Eng. & Tech. Journal, Vol.30, No. 2 , 2012

Mechanical Properties and Dynamic Response of Lightweight Reinforced Concrete Beam

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Received on: 24/7/2011 & Accepted on : 3/11/2011

ABSTRACT

The study is conducted to perform two goals: The first geal is to produce a lightweight concrete using major components which are locally available with some standard admixtures.Many mixtures are prepared using many ratios of superplasticizer (SP) and silica fume (SF) admixtures to yield a lightweight aggregate concrete, the effects of using different ratios of these admixtures on unit weight, compressive strength and flexural strength are studied individually and accumulatively. The secondis to study the dynamic specifications of normal and lightweight reinforced concrete beams.

The results showed that the increasing in dosage of superplasticizer (SP) for (LWAC) increases the density of (LWAC), and the increasing in dosage of silica fume (SF) decreases the density of (LWAC). The experimental impact tests for R.C. beams shows that the lightweight R.C. beams have a better response under impact loading with respect to the maximum dynamic deflection (2.955mm for normal weight beam and 1.58mm for lightweight beam). Also,Impact force transferred to supports reactions of lightweight beams is smaller within 45% than the impact force transferred to reaction of normal weight concrete under the same impact load, and the time to reach 90% damping equal to 1.223 sec and 1.6 sec for lightweight and normalweight R.C. beams respectively. Also, the reinforced concrete beams are tested under repeated impact load up to failure. The tests showed that the no. of blows to cause first crack for lightweight concrete beams more than twice of this for normalweight concrete beams.

Keywords: Reinforced Concrete, Dynamic, Impact, Mechanical Properties.

الخصائص الميكانيكية والاستجابة الديناميكية للعتبات الخرسانية المسلحة خفيفة الوزن

الخلاصة

للدراسةهدفين رئيسيين:- الهدف الاول هوانتاج خرسانةخفيفةالوزن باستخدام مكونات رئيسية محليةالصنع مع بعض الاضافات القياسية. عدةخلطات تم تحضيرها باستخدام نسب مختلفة من ىالملدن الفائق (SP) وغيار السيلكا (SF) . أن تأثيراستخدام تلك النسب المختلفة من هذه الاضافات على وحدة الوزن ومقاومةالانضغاط ومقاومةالشد تم دراستها بشكل منفصل وتراكمي.

الهدف الثاني هودراسةالخصائص الديناميكية للعتبات الخرسانية الاعتيادية والعتبات الخرسانية خفيفة الوزن.

اظهرت النتائج ان الزيادة في نسبة الملدنالفائق تزيدمن كثافة الخرسانة ذات الركام خفيف الوزن بينماالزيادة في نسبةغبار السليكا تقلل من كثافةالخرسانة ذات الركام خفيف الوزن. التجارب العمليةالتي اجريت لقياس الخصائص الديناميكية للعتبات الخرسانية بين تان العتبات الخرسانية خفيفةالوزن تمتلك استجابة ديناميكية جيدة تحت احمال الصدمة بالاعتمادعلى الانحناء في منتصف العتبة (2.955 ملم للأعتاب الاعتيادية و 1.58 ملم للأعتاب خفيفةالوزن)،كذلك فان قوةالصدمةالمنقولةالى المسند (ردالفعل) للعتبات خفيفة الوزن اقل بمقدار 45% مقارنة بقوة الصدمةالمنقولةالى المسندفي حالةالعتبات الاعتيادية تحت نفس حمل الصدمة المسلط.امابالنسبة للزمن اللازم للوصول الى اخماد بمقدار 90% فانه يساوي 1.233 ثانيةو 1.6 ثانية للعتبات خفيفة الوزن والعتبات الاعتياديةعلى التوالي. كما تم فحص العتبات تحت تأثيرالاحمال الساقطةالمتكررة لحدالفشل. اظهرت نتائج هذاالفحص ان عددالضربات اللازمة لإحداث الشقال اول للعتباب خفيفةالوزن اكثربمرتين من عدد الضربات اللازمة لإحداث الشقال اول في العتبات الاعتيادية.

INTRODUCTION

One of the most disadvantages of traditional concrete (2200 to 2500 kg/m3) is heavy self-weight. Therefore, the self-weight of the building is conceived in the production and use of lightweight concrete of less than 2000 kg/m^3 [1]. Lightweight aggregate concrete (LWAC) had been used successfully for structural purposes for many years. A decreased density for the same strength level permits a saving in dead load for structural design and foundation. Moreover, lightweight concrete is more resistant to fire and provides better heat and sound insulation than concrete of normal density.

