Indian J.Sci.Res. 17(2): 1-10, 2018 ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

A COMPARATIVE STUDY OF THE LATERAL FORCE RESISTING SYSTEMS FOR EXTREME AND MODERATE SEISMIC LOADINGS – A CASE STUDY OF SAN DIEGO, USA AND AL AIN, UAE

[1]Prathibha Gowrishankar, [2]Engineer Alaa Habrah, [3]Dr. Abid Ul Razzaq Abu- Tair
[1]Department of Structural Engineering
[2]Faculty of Engineering and IT
[3] Faculty of Engineering and IT, British University in Dubai, United Arab Emirates

Abstract -The objective of this paper is to discuss the results and findings of a project which was carried out for Earthquake Resistant Design of Structures. The primary motive behind this paper is to discuss the seismic design and analysis of a 12-story mixed-use building for both extreme and moderate seismic loadings. For extreme and moderate seismic loading, the structure was assumed to be located at San Diego in the United States of America and at Al Ain in the United Arab Emirates respectively. The paper focuses more on the lateral force resisting systems incorporated in the proposed structure and its response to the seismic forces the building was subjected to. Firstly, a review of the seismic events of both the locations, San Diego and Al Ain was carried out considering the geography, topography and seismic activeness of the locations. These factors played a vital role in the design and analysis of the superstructure of the proposed building. The paper also includes four design appraisals developed, two each for every location and justifications presented for the selection of the lateral force resisting systems chosen for each location. These is followed by a preliminary analysis of the four concepts using Linear Static approach – Equivalent Lateral Force (ELF) method and discusses and compare the results to arrive at two final qualified solutions, one each for every location. These two concepts are then analyzed using Linear Dynamic procedure such as the Modal Response Spectrum (MRS) analysis for the detailed design and final member sizes using a commercial software. Comparisons of the results from the two approaches were made to arrive at the best method of analysis for each location. It was inferred that the MRS analysis held an upper hand over ELF analysis and the MRS results are more reliable.

Keywords - Earthquake resistant design of structure, mixed-use building, San Diego, Al Ain, extreme and moderate seismic loading, Equivalent Lateral Force analysis, Modal Response Spectrum analysis.

I. Introduction

The primary motive of this paper is to perform a seismic design and analysis of the proposed 12-story structure such that, the focus is more on the lateral force resisting and response of a structure specially to the seismic forces. The proposed structure is a 12 – story, mix – use building which houses a basement car parking, a shopping center, typical office floors and a double story restaurant. This structure is analyzed for both high and moderate seismic loading. For the extreme loading, the building is assumed to be located in San Diego, in the United States of America and for the moderate loading, the building is assumed to be located in Al Ain, in the United Arab Emirates. Firstly, a review of the seismic events of both the locations, San Diego and Al Ain is carried out considering the geography, topography and seismic activeness of the locations. These factors play a vital role in the design and analysis of the superstructure and substructure of the above building.

Considering the San Diego County, seismic design and analysis is very significant as this state experiences frequent earthquakes due to its location on one of the highly active faults of the region. But seismic analysis is not of much importance to Al Ain as it barely experiences significant tremors although some minor aftershocks are felt. But the main objective of this paper is to assess the seismicity of the two locations, propose suitable conceptual designs and lateral force resisting systems, their preliminary design and finally the detailed design.

San Diego, United States of America

San Diego is a major city/county in California State. It is located on the coast of Pacific Ocean in southern California, South of Los Angeles and adjacent to the border of Mexico. San Diego County, as it is called, is far more vulnerable to earthquakes according to the Southern California earthquake center, United States Geological Survey (USGS).

California is one of the states in the US, most prone to earthquakes specifically severe earthquakes. Southern California is bound by the San Andreas fault and the San Jacinto fault which is the second most active fault in the world. The San Jacinto fault runs through the northeast of San Diego county. Also, another major fault which poses a severe threat to San Diego, the Rose Canyon, cuts right through the heart of downtown San Diego. The geology of San Diego proves that it stands on a very unpredictable topography surrounded by active faults which is an alarming concern. The proximity of the Rose Canyon fault

[1]Corresponding Author

to the city center and main economic hubs could put the entire area on hold for months/years if struck by a severe earthquake.

According to the ASI Data Center historical documents, Seismographic record of earthquakes in the US began not until 1934.Since then the highest recorded earthquake was the 6.9 magnitude tremor that occurred in 1986 (Agnew et al. 1990) [1]. The following are the records of major earthquakes that struck San Diego.

- Feb 9th 1956 – M6.8 – Strongest earthquake felt since 1940, epicenter at ,San Diego – No data available
- July 13th 1986 – M6.4 – Coast of oceanside on Coronado Bank fault. Cracked walls and collapse of unstable buildings.
- June 12th 2005 – M5.6 – Six miles southeast of Anza. Cracked walls of buildings and foundations of North San Diego county fire station.

Figure 1: Probability of shaking – San Diego

With the data available from the USGS, we get an idea of how strong a quake could probably damage San Diego as a result of ground motions. Also, the historical trends of major earthquakes show that there hasn't been a major earthquake in the past 10 years which implies an impending disaster. Inspecting the peak ground acceleration maps for ground motions having 10% probability of being exceeded in 50 years and 2% probability of being exceeded in 50 years. This shows that the ground motion for San Diego is as high as 30% g.

