Patterns

3. LATERAL LOAD DISTRIBUTION

In this analysis, four different lateral load patterns were used to represent approximate distribution of inertia forces imposed on the structure during seismic event and these lateral load patterns are described as follows. Note that the storey forces are normalized with the base shear to have a total base shear equals to unity

3.1 'UNIFORM' LATERAL LOAD PATTERN

The lateral force at any storey is proportional to the mass at that storey, i.e.,

$$F_i = \frac{m_i}{\Sigma m_i} \qquad (1)$$

Where F_i: lateral force at i-th storey
    m_i: mass of i-th storey

3.2 'ELASTIC FIRST MODE' LATERAL LOAD PATTERN

The lateral force at any storey is proportional to the product of the amplitude of the elastic first mode and the mass at that storey, i.e.

$$F_i = \frac{m_i \varnothing_i}{\Sigma m_i \varnothing_i} \qquad (2)$$

Where $\varnothing_i$: amplitude of the elastic first mode at i-th storey

3.3 'FEMA-273' LATERAL LOAD PATTERN

The lateral load pattern defined in FEMA-273 is given by the following formula that is used to calculate the lateral force at any storey:

$$F_i = \frac{m_i h_i^k}{\Sigma m_i h_{ii}^k} \qquad (3)$$

Where h: height of the i-th storey above the base

    k: a factor to account for the higher mode effects
(k=1 for $T_1 \leq 0.5$ sec and k=2 for $T_1 > 2.5$ sec and varies linearly in between T_1 fundamental time period)

3.4 'MULTI-MODAL (OR SRSS)' LATERAL LOAD PATTERN

The lateral load pattern considers the effects of elastic higher modes of vibration for long period and irregular structures and the lateral force at any storey is calculated as Square Root of Sum of Squares (SRSS) combinations of the load distributions obtained from the modal analysis of the structures as follows:

1. Calculate the lateral force at i-th storey for n-th mode from Equation (5)

$$F_{in} = P_n * m_i * \varnothing_{in} * A_n \qquad (5)$$

Where P_n: modal participation factor for the n-th mode

    $\varnothing_{in}$: amplitude of n-th mode at i-th storey

A_n: pseudo-acceleration of the n-th mode SDOF elastic system

2. Calculate the storey shears,

$$V_{in}= \sum_{j\geq1}^{N} F_{jn} \qquad (6)$$

Where N is the total number of stories

3. Combine the modal storey shears using SRSS rule.

4. Back calculate the lateral storey forces, F_i, at storey levels from the combined storey shears,
V_i starting from the top storey.

5. Normalize the lateral storey forces by base shear for convenience such that

$$F_i'= \frac{F_i}{\Sigma F_i}. \qquad (7)$$

The contribution of first three elastic modes of modal analysis was considered to calculate the 'Multi-Modal (or SRSS)' lateral load pattern in this study. Elastic First Mode', 'FEMA-273' and 'Multi-Modal (or SRSS)' lateral load patterns represents the inverted triangular lateral load patterns. 'Uniform' lateral load patterns represent the extreme case for invariant lateral load distribution.

4. DESCRIPTION OF THE STRUCTURES

Figure 3.1 Elevation of 12 storey(L Shape) and 12 storey(C Shape) RCC Building
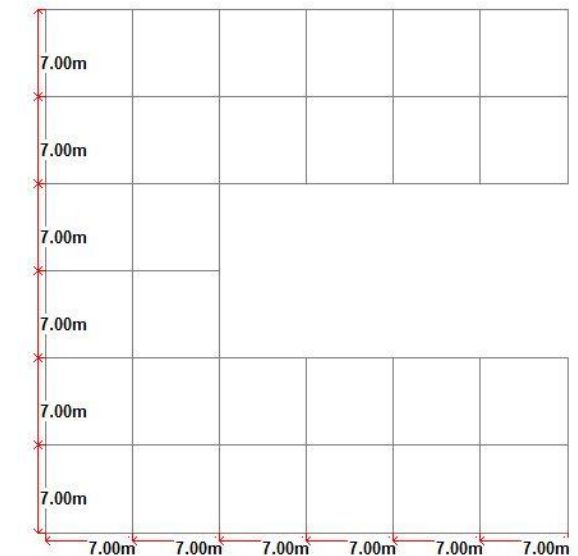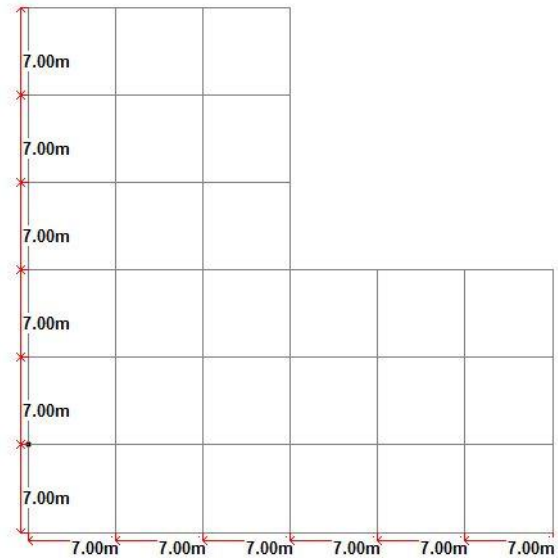
Fig 3.2 Plan of 12 storey (L SHAPE) and 12 storey(C SHAPE) RCC building

