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Research Article

The Impact of Concrete Strength on the Structure Performance under Repeated Loads

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Abstract

Reinforced concrete structures such as RC buildings and rigid pavements are exposed to tensions within the impact of repeated loads. Earthquake and wind load could be given as the examples for repeated loads. In this study; compression tests have been conducted under the repeated loads for the attained reinforced concrete samples. Three different samples have been prepared in the study and they have been subjected to compression test. Repetitive compression tests have been applied to each sample and loading has been continued until the concrete is in the status of not being able to bear any more loads. Structure performance analyses have been carried out for the sample reinforced concrete building selected with the use of the concrete compression strengths attained under the repeated loads. The purpose of the study is to reveal how the repeated loads affect the compression strength of the concrete. At what degree these attained concrete compression strengths affect the structure performance has been examined.

Keywords: Repeated Loads, Concrete, Strength, Reinforced, Performance

1. Introduction

What expected from the hardened concrete is to be of high strength, resistant and economic. When the reinforced concrete structures heavily damaged during the recent earthquakes have been examined, it has been clearly revealed that the basic information regarding the concrete has not been used and the necessary inspections have not been carried out. The most important necessity for the strength and resistivity is to produce the concrete that has little space and that is impermeable as much as possible. Today, the production of the concrete in the desired performance is not a problem. It should not be forgotten that the production of concrete requires technology and knowledge. When the importance given to the aggregate quality and the minimum dosage and maximum water/cement ratio are taken into consideration, the concrete providing the desired performance could be produced. However there are changes in the performance of the concrete depending on the status of the affecting loads.

Sufficient rigidity, strength and ductility are the main principles that should be taken into consideration in the reinforced concrete buildings under the impact of earthquake. The damage is primarily related to the concrete strength in the reinforced concrete type structures after the earthquakes. The rigidity of the structure increases means the material strength increases (Ülker et al., 2016). The main reason causing to structural damage in the reinforced concrete buildings is the earthquake. The earthquakes occurring in the previous years have shown that such kind of structures are damaged depending on many reasons after a lightly or strongly severe earthquake. The damage probability of the buildings to which the necessary attention has not been paid during the design and construction changes depending on the magnitude of the earthquake (Celep and Kumbasar, 2007).

A reinforced concrete structure whose earthquake safety has been provided should have the sufficient strength, ductility and rigidity. The arrangement of the structure bearing system as of the foundation and the precision given to the details in the reinforcement arrangement in the material strength and bearing elements are in direct proportion to the provision of necessary strength, ductility and rigidity to the structure. Earthquake is the most convenient example for the loading repetitions in the structure. The probability of a structure that has experienced an earthquake and that has stood up is high for exposure to an earthquake again. The concrete will be easily shapeable by means of the repetition of the loads. The purpose of this study is the experimental calculation of the change amount occurring in the compression strength of the concrete in the event of the repetition of the load. For this purpose; concrete samples have been prepared and compression has been applied until the concrete is not able to bear any more load. It has been examined how the concrete compression strengths attained as a result of the tests change the behavior of the structure under load.

2. Mechanical Properties of Concrete

Concrete which is one of the most important structure materials in our age is made of the mixture of sand–pebble (aggregate), cement, water and additive

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substances when necessary. Pebble (coarse aggregate) forms the skeleton of the concrete. Sand (fine aggregate) fills the spaces between the pebbles and provides the increase in the strength and resistance of the concrete. Cement and water forms the cement paste binding the grains to one another. In addition; when necessary, various minerals and chemical additives could also be used for the purpose of changing certain properties of the concrete (for example; shortening or extending the setting period, increasing the penetrability etc.).

It is a construction material which can be shaped easily through concrete moulds, which have good compressive strength and which is commonly used. Besides that compressive strength, it's quite far from providing sufficient ductility. Thus, it is required to confine the concrete elements. Core concrete is confined through transverse reinforcements at specific intervals. Concrete top layer (concrete cover) is used to protect the transverse and longitudinal reinforcements against external effects. The pattern, concrete strength and axial load level of longitudinal reinforcement as well as the amount, diameter, interval, strength and pattern of the transverse reinforcement affect the behavior of confined concrete. The typical stress & strain relation of any concrete has been shown in Figure 1 (Türk, 2011).

