Reinforced Concrete Structure under Earthquake Loading Using Concrete-polymer Composites

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Abstract: The dissipation of the energy coming from the earthquake is the first problem facing the engineers which conventional concrete is characterized by some feeble ability of dissipation of vibration. This work present new approach for using the building itself to mitigate vibrations by changing the qualitative characteristics of the concrete used in construction by adding polymers to resist strong earthquake. Firstly, the response of structure was studied for the three smart materials were chosen for using in this study; polymer concrete, and polyester polymer concrete with glass and carbon fibers, which have been applied in the structure on two different levels: partial level use and total level use, the controllability method was used to determining the optimal placement for using the concrete-polymer composites in the structure for the partial use cases. Secondly the failure of concrete under series of earthquakes was studies for the best case of the former part .The results show that the proper use of concrete-polymer composites it can reduce the peak response and diminish the maximum principle stress of the concrete of structures subjected to seismic forces.

Key words: seismic excitation, polymer concrete, fiber reinforced polyester polymer, controllability index.

INTRODUCTION

The earthquake takes much importance in the design of structures; the dissipation of the energy coming from this factor is the first problem facing the engineers therefore several researches have been held to solve this problem by increasing the energy dissipation properties of structures, whether by using active damping or passive damping, because the concrete whether with or without reinforcement is characterized by some feeble ability of dissipation of vibration. Since 1940 some research work has been done to ameliorate the characteristics of concrete to increase their capacity by adding polymer, which gave good result.

A wide range of concrete-polymer composites is being investigated although only some of them already applied. The most important are the following:
- Polymer impregnated concrete (PIC).
- Polymer cement concrete (PCC).
- Polymer concrete (PC).
- Fiber-reinforced concrete (FRC).
- Fiber-reinforced polymer concrete (FRPC).

Two ranges of concrete-polymer composites have been chosen for using in this study; polymer concrete, and fiber-reinforced polymer concrete.

However, their use has become clear in the nuclear and industrial constructions; this work is an attempt to see their effectiveness in the field of earthquake.

The structure taken for this study is 12 story frame structure studied by lu xi lin et all a series of shaking table testes was carried out using a 1/10 scale model of this structure. Test stages and obtained result have used as steps followed in this research. The seismic wave used in the test was; El Centro wave, Kobe wave, Shanghai artificial wave and Shanghai bedrock wave. The first two phases of this research and acceleration values are presented in table1.

The tests done for improve the damping characteristic of concrete are still a few, withal there have been several well documented experimental studies was founded; while two useful works have been chosen for this study.

Ke guo jun tested six classes of concrete, polymer concrete was one of them. Free vibration method was employed to measure the damping ratio of concrete as well as the compressive strength and elastic modulus are measured .the result shown in table 2. According to the analysis of obtain test results, 10% and 15% was chosen as a best concentration of polymer, depending on the relationships between polymer concentration in concrete and its effects on compressive strength and young’s modulus.
and torsional vibration can be written:

\[
\delta (\Delta Y) = \delta (\Delta U_L) + \delta (\Delta U_f) + \delta (\Delta UT)
\] (1)

Where
\[
\delta (\Delta U) : \text{Total energy dissipated.}
\]
\[
\delta (\Delta U_L) : \text{Longitudinal energy dissipated.}
\]
\[
\delta (\Delta U_f) : \text{Flexural energy dissipated.}
\]
\[
\delta (\Delta UT) : \text{Torsional energy dissipated.}
\]

So the total damping of material consists of three different components: longitudinal, flexural and torsional damping is the sum of the three components. However we cannot literally use the rule owing to the structure used in this study is regular.

So there are suspicions to add torsional damping to total damping because there is no risk of torsion in frame members, whereas the torsional effect will be negligible.

