# A SIMPLIFIED PERFORMANCE-BASED SEISMIC DESIGN METHOD FOR RC BUILDINGS

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**Abstract**- The objective of this study is to develop a simplified seismic performance based design method which propose to reduce repetition cycles of the nonlinear process. The performance objectives are immediate occupancy, life safety and collapse prevention performance levels under the serviceability, design based and maximum considered earthquakes, respectively. The peak ground accelerations are estimated using earthquake data along the Sagaing Fault in Myanmar. The evaluated yield accelerations of twenty case studies of the seismic force resisting systems that complying with the performance objectives are documented as a data bank based on the current analysis and design procedure. Then, they are converted to a proposed yield acceleration equation using second-order polynomial regression. The proposed design method is introduced by using the yield acceleration as a design data bank. This method is also verified by the total of four buildings based on different number of stories and various plan configurations. By introducing, this proposed yield acceleration at the initial stage of analysis and design as a simplified method, some repetitions of the nonlinear process can be reduced.

**Keywords–** A Simplified Performance-Based Seismic Design, Performance Objectives, Yield Acceleration, Second Order Polynomial Regression, Repetition Cycles.

## I. INTRODUCTION

Performance-Based Seismic Design (PBSD) has been considered as an essential part of earthquake engineering. New developments and methods for the application of PBSD methodology are needed because most existing PBSD approaches tend to provide guidance and tools for the evaluation of seismic performance of a building that has already been designed [9]. In other words, more research work is needed for development of initial design because there is no guideline provided in current PBSD practice [7].

Several approaches mainly provide a suitable design base shear that accounts for higher mode effects, system overstrength, yield displacement, effective stiffness, viscous damping, effective period, or displacement ductility. However, a major shortcoming of these approaches is that the rest of design work, involving design of yielding members (such as beams in moment frames) and design of columns, is still based on conventional elastic and capacity design approach. Additionally, iteration during the design process is still required. Thus, practical methods based on these approaches are still under development and improvement [3].

## II. PROPOSED SIMPLIFIED METHOD

The Simplified Method is introduced by using yield accelerations. The proposed yield acceleration for the approach is described in detail.

### *A.* Proposed Yield Acceleration, $S_{ayT}$

In this study, the $S_{ayT}$ are indicated in term of the fundamental periods of buildings. Equations are derived using second-order polynomial regression based on the average evaluated yield acceleration. The second-order polynomial regression is shown in Equation 1.

$$S_{ayT} = a_0+a_1T+a_2T^2 \quad (1)$$

where, $S_{ayT}$ = proposed yield acceleration

T = fundamental period

$a_0$, $a_1$, and $a_2$ = coefficients

The coefficients can be determined by using the following set of equations.

$$(n)a_0 + (\sum_{i=1}^{n} T_i)a_1 + (\sum_{i=1}^{n} T_i^{\,2})a_2 = \sum_{i=1}^{n} S_{ayT\ i}$$

$$(\sum_{i=1}^{n} T_i)a_0 + (\sum_{i=1}^{n} T_i^{\,2})a_1 + (\sum_{i=1}^{n} T_i^{\,3})a_2 = \sum_{i=1}^{n} T_i S_{ayT\ i}$$

$$(\sum_{i=1}^{n} T_i^{\,2})a_0 + (\sum_{i=1}^{n} T_i^{\,3})a_1 + (\sum_{i=1}^{n} T_i^{\,4})a_2 = \sum_{i=1}^{n} T_i^{\,2} S_{ayT\ i}$$

where, n= number of set of data

### *B.* The Proposed Simplified Seismic Design Method

A proposed simplified seismic design method using $S_{ayT}$ is shown in Figure. The $S_{ayT}$ is used in this method.