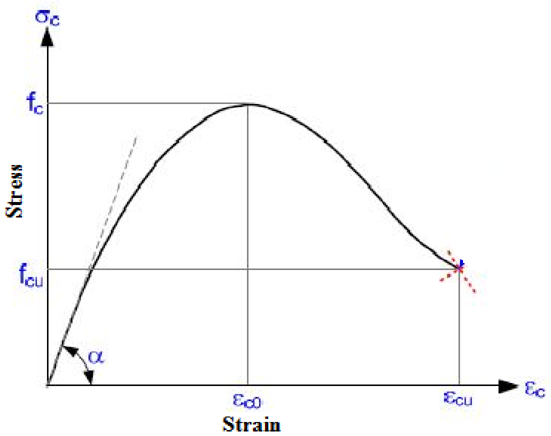

Figure 1. Stress-strain relation for any concrete class

When the concrete is reached to the largest stress, it does not break; yet, it breaks when it reaches to a specific deformation. The stress-deformation features of the concrete vary as per quality of concrete. When the compressive strength of concrete increases, its deformation ability decreases; however, the initial inclination (modulus of elasticity) of stress-deformation curves increases and their peak points get sharper. Stress-strain relation for different concrete classes has been shown in Figure 2 (Çağlar, 2016).

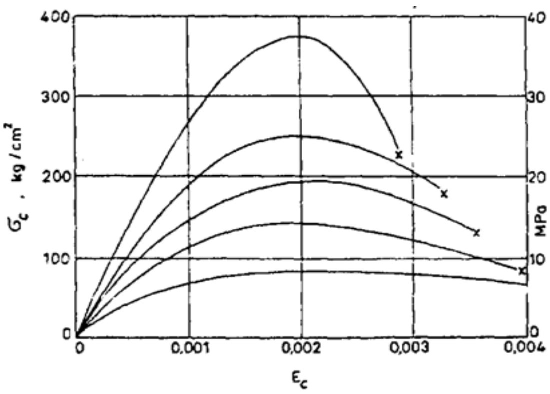

Figure 2. Stress-Strain relation for different concrete classes

3. Behavior of Concrete under Repeated Loads

The behaviors of the materials under load have a significant role for especially the material strength values in the structure design. The behavior of any material under load is expressed in stress-deformation.

Structures are affected from several loads during their service life. The loads occurring due to earthquake, wind and machine movements are some of these loads. The structure materials forming the structure elements are dimensioned for the purpose of bearing these loads. The repetitive effect of several loads having and effect during the service life of the structures on the structures changes the behavior of the structure under load. A decrease will occur in the strength of the structure material under repetitive loads. In this study, how the compression strength of the concrete changes under the repetitive loads has been attained via experimental (test) samples.

The concrete is exposed to repeated tensions under repeated loads occurring from the earthquake, wind and machine movements. The relation of tension-unit shortening should be known in the unloading and re-loading states under repeated tensions. The relation of stress-deformation attained under the repeated loads for any concrete is shown in Figure 3 (Ersoy ve Özcebe, 2007).

