Seismic Performance and Strengthening Study of Concrete Frame Structure Building

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***Abstract*—In the past, buildings have been constructed either without accordance with the country standards or were constructed based on codes of practice from other countries. The existing buildings usually are of framed structure system and may be designed for the vertical loads only. Therefore existing buildings should be checked for latest country code based lateral loading particularly for earthquakes loadings. The paper presents the performance and strengthening study of non-seismically designed concrete framed structure building. The framed structure system of existing building is converted to shear wall coupled structure system for seismic strengthening as the structure of building is found unsafe under the seismic loading. The comparative evaluation of the different options for seismic strengthening by providing different height and location of shear wall in the existing frame structure building is also carried out. The seismic load and other loading are adopted as conforming to ACI Code. A general-purpose software SAP2000 has been used for modeling and analysis of the building with framed structure and with different options of providing shear wall in framed structure building. The coupled shear wall structure analysis results are compared with the complete frame structure building. It is found that the provision of shear wall is an appropriate strengthening technique for the building under seismic loading.**

Keywords— Concrete Building, Lateral Loads, Earthquake loading, Drift, Deflection

I. INTRODUCTION

The seismicity or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time. An earthquake (also known as a quake, tremor or temblor) is the result of a sudden release of energy in the Earth crust that creates seismic waves. In the past thirty years moderate to severe earthquakes have occurred in world at intervals of 5 to 10 years. Such events have clearly shown the vulnerability of the building stock in particular and of the built environment in general. The buildings, that were constructed five decades ago, were usually framed structure and designed for the vertical loads only. Therefore old buildings should be checked for lateral loading particularly for earthquakes loadings. For unsafe buildings, the economically and structurally sound strengthening system should be selected and system should be provided in building with proper design. A seismic strengthening provides existing structures with more resistance to seismic activity due to earthquakes. A seismic strengthening to buildings typically includes a combination of concrete shear walls, column fiber wrapping and steel collectors. Based on the knowledge gain on seismic strengthening, concrete shear walls prove to be the best option for strengthening of concrete buildings to increase the strength, stiffness and stability of the building structure.

In the recent years, shear walls have become the primary design feature for tall buildings and an important one in low rise building. They act as very deep beams which carry loads in shear in addition to bending and so do not suffer from the same deflections as a basic design without shear walls [1]. Many works have been reported in the literature related to the study of behavior of shear wall building structure under seismic loading. The development of Saudi building code specially the seismic provisions to building structures is also cited in the literature. Seismic provisions are provided for Kingdom of Saudi Arabia in the code named as SBC (Saudi building code): 301 (Design Loads for Building and Structures) [2]. IBC (International building code) and ASCE- 7 were chosen to be the source codes where extensive modifications have been carried out to reduce complexity and to account for differences in the seismicity level, construction materials, structural systems and quality control between USA and the Kingdom. Various engineers have reviewed the background of the development of SBC pertaining to concrete durability and hot weather concreting [3]. Also the effect of concrete cracking on the lateral response of high rise building structures have been investigated .Moreover, a review of two dynamic analysis procedures, linear (elastic) dynamic analysis and nonlinear (inelastic) response history analysis for use in earthquake resistant design has been conducted [4][5]. Nonlinear dynamic analyses were performed for evaluating the seismic response of systems characterized by different strength and stiffness configurations [6]. Major guidelines have been outlined to reduce seismic hazards of existing building in FEMA (Federal emergency management agency) 310 (Evaluation Hand Book) and FEMA 273 (Rehabilitation Guidelines) [7] [8]. In Past, various engineers performed push over analyses and nonlinear time history analysis to study the effects of staircase on the seismic performance of the RCC frame buildings of different heights and different plans [9]. Bagheri et al. (2012) have performed static and dynamic analysis for Multi-storey irregular buildings with 20 stories using software packages ETABS and SAP2000 [10] [11]. They also discuss the effect of the variation of the building height on the structural response of the shear wall building. There has been a considerable increase in the number of tall buildings, both residential and commercials, and the modern trends is towards taller and taller and more slender structures. The effect of horizontal loads like wind loads, earthquake forces and blast forces etc. are attaining increasing importance and almost every designer is faced with the problem of providing adequate strength and stability against horizontal loads. This is a new development, as the earlier designer usually designed for the vertical loads, and as an afterthought, checked, the final design against horizontal loads as well. Generally those buildings had sufficient strength against lateral loads due to numerous partitions and short span beams and cross beams, and no modification in designed was needed. Now the situation is quite different and, a clear understanding of the horizontal loads on a building and the behavior of various components under these loads, is essential.