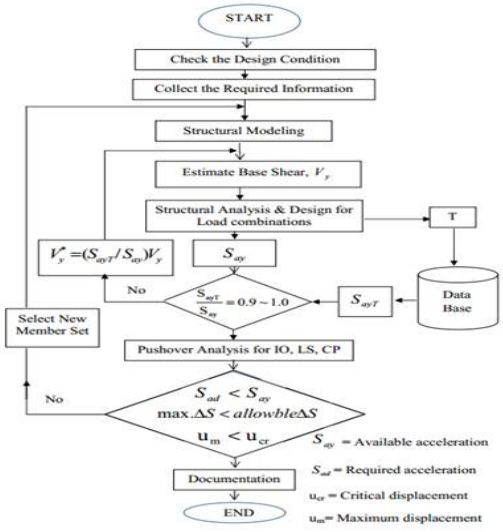



**Fig.1 The Proposed Simplified Seismic Design Method**

### C. Algorithm of Proposed Seismic Method

1. Checking of design condition and obtaining the design requirement are required. Then, the structural model was developed.
2. Estimation of the base shear using R factor according to the UBC-97 and analysing of the model were included. Then the member design was done based on moment, shear, and axial force from the analysis and the $S_{ay}$ was calculated. The required data for this equation can be obtained from the analysis.
3. Checking of the $S_{ay}$ with the $S_{ayT}$ from the proposed Equation 6 was required. If they are not nearly equal, go to the step-2 to determine new structural member set by adjusting R factor for the based shear. Then calculation of $S_{ayT}$ and comparison with the $S_{ayT}$ was done until they are almost equal.
4. The pushover analysis was done to check the three limit states such as IO, LS, and CP.
5. To check the IO level, the minimum required Sad from the performance point at under SE was obtained and with the evaluated $S_{ay}$ calculated from the step-3 was compared. To check the LS and CP levels, the story drifts are calculated using the structural deformations under DBE and MCE. Then, they were compared with the maximum drift limitations. If one the three limit states check is not acceptable, it was required to repeat the step-4 by increasing stiffness to upgrade yield acceleration until they were acceptable.

## III. METHODOLOGY AND MODEL DEVELOPMENT

***A.*** Seismic Hazard Analysis for Mandalay City Area

In considering earthquake hazard environment of Mandalay City, the probability of exceedance in 50 years is 50% for the operational earthquake level (MOE), 10% for the design basic level earthquake (DBE) and 2% for the maximum considered earthquake level (MCE) [4].

$$T = \frac{1}{1-(1-p)^{1/n}} \qquad (2)$$

where, p = Probability of exceedance in 50years
T= Return period
n=50 years

Magnitude probability for Guntenberg-Richter law of Equation [1].

$$F_M(m) = \frac{1-10^{-b(m-m_{min})}}{1-10^{-b(m_{max}-m_{min})}} \qquad (3)$$

where $m_{max}$ the maximum and $m_{min}$ the minimum earthquakes.

$$P(M=m_j) = F_M(m_{j+1}) - F_M(m_j) \qquad (4)$$

where $m_j$ are the discrete set of magnitude, orderd so that $m_j < m_{j+1}$.

**TABLE I**
**. MAGNITUDE PROBABILITIES FOR SAGAING FAULT**

| $m_j$ | $F_M(m_j)$ | $P(M=m_j)$ |
|---|---|---|
| 5 | 0 | 0.4381 |
| 5.25 | 0.4381 | 0.2464 |
| 5.5 | 0.6845 | 0.1385 |
| 5.75 | 0.823 | 0.0779 |
| 6 | 0.9009 | 0.0438 |
| 6.25 | 0.9447 | 0.0246 |
| 6.5 | 0.9693 | 0.0139 |
| 6.75 | 0.9832 | 0.0078 |
| 7 | 0.991 | 0.0044 |
| 7.25 | 0.9954 | 0.0025 |
| 7.5 | 0.9978 | 0.0014 |
| 7.75 | 0.9992 | 0.0008 |
| 8 | 1 | 0 |

Estimation of peak ground acceleration is based on earthquake data from the Sagain Fault [2].

$$\ln(PGA) = -0.152+0.859Mw-1.803\ln(R+25) \qquad (5)$$

where, PGA = Peak ground acceleration
Mw = Moment magnitude
R = Source Distance

**TABLE II**
**ESTIMATE SEISMIC HAZARD ANALYSIS**

| Earthquake Type | SE | DBE | MCE |
|---|---|---|---|
| Return Period | 72 | 475 | 2475 |
| Moment magnitude | 6.5 | 7.325 | 7.875 |
| Acceleration at the base rock (g) | 0.166 | 0.331 | 0.508 |
| Amplification (Cg) | 1.2 | 1.2 | 1.2 |
| **Acceleration at the ground surface (g)** | **0.2** | **0.4** | **0.6** |