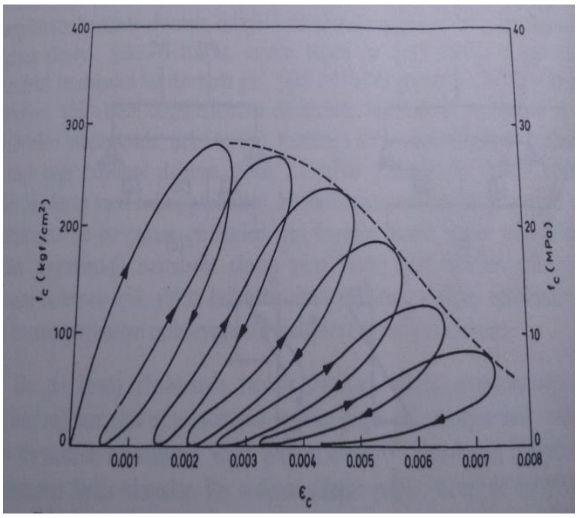

Figure 3. Stress-Strain relation for concrete classes under repeated loads

As the load repetition increases, the output slope of the curve defined also as the rigidity of the concrete also decreases. The elasticity module of the concrete changes significantly. Another property of the curve given in this way is that the stress-deformation curve drawn although the load is repeated is equal to the curve drawn under the permanently applied loads. This could also be called as the softening of the concrete (Ersoy and Özcebe, 2007; Doğangün, 2013). It is seen that the concrete becomes more shapeable by means of the loading repetitions. The permanent shortenings of the concrete permanently increase under the repeated load that forms great deformations. The concrete practically becomes unable to bear any load after a certain repetition. The similar situation occurs in a certain scale under the earthquake impact (Celep and Kumbasar, 2007).

4. Performance Based Assessment

The importance of studies, researches and prevention from earthquakes have risen after destructive earthquakes in the world recently. The damages of earthquakes increase through vulnerability of urban and rural building stocks. The size of earthquakes and the negative structural features increase the damage amount. To know the properties of buildings to be negatively affected the seismic behavior of buildings under earthquakes are put forward to ensure more serious approaches to reduce the level of damage risk after earthquakes. In order to reduce the damages of the earthquakes, the performance of buildings needs to be determined at first. The earthquake safety of existing buildings has gained considerable importance after earthquakes occurred in our country especially in the last 30 years. Performance based assessment methods have been widely used for existing reinforced concrete structures. In performance based design and assessment method, it is possible to determine the quantities of damage levels arising under the design ground motion within the structural system elements. Whether this damage stays under the acceptable damage levels for each relevant element is checked. Acceptable damage limits are defined in a way to be consistent with the foreseen performance targets at various earthquake levels (Aydınoğlu, 2007; Doran et al., 2011; Kutanis and Boru, 2014).

The assessment procedure targets to estimate the earthquake force demand at which the building would sustain the performance objectives. Demand spectrum used in determining the performance of the building's system shows the maximum response that a building gives against seismic activities during an earthquake (Ilki and Celep, 2011). The earthquake demand and capacity are two fundamental parameters of performance based design and assessment (Fajfar, 1999; Özer, 2007). Earthquake demand represents the earthquake ground movement; however, the capacity represents building's reaction under the effect of an earthquake. Structural capacity is represented by static pushover and capacity curve. This curve is derived by drawing the function between base shear force and building's roof displacement. Capacity curve is derived by calculating building system with gravitational loads and proportionately increasing lateral forces up to the target point where structural capacity comes to an end. The real purpose of the nonlinear static method is to determine the target displacement of a building and then by performing a final pushover analysis by increasing the lateral loads up to the target displacement. As a result, the demand values such as internal forces, rotations, strains and displacements are computed and the performance of the analyzed section is then evaluated by comparing the strains obtained from the total curvature of the section with the upper boundary strains which are designated for different cross-sectional performance levels (Işık and Kutanis, 2015).

5. Experimental Determination of the Strength of Concrete under Repeated Loads

This study covers the concrete compression test applied on the hardened concrete samples formed with the mixture of cement and water having the strength of PC 32.5 taking place in the market and to be used in the concrete together with the aggregate samples taken from crushed stone facility taking place in Bitlis region and the compression tests repeated on the same samples.

5.1. Extraction of Hardened Concrete Samples

Sieve analysis test has been conducted on the aggregate samples attained from the pit. The square-mesh sieves with the aperture sizes of 0.25 mm, 0.50 mm, 1 mm and 2 mm in accordance with TS 1227 (1985) and the square perforated wire sieves with the aperture sizes of 4 mm, 8 mm, 12 mm, 16 mm and 22.5 mm in accordance with TS 1226 (1985) have been used for the aggregates, they have been separated into different fractures and they have been made ready for the purpose of using in the concrete sample. The sieve analysis results and granulometry curve belonging to the aggregates are shown in Figure 4.