The approximate threshold of ground motion capable of causing severe damage is 10% g. So, 30% g is catastrophic shaking and it has about 1 chance in 10 of occurring in San Diego in 50 years. In 20 years this would be about 1 chance in 25 years.

Relevant codes available for design

The *NEHRP Provisions* state that the entire United States community had three organizations (for each major geographic region) publishing model codes. This was because the United States is a vast country with a varied topography.

- The *National Building Code (NBC)* – published by the Building Officials and Code Administrators International (BOCAI) – was widely used in northeastern and central states.
- The *Standard Building Code (SBC)* – published by the Southern Building Code Congress International (SBCCI) – was used for the southern part of United States.
- The *Uniform Building Code (UBC)* – published by the International Conference of Building Officials (ICBO) – commonly adopted in the western United States.

As years followed, following building codes for specific regions was more of a tedious and confusing concern. Hence, several professional associations such as the American Concrete Institute (ACI), American Institute of Steel Construction (AISC), Structural Engineering Institute of the American Society of Civil Engineers (ASCE/SEI) along with the guidance of the American National Standards Institute (ANSI) issued the model building codes that comply the standards and requirements of the respective industry's specialized materials and systems (concrete, steel, wood, masonry etc.)

Statistics from the geological surveys showed that the western states of the United States, specifically California, Alaska, Washington were more vulnerable to earthquake. The Congress then in late 1900's established the National Earthquake Hazards Reduction Program (NEHRP). This constituted the four federal agencies, the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the United States Geological Survey (USGS) and the National Science Foundation (NSF). These four agencies hand helped develop the NEHRP Recommended Seismic Provisions and building codes and standards. The ASCI/SEI 7 standard adopted the 1997 edition of NEHRP Provisions which we shall follow for the design and analysis of the San Diego building.

Al Ain, United Arab Emirates

Al'Ayn (as denoted on the USGS website) also called Al Ain, is a city located in the south-eastern part of the United Arab Emirates closer to the borders of Oman. Out of all the Emirates in the UAE, Abu Dhabi and specially Al Ain city in Abu Dhabi is least active as it falls in the mid regions of the country which is relatively less seismically active (Abdallah & Hamoud 2004) [2]. Tectonically, the UAE is situated in the south-eastern part of the Arabian Plate – one of the youngest plates that make up the surface of Earth (Bosworth et al. 2005) [3]. This plate has been moving northwards every year by around

20-25mm colliding with the Eurasian plate which is one of the cause for earthquakes in the Arabian Peninsula. One such collision, back in history, resulted in the formation of the Zagros fold belt. The Zagros belt is one of the most active fold belts in the world, and the primary cause for frequent earthquakes in southern Iran, along which the belt crosses. These shockwaves from Iran travel all the way till the UAE as far as Al Ain (Abdallah & Hamoud 2004) [4].

Figure 2: Arabian Plate

In 2003, one of the strongest earthquakes was recorded in Bam (Iran) that registered a magnitude of 6.6 on the Richter scale which claimed many lives. In the following weeks UAE experienced almost 25 aftershocks ranging between 4 and 4.8 on the Richter scale. This earthquake and its after shocks were alarming as this area was previously not thought to be seismically active. This was followed by the installation of monitoring stations across the United Arab Emirates. Since then, it has enabled us to understand the effects of seismic activity within UAE and the risk of future earthquakes. Also, the studies of Musson (Musson et al. 2006) [5] presented the results on seismic hazard of UAE which was carried out by the British Geological Survey on behalf of the UAE Government.

Figure 3a: History of highest earthquake in Arabian Plate

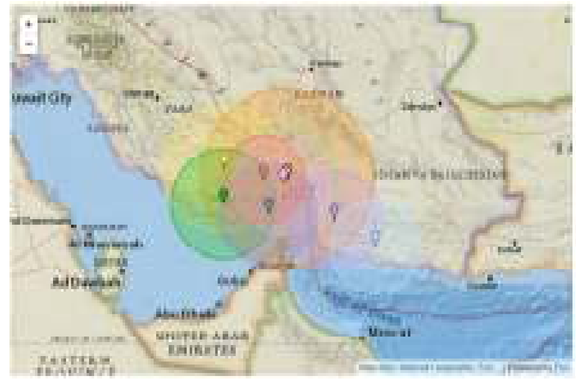


Figure 3b: History of highest earthquake in Arabian Plate

Relevant codes available for design

The Abu Dhabi International Building Code (ADIBC) standards are adopted and made mandatory for the development of any project in the Abu Dhabi emirate. These standards have been developed by the Department of Municipal Affairs of the Abu Dhabi Municipality. The same regulations, provisions and code is applied to the Al Ain municipality also. The ADIBC uses the provisions in the ASCE/SEI_7 but with modifications and amendments to suit the geography and topography of Abu Dhabi. Hence, we follow the ASCE code followed for the building along with the ADIBC provisions.