**Table 1:** Test loading system

<table>
<thead>
<tr>
<th>Test cases</th>
<th>Name Case</th>
<th>Input signal</th>
<th>PGA(g) prototype</th>
<th>X dir</th>
<th>Y dir</th>
<th>Z dir</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1WN</td>
<td>White noise 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>EL1</td>
<td>El Centro</td>
<td>0.035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SH1</td>
<td>S-h artificial</td>
<td>0.035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>KB1</td>
<td>Kobe</td>
<td>0.035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SJ1</td>
<td>S-h bedrock</td>
<td>0.035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>EY1</td>
<td>El Centro</td>
<td>0.035</td>
<td>0.030</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>KY1</td>
<td>Kobe</td>
<td>0.035</td>
<td>0.030</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>EL2</td>
<td>El Centro</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>SH2</td>
<td>S-h artificial</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>KB2</td>
<td>Kobe</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>SJ2</td>
<td>S-h bedrock</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>EY2</td>
<td>El Centro</td>
<td>0.1</td>
<td>0.085</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>KY2</td>
<td>Kobe</td>
<td>0.1</td>
<td>0.085</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>EZ2</td>
<td>El Centro</td>
<td>0.1</td>
<td>0.085</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>KZ2</td>
<td>Kobe</td>
<td>0.1</td>
<td>0.085</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>16WN</td>
<td>White noise 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2:** Test results of polymer concrete.

<table>
<thead>
<tr>
<th>Strength grade</th>
<th>Compressive strengthMPa</th>
<th>Elastic modulus10^4 Mpa</th>
<th>Damping ratio %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C30+0%</td>
<td>38.1</td>
<td>3.37</td>
<td>1.45</td>
</tr>
<tr>
<td>C30+5%</td>
<td>21.1</td>
<td>2.52</td>
<td>1.45</td>
</tr>
<tr>
<td>C30+10%</td>
<td>23.2</td>
<td>2.40</td>
<td>1.92</td>
</tr>
<tr>
<td>C30+15%</td>
<td>19.2</td>
<td>1.99</td>
<td>2.50</td>
</tr>
<tr>
<td>C30+23%</td>
<td>22.9</td>
<td>1.31</td>
<td>2.86</td>
</tr>
</tbody>
</table>

Kallal sett and C.vipulanandan\(^{11}\) studies the effects of adding glass and carbon fibers in polyester polymer. The response of cylinders and prisms in the three fundamental modes of vibration, namely, longitudinal, transversal, and torsional. For the FRPC systems, resin contents were chosen based on workability. The resin contents chosen for this study were 18 and 20% (by weight of composite) for GFRPC and CFRPC, respectively. The results are shown in table 3.

It’s evident that the adding of glass and carbon fibers in specimen No1 gave good result; based on that was selected for this work.

R.D.adams\(^{14}\) proposed that the total energy dissipated in the element under longitudinal, flexural and torsional vibration can be written:
Table 3: Test results of GFRPC and CFRPC:

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Compressive Mpa</th>
<th>Tension Mpa</th>
<th>Modulus Gpa</th>
<th>Longitudinal %</th>
<th>Transversal %</th>
<th>Torsional %</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFRPC</td>
<td>0% fiber</td>
<td>1</td>
<td>55</td>
<td>19.9</td>
<td>0.92</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>50</td>
<td>-</td>
<td>19.6</td>
<td>0.86</td>
<td>1.2</td>
</tr>
<tr>
<td>4% fiber</td>
<td>1</td>
<td>65</td>
<td>3.8</td>
<td>1.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>63</td>
<td>-</td>
<td>18.2</td>
<td>1.05</td>
<td>1.52</td>
</tr>
<tr>
<td>6% fiber</td>
<td>1</td>
<td>80</td>
<td>13</td>
<td>21</td>
<td>1.17</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>82</td>
<td>12.5</td>
<td>21.6</td>
<td>1.23</td>
<td>1.7</td>
</tr>
<tr>
<td>CFRPC</td>
<td>0% fiber</td>
<td>1</td>
<td>61</td>
<td>18.57</td>
<td>1.18</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>59</td>
<td>7.5</td>
<td>18.21</td>
<td>1.1</td>
<td>1.82</td>
</tr>
<tr>
<td>4% fiber</td>
<td>1</td>
<td>60</td>
<td>10.55</td>
<td>17.8</td>
<td>1.71</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>55</td>
<td>10.6</td>
<td>17.1</td>
<td>1.69</td>
<td>0.27</td>
</tr>
<tr>
<td>6% fiber</td>
<td>1</td>
<td>65</td>
<td>11.5</td>
<td>17.5</td>
<td>1.98</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>68</td>
<td>11.3</td>
<td>17.6</td>
<td>1.89</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Therefore the total energy dissipated in the element rewritten:

\[
\delta (UA) = (UA_L) + (UA_F) \quad (2)
\]

Controllability index method: Owing to economy and performance we can not only use the concrete-polymer composites in the hole beams and columns of structure, for this reasons controllability method was used for determined the optimal location for using concrete-polymer composites.

