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Efficiency of Shear Wall Location on Reinforced Concrete Buildingsin Ethiopia under Seismic Excitation

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Abstract: Shear walls play a key role in the lateral-load resistance process in high-rise buildings, as well as resisting the lateral loads generated by seismic forces. This paper examines the effect of shear walls in rectangular, L, and U type and their locations in RC building under seismic excitation. Seismic impact is primarily concerned with structural protection, particularly during the earthquake and also with high-rise buildings, ensuring adequate lateral rigidity to withstand seismic loads is very critical.

Rectangular, L and U shaped shear walls was analyzed and compared at various location using non-linear analysis. For analysis three models were considered with various above said shapes at different locations of high rise buildings in high seismic regions of Ethiopia. The structure's seismic capacity and demand were analyzed using non-linear pushover analysis based on displacement. Regular in plane and elevation building for this investigation G+7 was targeted to estimate the structure's seismic response and resistance capacity

Non-linear dynamic time-history analysis was performed for comparison, by applying 30 artificially generated ground motion for all sample buildings. The capacity curves of the structures, as derived by pushover analysis were compared for buildings with rectangular, L and U shape shear walls using Seismo-Struct software. Also, the performance levels of structures are estimated and compared using Seismo-Struct software to perform non-linear dynamic time-history analysis.

Keywords: Seismo-Struct software, Shear wall, High rise RC structures, Seismic response, non-linear dynamic time-history analysis, non-linear static pushover analysis.

I. INTRODUCTION

1.1 General: Earthquake is the most dangerous natural hazards that effect into great loss of life and livelihood.Generally earthquake takes place due to rupture of bed-rock under the surface of the earth. Earthquake forces are accidental and sudden in natural hazards, which are generated by sudden release of energy in earth's crust. Earthquakes are associated with the release of stored energy from the fault region that spreads out in all directions in the form of seismic waves or forces that travel through the surface of the Earth.

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Therefore, Earthquake loads are modeled to identify the behavior of structure with a clear surety that hazards is to be minimized. In this paper an analytical study was conducted to know the behavior of various shear wall shapes situated at different locations of structure using non-linear static and dynamic analysis. Non-linear time-history analysis and Non-linear static pushover analysis has been performed for seven story regular structure in Seismo-struct. In case of time-history analysis artificial accelerogram was generated from Seismo-Artif software and taken into consideration to know the response of the structure. To know the behavior of structure top story displacement for regular structure has been compared.

1.2 Seismic actions

The seismic activity is being considered mainly for purposes of development. It should be based on predicting the ground movement and lateral movement predicted in the future at each seismic zone site, i.e. it should be based on the evaluation of the seismic hazard. Seismic risk was usually represented by a curve showing the excessive probability of a certain seismological parameter(normally assuming a rock ground condition).Unplanned vertical irregularity structures are more critical than irregular plan structures [6].

1.3 Method of analysis

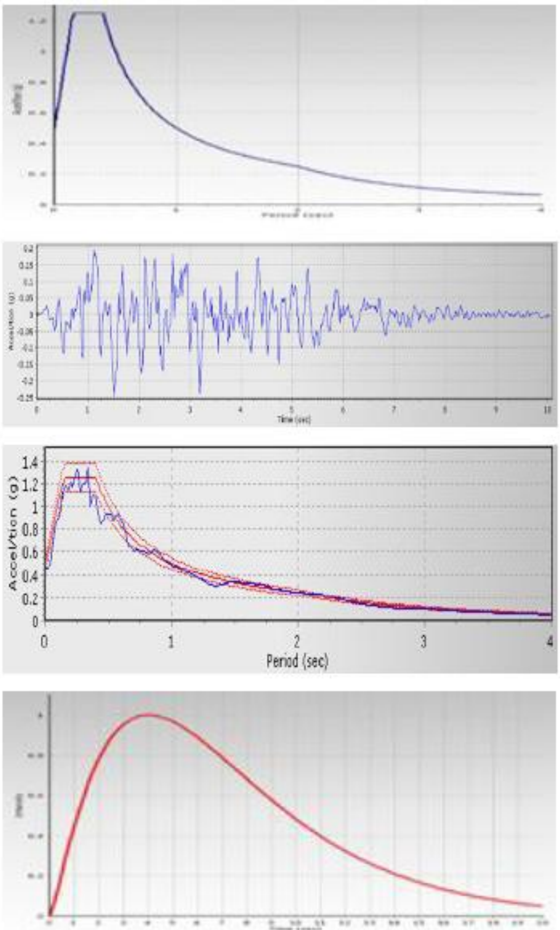
A structural analysis was needed under seismic performance evaluation to evaluate the demands of force and displacement in different components of the structure. Seismic output of framed reinforced concrete (RC) construction can be evaluated with various analytical tools that can be loosely categorized as linear elastic procedures or non-linear or inelastic analytical procedures. Since the reinforced concrete structures generally go in the inelastic range due to seismic loading, inelastic method predicts the performance of the structures in a much better and realistic way than the linear elastic method. By identifying failure modes and the potential for progressive collapse, inelastic analytical method helps us understand the actual behavior of structures. Inelastic analytical procedures basically include inelastic analysis of time-history and inelastic static analysis, also known as pushover analysis.Inelastic approach of evaluating the quality of buildings is primarily non-linear static pushover analysis and non-linear dynamic analysis of time-history.As a consequence, non-linear dynamic time-history analysis and non-linear static pushover analysis were used to determine the seismic demand and capability of the sample buildings. In the non-linear static analysis of asymmetric buildings, the torsion effects are considered by specifying the target displacement before failure for each resisting component.