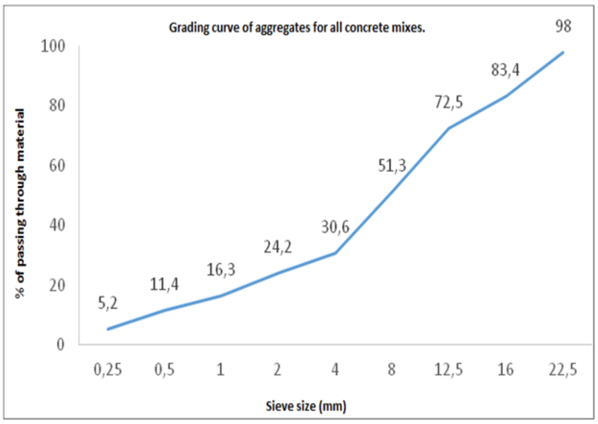

Figure 4. Grading curve of aggregates for all concrete mixes

Three compression tests have been successively carried out for three different samples for the compression strength of the concrete under repeated loads. The average of the attained values has been taken. The compression test has been repeated as the concrete samples have sustained taking loads and the tests have been stopped when the concrete has been unable to bear any other load and come to the point of dispersion. It has become unable to bear any load as a result of the third test in all three samples. The deformations have started to disperse from the corner points of the used cube samples. A concrete mixture in which concrete class is C30, ambient temperature is 10˚C, concrete temperature is 11˚C and slump value is 10 cm has been prepared. The attained concrete samples have been attained as the cube materials with the dimensions of 15×15×15 cm. The number of samples is 3 and the averages of daily compression strengths have been attained for 28 days. The samples have been kept in the cure pool whose temperature is 20˚±5˚C. The concrete compression strengths of the samples kept in the cure pool for 28 days have been measured. The concrete compression test has been repeated on the same samples for 3 times on condition that the same fracture load and same periods will be applied on the measured concrete samples. The results of the concrete compression strength conducted on the hardened concrete samples are expressed in the Table 1.

6. Building Performance Analysis under Repeated Loads

The selected reinforced concrete frame building has four stories and each of story height is 3 m. The material used in the structure is C30-S420. The reinforcements used in the beams and columns were selected as Φ14. The blueprint of building is given in Figure 5. The 3D model of the structure is given in Figure 6. Columns were selected as 30*50 cm and beams were selected as 25×50 cm. The transverse reinforcements (stirrups) used in both elements were selected as Φ10/10. The columns and beams used in the selected structure are shown in Figure 7. The comparison of static pushover analysis curves for X and Y direction for all samples that used in this study were given in Figure 8.

Table1. Compressive strength of hardened concrete of samples

Sample Number	Compressive strength for 1. loading (28days) f_c (MPa)	Compressive strength for 2. loading (28days) f_c (MPa)	Compressive strength for 3. loading (28days) f_c (MPa)	Compressive strength of standard concrete (28days) f_c (MPa)
1. Sample	35.44	27.58	17.44	30
2. Sample	34.90	24.16	20.14	30
3. Sample	33.84	25.54	18.24	30
28 Days (Mean)	34.72	25.76	18.60	30