### *B.* Performance Criteria

**TABLE III**
**PERFORMANCE CRITERIA**

| Seismic Hazard Level | Performance Level | Probability/year | Critical Limit |
|---|---|---|---|
| SE | IO | 50%/50yr | 1% |
| DBE | LS | 10%/50yr | 2% |
| MCE | CP | 2%/50yr | 4% |

### *C.* Case Study for Building Configurations

The present research is a study of nonlinear behaviors of irregular concrete framed buildings which are divided into four groups based on bay spans and length to width ratios. Each group consists of five case studies and total of twenty case studies are considered.

The case studies of Group 1, 2, 3 and 4 are prepared based on 20 feet span and length to width ratios of 1.25 to 2 with different number of stories. The frames are configured with all bays 20 feet wide and each storey 11 feet high. The dimensions of buildings for case studies included are shown in Table IV.

**TABLE IV**
**BUILDINGS CONFIGURATIONS OF CASE STUDIES**

| Case | L/B | L (ft) | B (ft) | H (ft) | No of Storey |
|---|---|---|---|---|---|
| 1 | 1.25 | 100 | 80 | 11 | 3,5,7.9,12 |
| 2 | 1.5 | 120 | 80 | 11 | 3,5,7,9,12 |
| 3 | 1.75 | 140 | 80 | 11 | 3,5,7,9,12 |
| 4 | 2 | 160 | 80 | 11 | 3,5,7,9,12 |

### *D.* Performance Evaluation

The moment resisting frames are designed as the lateral load resisting elements of frame structure. Analytical results such as hinge formation maximum considered earthquake are shown from Fig. 2.