Fragility Curve Development

Fragility curve analysis is an effective tool for risk assessment and vulnerability of structural systems. The fragility curve, which was developed from the structure capacity or behavior model and a suite of ground motions, is a graphical representation of the seismic vulnerability of a structure. To address the physical aspects of the seismic performance of buildings with different shear wall location, fragility functions or damage probability matrices was developed and used for evaluation purposes.

1.4 Earthquake Records

There are three ways to obtain earthquakes or lateral ground-motion records (time records) for measurement purposes via advanced structural engineering research. [1]. Artificial records of acceleration are choices for producing signals that satisfy technology requirements that are not related to the generation and propagation of earthquake stress wave physics. Accelerogram can be represented by random motion theory mathematically. It has proposed stationary and non-stationary random processes [2]. The generation of synthetic accelerogram requires three elements: I power spectral density, (ii) random phase angle generator, and (iii) envelope function. Indeed, it is possible to calculate the simulated motion as the sum of several harmonic excitations. The reliability of the artificial movement is thus evaluated by means of an iterative algorithm that tests the frequency content.



a. Acceleration vs Period (spectrum)
b. Acceleration vs Time (synthetic accelerogram)
c. Acceleration vs Period (Response spectra)
d. Intensity vs Time (envelope shape)

1.5 Seismic zoning for Ethiopia

The probabilistic approach is credited for the initial attempts in producing the first seismic hazard map of Ethiopia. For the purpose of this standard, the country has been subdivided in accordance with figure D1, D2 and Table D2 into seismic zones, depending on the local hazard. The hazard map is preliminary and is processed from instrumentally recorded earthquake catalogue.

Table 1.1. D1: Bedrock Acceleration Ratio α0

Zone	5	4	3	2	1	0
$\alpha_0 = a_g/g$	0.2	0.15	0.10	0.07	0.04	0

The hazard is described in terms of a single parameter for the application of this standard, i.e. the value ag of the effective peak ground acceleration in firm soil rock, hence the fourth "design ground acceleration." The model ground acceleration selected for seismic area in Figure D1 and D2 Table corresponds to a 475-year reference return period (10 percent chance of excess in 50 years). An important factor I equal to 1.0 is assigned to this reference return period.

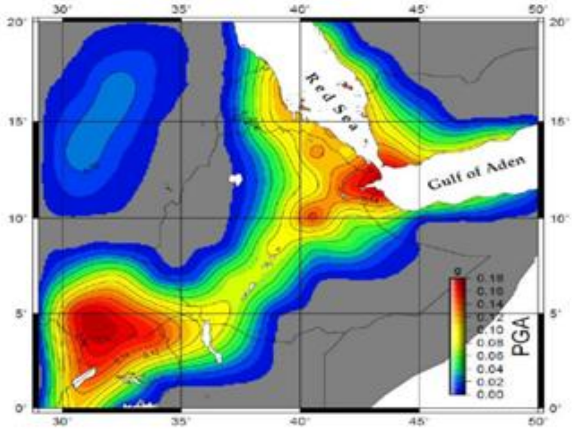


Figure 2.0 D1 seismic hazard map along the

II. METHODOLOGY

2.1 Methods to Perform Non-linear Analysis

Seismic performance of buildings depends on uncertainties. The major uncertainties are in the material properties of concrete and steel, time-history data, building geometries etc. Due to the uncertainties involved the seismic performance evaluation requires probabilistic approaches rather than deterministic approaches.