In the present work, a five storey concrete large spans framed structure building designed without considering seismic actions and country standards is proof checked under seismic loading and redesigned with framed structure coupled with shear wall. Building structure elements are checked for stiffness requirement as per the Saudi Building Code when the building structure is without shear wall or provided with shear wall. The comparative performance of the different options for seismic strengthening by providing different height and location of shear wall in the existing frame structure building is also assessed. The coupled shear wall structure analysis results are compared with the complete frame structure building.

II. Modelling of Building Using SAP2000

To model a building in any software, we must know the inputs to be given to software like material properties, equilibrium and compatibility equations, energy and work principals, incompatible elements, boundary conditions, general constraints, analysis methods, design principal and philosophy. Without knowing these parameters and proper input format software will always give wrong and misleading results.

Before modeling any building, we must have following information

- Number of frames in longitudinal and transverse direction with spacing of columns.
- Usage of building with number of stories and type of diaphragm.
- Soil condition
- Seismicity and Wind condition

Information regarding grade of concrete, main steel and secondary steel to be used in construction must be known. If more than one grade of material is to be used, the properties should be defined separately. Other properties of material such as modulus of elasticity, mass, weight, Poisson's ratio, coefficient of thermal expansion, material damping and stress-strain curve are also to be known. Tentative sizes of members for initial analysis should be fixed, for beams based on deflection criteria as per code provisions and for columns axial load from corresponding tributary area. Gravity load on building depends on material and usage of building. Calculation of dead load and imposed load on building should be calculated based on relevant code. For distribution of gravity load on slab yield line pattern should be used. Earthquake load on a building can be applied in three ways, viz. as equivalent static method, using response spectrum and using time history. Wind load, Snow load and other loads should be calculated based on relevant code provisions. Analysis is performed after application of these loads on building and mass source.

III. Illustrative Building

The five-storey building with concrete framed structures, constructed five decade ago without considering earth quake loads, is used to study the seismic behavior of the building subjected to seismic loading as per the local code. The building has 3×4 bay space frame. The space frame has an equal bay width of 5 m in both directions with equal story height of 3.5 m. The assumed building is founded on firm soil. The seismic strengthening of the illustrative building structure is also suggested by coupling the framed structure with shear walls. The framing plan and elevation of framed structure building is shown in Fig.1 and Fig. 2. The assumed loading and material data for the building structures are given below:

Dead load = 15.00 KN/m^2 (including old thick partition wall load)
Live load = 5.00 KN/m^2(including corridors, assembly type rooms)
Size of beams and columns = 300 mm x 300 mm with size of shear wall as 200mm
Density of Concrete = 25 kN/m^3
Concrete Compressive strength = 25 MPa
Concrete Elastic Modulus = 28500 MPa