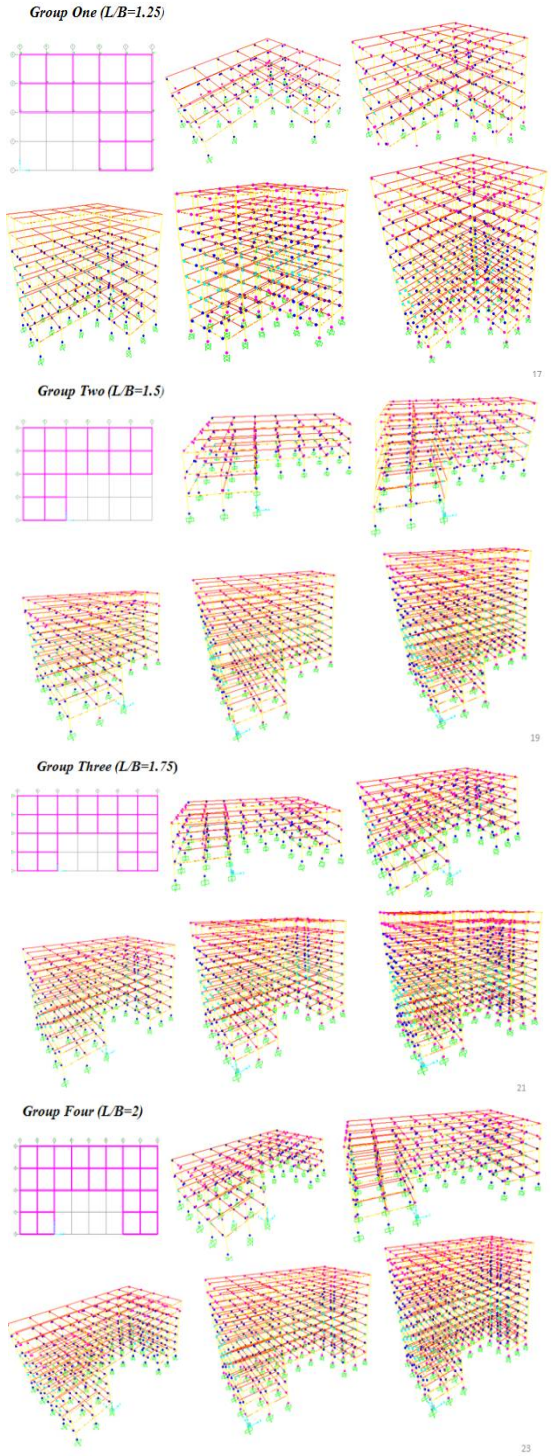



**Fig. 2 Summary of Case Studies**

### *E.* Evaluated Yield Acceleration

The Evaluated $S_{ay}$ for Four Group based on performance based seismic design of RC building. The minimum requirements of $S_{ay}$ for Immediate Occupancy are shown in Table V.

**TABLE V**
**SUMMARY OF EVALUATED, $S_{AY}$**

| No. of Storey | 3 | 5 | 7 | 9 | 12 |
|---|---|---|---|---|---|
| **T** | **0.413** | **0.606** | **0.78** | **0.942** | **1.168** |
| $S_{ay}$ for Group 1 | 0.672 | 0.475 | 0.431 | 0.348 | 0.283 |
| $S_{ay}$ for Group 2 | 0.67 | 0.467 | 0.384 | 0.339 | 0.272 |
| $S_{ay}$ for Group 3 | 0.658 | 0.461 | 0.375 | 0.332 | 0.251 |
| $S_{ay}$ for Group 4 | 0.656 | 0.457 | 0.373 | 0.323 | 0.249 |
| **Average $S_{ay}$** | **0.664** | **0.465** | **0.391** | **0.334** | **0.263** |
| Standard deviation $x10^{-3}$ | 8.16 | 7.83 | 27 | 10 | 16 |

The average $S_{ay}$ and time period T are considered as a proposed yield acceleration for the proposed design method.

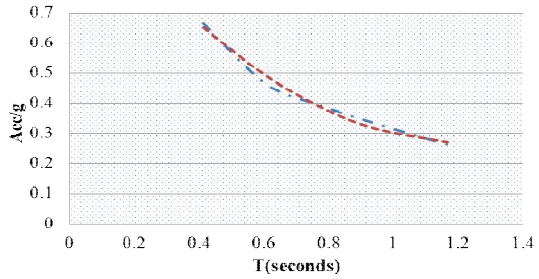



**Fig. 3 Proposed $S_{ayT}$ in Term of T**

Proposed SayT for proposed performance-based seismic design method

Evaluated Say by using performance-based seismic design data bank

### *F.* The Proposed Equation Using Yield Acceleration with SF $\geqslant$ 1

In this approach, the proposed equation is determined by using on yield accelerations based on the minimum safety factor of 1.0 for IO level. The proposed yield acceleration is shown in equation 6.

$$S_{ayT}=1.135-1.406T-0.571T^2 \qquad (6)$$

### *G.* Computation of an Error Analysis

The computation of an error analysis is for the proposed yield acceleration. The correlation coefficient is usually used to check whether the proposed yield acceleration is excellent fit or not for the proposed performance-based seismic design method for reinforced concrete buildings.

$$R = S_{xy} / (S_{xx}^{0.5} \times S_{yy}^{0.5}) \qquad (7)$$

where R = the correlation coefficient =0.956

$$S_{xx} = T_i^2 - n\overline{T}^2$$

$$S_{sy} = T_i S_{ayi} - n\overline{T}\,\overline{S_{ay}}$$

$$S_{yy} = S_{ayi}^2 - n\overline{S}_{ay}^2$$

The correlation coefficient R=0.956 indicate that the proposed yield acceleration is excellent fit.

**H. Range of Applicability**

1.Speial concrete moment resisting frame with fundamental period $0.413 \leq T \leq 1.168$ seconds.
2. Irregular structure located in seismic zone 4.
3. The L/B ratio must be between 1.25 to 2.

## IV. VERIFICATION

The four verification examples are considered according to various number of stories and plans.

