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Effect of Re-vibration Process on Axial Capacity of Short Reinforced Concrete Circular Columns

Abstract- *A considerable amount of research work has been performed on the effects of vibrating of fresh concrete on the reduction of shrinkage and creep, the improvement bond stress between reinforcing bar and concrete, reduction the concrete permeability and improvement of the mechanical properties of concrete (tension and compression). Series of tests on reinforced concrete circular column, cubes and cylinders were carried out to study the effect of re-vibration duration on axial strength of column, compression strength of concrete cubes, and tensile strength of cylinders. Different compressive strengths of concrete and different size of aggregate were considered in this investigation. The test results show that, the re-vibration operation improves the tensile and compressive strength of concrete. The stiffness of columns increased with increasing the re-vibration duration up to1.5 times the initial vibration duration. Size of aggregate has significant effect on the improvement properties of concrete due to re-vibration. Increase the time duration of re-vibration delay the appearance of first crack.*

Keywords- *Re-vibration, Reinforced concrete, Axial load, Circular columns.*

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1. Introduction

Repeating the operation of vibration of the fresh concrete after a period, which is called re-vibration, which may be beneficial to improve the properties of concrete especially when successive layer of fresh concrete was placed and the upper layer of fresh concrete was partially hardened. Re-vibration after time re-arranged the aggregate particles and eliminates entrapped water, which may improve the tensile strength, compressive strength and bond strength between the reinforcing bar and the concrete. Plastic shrinkage cracks for the exposed concrete can also be eliminated by the operation of re-vibration. Re-vibration affect significantly by the time duration of re-vibration.

Auta et al. [1] studied the flexural strength of re-vibrated reinforced concrete beam with saw dust ash as partial replacement for cement. They tested seven beams of size 150 x 150 x 600 mm reinforced with 12 mm diameter steel bar. The beams were re-vibrated for 20 seconds at an interval of 10 minutes successions up to one hour after initial vibration. They concluded that the re-vibrated had improved the flexural strength of reinforced beams. Rao et al. [2] investigated the effect of re-vibration on compressive strength of concrete with a wide range of water to cement ratio varying from 0.35 to 0.7 and with more numbers of re-vibration time ranging from 0.5 to 4 hours. The results show that the compressive strength of concrete increased with re-vibration up to certain time then decreased thereafter. Abdel Rahman [3] tested beams of size 100 x 100 x 500 mm to study the effect of vibration and re-vibration on the flexural strength of beams. They concluded that the re-vibration improved the flexural strength of concrete within the first one hour. Kassim [4] studied the influence of re-vibration on the compressive strength of retarded cylinders concrete examined at the time interval ranged from 2 to 8 hrs. The results showed that the maximum compressive strength of concrete is achieved after 2 hrs and 35 minutes. Hashim [5] studied the effect of internal and external vibration on compressive strength of concrete. It was noticed that the internal vibration is more effective on the compressive strength of concrete than the external vibration. Gamal [6] studied the effect of re-vibration on the quality of concrete. The compressive strength of concrete was measured by 150 x 150 x 150 mm cubes and bond strength was measured by pull-out test using cylinder 150 mm in diameter and 300 mm in length. It was showed that the increase in compressive strength and bond strength in re-vibrated concrete and the maximum gain in compressive strength and bond strength occurred when the re-vibration was at the initial setting time. Larnach [7] studied the effects of external initial vibration and then re-vibration on the bond and compressive strength. He found that the external re-vibration produced reductions in bond strength ranging from 6% for re-vibration after 1/2 an hour to 33% after 3 hrs. In addition, the reduction in compressive strength was 14% and 16% for the same time above.

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According to the review of previously experimental results, there is no clear understanding to the effect of time duration of re-vibration on the compressive and tensile strength of concrete, so, the main objectives of this study are:

- Study the effect of re-vibration duration on the compressive and tensile strength of concrete through testing circular columns, concrete cubes, and concrete cylinders.
- Study the modes of failure of circular concrete column subjected to axial compressive force after different re-vibration duration.
- Determine the optimum period of re-vibration that improved the mechanical properties of concrete.