Lightweight Aggregate Concrete (LWAC) has known since ancient times, so it is possible to find a good number of references in connection with the use of LWAC. It was made using natural aggregates of volcanic origin such as pumice, scoria, etc. Sumerians used these aggregates in building Babylon in the 3rd millennium B.C., the Greeks and the Romans used pumice in building construction [2].

Many researchers studied mechanical properties of lightweight aggregate concrete with and without admixtures [3-14], but very little research about dynamic response of lightweight concrete and as to the knowledge of the authors no previous researches were made to deflection-time curve of lightweight reinforced concrete beams under impact or repeated impact loads.

This work aims to investigate the mechanical properties of lightweight concrete beams using different types of high range water reducing admixture (Superplasticizer) (HRWRA) and mineral admixtures, silica fume (SF) with lightweight aggregate which will give a better understanding of the behavior of lightweight concrete beams.

In addition the present research also aims at providing experimental investigation to the dynamic response of lightweight concrete beams.

EXPERIMENTAL WORKS

Materials

Cement:- Iraqi standard ordinary Portland cement produce by (UCC United Cement Company).

Fine Aggregate:-Graded fine aggregate from Tuz city-Iraq.

Coarse Aggregate:-Graded coarse aggregate from Tikrit City-Iraq.

Crushed Coarse Aggregate:- Graded crushed coarse aggregate from Tikrit City-Iraq.

Lightweight Coarse Aggregate:- Graded crushed limestone from Al-Siniya city – SalahEldeen governorate-Iraq.

Superplasticizer (SP):- High Range Water Reducing Admixture (HRWRA) Sikament®FFN.

Silica Fume:-SikaFume® HR/TU from Sika Company meeting BS EN 13263-1:2005 requirements.

Steel Reinforcement:- Ukrainian deformed steel bars (8mm, and 6mm),to be checked fy equal to 404 and 400 MPa for 6mm and 8mm respectively, also fu equal to 441 and 438 for 6mm and 8mm respectively.

Mixing

Detail of mixes for the lightweight aggregate concrete as shown in Table(1). Also Table (2) show SF and SP ratios with mechanical properties for all mixes..

CONCRETE-TESTING PROGRAMS

Compressive Strength

The compressive strength test was performed according to B.S. 1881: part 116: 1989. This test was conducted on cubes using an electrical testing machine with a capacity of 2000 kN at loading rate of 5 kN per second.

FLEXURAL STRENGTH

Flexural strength of concrete was measured on (100×100×400 mm) prism specimens in conformity with ASTM C78-00. The prisms were subjected to four-point loading, the loading rate was 1 MPa/min. The specimens were tested at age of 28 days and the average of three specimens in each mix was taken.

UNIT WEIGHT OF HARDENED CONCRETE

The test was performed according to ASTM C567-00 [15] using 100×200mm cylindrical specimens.

DYNAMIC RESPONSE TESTS FOR R.C. BEAMS

This test is one of the most important tests in the investigation of the behavior and dynamic response of lightweight and normalweight R.C. beams. This test was done using (150mm)width, (200mm)height, (1400mm)length; R.C beams specimens; as shown in Fig. (1).

The dynamic load was applied by dropping steel rod of 22mm in diameter with a spherical end. This rod carries an upgradable load (6 kg) to enable the application of different amounts of impact loads by increasing or decreasing the weight of loads on the steel rod. In addition, the rate of impact load can be increased or decreased by controlling the height of weight before it falls. In the present test, the height of weight was 70 cm. This action can be repeated with respect with known period.The device used in the examination was synthesized manually and consisted of several parts:

MAIN STEEL LOADING FRAME

It was fabricated using I and U steel sections and welded together as shown in Fig.(1) to perform a dynamic loads (drop weight) and carry R.C. beams.

LOAD CELLS SYSTEM

Two load cells (Fig. (1)) were put one under the dropping steel rod and the other under the hinge support. The purpose of using this sensor is to measure the amount of impact loads with time to get and draw the impact load vs. time curve.

-LVDT

This sensor (Fig.(1)) was fixed at bottom face in the midpoint of the beams to measure the linear displacement and response of the beams during and after applying the impact load. The rate had transformed to a displacement under the beam with small interval time up to 1/2500 second by the data acquisition board.