### *C.* Verification for Different Numbers of Storey

Verification Example 1, (135'x85'x55'), L/B=1.59

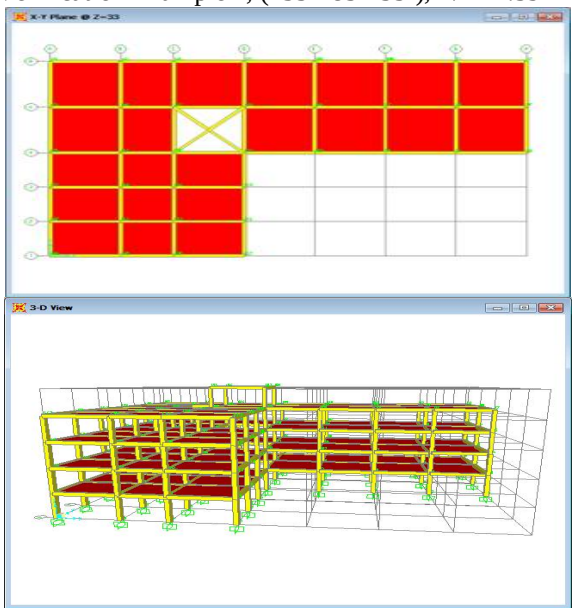



**Fig.4 Plan and 3D View of Four Storeyed Building**

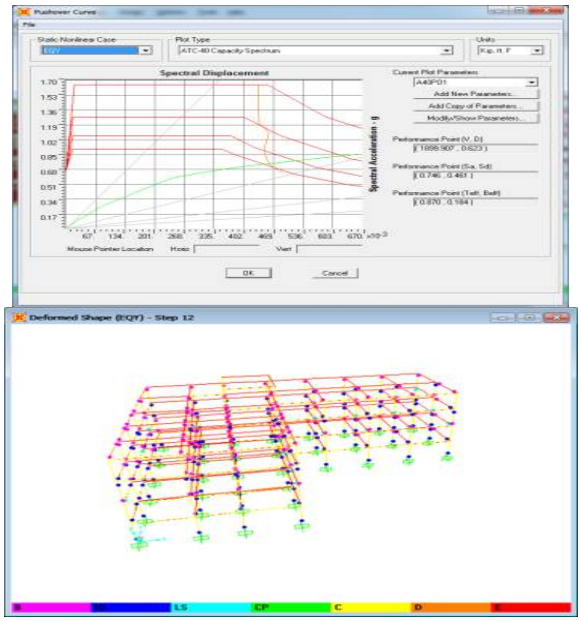



**Fig. 5 ATC-40 Capacity Spectrum Curve and Hinge formation for MCE**

The performance level of structure in Maximum Considered Earthquake is shown in Fig. 5. This spectrum curve points out the performance point at Life Safety level, the spectral acceleration 0.746g and spectral displacement 5.532in. It is occurred between step 12 and 13.