2. Experimental Program

At the laboratories of Building and Construction Engineering Department (UOT), experimental program was conducted as follows:

Twelve concrete circular columns, thirty-six cubes and thirty six cylinders in three groups were tested. In each group, the first specimen was initially vibrated with 20 second, second specimen was re-vibrated with 20 second, third specimen was re-vibrated 30 second and finally, the fourth specimen was re-vibrated with 40 seconds.

In Group A, the designed compressive strength of concrete was 35.26 MPa and maximum size of aggregate was 10 mm. In Group B, the designed compressive strength of concrete was 35.95 MPa and maximum size of aggregate was 19 mm. For Group C the designed compressive strength of concrete was 63 MPa and maximum size of aggregate was 10 mm. The characteristics tested specimens in each group were presented in Table 1.

It may be noted that, the waiting time before the process of re-vibration in all specimens was selected to be one hour. This is due to the fact that, the waiting time should be not more than the initial setting time of concrete (1.22 hrs). The initial setting of concrete was investigated in the present study according to Iraqi specification No.5/1984 [8].

Table 1: Characteristics of tested specimens

Group	Specimen Type	Specimen Name	f_{cu} (MPa)	Size of aggregate (mm)	Duration of Initial vibration (sec)	Duration of re-vibration (sec) after one Hour
Group-A	Column, Cubic and Cylinder	Ref. A-V20	35.26	10	20	---
		A-Dur.1	38.4	10	20	20
		A-Dur.2	40.5	10	20	30
		A-Dur.3	37.5	10	20	40
Group-B	Column, Cubic and Cylinder	Ref. B-V20	35.95	19	20	---
		B-Dur.1	41.15	19	20	20
		B-Dur.2	38.45	19	20	30
		B-Dur.3	34.81	19	20	40
Group-C	Column, Cubic and Cylinder	Ref. C-V20	63.03	10	20	---
		C-Dur.1	64.13	10	20	20
		C-Dur.2	65.01	10	20	30
		C-Dur.3	63.8	10	20	40

3. Materials

The material used in the present investigation are: Ordinary Portland cement –type I; Coarse aggregate with maximum size of 19 mm; sand and potable water. The chemical and physical properties of portland cement were conformed with the provisions of Iraqi specification No.5/1984 [8] .The properties of fine and coarse aggregate were conformed with the provisions of Iraqi specification No.45/1984 [9].

The initial setting time of cement was 1.22 hrs and the final setting time of cement was 3.45 hrs. These values were calculated according to Iraqi specification No.5/1984 [8]. In the experimental program, group A and B were designed to have a compressive strength of cubic of 35 MPa and 63 MPa for group C. Three samples of 150 x 150 x 150 mm cube were used to determine the strength of concrete in compression at 28 days according to ASTMC39 [10]. Three cylinders of 150 mm in diameter and 300 mm in length were used to determine the strength of concrete in tensile according to ASTM C496 [11]. The mix design compositions for each group are listed in Table 2.

Table 2: Compositions of concrete mix design

Materials	Mix design of group-A (f_{cu} =35.26 MPa)	Mix design of group-B (f_{cu} =35.95 MPa)	Mix design of group-C (f_{cu} =63.03 MPa)
Cement (kg/m^3)	410	385	480
Fine aggregate (kg/m^3)	780	740	640
Coarse aggregate (kg/m^3)	920	1024	920
Water (kg/m^3)	215	200	175
W/C	0.52	0.52	0.36
Size aggregate (mm)	10	19	10
Slump (mm)	91	89	95
Superplasticizer (Liter/100kg of cement)	------	------	4.8

4. Column Specimens Description

The tested specimens (circular short column) had the circular cross section of 150 mm in diameter and 600 mm in length. These columns were reinforced with the 6-ϕ8mm longitudinal bars and 7-ϕ4mm stirrups uniformly distributed. The yield stress of main reinforcement (ϕ8) was 435 MPa and the ultimate tensile strength was 550 MPa. These values were measured according to ASTM A996M-05 [12]. The concrete cover in all sides was taken to be 30 mm. Figure 1 and 2 shows the details of tested specimens.

