Behavior of conventional and fibered concrete shear walls during earthquake, an analytical simulation in SAP2000

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Abstract. The investigation of this paper was about non-liner behavior of shear walls against seismic wave by using conventional and fibered concrete. Case of earthquake study was Irpinia 1980, Italy with Ms = 6.9 and fourth kind of shear walls with glass fiber, basalt fiber, steel fiber concrete and conventional concrete shear walls simulated in SAP2000 with dynamic analysis method. Analysis shows that glass fiber concrete and conventional concrete shear walls had similar behavior, also these shear walls had more suitable response. All shear walls behavior were same at the beginning of earthquake but at the end of earthquake basalt and steel fiber concretes had a lot of displacement. Furthermore, behavior of steel fiber concrete shear wall could not return at the last moments of earthquake. Beside modulus of elasticity and compressive strength had most effect on reaction of shear walls such that modulus of elasticity was the cause of doing linear behavior of shear walls during all times of earthquake, on the other hand compressive strength had most efficiently in dissipation energy. Best result in earthquake was with conventional concrete due to modulus of elasticity and compressive strength.

Keywords: fiber concrete, shear wall, earthquake analysis, dynamic structure analysis, hysteresis graph.

1. Introduction
The zone of Irpinia is active in terms of earthquake wave in Italy. 1980 occurred a massive earthquake with Ms = 6.9 in the Southern Apennines [1]. Previous research in Irpinia showed that this earthquake was a complex event in 40 seconds period time in phase of Geology [2], also a pure normal faulting was cause of this earthquake with almost 40 km external Earth's crust fracture [3]. Generally, aftershocks continue after main shock as well as main shock complete an earthquake process [4], and if the most constructions were masonry with poor design [5], researchers concluded that design codes could not satisfy safety of structures against aftershock [6]. So these problems illustrated that structures need efficient components against different levels of seismic waves.

Researches showed that reinforced concrete shear wall (RC) had great effect averse to earth-quake waves [7]. Massone et al. [8] in one research described that damaged buildings by RC in 2010 Chile earthquake with Mw = 8.8 were just 2%.

Several studies had been conducted on RC that represent different sort of RC in terms of concrete sets with several result. For instance Huang et al. [9] investigated glass fiber concrete in shear wall that decrease deformation of plate, also glass fiber in RC upgrade deformability and forbear buckling in plate. Mohamed et al. [10] presented shear crack that had been managed against lateral shear resistance with added glass fiber to RC. Furthermore, Shen et al. [11] reported that basalt fiber in RC is good to improve earthquake resistance of structure. Sim et al. [12] concluded that basalt fiber in RC have more positives rather than carbon fiber in CSW such as malleable. Shen et al. [13] in their tests illustrated that basalt fiber increased earthquake efficiency of shear wall under cycle loading.

This study addresses the behavior of different sets of concrete such as glass fiber reinforced concrete shear wall (GFRC), basalt fiber reinforced concrete shear wall (BFRC), steel fiber reinforced concrete...
shear wall (SFRC) and reinforced conventional concrete shear wall (RC) against seismic wave by simulate in SAP2000 software by case of study of 1980 Irpinia, Italy earthquake's with Ms = 6.9 in the Southern Apennines.

2. Simulation model and method of simulating

2.1. Design method, diameters and reinforcement
This study was simulated in one design type of shear wall with four sets of concrete such as GFRC, BFRC, SFRC and RC shear wall in SAP2000 software in 2D, simulation was Non-linear according to defining material in three ways, unconfined concrete material as isotropic, confined concrete material as isotropic and uniaxial steel reinforcement. The shear wall was designed for conventional concrete shear wall and this design was simulated for GFRC, BFRC, SFRC and RC shear walls. The basic design details were as follows:
- $f_{c'} = 27.5$ MPa
- $f_y = 344$ MPa
- Vertical reinforcement = $\phi 16 @ 45.72$ cm
- Horizontal reinforcement = $\phi 12 @ 40.64$ cm
- Three stories building
- Modulus of elasticity =24,855 GPa

The diameters and loadings of base shear wall are shown in figure 1.

2.2. Loading cases and time history
Time history function was conforming to 1980 earthquake in Irpinia, Italy, in addition the geometric Non-linearity parameters were P Delta method, as well as for analyzing for Non-liner method in shear wall Live load and Dead load distributed in Gravity load with 0.25 scale factor and 1 scale factor respectively, also Push over load pursuant to Gravity load. The time history is presented in figure 2.
3. Analysis and results of simulating models
The simulating outcomes of each of concrete shear wall sets demonstrated in several parts and analyzed due to hysteresis graph, dissipation energy and displacement in three time periods, 0-5 second, 5-15 second and 15-40 second.