Verification Example 2, (114'x72'x77'), L/B=1.58

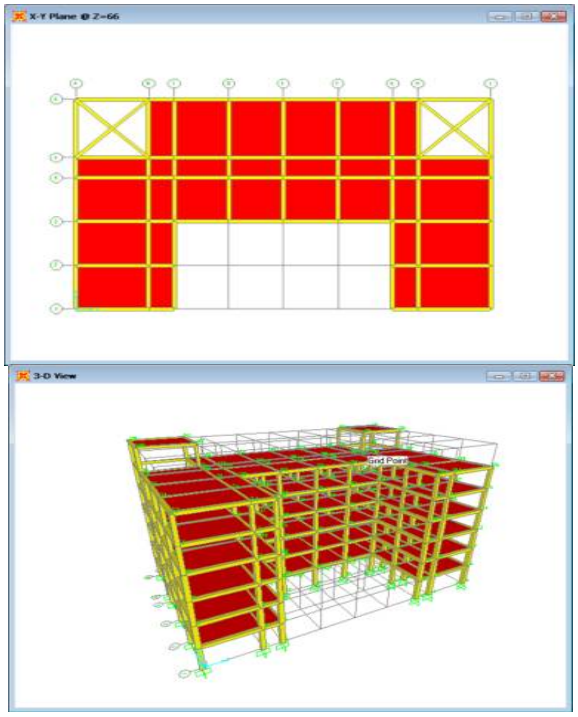



**Fig. 6 Plan and 3D View of Six Storeyed Building**

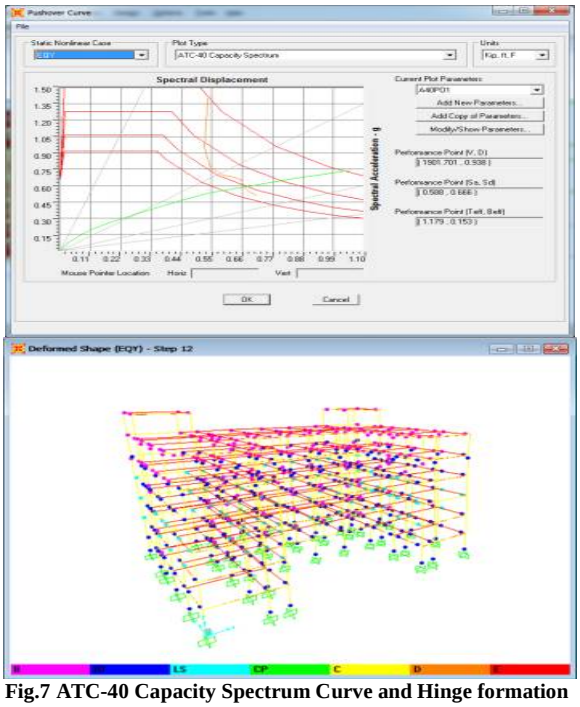



**Fig.7 ATC-40 Capacity Spectrum Curve and Hinge formation for MCE**

The performance level of structure in Maximum Considered Earthquake is shown in Fig. 7. This spectrum curve points out the performance point at Life Safety level, the spectral acceleration 0.588g and spectral displacement 7.992in. It is occurred between step 12 and 13.