II. Problem Definition

The proposed 12-story mix use building needs to be designed for both moderate and extreme seismic loadings. The conceptual designs proposed for each location should be structural systems capable of resisting the lateral seismic forces and enhance response and performance at the time of seismic activity. The building has 11 stories above grade and one story below grade. It is laid on a rectangular grid, with seven bays along the X direction and five bays along the Y direction. The plan and elevation of the structure has setbacks occurring at Levels 1 and 9. The basement is a car parking floor surrounded by retaining walls on three sides. Ground and mezzanine floors have a shopping center with a large opening in the mezzanine floor. Floors 2 to 8 are typical office floors with a 20% of each floor intended to be used as storage space. The last two upper floors are double-story restaurant with a terrace on the 9th floor and an opening in the 10th floor. The building is observed to have great lateral stiffness offered by the cores in the right-hand side of Grid E while to the left side of the Grid E, stands weaker in lateral force resisting capacity along the east-west direction. Considering the extremity of the location in times of earthquakes, it is required to assure that the concepts proposed below satisfy ductile, stiffness, economic aspects of construction.

III. Conceptual Designs

The following design appraisals were proposed for each location and a review of how the system supports the lateral force resisting capacity of the structure.

San Diego, United States of America

For the San Diego location, considering the extreme seismic loading a structural steel system is preferred for both concepts. Steel is preferred over concrete attributing to the more efficient performance of steel during earthquakes. This is because steel is more ductile as compared to concrete. Steel is also believed to be eight times stronger in tension and shear than concrete. The following are the two conceptual designs for the above location.

Concept 1

- E-W direction – Special steel moment resisting frame
- N-S direction – Special steel moment resisting frame

The figure 4 shows basic structural configuration of the above concept. The lateral force resisting system (LFRS) in N-S direction and E-W direction consists of special steel moment resisting frames. The structural system is simple with moment frames along both directions of loading and no dual systems incorporated. This SMF system along both directions have a response modification coefficient (R) of 8 and deflection amplification factor (Cd) of 5.5 (*Table 12.2-1 ASCE 7-10)*. The SMF frame along E-W direction consists of five 5m bays and two bays each, spanning 7 and 8 meters. The configuration of the structure also consists of two stair cores between Grids 1 and 2 and Grids 5 and 6. There is also a lift core along the Frame J which extends 3m into the W-E direction. Although the entire structural frame is made of steel, these cores are made of reinforced cement concrete and these cores do not form part of the lateral force resisting system. The diaphragm of the structure consists of deck slab. The specialty of theses moment frames is that they have moment connections.

Concept 2

- E-W direction – Special steel moment resisting frame + Special Reinforced Concrete Shear Wall (dual system)
- N-S direction – Special steel moment resisting frame + Steel buckling-restrained braced frames (dual system)

The figure 4 shows basic structural configuration of concept 2. This concept is very different from Concept 1 as the structural systems adopted for both directions of loading in are dual systems. In the E-W direction the LFRS is a special steel moment frame incorporating a special reinforced concrete shear wall in it. This system has a Response modification factor R value equal to 7 and a Cd value of 5.5 (*Table 12.2-1 ASCE 7-10).* The shear wall in this system span the 7m bay along Grids 1 and 6. The LFRS along the N-S direction has a special steel moment resisting frames incorporating buckling restrained braced frames (BRB frames) with R value of 8 and Cd value of 5 (*Table 12.2-1 ASCE 7-10)* unlike the one with concrete shear walls. The two 7m bays along Frame A and the 7.2m bay along Frame J consist of BRB frames while all the other lift/stair cores are made of ordinary reinforced concrete. BRB frames are good at lateral resistance to buckling during earthquakes. These steel frames are highly capable of effective dissipation of energy at times of seismic activity. According to Kiggins (Kiggings & Uang 2006) [6] low post-yield stiffness of BRB's make the system vulnerable to unfavorable behaviors such as permanent deformation which demands for a dual system of the same with MRF's. This helps reduce permanent deformations. The diaphragms are either deck slabs. Hence, we have the dual system of special steel moment frame with special reinforced concrete shear walls along the Grids 1 and 6 in the E-W direction and dual system of MRF with BRB along Grid A and J in N-S direction.

Al Ain, United Arab Emirates

For the Al Ain location, considering the moderate seismic loading it will be subjected to, two conceptual designs are proposed. Both the systems are concrete structural systems as providing steel systems would be uneconomical and over rating the LFRS for a moderate seismic loading in a low seismic zone like Al Ain.

Concept 1

- E-W direction – Intermediate reinforced concrete moment resisting frames
- N-S direction – Ordinary reinforced concrete shear walls

The Figure 4 shows the structural configurations of the above concept. This concept consists of intermediate reinforced concrete moment resisting frames (IMF) along all the 7 bays in the E-W direction. An IMF is apt for moderate loading and capable of withstanding an inter-story drift of less than 0.02 radians. The LFRS in the N-S direction consists of a concrete wall integrated into a moment resisting frame. In the N-S direction, the two 7m span bays along Grid A and the 7.2m span bay along Grid J are concrete shear walls. While in the E-W direction, the frames along Grids 1,2,5 and 6 is the intermediate concrete moment frame. Both systems, the concrete MRF along the E-W direction and the ordinary concrete shear wall, have a response modification coefficient (R) equal to 5 and a deflection amplitude coefficient (Cd) equal to 4.5 *(Table 12.2.1 ASCE 7-10).* All the cores are made of reinforced cement concrete. While the floor system is a flat slab system. Both concepts 1 and 2 share the same framing plan as in Figure 4 however the change in lateral system along the N-S direction for Concept 1 is shown in the sectional view of the structure in Figure 4.