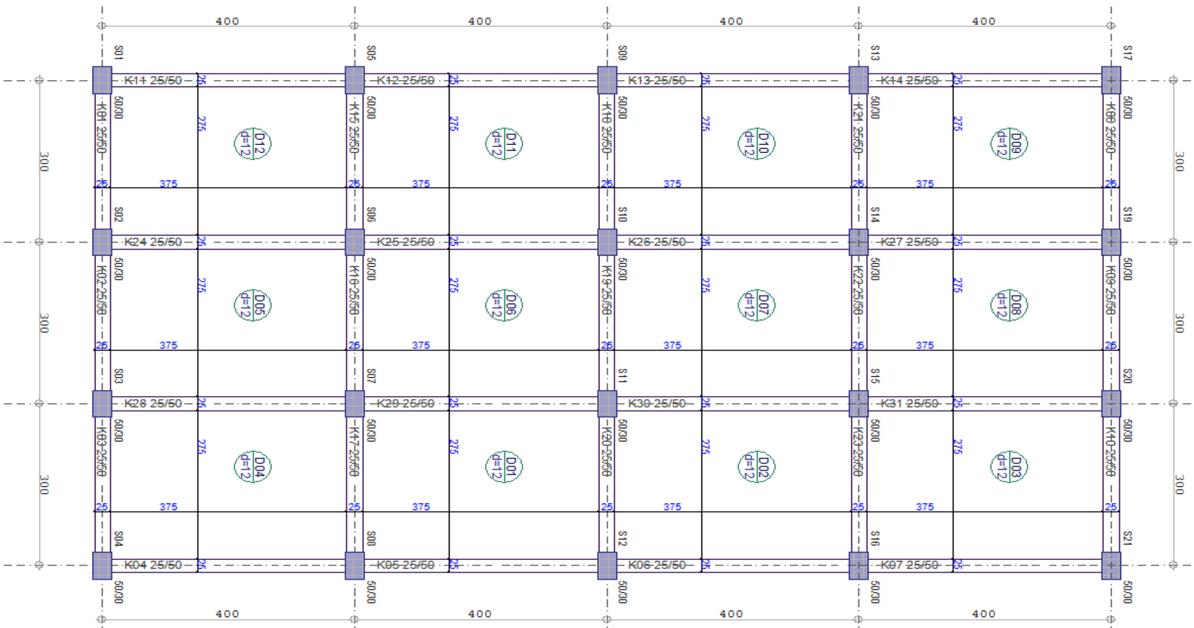

Figure 5. The blueprint of selected RC building

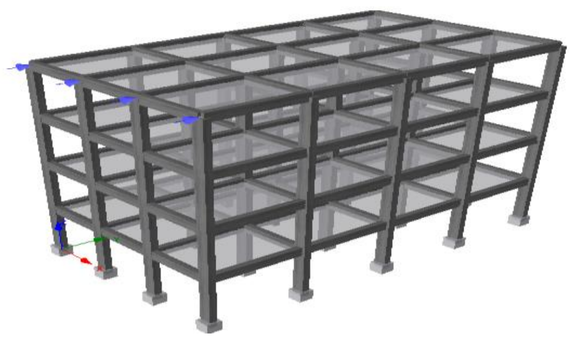

Figure 6. The 3D model of the building

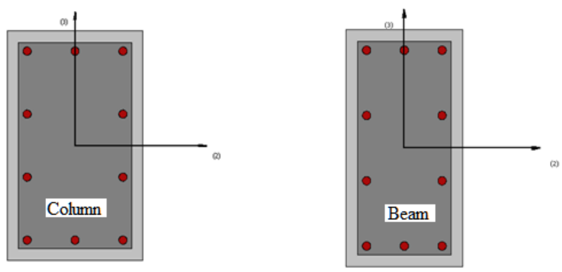

Figure 7. The cross-section of column and beam that used in this study

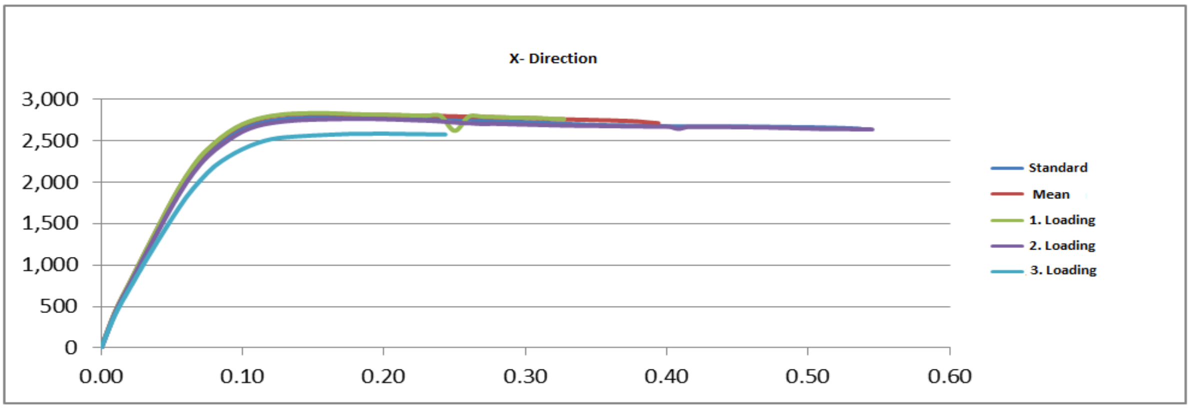

Figure 8a . Pushover curves for X-direction for 1. Sample

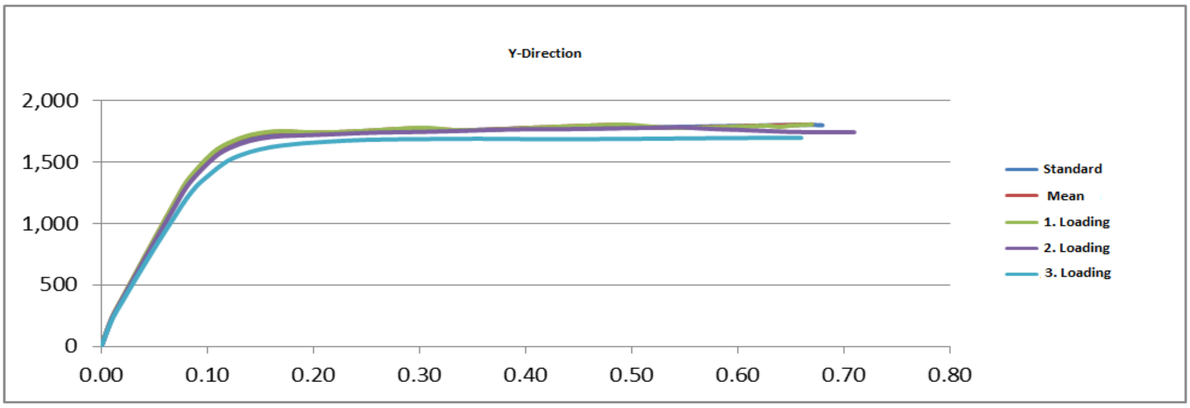

Figure 8b. Pushover curves for Y-direction for 1. Sample

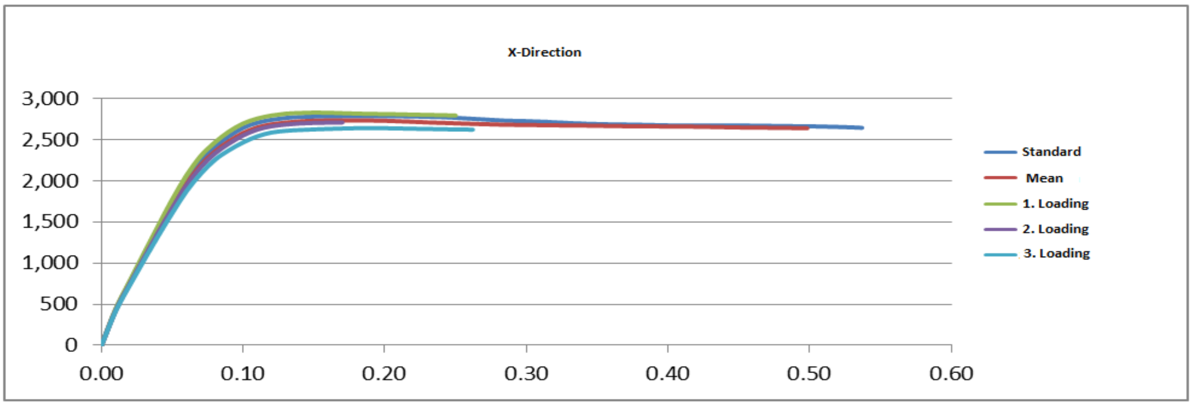

Figure 8c. Pushover curves for X-direction for 2. Sample

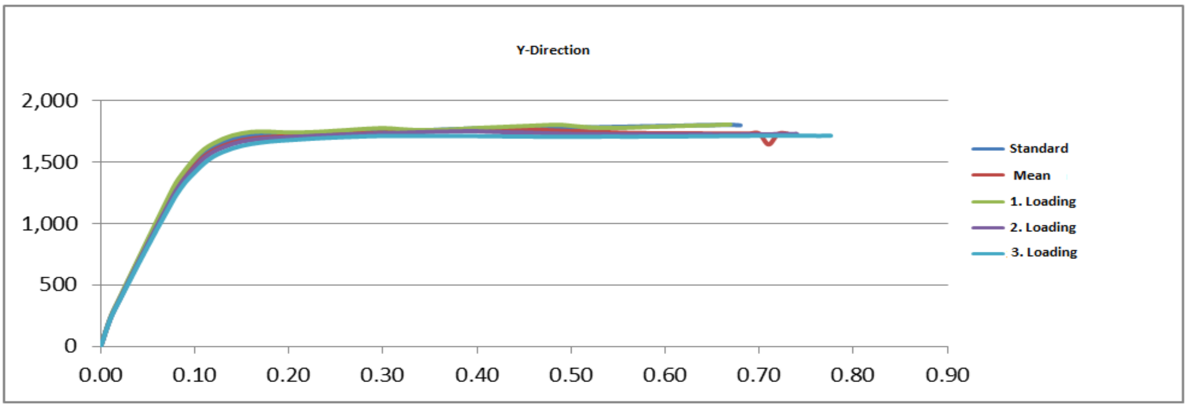

Figure 8d. Pushover curves for Y-direction for 2. Sample

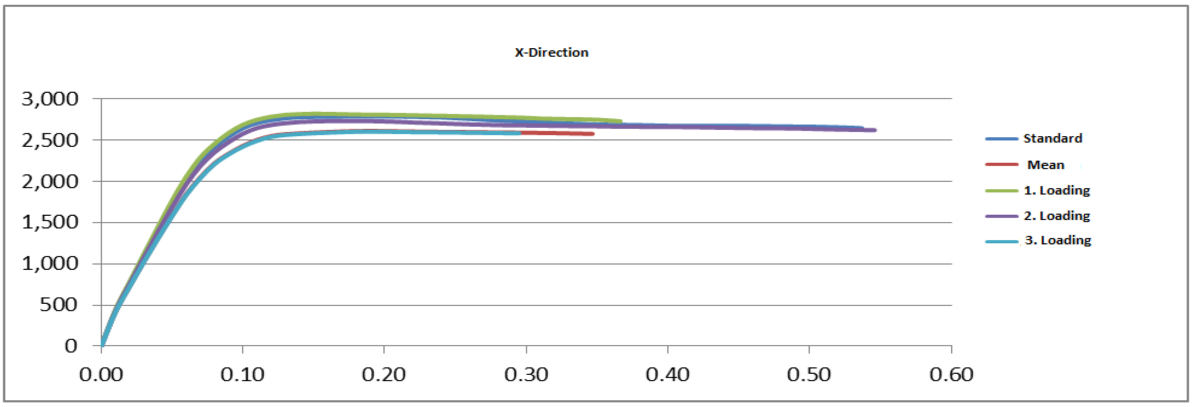

Figure 8e. Pushover curves for X-direction for 3. Sample

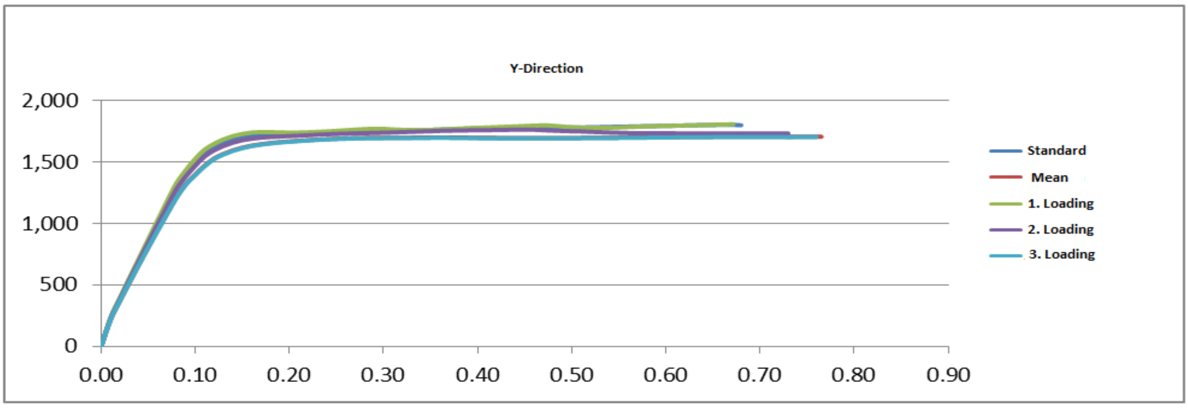

Figure 8f. Pushover curves for Y-direction for 3. Sample

The comparison of peak displacement amounts obtained for different concrete samples under repeated loads for X- direction are shown in Table 2.

Table 2. Peak Displacement for X-direction

X-Direction	1.Loading	2.Loading	3.Loading
1. Sample (f_c)	35.44	27.58	17.44
Displacement (cm)	32.73	54.52	64.33
2. Sample (f_c)	34.90	24.16	20.14
Displacement (cm)	17	25	26.21