Verification Example 3, (115'x70'x99'), L/B=1.64

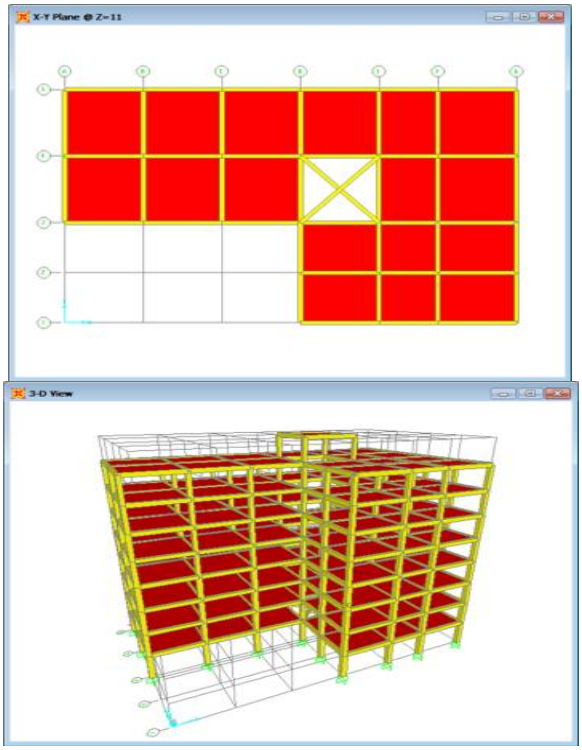



**Fig. 8 Plan and 3D View of Eight Storeyed Building**

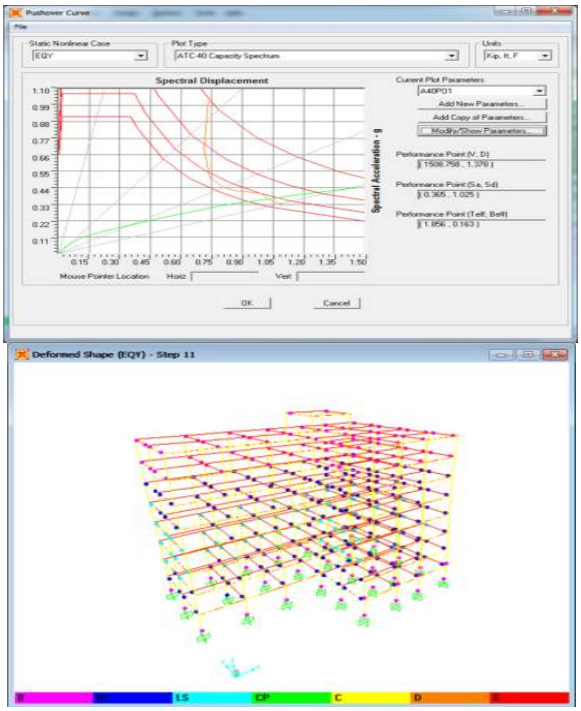



**Fig.9 ATC-40 Capacity Spectrum Curve and Hinge formation for MCE**

The performance level of structure in Maximum Considered Earthquake is shown in Fig. 9. This spectrum curve points out the performance point at Life Safety level, the spectral acceleration 0.365g and spectral displacement 12.3in. It is occurred between step 11 and 12.

Verification Example 4, (114'x87'x121'), L/B=1.31

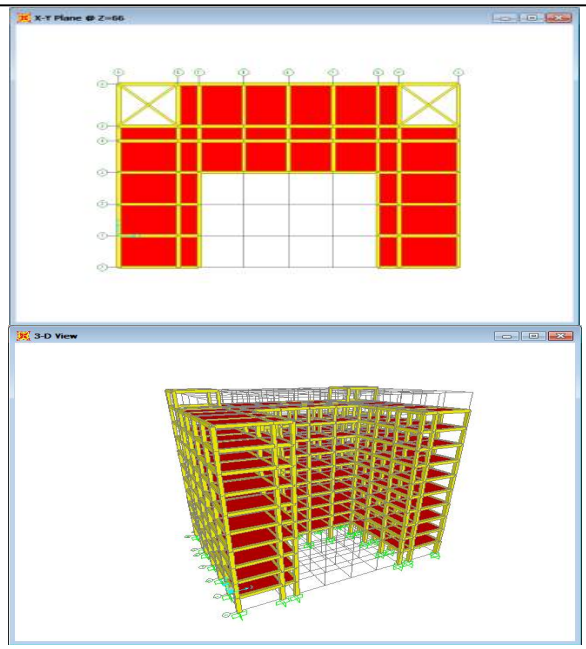



**Fig. 10 Plan and 3D View of Ten Storeyed Building**

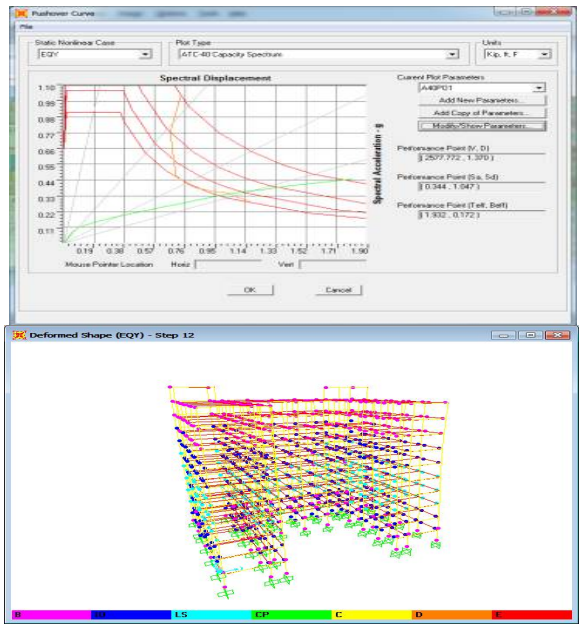



**Fig.11 ATC-40 Capacity Spectrum Curve and Hinge formation for MCE**

The performance level of structure in Maximum Considered Earthquake is shown in Fig. 11.This spectrum curve points out the performance point at Life Safety level, the spectral acceleration 0.344g and spectral displacement 12.564in. It is occurred between step 12 and 13.

### *D.* Summary of Analytical Results for Different Number of Storey

The evaluated $S_{ay}$ based on the analytical results of each case study are shown in Tables VI. The minimum requirements of for IO and maximum interstory drift limitations for LS and CP are also checked.