Shukla and data \(^{(5)}\) defined a criterion called controllability index for optimal damper placement, which it’s using in this paper for determine the optimal polymer concrete floors place.

\[
\chi = \max \left[ \frac{\sigma_i}{h_i} \right], 1, 2, ..., n. \quad (3)
\]

Where \(\chi\) and \(\sigma_i\) are the value of index and root-mean-square value of interstory drift at ith story, respectively; \(h_i\) is the ith story height.

The optimal location when \(\chi\) is maximum, from figure.1 we choose to use concrete-polymer composites in beams and columns of 12, 11, 10, 7, 6 and 2 floors for the partial use case.

Beams 0.3x0.6m, and slabs thickness is 0.12m. Columns and beams elements model have been developed in Ansys using Beam188 element, this element is commonly used for analyzing slender to moderately stubby/thick beam structure,beam188 is linear two mode or a quadratic beam element in 3D, it has six degrees of freedom at each node. And slabs was modeled using Shell143 element, this element is four-node, plastic, small strain, large rotation mindlin shell element, the transverse shear, stresses are assumed to be constant through the thickness for this element.

Table 4: Determination of controllability index

<table>
<thead>
<tr>
<th>Floor</th>
<th>1st mode</th>
<th>2nd mode</th>
<th>3rd mode</th>
<th>(x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0133</td>
<td>-0.0444</td>
<td>-0.0791</td>
<td>0.0176</td>
</tr>
<tr>
<td>2</td>
<td>0.0425</td>
<td>-0.1325</td>
<td>-0.2138</td>
<td>0.0314</td>
</tr>
<tr>
<td>3</td>
<td>0.0785</td>
<td>-0.2197</td>
<td>-0.2933</td>
<td>0.0237</td>
</tr>
<tr>
<td>4</td>
<td>0.1164</td>
<td>-0.2793</td>
<td>-0.2628</td>
<td>0.0148</td>
</tr>
<tr>
<td>5</td>
<td>0.1539</td>
<td>-0.2963</td>
<td>-0.1270</td>
<td>0.0273</td>
</tr>
<tr>
<td>6</td>
<td>0.892</td>
<td>-0.2659</td>
<td>0.0599</td>
<td>0.0370</td>
</tr>
<tr>
<td>7</td>
<td>0.2215</td>
<td>-0.192</td>
<td>0.2199</td>
<td>0.0344</td>
</tr>
<tr>
<td>8</td>
<td>0.2498</td>
<td>-0.0859</td>
<td>0.2853</td>
<td>0.0245</td>
</tr>
<tr>
<td>9</td>
<td>0.2737</td>
<td>0.0356</td>
<td>0.2267</td>
<td>0.0263</td>
</tr>
<tr>
<td>10</td>
<td>0.2928</td>
<td>0.1548</td>
<td>0.0643</td>
<td>0.0389</td>
</tr>
<tr>
<td>11</td>
<td>0.3073</td>
<td>0.2562</td>
<td>-0.1453</td>
<td>0.0449</td>
</tr>
<tr>
<td>12</td>
<td>0.3180</td>
<td>0.3338</td>
<td>-0.3444</td>
<td>0.0411</td>
</tr>
</tbody>
</table>

\[12\]
\[11\]
\[10\]
\[9\]
\[8\]
\[7\]
\[6\]
\[5\]
\[4\]
\[3\]
\[2\]
\[1\]

Fig. 1: Controllability index of frame structure

The damping matrix: Because we have two kinds of material we use this method for solving the model The finite element modeling of structure:
Where \([M]\) and \([K]\) are element mass matrix and element stiffness matrix respectively; \([M]\), \([K]\) and \([C]\) are mass, stiffness and damping matrix of whole structure respectively; \([M']\), \([K']\) and \([C']\) are element foundation mass, stiffness and damping matrix of normal reinforced concrete part in structure respectively; \([M'']\), \([K'']\) and \([C'']\) are element foundation mass, stiffness and damping matrix of concrete-polymer composites part in structure respectively. Which \([\eta]\) and \([\eta']\) are matrices of shape functions of conventional and concrete-polymer composites respectively.