Capacity: The strength and deformation capacities of the structural individual components are decides the overall capacity of a structure. To find the capacities of the structures beyond the elastic limits means push over analysis is required in the form of nonlinear analysis methods. This method uses to develop the approximate force displacement capacity diagram for overall in superimposed also analyze the series of sequential elastic for the structures.

Demand (Displacement): horizontal displacement patterns in structures it may vary with time during earthquake. The lateral displacement of ground based on the impact of earthquake in particular time period. Tracking this lateral movement or motion of the structures at every time of earthquake is impractical.

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For that non-linear methods easy and more direct to identify the set of lateral displacements as a design condition.

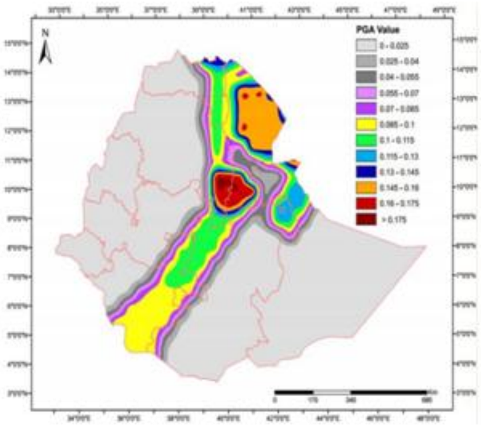


Figure 2.1 Ethiopia's seismic hazard map interms of peak ground acceleration

Performance: A reliability test verifies that structural components are not over beyond the acceptable limits of the structural performance criterion for the forces and displacements indicated by the displacement application.

2.2 Modeling and Analysis of Building with Shear Wall

The structural model of the building which represents the building type & structural system are selected to demonstrate the effect of locating shear wall in different locations. The buildings are assumed to cover the same plan area of 30.5x18.3 meter as shown in figure 2.1. The sample building has four cases of study based on shear wall location for rectangular, L and U shape shear wall. Generally, we have 10 types of case study for this paper work.

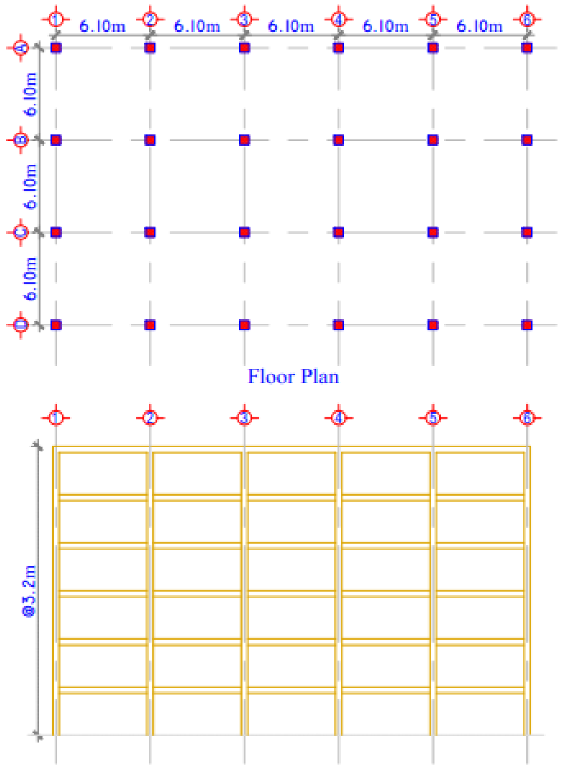


Figure 2.1 Sample building structure used for this study (dimension is in m)

The analysis of a structural building with shear walls subjected to horizontal seismic and vertical load is essentially a three-dimensional problem. For this paper we have considered G+7 building model with three different shear wall types positioning at external edge, middle and center of the building floor plan. The building is assumed as a typical plan of G+ 7 floors with a 3.2m height for each story. It is also assumed that the building is regular in plan and elevation. The building is fixed at the base and the sections of structural elements are square and rectangular in the sample model. Each sample buildings are modeled and analyzed according to the EBCS seismic design requirements and EURO codes. The building is assumed as hospital located in high seismic zone, which is zone 4 according to EBCS-8 [4, 5]. The structural frames are modeled with G+7 regular building by positioning of three different type of shear wall at ten different locations using ETABS software.

2.3 Designing of sample building models

The sample building has a moment resisting RC elements with shear walls and is supposed to be in a high-seismicity region of Ethiopia, which is designed according to EBCS-2 [3] and EBCS-8 [5] based on seismic design requirements by considering seismic and gravity loads. A subsoil class A was adopted to obtain the site coefficient S. ETABS software was used for the analysis and design of the building and earthquake load was also considered in the sample building based on the software inputs. The building model was designed with rectangular, L and U shape shear wall located at the corner and middle of the floor plan. In designing the sample building model earthquake load are specified by EBCS-8 [4].