DATA ACQUISITION SYSTEM

This system is responsible for receiving encrypted data from all sensors and adapted to understandable data and curves. The final output of this device is (impact load vs. time) curve and (displacement in the midspan point of beam vs. time). This device can receive ten signals from ten sensors and analyze them at the same time; this device is connected to a PC or can work without a PC.

DROP WEIGHT TEST

Several investigators have employed a variety of tests including Charpy and drop weight tests to assess the impact resistance of reinforced concrete[17] .A drop weight type test was employed described for carrying out impact tests. The reinforced concrete beam (as description in the section above) was supported on a span of 1300 mm. A 20 kg hammer 100 mm in diameter with a circular flat face and having a controlled drop of 300 mm to the steel ball having 120 mm diameter was used. The hammer was dropped repeatedly and the number of blows required to produce the first, second…etc. visible crack in the specimen and for failure and ultimate failure were recorded. The failure was assumed to have been reached when the crack, which initiated from bottom, propagated up to the top surface of the beam and the ultimate failure was assumed to have been reached when the concrete crushing (at compression zone) or when cracks are joining together and/or concrete crusting occurred at tension zone.

Compressive Strength

Figs. (2) and (3) show the effect of SP and SF on the compressive strength of lightweight concrete. These figures show that increasing SF from zero to 10% increases compressive strength. Byond 10% these may be small increases on drops in compressive strength. Also these figures show the positive effect for adding SP with and without SF.

FLEXURAL STRENGTH

Fig.(4) shows the effect of SP and SF on the flexural strength of 100x100x400 mm concrete prisms. Superplasticizer (SP) increases flexural strength but Silica Fume (SF) decreases flexural strength, this is because adding silica fume to the mix increases w/cm ratio.

Unit Weight

Results show that lightweight aggregate concretes with SP have higher densities than those without SP and those containing SF as shown in Fig.(5). This is attributed to lower air voids because the SP enhances the degree of compaction. It is evident that lightweight aggregate concrete with SF has lower density as shown in Fig.(5). This is because the fact of lower relative density of SF compared with Portland cement.

Dynamic Response Of Lightweight R.C. Beams

The best mix with respect to the unit weight, compressive and flexural strength was mix No.10 and three R.C. beams had been cast and tested for each reinforced lightweight concrete beam and reinforced normal weight concrete beam. The results of tests for NWC beam are shown in Figs. (6),(7),(8) and the results of tests for LWC beam are shown in Figs.,(9),(10),(11).These results and curves contain the impact load diagram, load diagram under hinge support and vertical deflection at the midspan of beams under impact load; all of these amounts are taken with time.Theprocedure [16]for determining the dynamic characteristics of R.C. beams as shown in Table (3).

Drop Weight

The results of drop weight test for normalweightand lightweight RC beams is shown in Table (4) and figures (12 and 13). The number of blows to first visible crack for lightweight concrete beam is more than for normalweight concrete beam, but the number of blows to failure and/or ultimate failure less than of this for normalweight RC beam. This result means that the lightweight concrete has good damping up to first crack.

CONCLUSIONS

From the experimental results the following conclusions can be drawn:-

Unit weight

-Lightweight aggregate concrete can be produced from local material with oven dry unit weight less than 2000 kg/m3 without any admixtures and additives.

-The increases in dosage of superplasticizer (SP) increases the density of (LWAC); [3% increase in oven dry unit weight with 3% dosage of (SP) without (SF)].

-The increases in dosage of silica fume (SF) decreases the density of (LWAC); [3.76% decrease in oven dry unit weight with 15% dosage of (SF) without (SP)].

Flexural Strength

-(SP) is more effective on flexural strength than (SF).

Dynamic Properties of Rc.Beams

-The experimental impact tests for R.C. beams shows that lightweight R.C. beams have a better response under impact loading with respect to the maximum dynamic deflection (2.955mm for normal weight beam and 1.58mm for lightweight beam).

-The required time toreach 90% of vibration dampingfor lightweight RC. beams is smaller than same time for normalweight RC. beams; (1.223 sec. for lightweight RC. beams and 1.6 sec. for normalweight RC. Beams).

-Impact force transferred to supports reactions of lightweight beams is smaller within 45% than the impact force transferred to reaction of normal weight concrete under the same impact load amount.

-The lightweight RC beam has good damping for impact loads up to first crack.