Concept 2

- E-W direction – Intermediate reinforced concrete moment resisting frames
- N-S direction – Intermediate reinforced masonry shear walls

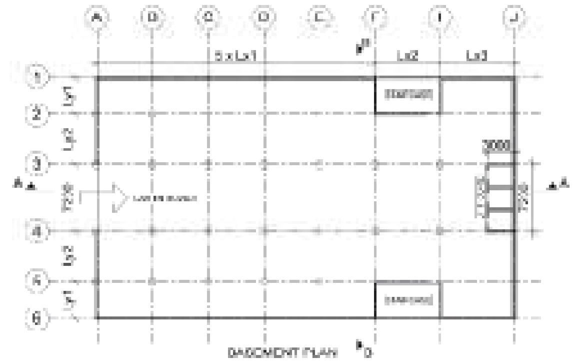
The figure 4 shows the structural configuration of the above concept 2. In this concept, intermediate reinforced concrete moment frames are adopted just like that of the concept 1 for this location. These frames are in the E-W direction along grids 1,2,5 and 6. While along the N-S direction we have adopted a wall integrated into a moment resisting frame. This is adopted in the 7m bays along grid A and along grid J for the 7.2m bay. The wall integrated into the moment frame is a masonry wall unlike concept 1. Also, as it is a masonry wall it is intermediately reinforced. The R value for the intermediate moment frame is equal to 5 and Cd value is 4.5 *(Table 12.2.1 ASCE 7-10).* While the intermediate reinforced shear wall has a R value equal to 4 and Cd equal to 4 *(Table 12.2.1 ASCE 7-10).* The cores are all made of the same intermediate reinforced masonry shear walls and the diaphragms constitute the flat slab system.

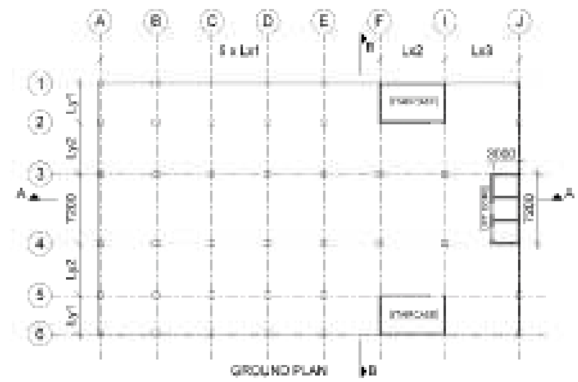
Note:

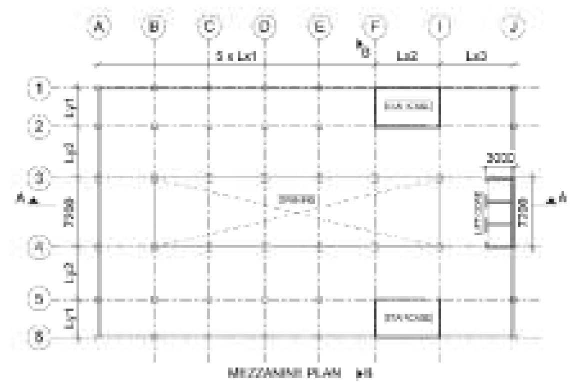
Firstly, in both the conceptual designs developed for Al Ain, the flat slab system is adopted as the proposed structure is a medium-rise structure. As it allows for lesser dead weight due to absence of beams and allows for greater floor to floor heights. However, Muralidhar (Muralidhar & Swathi 2016) [7] state in their paper that, high-rise buildings with flat slabs (that have drops or heads) show more of unfavorable behavioral characteristics during a seismic activity in terms of lateral displacement and story drift. Thus, they suggest having an efficient LFRS for such buildings with flat slabs. This is because a LFRS helps reduce the lateral displacement significantly.

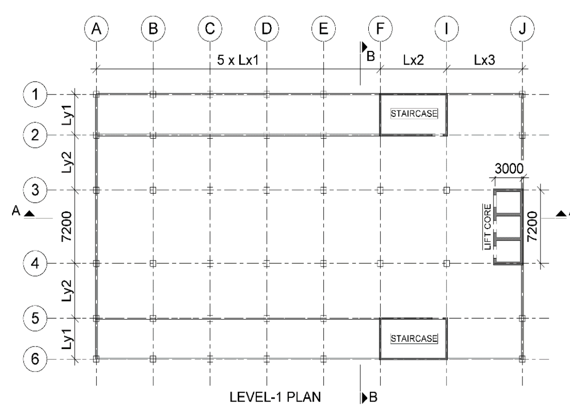
Secondly, in both conceptual cases a shear wall is chosen as the LFRS. This is because the time period of a building with flat slab and shear wall is comparatively less as compared to the time period of a building with flat slab and any other LFRS (Muralidhar & Swathi 2016) [7].