2.4 Non-linear analysis methodology

Where there was a need for a static pushover and dynamic analysis, the developer should fully understand the behavior of shear wall construction and failure modes. We consider non-linear static pushover in this paper and for the sample buildings selected.The pushover analysis of the sample buildings can be carried out in SeismoStruct software, a frame element was modeled by element connectivity using node for the vertical or column and horizontal or beam element.

The sample building models are considered to account the artificially generated earthquake records distributed at the base of the structural model in both x and y direction. For each sample building event, 30 non-linear dynamic time-history analyzes were carried out using the artificial earthquake and generally 600 non-linear dynamic time-history analyzes were carried out for all sample buildings in order to understand the seismic behavior of buildings. The analysis of non-linear dynamic time-history in this study was carried out using SeismoStruct software. The peak responses were recorded from each analysis result and plotted against the value of the intensity measure for the ground movement and the regression analysis of these data was used to develop the seismic demand model of probabilism.

2.5 Description of case study models

Based on the shear wall arrangements, there are three cases of study for each sample building model. In all cases, shear walls are arranged symmetrically, so that torsional effects are not introduced in the sample buildings.

Case One:

G+7 regular building with rectangularshear wall placed symmetrically at the outer edge, middle and center of the structure floor plan is shown in the figure below.

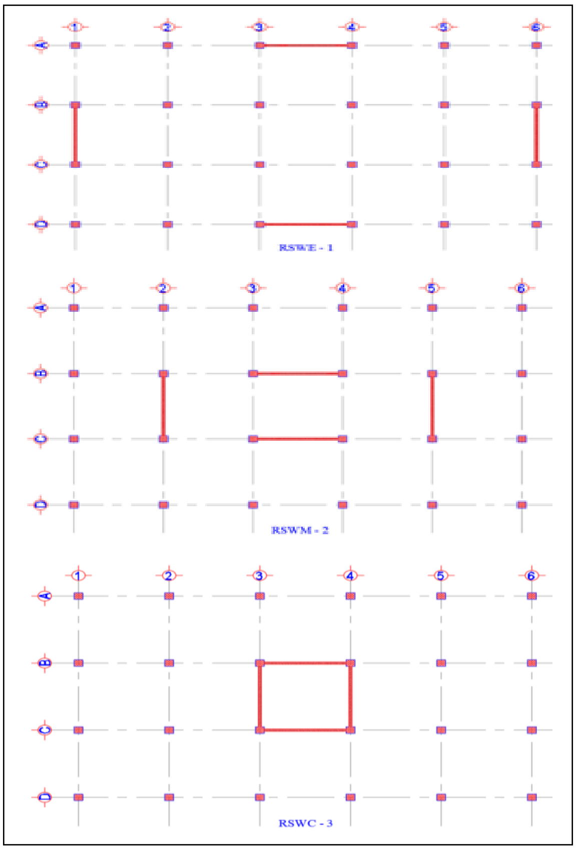
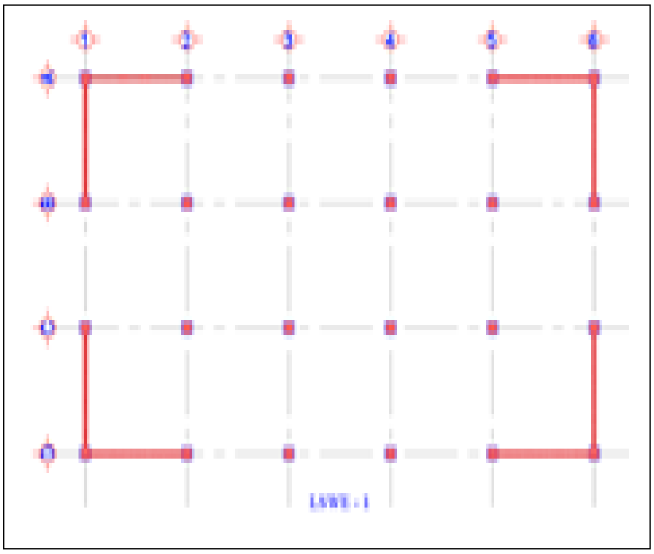


Figure 2.2 Sample building structure with rectangular shear wall location

Case Two:

G+7 regular building with L- shape shear wall placed symmetrically at the outer edge and middle of the structure floor plan is shown in the figure below.