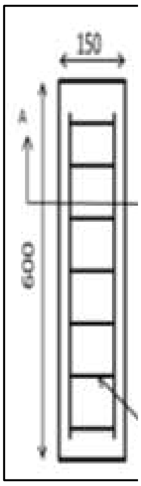

Figure1: Details of tested specimens

Figure 2: Molds and reinforcement of tested specimen

5. Curing Process

After cast the concrete, the specimens were laid in water tank for 28 days with a temperature of 22 C^o. Then, the specimens were laid in laboratory till the date of testing.

6. Test Setup and Test Procedure

The tests for column specimens were conducted using a hydraulic machine of 2500 kN as shown in Figure 3. Top and bottom compressive forces were applied to the tested specimens (columns) through the (7 cm) thick steel plate. The calibrated load cell in hydraulic machine was used to measure the applied load. Dial gages were used to measure the vertical displacement at the top of specimen. The applied vertical load was increased incrementally with (5 kN).

The cubes were tested according to BS1881-116 [13] using hydraulic jacks of 3000 kN with loading rate increments of 6 kN/sec, Figure 4 shows the concrete cubic under test.

The cylinders were tested according to ASTM C496 [11] using hydraulic jacks of 3000 kN with loading rate increments of 0.94 kN/sec, Figure 5 shows the concrete cylinder under test.


Figure 3: Column specimen under test

Figure 4: Cubes compressive test


Figure 5: Cylinders splitting tensile test

7. Test Results

I. Effect of re-vibration duration on behavior of specimens of Group A

In this section, the circular columns, cubes and cylinders of group A were tested with initial vibration of 20 second and with 20, 30 and 40 second re-vibration. The results are listed in the following sections.

1) Axial Strength

According to test results in Table 3, the axial strength of specimen Ref.A-V20 column (reference column with 20 second initial vibration, i.e without re-vibration) was 520 kN. The re-vibration of circular column increases the axial strength of the column by 3.8% and 15.4% when re-vibration duration was 20 second for specimen A-Dur.1 specimen and 30 second for A-Dur.2 specimen. While, when the re-vibration duration was 40 second, the axial strength of the column decreased by 15.4% in comparisons with the 30 second re-vibration.

The increase in axial strength of the re-vibrated column is due to facts that, the re-vibration operation re-arranged the coarse aggregate which consequently improve the axial strength of the column.

From Table 3, Figures 6, the longitudinal displacement decreases with the increase of re-vibration duration up to 1.5 times of the initial vibration then the longitudinal displacement increased at 2 times the initial vibration.

Neglecting nonlinearities at the start of testing, caused by test setup, the load-longitudinal displacement was linear until about 80% to 90% of the peak load and then non-linear behavior till the maximum compressive strength. The descending part after peak compressive force was not considered in this study.

The main scope of this study was study the effect of re-vibration duration on the strength of concrete column. This was depicted in Figure 7 through the relation between the axial strength of column and the re-vibration duration, in which, the maximum axial strength of the column was at the 30 second re-vibration (1.5 times the initial vibration duration).

During the testing of the circular column, the load at which the first crack appears was recorded and the test results were listed in Table 3. The first crack appeared at approximately of 53% to 55% of the ultimate load. The re-vibration, delay the appearance of the first crack especially at the 30 second re-vibration duration (optimum value of time duration of improving the axial strength of column). Figure 8 shows the location of the first crack for each specimen.