3. Sample (f_c)	33.84	25.54	18.24
Displacement (cm)	36.64	54.59	59.48
Mean (f_c)	34.72	25.76	18.60
Displacement (cm)	39.4	49.83	54.67
Standard (f_c)	30		
Displacement (cm)	53.7		

The comparison of peak displacement amounts obtained for different concrete samples under repeated loads for Y- direction are shown in Table 3.

Table 3. Peak Displacement for Y-direction

Y-Direction	1.Loading	2.Loading	3.Loading
1. Sample (f_c)	35.44	27.58	17.44
Displacement (cm)	67	71	76
2. Sample (f_c)	34.90	24.16	20.14
Displacement (cm)	66.93	74	77.6
3. Sample (f_c)	33.84	25.54	18.24
Displacement (cm)	67.17	73	76
Mean (f_c)	34.72	25.76	18.60
Displacement (cm)	67	73	76.53
Standard (f_c)	30		
Displacement (cm)	68		

7. Results

The concrete properties primarily take place in the issue of the strength of the reinforced concrete structures to earthquake. Concrete quality is one of the most important factors in the generally damaged reinforced concrete structures. Concrete production, maintenance, selection of the concrete in accordance with the purposes and the behavior of the concrete under load are among the most important parameters in the design of the reinforced concrete structure. The durability of the concrete is dependent on the concrete quality; and the processes