RECOMMENDATIONS FOR FUTURE WORK

-More investigations and laboratory tests should be done to study other mechanical properties of local lightweight aggregate and lightweight aggregate concrete made from local material, such as thermal conductivity, electrical conductivity, abrasion,durability, chemical attack and corrosion resistance.

-Studying the dynamic response of lightweight composite R.C. beams.

-Studying the effect of adding different types of fibers on the dynamic properties of lightweight RC. beams.

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Table (1) Detail of mixes for the lightweight aggregate concrete (Volume of mix=0.05m3) cement

Mix.	FA kg.	LWFA kg.	LWCA kg.	Cement kg.	(SF)/C %	(SP)/C %	Water kg.	w/cm	Slump mm
1	11.96	--	53.74	20.54	0	0	10	0.487	71
2	14	--	48.82	20.5	5	0	9	0.418	72
3	9.5	--	48.82	20.87	10	0	9.8	0.423	80
4	12	--	48.82	17.45	15	0	10.25	0.499	72
5	12	--	48.82	20.54	0	1	6.75	0.329	74
6	12	--	48.8	20.54	0	2	7.5	0.365	72
7	12	--	48.8	20.54	0	3	7.05	0.343	100
8	12	--	48.8	19.5	2.5	1	8.3	0.415	73
9	12	--	48.8	18.49	10	1	8.6	0.419	73
10	12	--	48.8	17.46	15	1	9.45	0.46	74
11	12	--	48.8	19.5	5	2	7	0.341	71
12	12	--	48.8	18.49	10	2	7.2	0.351	75
13	12	--	48.8	17.44	15	2	7.8	0.38	75
14	12	--	48.8	19.5	5	3	6	0.292	100
15	12	--	48.8	18.49	10	3	6.5	0.316	70
16	12	--	48.8	17.4	15	3	7	0.342	81
17	--	12	48.8	17.4	15	3	9.2	0.449	72
18	--	12	48.8	20.5	0	3	7.3	0.356	89

Table (2): Oven dry density and strength for all mixes

Sample	SF%	SP%	w/cm	Slump (mm)	Oven dry density (kg/m3)	Compressive strength (MPa)	Flexural strength (MPa)
1	0	0	0.487	71	1970	18	4.4
2	5	0	0.418	72	1960	19.7	4.335
3	10	0	0.423	80	1929.45	20	4.26
4	15	0	0.499	72	1896.2	18	3.6
5	0	1	0.329	74	1999	22.6	4.68
6	0	2	0.365	72	2025	22.0	4.6
7	0	3	0.343	100	2030.15	22.8	4.77
8	2.5	1	0.415	73	1991.2	23.95	4.5
9	10	1	0.419	73	1970	24.6	4.35
10	15	1	0.460	74	1946.55	23.60	4.18
11	5	2	0.341	71	2008.3	23.8	4.39
12	10	2	0.351	75	1992.15	24	4.3
13	15	2	0.380	75	1967.45	21.28	3.9
14	5	3	0.292	100	2021.6	24.20	4.59
15	10	3	0.316	70	2004.5	25	4.42
16	15	3	0.342	81	1990.25	23.82	4.38
17	15	3	0.449	72	1941.8	20.57	3.21*
18	0	3	0.356	89	1983.6	19.59	4.44**
NWC	0	0	0.399	85	2306	27.3	7.86 **

* Lightweight fine aggregate used
** Normalweight concrete
Cm:- cementitious materials (cement and/or silica fume)
(hatched) Selected best mix