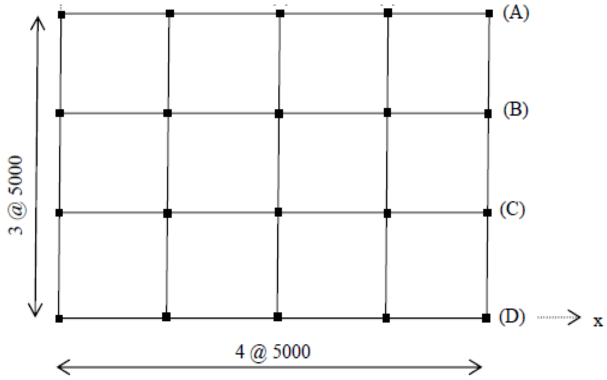

Fig.1 . Building Plan

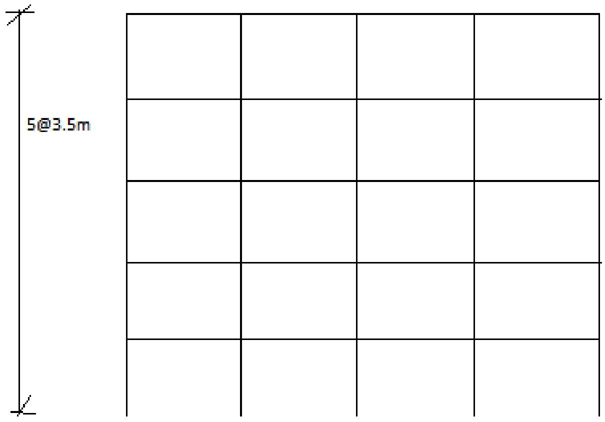

Fig.2. *Building Elevation*

The seismic base shear is evaluated as per the Saudi building code SBC 301-2007 [12], acting on a regular five-story building frame system and also acting on frame system with reinforced concrete shear walls in the principal directions on outer periphery of the building. The building which is located in region 6 of seismic contour map having Occupancy category I. The building is founded on rock with average shear wave velocity range 760 - 1500 m/s, a site class definition of B as per the SBC 301-2007. The design story drift (Δ) shall be computed as the difference of the deflections at the top and bottom of the story under consideration (Section 10.9.7, SBC-301). The deflections of Level x at the centre of the mass (δ_x) (mm) shall be determined in accordance with the following equation:

$$\delta_x = C_d\, \delta_{xe} / I \quad (1)$$

Where, C_d = Deflection amplification, δ_{xe} = Deflections determined by an elastic analysis, I = Importance factor

The design story drift (Δ) determined in Section 10.9.7: SBC-301 shall not exceed the allowable story drift (Δ_a). For general structure and I occupancy category, the allowable story drift is 0.02 h_{sx}, where h_{sx} is the story height below Level x. SAP 2000 is used to model and analyze the framed structure concrete building. Fig. 3 & Fig.4 shows the models of framed and shear wall building [13].