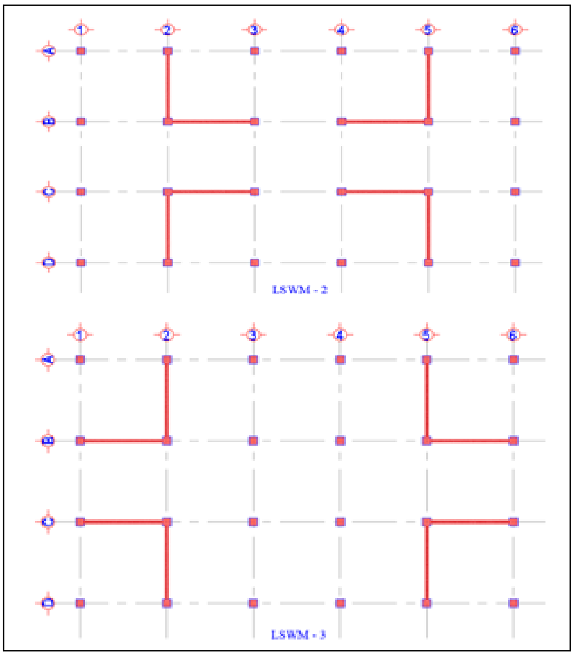


Figure 2.3 Sample building structure with L- shape shear wall location

Case Three: G+7 regular building with U-shape shear wall placed symmetrically at the outer edge, and middle of the structure in x-direction of the floor plan is shown in the figure below.

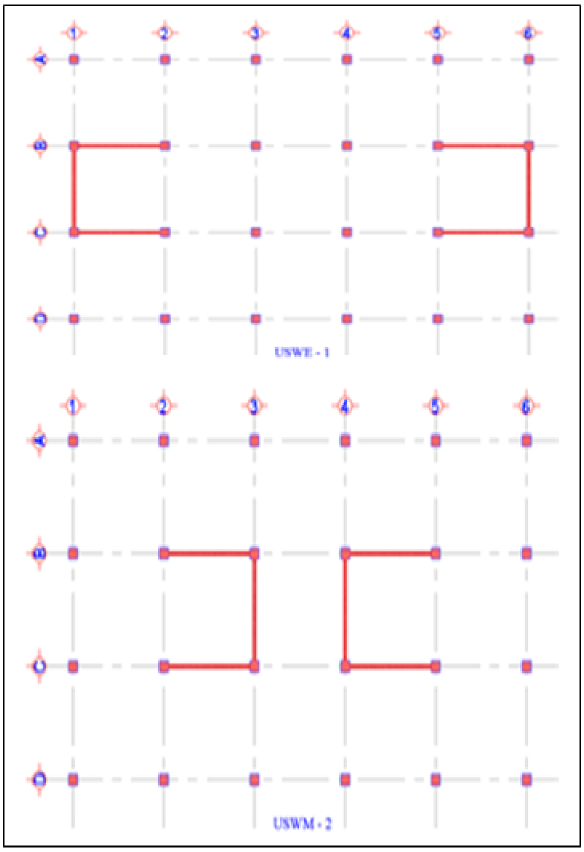


Figure 2.4 Sample building structure with U-shape of shear wall location in x-direction

Case Four: G+7 regular building with U- shape shear wall placed symmetrically at the outer edge, and middle of the structure in y-direction of the floor plan is shown in the figure below.