Table (3): Dynamic Characteristics of R.C. Beams

Normalweight concrete R.C. beam:-	Lightweight concrete R.C. beam):-
Peak No. 1, t=4.133 sec, Disp.=2.97412 mm Peak No. 8, t=4.893 sec, Disp.=0.67954 mm $T_D = \frac{t_n - t_m}{n-m}$ t_n, t_m: Time at peak No. **n** and **m** $T_D = \frac{4.893-4.133}{8-1} = 0.10857$ sec. *(Natural period damped vibration)* $\frac{1}{0.10857} = 9.21$ Hz*(Natural cyclic frequency)* $= 57.87$ rad/sec. *(frequency)* v_m, v_n: peak displacements at time **m** and **n** $\delta = \frac{1}{8-1} ln\left(\frac{2.97412}{0.67954}\right) = 0.211$*(Logarithmic decrement)*$\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}}$*Therefore* $\zeta = \sqrt{\frac{\delta^2}{4\pi^2+\delta^2}}$ $\zeta = \sqrt{\frac{0.211^2}{4\pi^2+0.211^2}} = 0.0336$*(Damping ratio)* *Damped frequency* *m = 105.8 kg.* *Damping coefficient:* $c = \zeta c_c = \zeta 2m\omega$ $= 0.0336 * 2 * 105.8 * 57.87$ *=411.44 kg. Sec/mm* *Time to reach 90% damping =1.6 sec.*	Peak No. 1, t=36.93sec, Disp.= 1.3045mm Peak No. 8, t=37.5sec, Disp.= 0.28727mm t_n, t_m: Time at peak No. **n** and **m** $T_D = \frac{37.5-36.93}{7} = 0.08143$*(Natural period damped vibration)* $f = \frac{1}{T} = 12.28$*(Natural cyclic frequency)* $\omega = \frac{2\pi}{T} = 2\pi f \omega = \frac{2\pi}{T} = 77.16$*(Frequency)* v_m, v_n: peak displacements at time **m** and **n** $\delta = \frac{1}{7} ln\left(\frac{1.3045}{0.28727}\right) = 0.21616$*(Logarithmic decrement)* $\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}}$*Therefore* $\zeta = \sqrt{\frac{\delta^2}{4\pi^2+\delta^2}}$ $\zeta = \sqrt{\frac{0.21616^2}{4\pi^2+0.21616^2}} = 0.0344$*(Damping ratio)* *Damped frequency*$\omega_D = \omega\sqrt{1-\zeta^2}$ *m = 85 kg.* *Damping coefficient:* $c = \zeta c_c = \zeta 2m\omega$ $= 0.0344 * 2 * 85 * 77.16$ *=451.23 kg. Sec/mm* *Time to reach 90% damping =1.223 sec*

Table (4) No. of blows from first crack up to failure for lightweight and normalweight RC concrete Beam

State	Normalweight RC beam	Lightweight RC Beam
First Crack	4	20
2nd and/or 3rd crack	18	30
First crack reach upper face (failure)	40	300
crushing Failure	2000	437
Ultimate failure	2200	720