Thirdly, while providing a shear wall system along the N-S direction frames, shear wall could result in more mass because of which the structure could experience greater base shear. To tackle this concern a moment resisting frame is provided along the direction transverse to that of the shear wall (Muralidhar & Swathi 2016) [7].









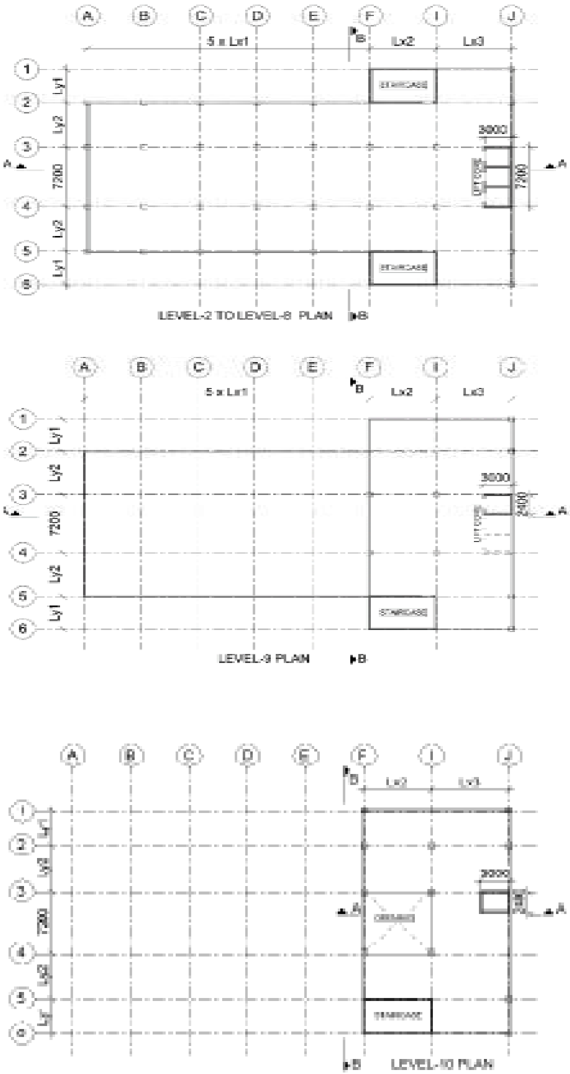


Figure 4: Plan of different Levels

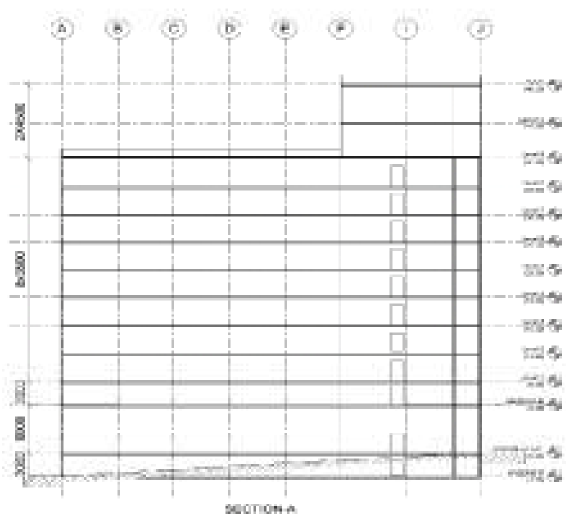


Figure 5: Sectional view of structure

IV. Preliminary Analysis – Equivalent Lateral Force Method (ELF)

The ELF method is used to analyze a structure preliminarily. This method of analysis provides us with the base shear and story forces acting at every level of the structure. It is the simplest method used for analyzing a structure for seismic forces. According to Ellis (Ellis et al. 1993) [8] the equivalent static loads applied to a structure is assumed to be proportional to the structure mass multiplied by selected values of horizontal and vertical accelerations. This includes considering the type of structural system adopted for the building, fundamental period, importance factor of structure etc.

The ELF analysis is carried out for all four concepts in both locations. This involves collecting basic seismic acceleration parameters for the region, modelling the structure, calculations and so on. The Base shear for each concept is calculated manually using the following data.

Basic Parameters

- Structural height (h_n) = 46 m (excluding basement and parapet)
- Site Class C soils
- Seismic weight

▪ Structural system – 3.35 kN/m^2

▪ Ceiling and Mechanical – 0.7 kN/m^2

▪ Fixed Partitions – 0.5 kN/m^2

▪ Ceiling and Mechanical (Roof) – 1 kN/m^2

▪ Exterior Cladding – 1.6 kN/m^2

▪ Masonry Wall – 12 kN/m

▪ Parapet – 2.8 kN/m^2

▪ Roofing – 0.57 kN/m^2

- With respect to table 1.5 – 1 Page 2 of ASCE 7_10, Risk Category. As the proposed building is a mixed-use building, having a shopping center, offices and a restaurant, this building doesn't pose much risk to life as a result of seismic activity. Hence, the building falls under Risk Category 1.
- With respect to table 1.5-2, Page 5 of ASCE 7_10, Importance factor As the above building falls under Risk Category 1, the seismic important factor Ie = 1.00.