Deformation Base shear force graphs that have hysteresis loop shapes decrease structural energy in front of dynamic loading, as well as the amount and the quality of reducing energy in structure related to the type of hysteresis graph shape [14]. Also hysteresis loop shows the amount of absorbing energy as damper behavior in different structure, in that respect typically reinforced concrete reduce stiffness gradually during cyclic loading, likewise capacity of hysteresis energy assimilation related on using damper or coefficient of damper in shell members [15, 16].

3.1. Glass fiber reinforced concrete shear wall (GFRC)
The information taken from an investigation by Faleschini et al. [17] presented concrete with adding glass fiber coated with epoxy. The average glass fiber equivalent thickness was 0.05 mm, average fiber ultimate tensile strength was 525.5 MPa, and average elastic modulus was 64.4 GPa. Also about mixing method, coarse to fine aggregate ratio was 1.22 and water/cement ratio was 0.6. In this simulation, they used C-20-G2 with $f_c$ (cubic) = 25.2 and modulus of elasticity increase 5% (= 26.46 GPa).

The graph in figure 3 (a) shows that displacement fluctuations amplitude between 5 and 15 seconds was maximum in first 40 seconds owing to shock seismic waves in the same time. Moreover, the maximum dissipation energy was in the last period, the extreme amount of potential energy converted to kinetic energy, as a result the dissipation energy in shear wall was high, according to figure 4.

![Figure 3. Displacement graphs of GFRC (a) and RC (b) shear walls.](image1)

![Figure 4. Energy graphs of GFRC: a) Kinetic energy, b) Potential energy.](image2)
Figure 5. GFRC hysteresis graphs: a) 0-40 sec., b) 0-5 sec., c) 5-15 sec., d) 15-40 sec.

Additionally, figure 5b shows that the structural behavior was elastic and liner in first period but after earthquake wave the behavior changed to nonlinear (figure 5c) and occurs big loops. In second period high dissipation energy in structure confirms with potential energy (figure 5b). As illustrated in figure 5d, by decreasing dynamic seismic loading the hysteresis became smaller, beside both kinetic potential energy reduces. So GFRC shear wall behavior was linear at first, and nonlinear after shock seismic wave in second period.

3.2. Basalt fiber reinforced concrete shear wall (BFRC)
According to Dilbas et al. [18] presentation, compressive strength of basalt fibered concrete was 42 MPa and elasticity modulus was 31855 MPa, basalt fiber percentage was 1, recycled aggregated percentages was 40 and water absorption percentages was 6.92. Specimen tRA2C-B100 was used for our simulating model for BFRC.

Displacement was far steps gap during to 5 to 11 seconds but after 11 second these steps became closer (figure 6a), and displacement frequency amplitude became negative after 11 second. Displacement as illustrated in figure 6b shows that fluctuations amplitude at first was stable as same as other displacement graphs but at the end it was in negative displacement period, furthermore displacement did not return to horizontal axis that conformed BFRC shear wall behavior was inelastic at the end of period times of earthquake

Besides, nonlinear behavior was illustrated at second period times although numbers of hysteresis loops were low (figure 7c). Also the numbers of hysteresis loops are vast and repeated at the end of third period that represented nonlinear behaviors were more appeared (figure 7d). Furthermore, kinetic energy in first period were more than potential energy (figure 8).
Figure 6. Displacement graph of BFRC (a) and SFRC (b) shear walls.

Figure 7. BFRC hysteresis graphs: a) 0-40 sec, b) 0-5 sec, c) 5-15 sec, d) 15-40 sec.

Figure 8. Energy graphs of BFRC time: a) kinetic energy, b) potential energy.
3.3. Steel fiber reinforced concrete shear wall (SFRC)

Nematzadeh et al. [19] studied the steel fiber reinforced concrete. This part of simulating model was according to specimen ST1.0R10-2 with silica fume 52 kg, fine aggregate 649.8 kg, coarse aggregate 977.4 kg, crumb rubber 12.7 kg, steel fiber 78.5 kg and SP 5.4 kg, w/c 0.31 for mixing. Test results showed the compressive strength was 56 MPa and the initial modulus of elasticity was 36.1 GPa.