Table 3: Test results of column specimens (Group-A)

Specimen	Re-vibration Duration (sec)	Maximum axial load (kN)	Load at first crack (kN)	Maximum longitudinal displacement (mm)
Ref.A-V20	---	520	280	5.5
A-Dur.1	20	540	295	5.2
A-Dur.2	30	600	330	4.7
A-Dur.3	40	520	285	5.4

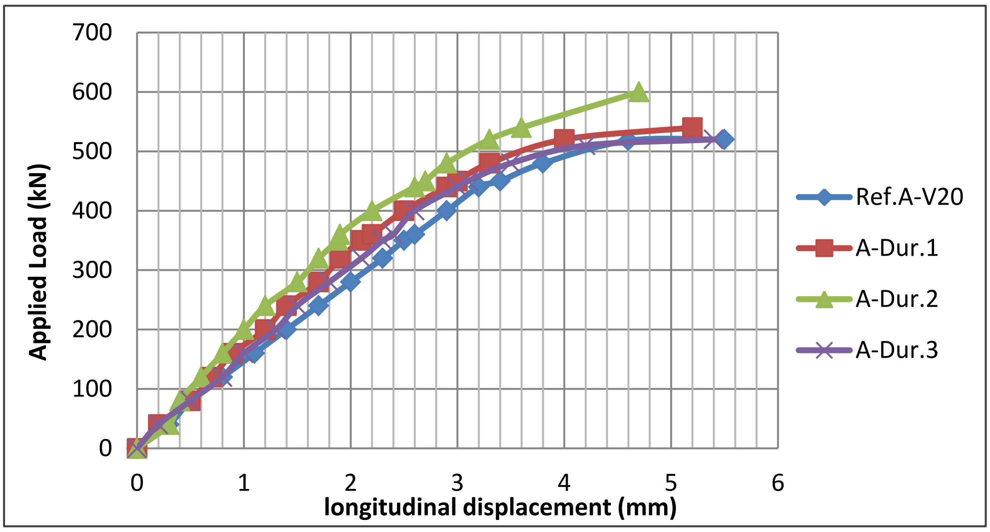

Figure 6: load-longitudinal displacement of main specimens

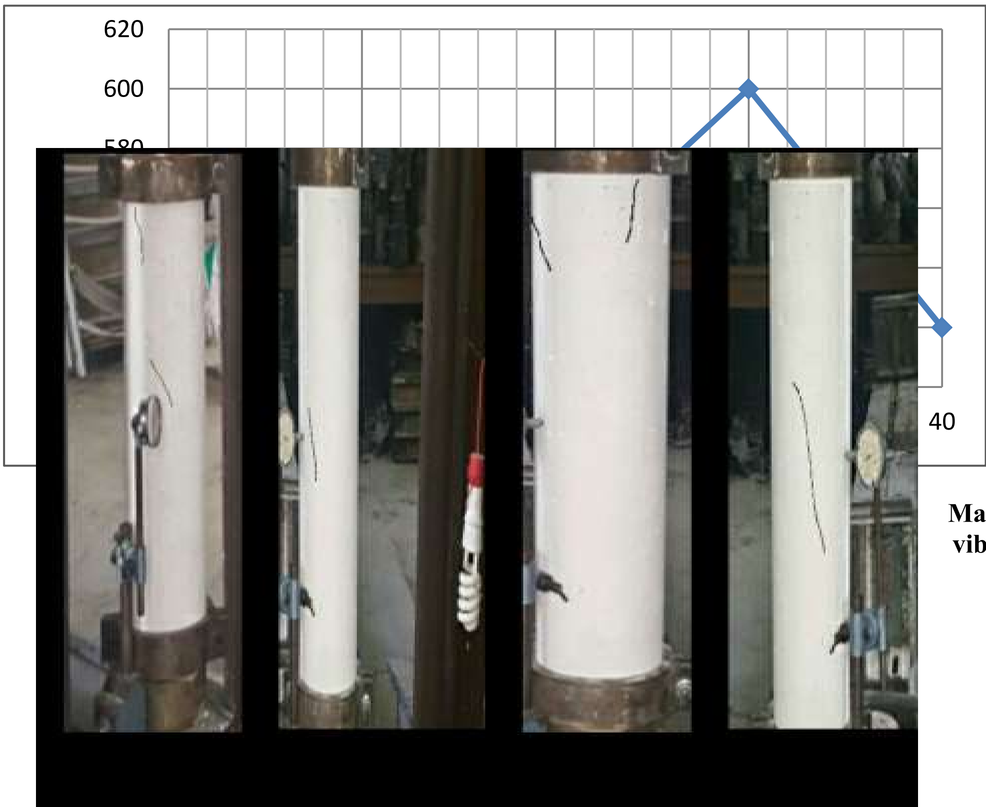

Figure 7: Maximum strength vs. re-vibration duration

Figure 8: First crack location for each tested specimens

2) Compressive and Tensile Strength of Concrete

Cubes of 100 mm edge length were used to measure the compressive strength of re-vibrated concrete and cylinders of 100 mm diameter and 200 mm length were used to measure the tensile strength of re-vibrated concrete. These specimens have the same re-vibration duration of the corresponding main specimens (circular columns). The compressive strength of cubes were tested according to BS1881-116 and the tensile strength of cylinders were tested according to ASTM C496, the results are listed in Table 4, in which, the compressive and tensile strength of concrete increased with the duration of re-vibration increasing till 1.5 times the initial vibration duration, then compressive and tensile strength decreased. Figure 9 and 10 shows the cubes and cylinders at failure.

Figure 9: Concrete cubes at failure

Figure 10: Concrete cylinders at failure

Table 4: Compressive and tensile strength of concrete

Specimen (cubes and cylinders)	Re-vibration duration (second)	Average compressive strength of cubes (MPa)	Average tensile strength of cylinders (MPa)