Two special moment resisting RCC frame buildings were selected as representative case studies to carry out the evaluation of different lateral load distributions. For the twelve storey reinforced concrete frame buildings analysis were performed using the SAP 2000 version 16, in particular the non-linear static analysis based on FEMA-356. Beams and columns elements are modelled for flexural and shear deformations, and axial deformation is considered in columns.

5. RESULTS AND DISCUSSIONS

This section presents a summary of the results obtained for the both structures, in particular, Global structure behavior and Storey displacements.

5.1 GLOBAL STRUCTURE BEHAVIOUR

The global pushover curves of analytical models are shown in figures 4.1 and 4.2. As mentioned before, four lateral load patterns are utilized in the nonlinear static analysis. Roof displacement versus base shear diagrams for each load pattern, which will be called as the "pushover curve" is plotted on the same graph to represent global behavior of the models.

        In view of the results obtained in the analysis, the deviation of the UNIFORM load pattern from the other lateral load cases increases as the number of stories increase, and also observed that the SRSS and FEMA 273 load patterns are shows consistent. EFM is in between the UNIFORM and SRSS.
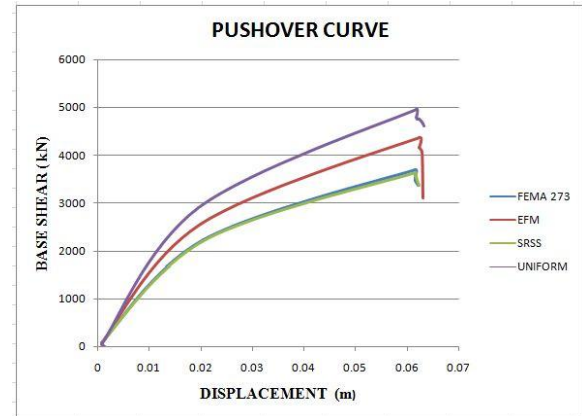
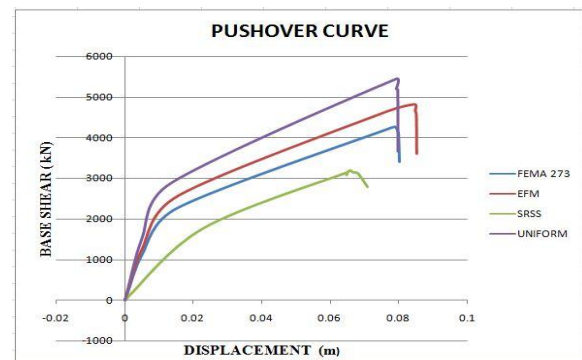Figure 4.1. Push over Curve for 12 Storey (L Shape) R/C building