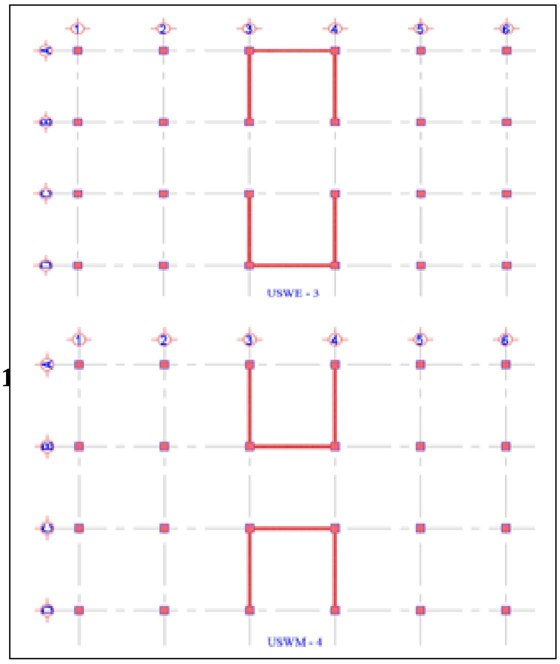
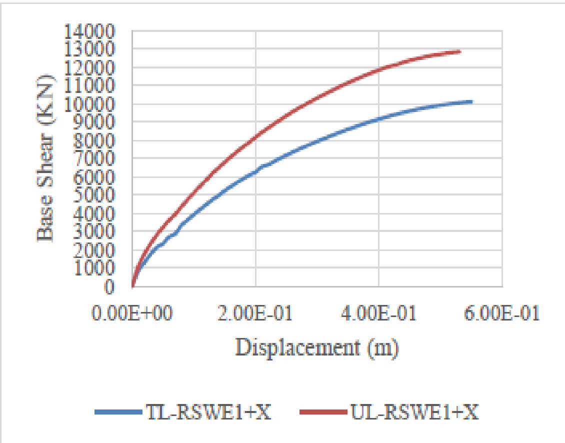
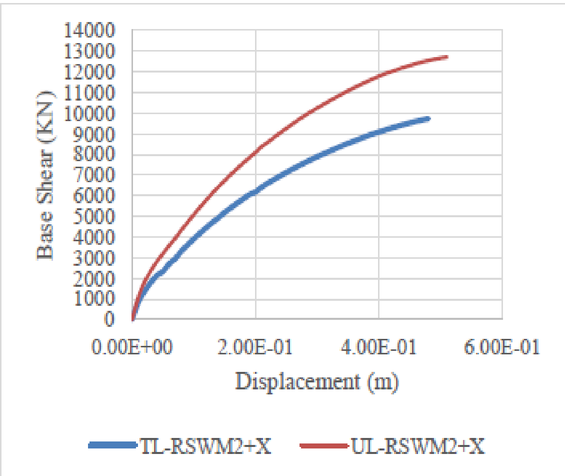
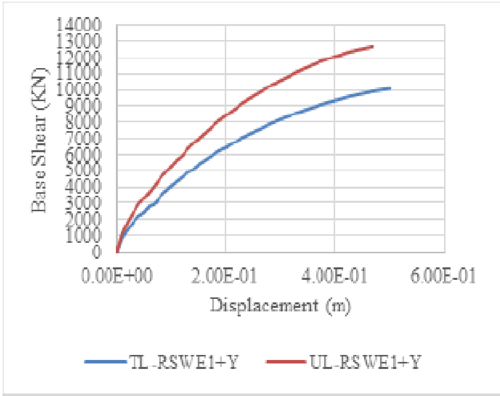


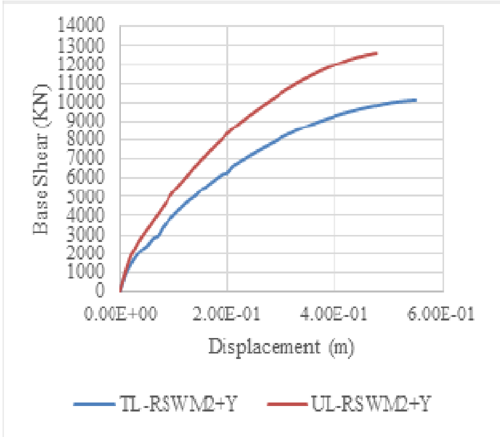
Figure 2.5 Sample building structure with U-shape of shear wall location in y-direction

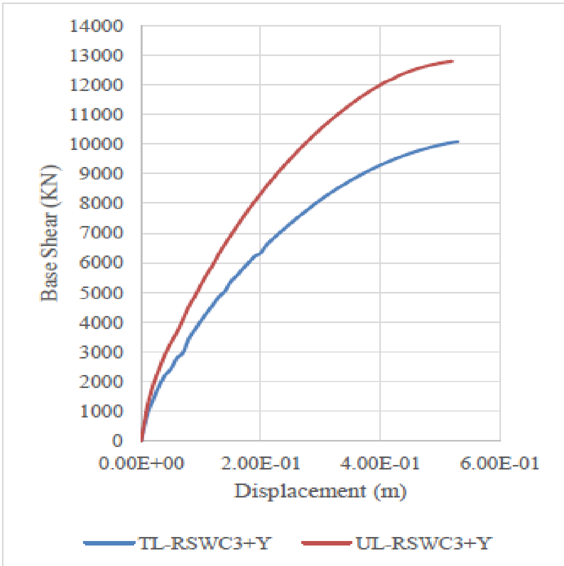
Static Pushover Analysis is conducted for the rectangular and L-shaped shear walls mounted above the structure are subject to a monotonous increase in lateral forces distribution until a target displacement is reached.