Ref.A-v20	-	35.26	3
A-Dur.1	20	38.4	3.2
A-Dur.2	30	40.5	3.4
A-Dur.3	40	37.5	3.1

II. Effect of Re-vibration duration on behavior of columns of Group B

The specimens of group B have a maximum size of aggregate of 19 mm. The columns, cubes and cylinders were tested with initial vibration 20 second and with 20, 30 and 40 second re-vibration. The results are discussed in the following sections.

1) Axial Strength

According to test results in Table 5, the axial strength of the reference column (Ref.B-V20), which was initially vibrated with 20 seconds, was 660 kN. The re-vibration of the column with duration of 20 seconds increased the axial strength of column by 3%. Increase the re-vibration from 20 to 30 and then to 40 second, decrease the axial strength of column by 2.9% and 5.8% respectively.

Figures 11 represent the axial load-longitudinal displacement relationship. These relations show at the beginning linear behavior, then, nonlinear relation till the maximum strength. From Figure 12, the maximum axial strength of the column occurs when the re-vibration was only one times the initial vibration (i.e 20 second); this is due to fact that, the increase in the size of aggregate affects in passive way on the re-arranged the aggregate particles. The first crack appears at a load approximately 50% to 56% of the maximum load. Table 5 shows the values of loads at which the first crack appear, in which, the maximum load at which the first crack appears occurs at 20-second re-vibration. Figure 13 shows the location of the first crack for each main specimen.