Table 1: Pre-Requisites – Seismic Load Parameters

Seismic Load Parameters	Al Ain	San Diego
S_S	0.25g	1.222g
S_1	0.09g	0.471g

Seismic Load Parameters	Al Ain	San Diego
S_{MS}	0.3g	1.222g
S_{M1}	0.153g	0.626g
S_{DS}	0.2g	0.815g
S_{D1}	0.102g	0.471g
T_0	0.102g	-
T_S	0.51g	-
T_L	8s	8s
SDC	C	D

The seismic load parameters for Al Ain are calculated manually where as for San Diego the values are obtained from the design maps available in the USGS official website.

Configuration Issues

Horizontal Structural Irregularities:

According to table 12.3-1 ASCE 7-10 we shall check the presence of following irregularities.

• *Type 1 (a) Torsional Irregularity*

Type 1 (b) Extreme Torsional Irregularity

The presence of a torsional irregularity cannot be determined without a structural analysis. But, it is likely that such an irregularity will occur. It will be assumed that the irregularity does exist and will be verified with analysis.

• *Type 2 Reentrant Corner Irregularity*

X_p / X = 25/40 = 0.625 > 0.15

= Irregular

Y_p / Y = 4/29.2 = 0.136 < 0.15

= No irregularity

The Reentrant Corner Irregularity exists at Level 1 along X direction as X_p/X is greater than 0.15.

- *Type 3 Diaphragm Discontinuity Irregularity*

No diaphragm discontinuity irregularity in Mezzanine floor and Level 10.

• *Type 4 Out of Plane Offset Irregularity*

This irregularity exists at Level 9, where a wall spans across Grid F, unlike the floors below. Hence, there are plane offsets in structural systems.

• *Type 5 Non-Parallel system irregularity*

Doesnot exist as all frames are aligned to N-S or E-W direction.

Vertical Structural Irregularities:

• *Type 1(a) Stiffness - Soft Story Irregularity*

Type 1(b) Stiffness – Extreme Soft Story Irregularity

Cannot be determined without a structural analysis. But it is highly likely that such an irregularity will occur. It is assumed this irregularity exists and will be verified later.

• *Type 2 Weight (Mass) Irregularity*

There is very little variation in weight of different levels of buildings so this irregularity does not exists. The effective mass of any story is not 150% greater than the effective mass of adjacent story.

• *Type 3 Vertical Geometric Irregularity*

All the Lateral Force Resisting Systems proposed for this building have same plan and dimension at each level. So this irregularity does not exist.

• *Type 4 In Plane discontinuity in Vertical Lateral Force Resisting Element Irregularity.*

There are no offsets so this irregularity does not exists.

• *Type 5 (a) Discontinuity is Lateral Strength- Weak Story Irregularity*

Type 5 (b) Discontinuity in Lateral Strength – Extreme Weak Story Irregularity

The presence of this irregularity cannot be determined until computed values are obtained from a model design.

The model is assumed to have a semi-rigid diaphragm.

With the help of the above pre-requisites the base shear V and story forces F were calculated for the four concepts. The structure was then modelled using a commercial software such as ETABS with load cases E_x and E_y for the seismic loading along X direction and Y direction respectively. The model was designed and analyzed for each of the four concepts. The outputs of the four concepts were compared for Torsional Irregularity, Stiffness-Soft story irregularity, Story Drift checks and Drift ratios, P-delta effect check and Stability Co-efficient Q, and Orthogonal loading effects. This comparison of results between two systems of each location was done to recommend one solution based on economical and seismic performance. Based on a study of the results, it was concluded that Concept 1 – IMF along E-W direction and ORCSW along N-S direction performed better than Concept 2 - IMF along E-W direction and IRMSW along N-S direction. Though the stiffness soft-story irregularity is observed at Level 9 it can be tackled by careful member proportioning in the final analysis – Modal Response Spectrum analysis (used to proportion members and check drift). Hence, the conclusion made is ***Concept 1 – Intermediate Moment Frame along E-W direction and Ordinary Reinforced Concrete Shear Wall along N-S direction is the final scheme chosen for Al Ain.*** Similarly, A thorough study of the results for San Diego showed that both results perform efficiently in terms of torsion, drift, stability, stiffness etc. But from the economical point of view, Concept 1(Special Moment Frames) need to have moment connections in steel along both directions which raises the cost scale. However, the production, installation, erection time and effort of BRB frames in Concept 2 is more expensive than making moment connections. According to (Baghbanijavid et al. 2010) [11] the large residual drifts observed in the analysis, present significant challenges while seeking to return buildings with BRB's to service after a potential seismic activity. This is another major drawback of BRB's. (Boston 2012) [12] provides a solution, by providing gravity columns as a part of dual system to reduce large residual drifts. All these effects could fairly increase the cost. In a high seismic zonelike San Diego, it is required that the structure has good proportionality between steel and concrete to provide appreciable seismic performance in terms of stiffness and ductility/flexibility. Concept 1 has lesser torsional irregularity, though, the stiffness soft-story irregularity is observed at mezzanine level it can be tackled by careful member proportioning in the final analysis – Modal Response Spectrum analysis (used to proportion members and check drift) which will be dealt in the next section. Hence, the conclusion made is ***Concept 1 – Special Moment Frame (steel) along E-W direction and Special Moment Frame(steel) along N-S direction is the final scheme chosen for San Diego.***