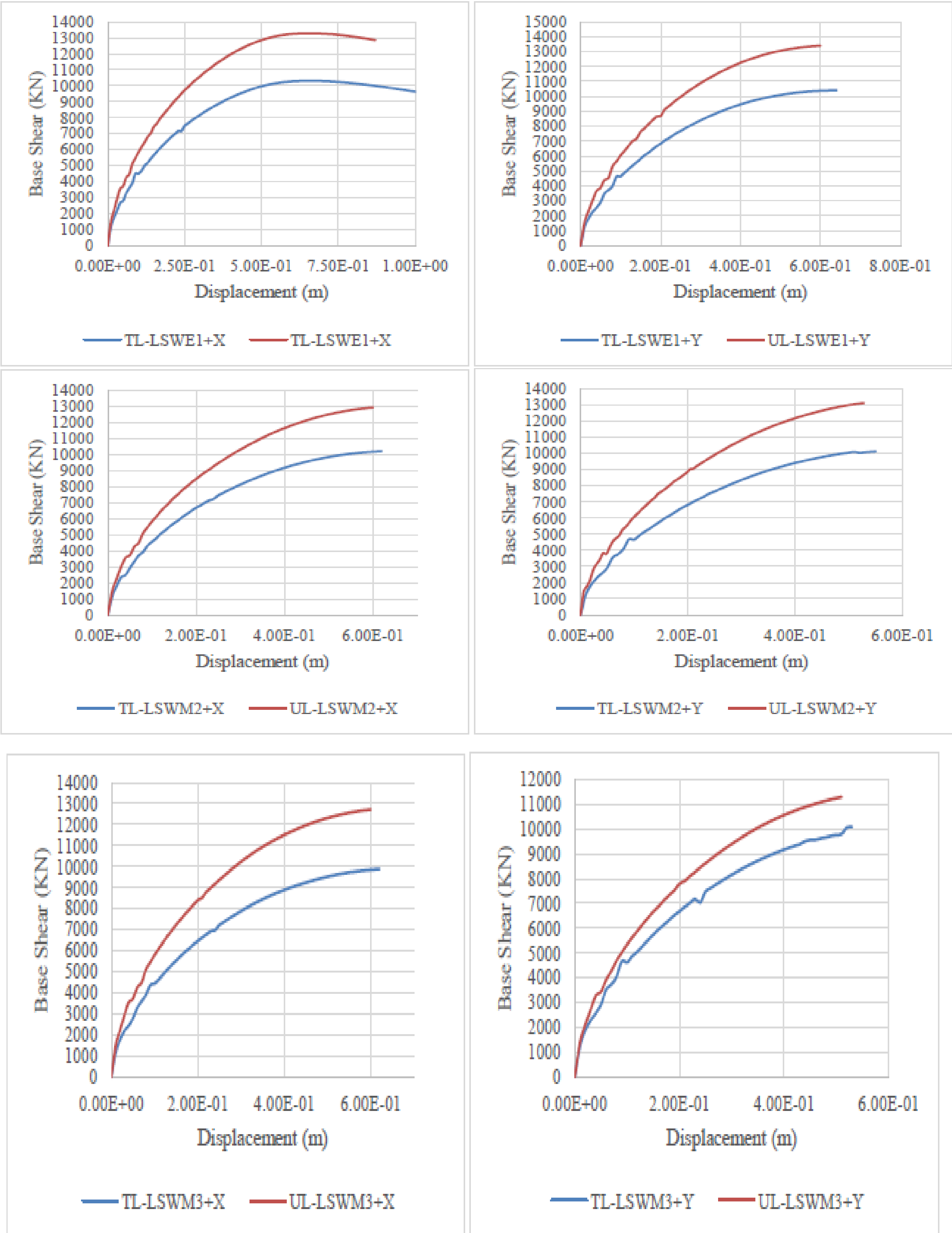


Figure 3.2 Pushover capacity curve of rectangular and L-shape shear wall for triangular and uniform loading

Result-The structural frames and shear walls of seven story buildings was considered in pushover analysis to represent structural system of reinforced concrete (RC) buildings mentioned in this study. The frame elements are modeled as non-linear frame elements. All buildings are pushed by triangular and uniform loading until roof displacement riches maximum. In pushover study, a capability curve that describes the relationship between the base shear force and the roof displacement defined the behavior of the structure.

III. NON-LINEAR DYNAMIC TIME-HISTORY ANALYSIS

As a major natural hazard, earthquakes may cause extremely damaging for structural buildings such as hospital, schools etc.

Time-history analysis method is the basic method which is commonly used for the seismic dynamic analysis. The top roof displacement for all buildings at 30 various earth-quake loads in x and y direction has been shown in figure 4.1 and 4.1 respectively.