**TABLE VI**
**SUMMARY OF PERFORMANCE EVALUATION OF THE VERIFICATION EXAMPLES**

| No of Storey | 4 | 6 | 8 | 10 |
|---|---|---|---|---|
| Period, T | 0.606 | 0.78 | 0.942 | 1.09 |
| Max Interstory drift% at SE% | 0.71 | 0.83 | 0.74 | 0.86 |
| Allowable Interstory drift,% | 1 | 1 | 1 | 1 |
| Check for IO | Pass | Pass | Pass | Pass |
| Max Interstory drift at DE,% | 1.25 | 1.27 | 1.42 | 1.39 |
| Allowable Interstory drift,% | 2 | 2 | 2 | 2 |
| Check for LS | Pass | Pass | Pass | Pass |
| Max Interstory drift at MCE,% | 1.68 | 1.79 | 2.28 | 1.95 |
| Allowable Interstory drift,% | 4 | 4 | 4 | 4 |
| Check for CP | Pass | Pass | Pass | Pass |

**TABLE VII**
**COMPARISON OF YIELD ACCELERATION FOR DIFFERENT NUMBERS OF STOREY**

| No. of Story | 4 | 6 | 8 | 10 |
|---|---|---|---|---|
| Period, T | 0.606 | 0.78 | 0.942 | 1.094 |
| **Proposed $S_{ay}$** | **0.492** | **0.385** | **0.317** | **0.28** |
| Evaluated $S_{ay}$ | 0.512 | 0.411 | 0.332 | 0.295 |
| Proposed $S_{ay}$/Evaluated $S_{ay}$ | 0.96 | 0.937 | 0.955 | 0.949 |

The four verification examples for different numbers of storey are selected. They are irregular buildings with L/B ratios between 1.3 and 1.64.

### C. DISCUSSION FOR DIFFERENT NUMBERS OF STOREY

As a result, it was found that the number of repetitions required for the analysis and design process to satisfy the three limit states are five times for Four storeyed building, six times for the Six and Eight storeyed buildings, and eight times for Ten storeyed building when the general design procedure is used.

However, when the simplified approach was used, the repetitions are decreased to one time for Four, Six and Eight storeyed buildings, and two times for the Ten storeyed building. The comparison of required numbers of repetition for the both methods is shown in Fig. 12.

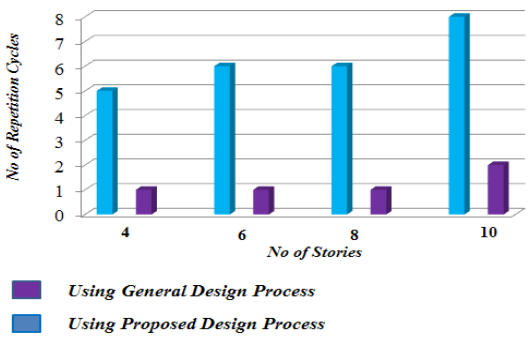



**Fig. 12 Comparison of Repetition Cycles**

In summary, the number of repetitions required for the simplified method is less than that of using the general procedure. In addition, there is no much L/B ratio effect on the proposed method as long as the building is irregular.

## CONCLUSIONS

In this study, the proposed yield acceleration $S_{ayT}$ or $V_y$ that will satisfy the basic safety objectives including acceptable story drift limits for LS, CP and minimum required $S_{ay}$ for IO. Therefore, the yield acceleration $S_{ay}$ are evaluated for concrete moment frames based on the total of twenty case studies. The yield acceleration, $S_{ay}$ decreases substantially with increased building height.

The proposed simplified seismic performance based design method is developed by using evaluated yield acceleration, $S_{ayT}$. The repetition cycles of nonlinear analysis and design process can be reduced by using the proposed method.

According to the documentations of the verification examples, when the general design procedures are used, the numbers of repetitions required for analysis and design process is greater than or equal to five times. However, when the proposed design procedure are used, the number of repetitions cycles is less than or equal to two times. There is no much L/B ratio effect on the proposed method as long as the building is irregular.

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