Figure 4.2. Push over Curve for 12 Storey(C Shape) R/C building

5.2 STOREY DISPLACEMENTS

After performing the pushover analysis using the four load patterns, the obtained storey displacements are plotted on the same graph for each deformation level. Using these curves, comparisons and investigations on the results can be made. It is observed from the analysis results that the storey displacements obtained from the pushover analysis for four load patterns are generally close to each other for the first 2 deformation levels. As deformation level increases the UNIFORM load pattern shows the higher values as compared to the FEMA and SRSS load patterns for both 12 stories (L & C shape) in 3, 4, 5 deformation levels .EFM pattern give the lowest values**.**
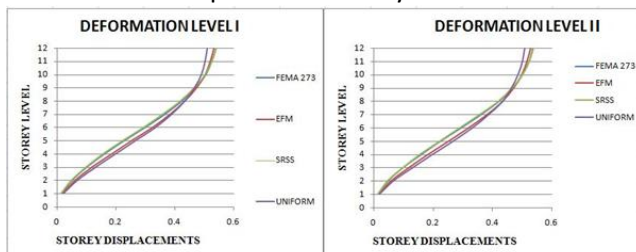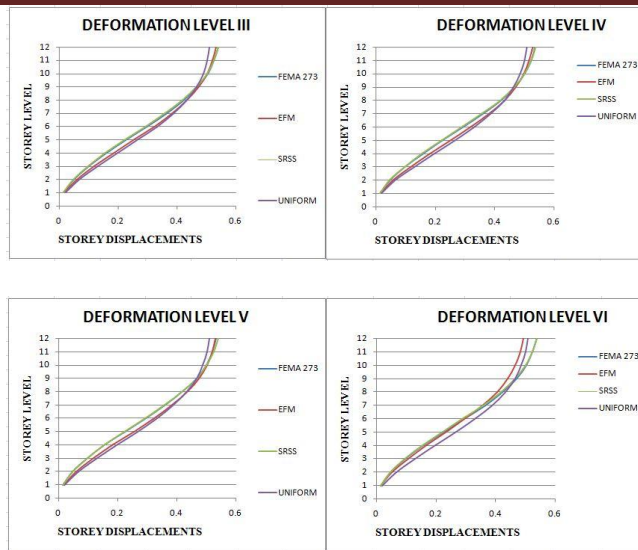
Figure 5. Storey displacements of 12 storey(L Shape) model for 6 deformation levels
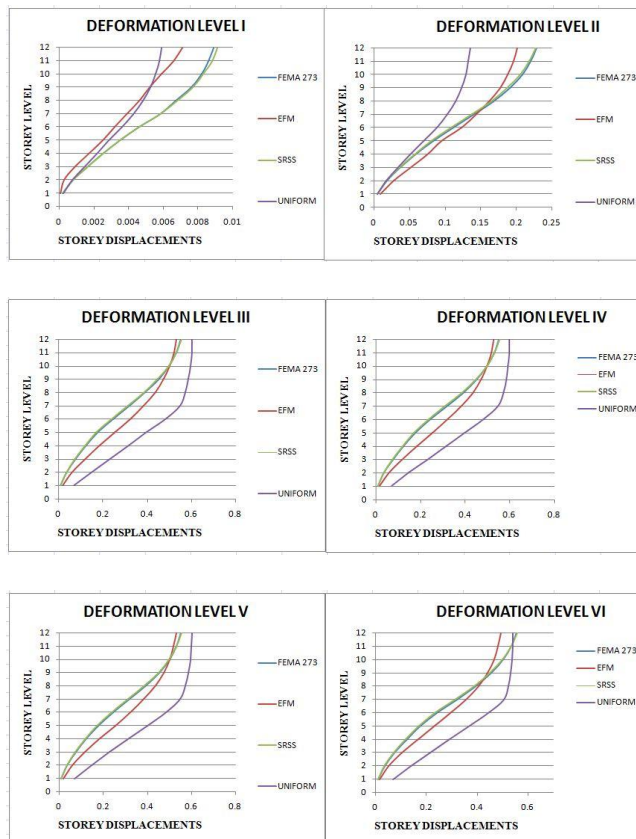

Figure 6. Storey displacements of 12 storey(C Shape) model for 6 deformation levels

6. CONCLUSIONS

The following conclusions have been arrived from the study.

1. The load patterns of 'FEMA-273' and 'Multi-Modal (SRSS)') gives almost similar results for both shapes (C & L buildings). The variation in between EFM and SRSS are also proportional with height of the building.

2. Considerable differences were observed in the seismic demand prediction of triangular lateral load patterns for high rise structure since the variation in the height-wise distribution of triangular lateral load patterns is significant for high-rise structures.

3. The storey displacement prediction from triangular lateral load patterns are mostly in between the predictions of 'Multi-Modal (SRSS)' and FEMA 273 lateral load patterns for both structures.

    Therefore, it would be better to estimate the storey displacement demand of structures by the average of the 'Multi-Modal (SRSS)' and 'FEMA 273' predictions.

4. In view of the results presented here, for pushover analysis of structures, the simplest lateral load pattern Elastic First Mode is recommended.

5. In view of the results presented here, the use of 'Uniform' load pattern is not recommended for all structures as it does not resemble a realistic distribution of inertia forces along the height as evidenced from the large discrepancies in the relevant results.

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