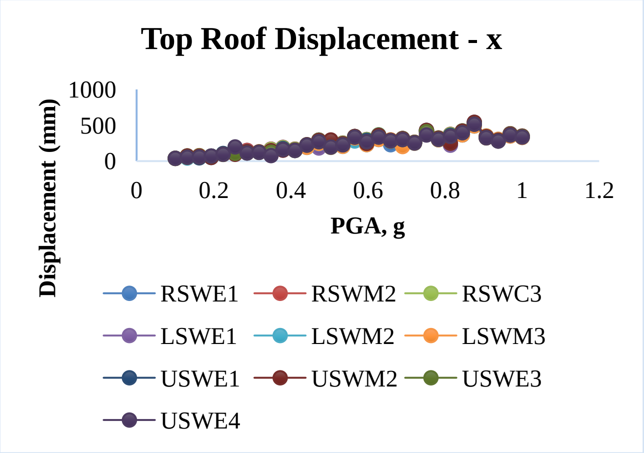


Figure 4.1 Top roof displacement for all buildings at 30 different EQ loads x-direction

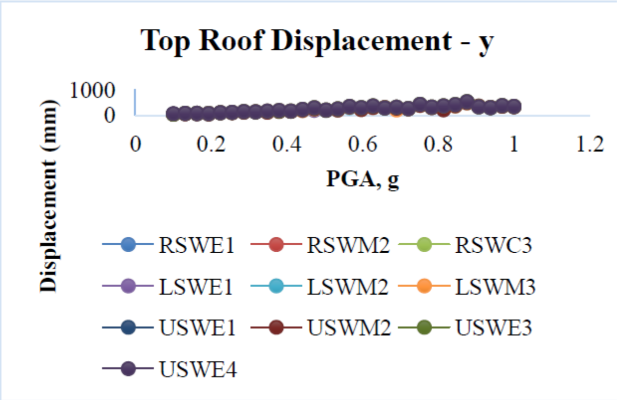


Figure 4.2 Top roof displacement for all buildings at 30 different EQ loads y-direction

IV. CONCLUSION

The pushover test is an ideal method used to analyze the structure's non-linear nature, determine the inelastic strength and reveal the weakness of the model. A relatively simple method for evaluating seismic efficiency of RC structures is the non-linear static analysis approach. The performance of the displacement-based Pushover analysis has been evaluated and compared with roof displacement and base shear reaction in the cases of rectangular, L and U shape shear wall buildings using Seismo-Struct software.The Static pushover analysis with triangular load pattern distribution gives higher roof displacement, while the uniform lateral load pattern gives higher base shear. The pushover curve was transformed to an idealized force-displacement plot when the structure was prepared to collapse.Among the three different locations of the shear walls, the one with shear wall placed at the edge of the building in both X and Y direction has better seismic resistance capacity than the other locations of shear wall in the building. The roof displacements at different damage level of the building in X and Y direction are influenced by the shear wall shapes and locations in the building. When the shear walls are placed in the outer side or at each end of the building, they undergo damage level (DL), significant damage (SD) and Collapse prevention (CP) performances with larger roof displacement than the shear wall placed in the middle or interior of the building respectively. The roof displacement or drift of the structural building with L-shape shear wall located at the edge of the building have a higher displacement than the buildings with rectangular and U-shape shear walls located at each end of the building cases.

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AUTHOR PROFILE

Dr. Vijay Singh Rawat was awarded his PhD in civil engineering from Pacific University, Udaipur, India in 2018 and authored a thesis titled "Re-analysis and Re-design of G+3 residential building by retrofitting techniques with cost comparison in seismic zone-III, Mumbai. In 2014 he has awarded M.Tech (Construction Engineering) from Bhagwant University Ajmer, and B. Tech from Rajasthan Technical University, Kota, India. Presently he has more than 8 years of teaching and industrial experience. He has published his research in peer-reviewed journals, International conferences and National conferences. Totally he has published 4 books and 13 research paper. Currently, he is working as an Assistant Professor in Adama Science and Technology University, Adama, Ethiopia since November 2017. His current area of research is the analysis and design of the residential building by retrofitting techniques in term of sustainability development.

Dr. P. Manikandan was awarded his PhD in structural Engineeirng from PeriyarManiammai University, Thanjavur, India (2019) under the title "Behaviour of Recycled E-Waste In Concrete". In 2014 has completed his Master of Technology in structural Engineering from SRM University (Deemed), Chennai, India and B. tech in Civil Engineering from PeriyarManiammai University, Thanjavur, India (2012). Currently he is working as a Lecturer, Building construction Technology,Federal TVET Institute Addis Ababa, Ethiopia. He is published many research paper in international journals, national journals and conferences. His current area of research is study of concrete in various aspects.