such as the compound materials (aggregate, cement, water, chemical and mineral additives) and the mixture rates, production method and the protection of the concrete when it is fresh and the environmental conditions in the service status are efficient. The concrete is not efficient all alone for the reinforced concrete structures damaged due to the earthquake. Poor quality of the concrete is one of the elements increasing the damage in the reinforced concrete structures. The concrete whose strength is low and seen as sufficient under the vertical loads cannot have the sufficient strength under horizontal loads.

In this study; C30 concrete has been selected as control sample, repeated loads have been applied on these samples and the compression strength of the concrete has been attained. Performance analyses have been carried out for a reinforced concrete structure selected by taking into consideration the concrete compression strengths attained as a result of the repeated loadings. It has been revealed how the concrete strengths attained under repeated loads affect the structure performance. A decrease has been observed in the strength of the concrete under repeated loads and an increase has been observed in the deformation amount of the concrete.

The fatigue of the material under repeated loads should be taken into consideration. The strength of the material fatigued under load decreases and its deformation amount increases. The impact of the repeated loads on the structures should not be neglected by considering the repetition probability of the earthquake in especially the structure design that is strength to earthquake. The load impact of the successive earthquakes that will occur especially after the main earthquakes sets an example for the repeated loads. The minimum compressive strength was determined as 28 MPa for rigid pavements and 30 MPa for building. The average compressive strength after second loading is under 28 MPa.

Static pushover curves have been attained for X and Y directions by taking the concrete strengths attained under repeated loads into consideration. There is no significant difference between the attained static pushing curves. The decrease in the concrete strength has not formed any difference in the static pushing curves. However; as the concrete strength has decreased, the structure peak displacement values have increased. This is in accordance with the general properties of the concrete.

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