Alpha damping and Beta damping are used to define Rayleigh damping constants \(\alpha\) and \(\beta\). The damping matrix \([C]\) of each material's substructure is calculated by using these constants to multiply the mass matrix \([M]\) and stiffness matrix \([K]\):

\[
[C'] = \alpha [M'] + \beta [K']
\]

(7)

\[
[C''] = \alpha [M''] + \beta [K'']
\]

(8)

When equations 7,8 is substituted in equation 5 we obtain:

\[
[C] = \alpha [M] + \beta [K] + (\alpha - \alpha) [M'] + (\beta - \beta) [K']
\]

(9)

**Finite Element Modeling:** The model of the structures, with floor height 3m, Dimension of columns 0.5x0.6m, and Dimension of Damping mechanisms in ANSYS: The damping matrix \(C\) in ansys can be use in transient analysis without damper or actuator, can be written:

\[
[C] = \alpha [M] + \beta [K] + \sum_{j=1}^{N_x} \beta_j [K_j]
\]

(10)

\(\alpha\) : Constant mass matrix multiplier.
\(\beta\) : Constant stiffness matrix multiplier.
\(\beta_j\) : Constant stiffness matrix multiplier material-dependent damping.

Material dependent damping \(\beta_i\) is the only parameter formulations are available in Ansys which can be assigned to a lot of materials.

For using the equation we neglect \((\alpha - \alpha)[M']\) part in equation 9.

**RESULTS AND DISCUSSION**

Time history analysis has been carried out for the model structure without concrete-polymer composites and with partial and total use of concrete-polymer composites in the structure; the maximum roof floor displacement and the time history response were compared for all the cases. The results of the observations are presented in the next sections.

3.1 **Polymer concrete:** The time history response at the roof level in x and y directions are presented in Figure 1 to Figure 4. The following inferences can be extracted:

![Fig. 1: Roof floor displacement of partial use of 10% polymer concrete: a) direction X, b) direction Y.](image-url)

The only reduction in peak response is 1.94% in the x direction response of the partial use of 10% polymer concrete in structure, whereas in the y direction the peak response increases about 8.21%.

There is no reduction in peak response for the total use of 10% polymer concrete case as seen in Figure 2 and it is more adverse in y direction which the displacement increases about 27.13% and increases about 4.54% in x direction.

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The peak response increases in the partial use of 15% polymer concrete case about 1.98% and 29.56% in x and y directions respectively.

For the total use of 15% polymer concrete case, the peak response as seen in Figure 4 is the worst response where the displacement increases about 3.62% and 45.61% in x and y directions respectively.

The obtained results evidence that the polymer concrete is incompetence to dissipate the energy coming from the earthquake; because the addition of polymer in concrete gives negative results for elastic modulus who describes the stiffness of material, which is the most important propriety in engineering design of structure.

It is clear that the increase of polymer concentration in concrete even if it improves the damping propriety but it has largest negative impact on the elastic modulus and a compressive strength of concrete which conduce the obtaining to reverse results to be obtained.

3.2 CFRPC: The time history response at the roof level in both x and y directions are presented in Figure5 to Figure8. The following inferences can be made from the figures:

There is no reduction in peak response and it is adverse in all cases of analysis. The peak response increases about 2.47% and 13.04% in x and y directions respectively in the partial use of 4% CFRPC in the structure, while the worst response was when the
Fig. 5: Roof floor displacement of partial use of 4% CFRPC: a) direction X, b) direction Y.

Fig. 6: Roof floor displacement of total use of 4% CFRPC: a) direction X, b) direction Y.

Fig. 7: Roof floor displacement of partial use of 6% CFRPC: a) direction X, b) direction Y.

Fig. 8: Roof floor displacement of total use of 6% CFRPC: a) direction X, b) direction Y.
total use of 4% CFRPC in structure with increase of 15.21% and 37.13% in x and y directions respectively. For the partial use of 6% CFRPC case, the displacement increases about 1.91% and 29.73% in x and y directions respectively.

The response as seen in Figure 8, for the total use of 6% CFRPC, shown that the displacement increases about 3.62% and 45.61% in x and y directions respectively.

From the above discussion, it can be concluded that the CFRPC is completely impractical for seismic engineering; and results obtained evidence that the impact on both damping ratio and elastic modulus was very bad. However; it can be used in elsewhere in the buildings to resist the tension effect, because the CFRPC gave a good tension strength.

3.3 GFRPC: The time history response at the roof level in both x and y directions are presented in Figure 9 to Figure 12. The following inferences can be made from the figures:

Fig. 9: Roof floor displacement of partial use of 4%GFRPC: a) direction X .b) direction Y.