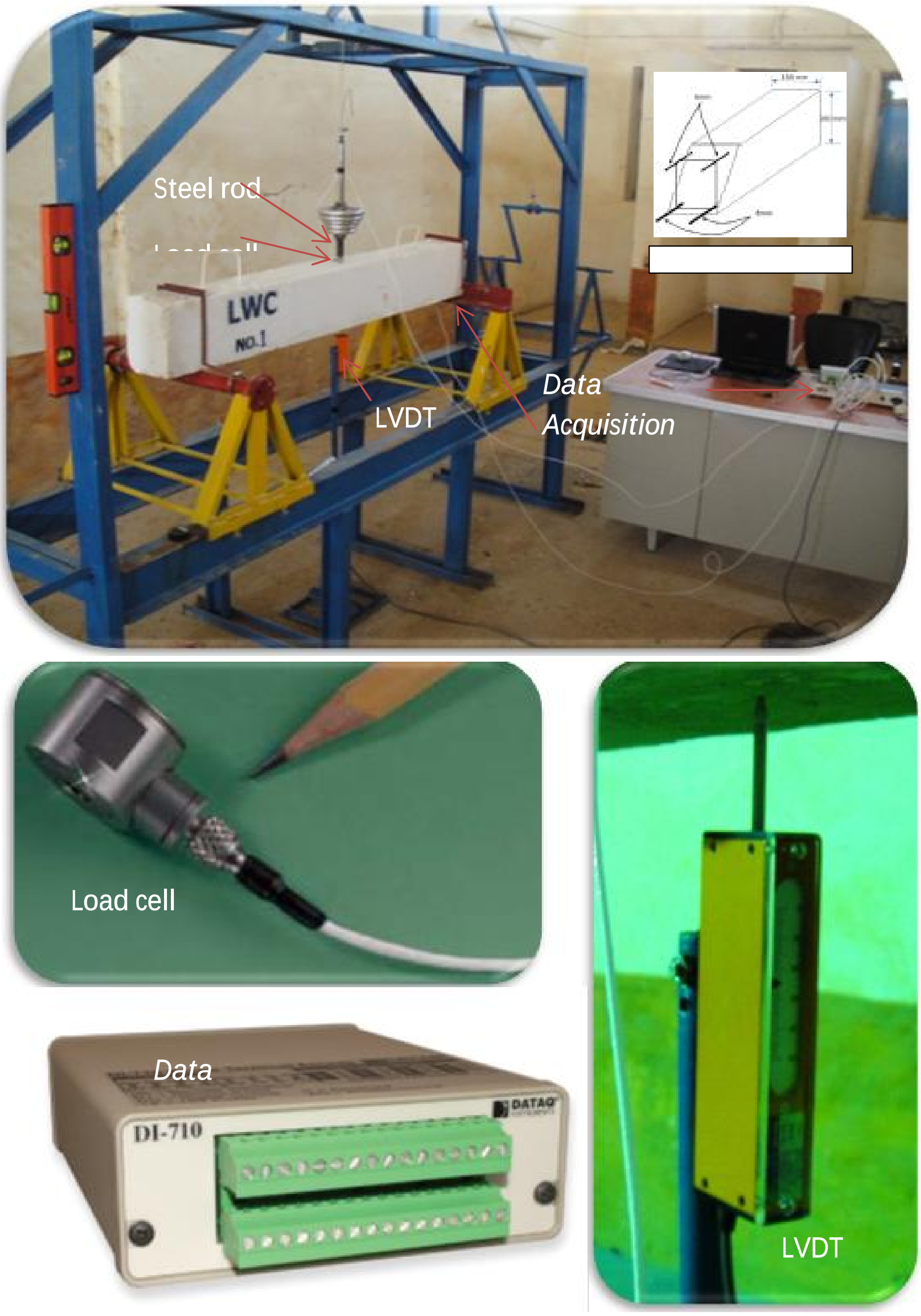

Figure (1) Dynamic Load frame and Sensors

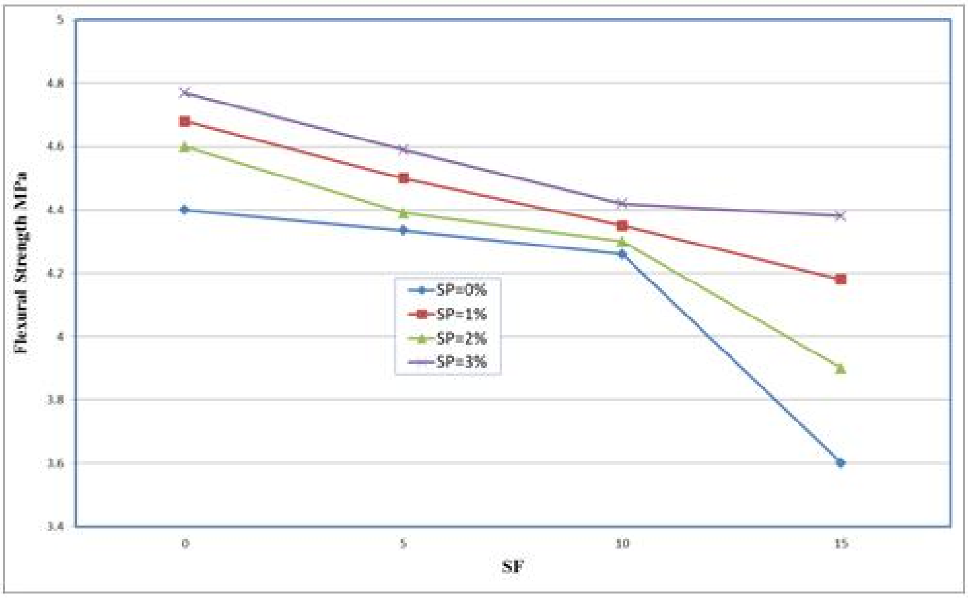

Figure (2) 7-day Compressive Strength of lightweight Concrete

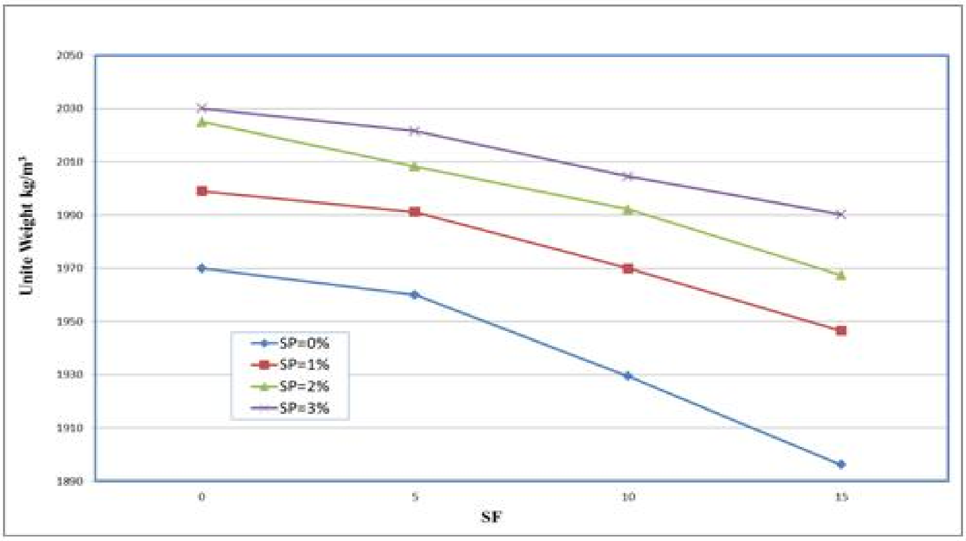