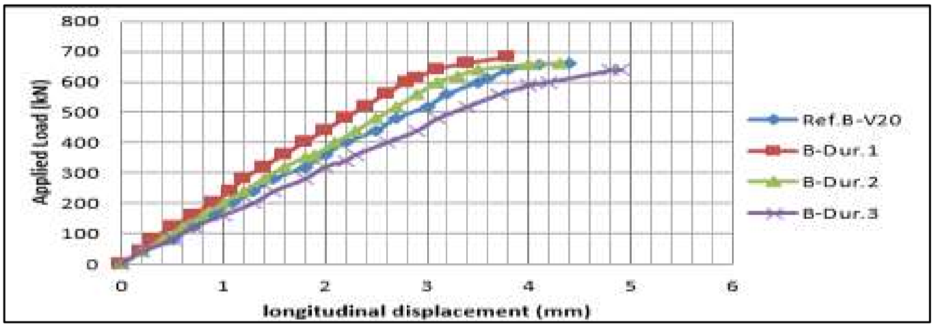

Figure 11: load-longitudinal displacement of main specimens

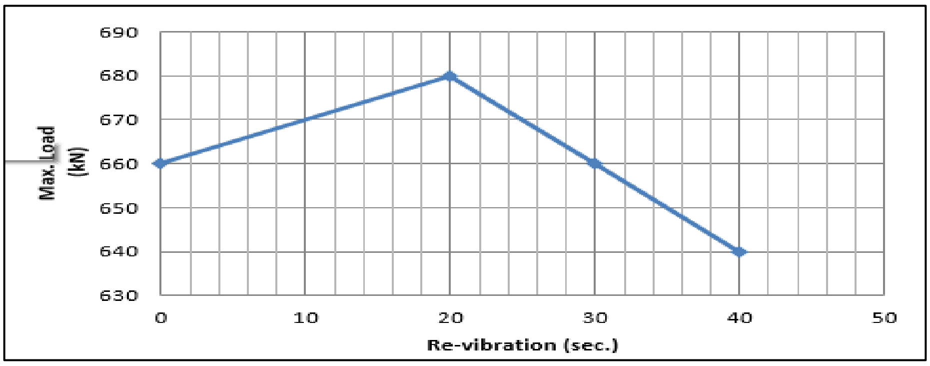

Figure 12: Maximum strength vs. re-vibration duration

Figure 13: First crack location for each tested specimens

Table 5: Test results of column specimens (Group-B)

Specimen	Re-vibration Duration (sec)	Maximum axial load (kN)	Load at first crack	Maximum Longitudinal

			(kN)	displacement (mm)
Ref.B-V20	---	660	340	4.40
B-Dur.1	20	680	380	3.80
B-Dur.2	30	660	360	4.30
B-Dur.3	40	640	320	4.90

2) Compressive and Tensile Strength of Concrete

Concrete cubes and cylinders have the same mix design of the main specimens (columns) were used to study the effect of re-vibration duration on the compressive and tensile strength of plain concrete. Table 6 listed the compressive strength of cubes and tensile strength of cylinders under 0, 20, 30, and 40 second re-vibration duration. Test results show that compressive and tensile strength of plain concrete increased when the re-vibration duration equal to one times the initial vibration and decrease with 1.5 and 2 times the initial vibration. Figure 14 and 15 shows the cubes and cylinders at failure.

III. Effect of Re-vibration Duration on Behavior of Columns of Group C

In this section, the circular columns, cubes and cylinders of group C (specimens with compressive strength of concrete f_{cu}=63 MPa) were tested first with initial vibration of 20 second and then with 20, 30 and 40 second re-vibration, the test results are listed in the subsequent sections.

1) Axial strength

As mentioned before, the main tested specimens in group C have re-vibrated with 0, 20, 30 and 40 second for Ref.C-V20, C-Dur.1, C-Dur.2, and C-Dur.3 specimen respectively, the test results were listed in Table 7.