The reduction in response for GFRPC utilization is good for all the cases and it’s maximum values are 26.14% and 34.12% in the total use of 6% GFRPC in x and y directions respectively, whereas the minimum values are 4.61% and 12.13% in the partial use of 4%GFRPC in x and y directions respectively.

The total use of 4% GFRPC and partial use of 6% GFRPC cases also show satisfactory reduction in deflection, the response reduction is about 6.43% and 23.22% for the total use of 4%GFRPC in x and y directions respectively, and around 11.52% and 28.57% for the partial use of 6% GFRPC in x and y directions respectively.

Fig. 10: Roof floor displacement of total use of 4%GFRPC: a) direction X .b) direction Y.

Fig. 11: Roof floor displacement of partial use of 6%GFRPC: a) direction X .b) direction Y.
After the analysis of results, noticed that good results obtained in all cases, which indicated that the reinforcing of polymer concrete with glass fiber give a very positive impact on the concrete propriety, and can also be used for resisting the earthquake whether with total or partial using in the building, but the economic reasons persuades us to make caution for total use of GFRPC in the buildings.

After analysis the results obtained from the three kinds of smart concrete used in this work, and owing to the economic reasons, partial use to of 6%GFRPC in the structure are selected to be the best case for reinforcing the structure under the earthquake.

The structure was studied under series of earthquakes to study the failure points of structure before and after using 6%GFRPC. The results of observations are presented in the next sections.

The allowable stress in mainly used to analysis the behavior of the structure through the maximum principal stress, p1 and minimum principal stress, p3. Cracking failure of the frame structure will occur if the maximum principal tensile stress, P1 larger then 0.1fcu. Crushing failure of frame structure will occur if minimum principal compressive stress, P3 is less than -0.8fcu.

Structure without GFRPC: Concrete cracking: The concrete element are assumed to be failed in cracking when the maximum principle stress, p1, of concrete exceeded 0.1 fcu i.e. 5.5MPa. In the initial stages of applied earthquakes, there are no sings of distress or visible cracking occurred at the structure, after the 9th situation, at step=3816 of Shangai artificial wave, the bottom of the floor second columns (element 1, node 1 and 3; element 11, node 12 and 14; element 21, node 23 and 25; element 31, node 34 and 36) start to crack. The P1 of concrete is about 7.825MPa, which exceeded the allowable tension stress.

Concrete crushing: Minimum principle, stress p3 is 0.8fcu i.e. 44MPa; the crushing failure will happen if p3 analysis less than allowable. The results shown that the value for minimum stress P3 analysis is larger than P3 allowable, so the crushing failure was not occur at this frame structure modeling.

Structure with GFRPC: Concrete cracking: The concrete element are assumed to be failed in cracking when the maximum principle stress, p1, of concrete exceeded 0.1 fcu i.e. 8MPa. At 9th situation of applied of earthquakes, there are no signs of cracking occurred at the structure. Which the maximum principal stress, P1 analysis = 6.38MPa is less than P1 allowable = 8 N/mm2.

Concrete crushing: Minimum principle, stress p3 is 0.8fcu i.e. 64MPa; the crushing failure will happen if p3 analysis less than allowable. The results shown that the value for minimum stress P3 analysis is larger than P3 allowable, so the crushing failure was not occur at this frame structure modeling.

Conclusion: The feasibility of using the concrete-polymer composites to reinforce the structure under earthquake was investigated analytically and the following conclusions can be drawn from the study.

The partial and total use of polymer concrete in the structure have negative impact in the response of structure in the most cases of study, because the addition of polymer in concrete gives negative results for elastic modulus.

The addition of carbon fiber to the polyester polymer concrete gave negative results, thus, is not useful to use the CFRPC for reinforcing the structure under earthquake.

This study affirmed that GFRPC is the best case for reinforced the structure to dissipate the earthquake energy which the other materials have negative impact on the elastic modulus and compressive strength of concrete.

The partial use of smart concrete n structure is effective which allows us to use it without worry about the cost.

The crack and the crush failure did not occur at the element of structure after using of GFRPC which the maximum principle stress diminishes about 20.25% from the allowable stress of the concrete.

Fig. 12: Roof floor displacement of total use of 6%GFRPC: a) direction X .b) direction Y.

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REFERENCES