Figure (3) 28-day Compressive Strength of lightweight Concrete

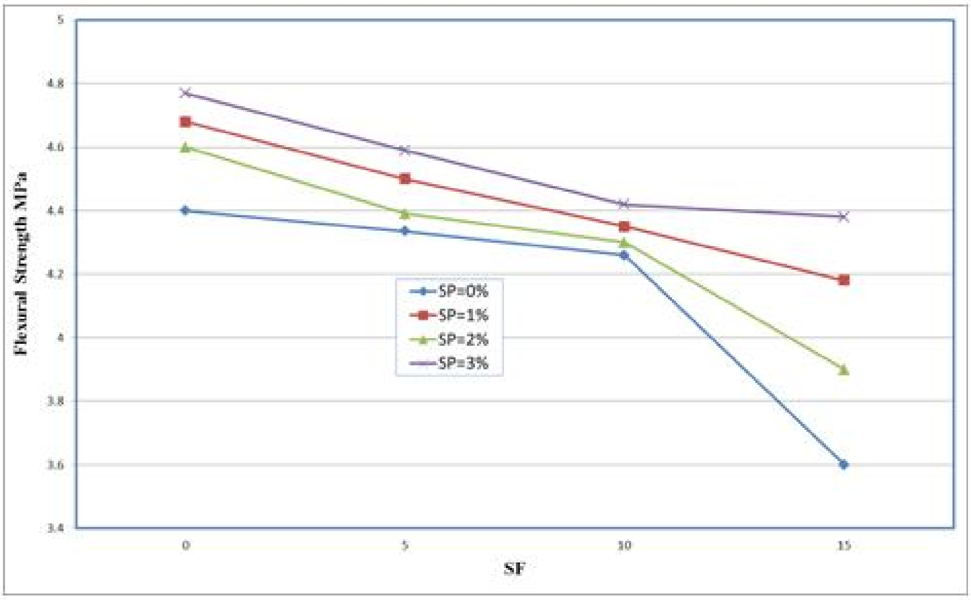

Figure (4) Flexural Strength of Light Concrete

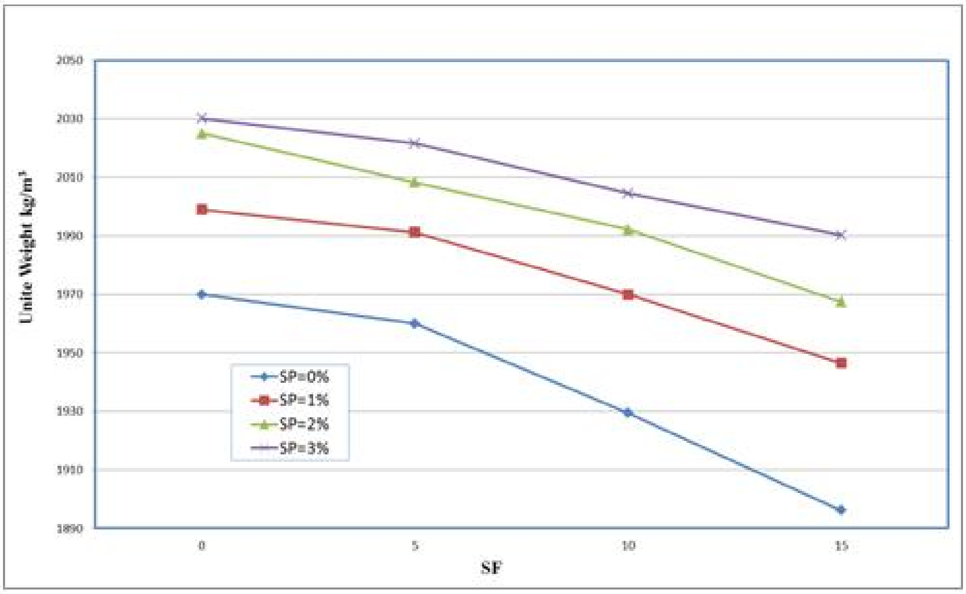

Figure (5) Oven Dry density Lightweight concrete