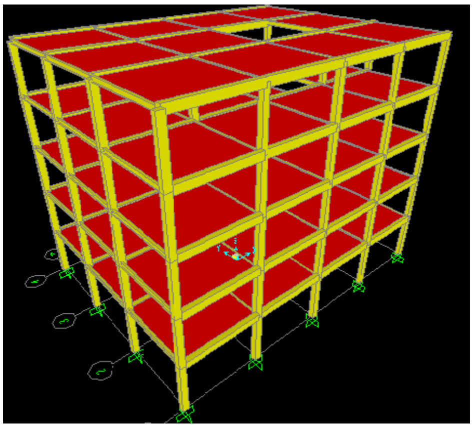

Fig.3. *3-D Frame structure*

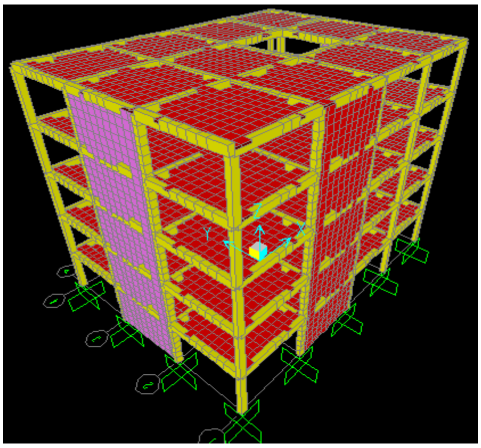

Fig.4. *Shear Wall Structure*

IV. Results and Discussion

The basic frame structure with and without shear wall is analyzed considering vertical and horizontal loading. Analysis of the structure has been done considering earthquake forces in y direction being critical direction for seismic response. Table 1 shows the results, deflection and drift of frame structure analysis when lateral load due to earthquake is applied in y direction and this table also show the analysis results of framed structure coupled with shear wall in two direction and continued up to the roof level. The storey drifts calculated in the Table 1 are more than the calculated allowable story drift as per the SBC-301: 2007 (Δ_a = 0.02 h_{sx} = 0.02 x 3500 = 70mm). Therefore, the framed structure existing building is not safe under seismic loading. The strengthening option is needed to increase the serviceability and stiffness of the building. Table 1 shows that by introducing the shear wall in the framed structure, the storey drifts of building are reduced considerably. The shear wall may be used to strengthen the framed structure building to increase its safety.

A. Options to Introduce Shear Wall for Strengthening of Frame Structure Building

The different option of provision of shear wall i.e. different height and different location of shear wall to strengthen the existing building is assessed. Fig. 4 to Fig. 7 show the deflected shape of SAP models of different options for seismic strengthening by providing different height and location of shear wall in the existing frame structure building.

Analysis results of different options for strengthening the complete framed structure have been presented in Table II and Fig. 8. The results in Table II show that by inclusion of shear walls in complete framed structure building, the side sway of building under the action of lateral loading is reduced. The reduction in deflection is smaller in lower storey's of the building. Table II and Fig. 9 depicts that shear wall on all four sides up to roof of building significantly decreases deflection and maximum deflection is recorded for shear wall in top most story. It can also be seen from the figure that by providing shear wall along the shorter direction up to full height will reduce more defection than providing the shear wall along longer direction. If shear wall is provided only in single storey, the second storey shear wall building will be stiffer than building with the shear wall in first storey only.

TABLE I. Storey deflection and drift of framed structure with and without shear wall

Storey Level	Deflection, δ_{xe} (mm)		Drift (Δ) , Framed structure (mm)		Drift (Δ), Shear wall (mm)	
	Framed structure	Shear wall	δ_x	Δ	δ_x	Δ
1	9	2.1	22.5	22.5	9.45	9.45
2	14	3.2	35	12.5	14.4	4.95
3	21	5	52,5	17.5	22.5	8.1
4	29	7	72.5	20	31.5	9
5	63	10	157.5	85	40	8.5