V. Final Analysis – Modal Response Spectrum Method (MRS)

Modal Response Spectrum as the name is self – explanatory, is an analysis technique used to analyze structures subjected to a seismic activation considering the sum of contribution from each natural mode of vibration. The total response of all the modes considered gives the expected dynamic behavior of an essentially elastic structure during a seismic activity. This method of analysis is generally carried out for Seismic Design Categories D, E and F or also for taller long-period systems in Categories B, or C that have horizontal irregularities or buildings possessing any other type of irregularities. The MRS method is more accurate than the ELF as it captures the response of systems with irregularities in the distribution of stiffness and mass. Also, there is a higher mode contribution to the response.

The Modal Response Spectrum analysis, according to ASCE 7-10 (12.9.1) requires that, "the analysis must include sufficient number of modes to obtain a combined modal mass participation of at least 90% of the actual mass in each of the orthogonal horizontal directions of response considered by the modal." Also, according to the codal provisions of ASCE 7-10, the base shear calculated from the response spectrum function must be at least equal to or greater than 85% of the base shear calculated from the linear static method along each direction.

These are the two parameters that are checked in the MRS analysis. The MRS analysis is done for the final schemes chosen from ELF analysis. The MRS analysis is also carried out using ETABS commercial software. This is done by defining a new Modal case and a new function named Response Spectrum which is later applied to a new load case. Once the response spectrum load case is defined the model is analyzed for the results. To make the Modal mass participating ratios greater than 90%, the number of modes under consideration for Al Ain model was increased from 12 to 30 and that of San Diego was increased from 12 to 40. The mode shapes for each mode was also observed. To adjust the Base Shear analysis results, the rescaling factor was changed until the base shear calculated from the response spectrum function must be at least equal to or greater than 85% of the base shear calculated from the linear static method along each direction.All other factors such as torsional irregularity, drift and P-delta effects are also checked for the two final schemes. However, the orthogonal effects need not be considered for the proposed building as there are no horizontal irregularities. The final member sizes are arrived at , using MRS analysis.

Al Ain Concept

The model was analyzed for concrete frame design check and detailing.

RCC Columns: 1400 mm x 600 mm

Peripheral beams: 550 mm x 1000 mm

Concrete Shear Wall: 300 mm

San Diego Concept

The model was analyzed for steel frame design check and steel connection design check followed by a detailing which gave following member sizes.

Columns: UC 356x406x467

Beams: UB 838x292x176

UB 686x254x125

UB 356x171x45

Connections: All connections are moment resisting connections

VI. Comparison between ELF and MRS analysis methods

Results from the Linear Static Procedure (ELF Procedure) clearly indicate the inconsistencies between the assessment and design. However, it does not give a very broad idea about the response of the structure to various performance objectives. The Modal Response Spectrum has a greater hand over Linear Static procedure because it gives a better understanding about the characteristic behavior of a structural system to the seismic response. This is possible as MRS incorporates all the natural modes of vibrations and their responses which are summed up to get the net behaviors of the structure (model should capture at least 90% of participating mass of structure). Both concepts, Al Ain and San Diego involve moment frames. According to Welt (Welt 2010) [13] moment frame assessment is better using modal response spectrum method than equivalent lateral force method. The structure element, beams, columns, joints are adequate in resisting the demands of the structure. The exception is only in the case of stiffness at Level 9 and Mezzanine for Al Ain and San Diego respectively. Also, higher overturning moments at the lower levels in San Diego cause torsional irregularity.

- The linear static base shears and story displacements/drifts are more than those obtained from modal response spectrum analysis for the Al Ain concept.
- The linear static base shears and drift/ displacement values are less than those obtained from modal response spectrum analysis results for the San Diego concept. From above we can deduce that this is because ELF analysis is not the practical solution for this concept and hence the results had discrepancies. We can rely on the MRS procedure for this concept.
- The P-Delta effects need not be included in any analysis for any location as per standards.

As per the ASCE 7-10, Table 12.6-1 enlists the types of structural systems permitted for different seismic design categories. For Al Ain, both ELF and MRS methods are permitted as per the table. For San Diego, ELF method cannot be implemented due to its drawbacks. The MRS results need to be considered genuine for San Diego.

However, the values of various performance objectives in the ELF analysis differ from those obtained from final analysis. This is because of the highly empirical nature of ELF analysis. Except for preliminary analysis ELF approach must not be used for explicit performance evaluation since it cannot reflect the location and yielding of the structure.

VII. Inferences and Discussions

The ELF analysis, included computations carried out manually for calculating the base shear and story forces. The structure was then modelled using a software to determine parameters such as Torsional irregularity, Stiffness-soft story, Story drift and P-delta effects which will show the response of the structure to seismic activity. However, the base shear calculated manually differs from those computed by the software, attributing to semi-rigid diaphragms assigns and accuracy and precision of software results. The detailed comparison of the outputs from the computer model and a study about the economic side and seismic performance of the structure it was concluded that,

Concept 1 – Intermediate Moment Frame along E-W direction and Ordinary Reinforced Concrete Shear Wall along N-S direction is the final scheme chosen for Al Ain.