Figure 14: Concrete cubes at failure

Figure 15: Concrete cylinders at failure

Table 6: Compressive and tensile strength of concrete

Specimen	Re-vibration Duration (second)	Average compressive strength of cubes (MPa)	Average tensile strength of cylinders (MPa)
Ref.B-v20	-	35.95	3.2
B-Dur.1	20	41.15	3.4
B-Dur.2	30	38.45	3.3
B-Dur.3	40	34.81	3.1

The axial strength of the reference column was 870 kN. The re-vibration of circular column increased the axial strength of the column by 3.4% and 16.6% when the re-vibration was 20 and 30 second respectively. While, increase the duration of re-vibration to 40 second decrease the axial strength of the column by 13.4% in comparison with 30 second re-vibration duration.
The relation of load-longitudinal displacement was depicted in Figure 16. From these Figures, the stiffness of load-deformation behavior increases with the re-vibration duration of 20 and 30 second, then decrease for 40 second re-vibration.
Figure 17 shows the relation between the maximum strength and revibration duration, in which, the maximum axial strength of the column occurs at re-vibration duration equal to 1.5 times the initial vibration.
In addition, from Table 7, the cracks appear at a load of 50% to 55% of the ultimate strength of main specimens. Increase the re-vibration duration from 20 to 30 seconds delay the appearance of the first crack. While, when the re-vibration duration was 40 second, the crack appears faster than the 30 seconds re-vibration. Figure 18 shows the first crack location in the main specimen.

2) Compressive and Tensile Strength of Concrete

According to test results in Table 8, the tensile and compressive strength of plain concrete increased when the re-vibration duration was 20 and 30 second in comparisons with the 0% re-vibration of the reference specimen (Ref.C-V-20). Maximum value of tensile and compressive strength was at 30 second re-vibration. While, these strength decreases when the re-vibration duration was at 40 second. Figure 19 and 20 shows the cubes and cylinders at failure.

IV. Modes of Failure

For columns in all groups, before failure, the ties prevent the concrete core and longitudinal reinforcement from moving outwards due to confinement effect. While, at failure, the concrete crushed outwards and the longitudinal reinforcement is buckled between the ties, no being so confined. The outer shell of concrete column spall off, which represent the typical failure of circular column. Figures 21 through 23 shows the failure of columns of group A, B, and C respectively. Figure 24 shows all columns together at failure.