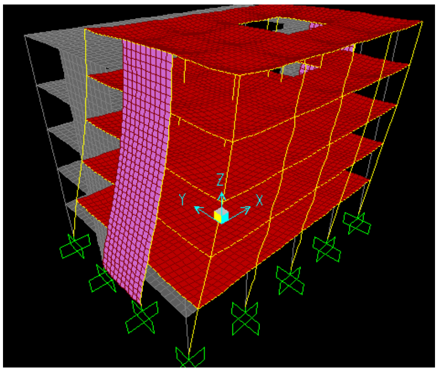

Fig.5. *Walls on shorter sides and up to roof*

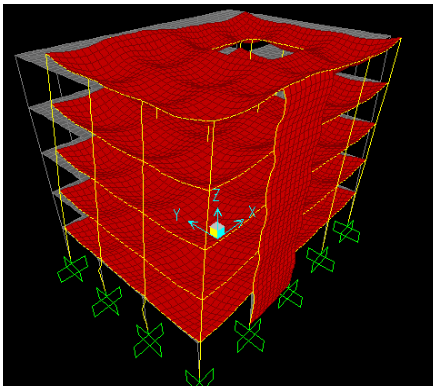

Fig.6. *Walls on longer sides and up to roof*

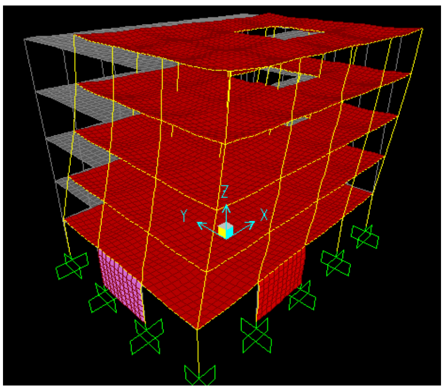

Fig.7. *Walls on sides and in first storey only*

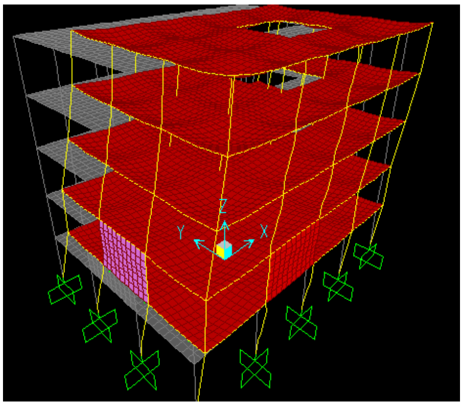

Fig.8. *Walls on sides and in second storey only*

TABLE II: Comparison of storey deflections for different options of strengthening

Lev	Complete Frame structured	4-Shear walls upto roof	2-Short side Shear Wall upto roof	2- Long side Shear Wall upto roof	4 shear wall on Ist storey	4- Shear walls on 2nd story
1	9	2.1	3.00	2.2	3.2	4.13
2	14	3.2	6.2	5.1	13.21	6.32
3	21	5	10.2	7.32	20.21	18.23
4	29	7	14.001	9.46	29.43	24.32
5	63	10	17.021	11.02	38.36	35.23

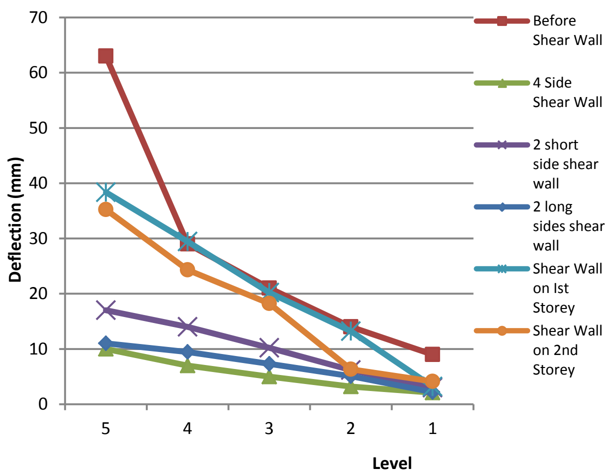

Fig. 9: *Storey deflections obtained for different options of strengthening*

V. CONCLUSIONS

The study on the performance of non-seismically designed concrete framed structure building under the action of seismic loading conforming to Kingdom of Saudi Arabia Code (SBC 301-2007)[12] is presented in this paper. A shear wall coupled structure system is adopted as seismic strengthening option as the structure of building is found unsafe under the seismic loading. The comparative study of the different options for seismic strengthening by providing different height and location of shear wall in the existing frame structure building is also presented. Significant conclusions of the study are summarized below:

- It is concluded from the present work that old building structures should be checked for safety and serviceability considering various type of expected loading, in particular lateral loading, according to the latest standards.
- The complete framed structure building should be proof checked for strength and stiffness under lateral forces. If found unsafe, appropriate strengthening technique should be applied.
- Due to the lateral loading due earthquake, serviceability and stiffness requirement is a major concern for complete framed structure concrete building.
- The provision of shear wall is an appropriate strengthening technique for stiffening the frame structure building under seismic loading.
- Among the different options of providing shear wall, the maximum reduction in the deflections and drifts will be with shear wall up to the roof of building.
- If shear wall is provided only in single storey, the second storey shear wall building will be stiffer than building with the shear wall in first storey only.

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