Concept 1 – Special Moment Frame (steel) along E-W direction and Special Moment Frame(steel) along N-S direction is the final scheme chosen for San Diego., are the recommended one solution for the respective locations. It was noted that the ELF analysis is not recommended for certain locations and structure heights. This implies that the analysis performed above is just a preliminary analysis and results obtained from the same cannot be accepted as final attributing to the empirical nature of ELF analysis. It was inferred from the above analysis that,

- The ELF – Equivalent Lateral Force procedure which is a Linear Static approach can only be adopted for preliminary analysis due to its highly empirical nature which causes discrepancies between the assessment and design.
- The MRS – Modal Response Spectrum is a Linear Dynamic approach which has an upper hand over ELF attributing to the reliability of results that sum up the responses of all the natural modes of vibrations considered in the structure. This enables the designer to get a better idea about the behavior of the structure at the time of a seismic activity.
- Selection of structural system needs to be carried out cautiously keeping in mind, the ability of the system to resist seismic forces but at the same time it must stand economical.
- It must be clearly understood that concrete imparts stiffness while steel imparts ductility/flexibility. Hence, a proportional system can prove more efficient at the time of earthquakes. The total dead load of the structure should be kept minimal to avoid excessive damage but not at the cost of strength, stiffness and resisting capacity.

VIII. Conclusions

The journey of designing the proposed structure starting from the study of given area seismicity and preparation of design appraisals to final analysis and design of member sections, incorporating step by step approach of analysis was not a simple task. But the section wise approach of preparing design appraisals followed by preliminary Linear Static ELF analysis and manual calculations and finally Linear Dynamic methods such as

Response Spectrum analysis helped to understand the process of nurturing this structure from the start in a greater depth. It also included research and homework's through a reading process which reflected on the topic positively thus enhancing the level of understanding about this subject Earthquake Resistant Design of Structures. It also helped in understanding the pros, and cons of each method adopted here and increased expertise on the commercial software used for modelling and computation. It was arrived at the conclusion that the MRS analysis results are more reliable as compared to ELF analysis this is because MRS analysis involves a more practical solution rather than empirical ones. Hence, this paper has reviewed the different structural systems, their preliminary analysis using ELF method, detailed analysis using MRS method and a review of the two methods of analysis for Earthquake resistant design of the proposed structure.

Acknowledgment

The author would like to thank the faculty of Engineering and IT, British University in Dubai for their guidance that has been instrumental in completing this project and paper.

References

[1] Agnew, D C Legg, M & Strand, C 1990; *Earthquake History of San Diego;* San Diego State University

[2] Abdalla, J A & Al Hamoud, A 2004; *Earthquake Hazard Zonation of Eastern Arabia;* 13th World Conference on Earthquake Engineering ; Vancouver, Canada; August 2004, Paper No. 1008

[3] Bosworth, W 1992., *Mesozoic and early Tertiary rift tectonics in East Africa*. Tectonophysics 209, pp 115–137

[4] Adballa, J A & Al Hamoud, A. 2004; *Seismic Hazard Assessment of United Arab Emirates and its surroundings;* Journal of Earthquake Engineering, Vol 8 ,No.6 , pp 817-837

[5] Musson, R M W et al. 2006, *The geology and geophysics of the United Arab Emirates*, Vol. 4: Geological Hazards. British Geological Survey, Keyworth, pp 237

[6] Kiggins, S &Uang, C M 2006, *Reducing residual drift of buckling restrained braced frames,* Engineering Structures 28(11): pp 1525-1532.

[7] Muralidhar, G B and Swathi Rani, K S 2016; *Comparison of performance of Lateral Load Resisting System in Multi Story buildings;* International Journal of Research in Engineering and Technology; Vol 5 , Issue 3.

[8] Ellis, LK James, PG Peter, HE 1993, *Fundamentals of Earthquake Resistant Construction,* John Wiley & Sons, Canada

[9] Mohammed Irfan , 2009 ;Thesis on *Seismic Site response, analysis and characterization of major cities in the UAE;* American University in Sharjah; United Arab Emirates; June 2011

[10] Teresa Guevara-Perez, L 2012, 'Soft Story and Weak Story in Earthquake Resistant Design: A Multidisciplinary Approach', *World Conference on Earthquake Engineering,* Universidad Central de Venezuela, Caracas

[11] Bhanghanijavid, Z Jalali,, A Yasserbinia, Y 2010 , ' Seismic Response of Buckling Restrained Braced Frames under near fault ground motions', *Journal of Applied Sciences, ISSN 1812-5654,* pp 2967-2977

[12] Boston, M 2012 , ' *Reducing Residual Drifts in Buckling-Restrained Braced Frames by using gravity columns as part of a dual system*' ,Masters Thesis, Brigham Young University

[13] Travis, W 2010,'Evaluation of Contemporary Design of Reinforced Concrete Lateral Resisting System using current performance objective assessment criteria', National Institute of Standards and Technology, US Department of Commerce: August 2010

[14] Official website of United States Geological Survey.