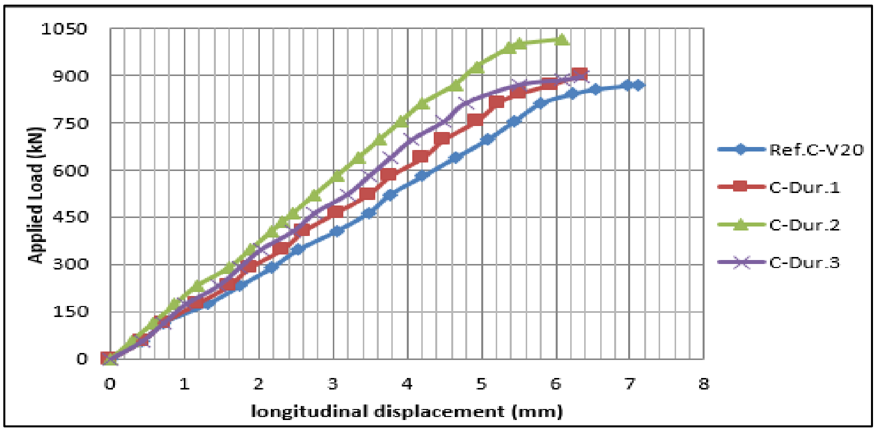

Figure 16: load-longitudinal displacement of tested specimens

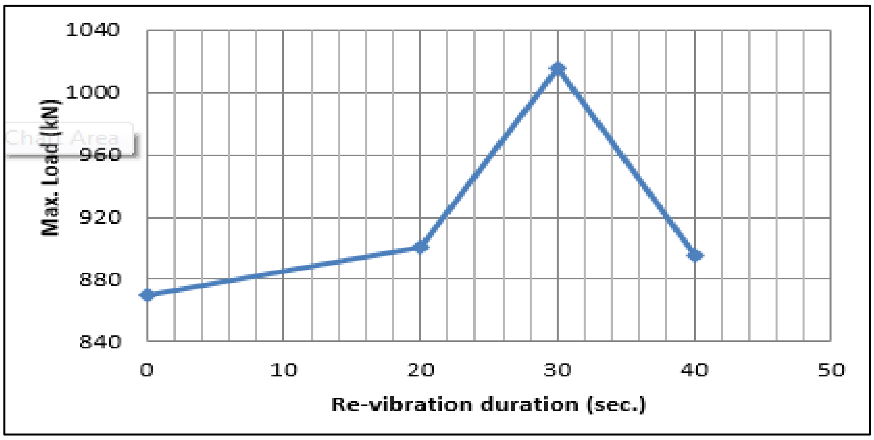

Figure 17: Maximum strength vs. re-vibration duration

Table 7: Test results of column specimens (Group-C)

Specimen	Re-vibration Duration (sec)	Maximum axial load (kN)	Load at first crack (kN)	Maximum Longitudinal displacement (mm)
Ref.C-V20	---	870	435	7.10
C-Dur.1	20	900	465	6.30
C-Dur.2	30	1015	555	6.09
C-Dur.3	40	895	475	6.20

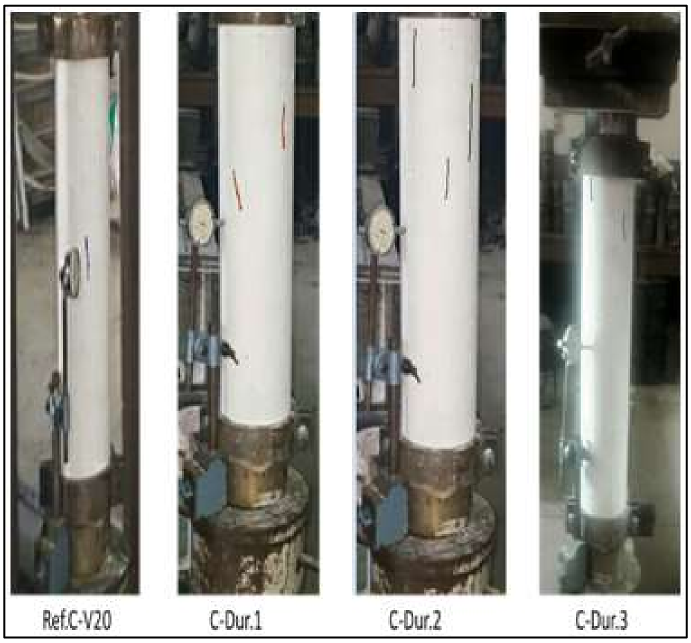

Figure 18: First crack location for main specimens

Table 8: Compressive and tensile strength of concrete

Specimens	Re-vibration duration (second)	Average compressive Strength of cubes (MPa)	Average tensile Strength of cylinders (MPa)
Ref.C-V20	-	63.03	3.8
C-Dur.1	20	64.13	4.2
C-Dur.2	30	65.01	4.4
C-Dur.3	40	63.80	4.2

Figure 19: Concrete cubes at failure

Figure 20: Concrete cylinders at failure

Figure 21: Modes of failure of columns in-group A

Figure 22: Modes of failure of columns in-group B

Figure 23: Modes of failure of columns in-group C

Figure 24: Modes of failure of all columns together

8. Conclusions

1) In general, the process of re-vibration improves the tensile and compressive strength of concrete.

2) The stiffness of columns increased with increasing the re-vibration duration until 1.5 times the initial vibration duration.

3) Optimum time duration to improve the properties of concrete due to re-vibration depend on the size of aggregate. Using 10 mm maximum size of aggregate, improve the tensile and compressive strength of concrete when the re-vibration was 1.5 times the initial vibration duration. While, Using 19 mm maximum size of aggregate, improve the tensile and compressive strength of concrete when the re-vibration was 1 times the initial vibration duration.

4) The improvement of mechanical properties of concrete remained significant when using concrete with high compressive strength.

5) Increasing the re-vibration duration delayed the appearance of first crack.

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