Analyzing different time steps SFRC shear wall hysteresis graphs in figure 9, it can be explained that the dissipation energy during third period with nonlinear behavior was reduced, moreover small spaces inside hysteresis loops affirmed that SFRC shear wall had not good response against seismic waves as well as SFRC shear wall collapsed or had inelastic behavior, since SFRC shear wall transferred more potential energy to kinetic energy, so movement of SFRC shear wall had more fluctuations at the end of earthquake (figure 10).

![SFRC hysteresis graphs](image1)

![SFRC hysteresis graphs](image2)

**Figure 9.** SFRC hysteresis graphs: a) 0-40 sec., b) 0-5 sec., c) 5-15 sec., (d) 15-40 sec.

![Energy graphs of SFRC](image3)

![Energy graphs of SFRC](image4)

**Figure 10.** Energy graphs of SFRC: a) kinetic energy, b) potential energy.
3.4. Reinforced conventional concrete shear wall (RC)

RC shear wall displacement graphs (figure 11) show that fluctuations displacement at the first time period had similar behavior as other types of shear walls and RC shear wall had mostly elastic behavior, but RC shear wall behavior was inelastic during at 12th and 33rd seconds, also after 33rd second RC shear wall behavior got close to elastic because graph line returned to horizontal axis. This graph (figure 11d) illustrates that hysteresis loops shifted to right and near the vertical axis, also the amount of dissipation energy became low, as a result RC shear wall had controlling reaction during time because force amplitude shifted to $\pm 5 \cdot 10^5$ KN from $\pm 1 \cdot 10^6$ KN, furthermore RC shear wall prevented collapsing.

In addition, the amount of kinetic energy was more than potential energy in maximum earth-quake fluctuations period time, thus dissipation energy was low which caused increasing displacement in this period, as illustrate in figure 12.

**Figure 11.** RC hysteresis graphs: a) 0-40 sec., b) 0-5 sec., c) 5-15 sec. d) 15-40 sec.

**Figure 12.** Energy graphs of RC: a) kinetic energy, b) potential energy.
The kinetic energy as dissipation energy in RC and GFRC shear walls are more than two other types of shear walls, furthermore two results are obtained:

- Dissipation energy is more related to base shear force;
- Dissipation energy has related to material properties.

For describing second result, the properties of GFRC and RC shear walls was almost similar together, so both behavior were nearby. On the other hand BFRC and SFRC shear walls properties were a little close and the dissipation energy in SFRC shear wall was less than BFRC shear wall (figure 11), additionally BFRC shear wall displacement was higher than SFRC at first of shock wave of earthquake due to modulus of elasticity and compressive strength.

The maximum displacement was for SFRC at the end of earthquake Proseccos, also SFRC shear wall had failure and collapse behavior in this period time, and SFRC shear wall as opposed to other shear walls did not returned to the horizontal axis, so SFRC shear wall had nonelastic behavior after shocking waves at first of earthquake (figure 6b). Finally, the elastic behavior of RC and BFRC were better than two other types of shear walls.

Physical and mechanical properties of materials are important in reaction and response of shear walls against seismic waves, so the compressive strength is not an important factor in failure, but elastic and nonelastic behaviors of shear walls, and also modulus of elasticity was another important factor for shear wall designing.

4. Conclusion
In the current study, four kinds of shear wall with different material properties had been simulated in SAP2000 software with Irpinia, Italy 1980 earthquake and obtained several results. The simulation results in current investigation can be concluded:

1) Total dissipation energy is sum of all hatched loops area in a hysteresis graph and dissipation energy depend on displacement.
2) Material properties are related with dissipation energy in response to shear walls against dynamic loading, and modulus of elasticity and compressive strength had maximum effects on dissipation energy.
3) Material properties had most effect on displacement, on the other hand increasing compressive strength is not the reason for preventing collapse and failure of shear wall.
4) Modulus of elasticity had equivalent value with compressive strength in shear walls dynamic loading response.
5) Shear walls behavior were suitable at the beginning of earthquake fluctuations amplitude but with prolongation of seismic time BFRC and SFRC had not suitable reaction and return ability to elastic behavior had not seen in these type of shear wall, it shows that shear wall structure had the ability of failure in long-term earthquake despite increasing compressive strength and modulus of elasticity.
6) SFRC and BFRC had low dissipation energy but RC and GFRC had high dissipation energy due to material properties which illustrates that lower compressive strength and modulus of elasticity had the ability of enhancing dissipation energy in a structure.

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