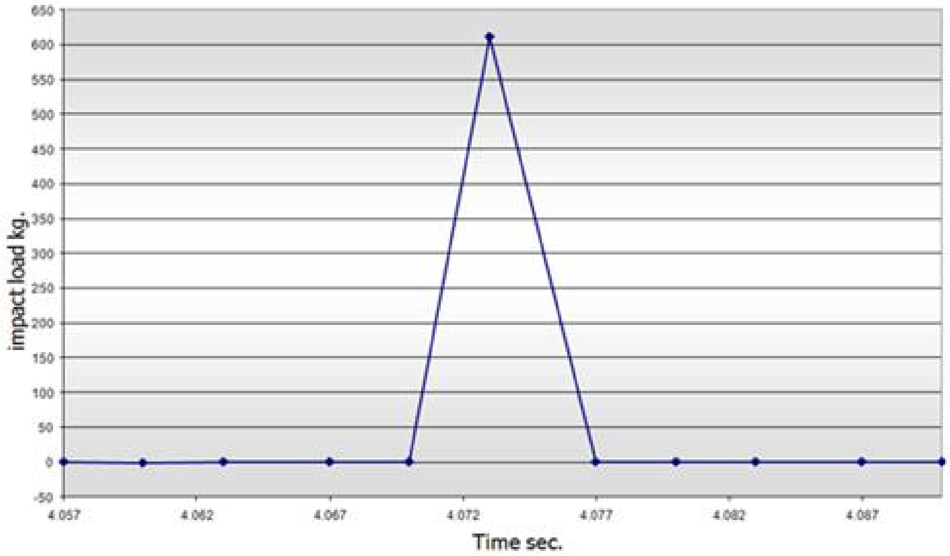

Figure (6) Impact load diagram for normalweight concrete beam

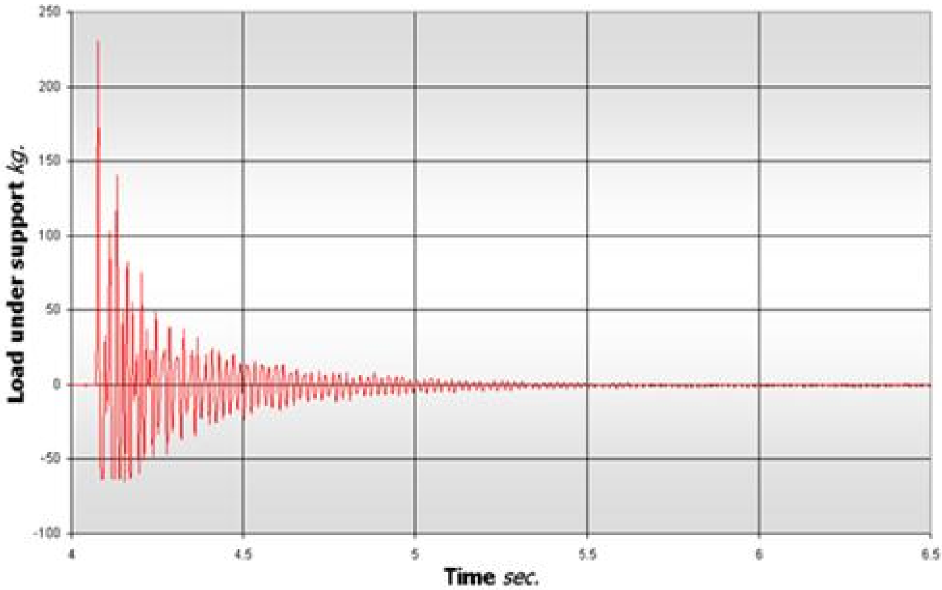

Figure (7) Load under hinge support for normalweight concrete beam

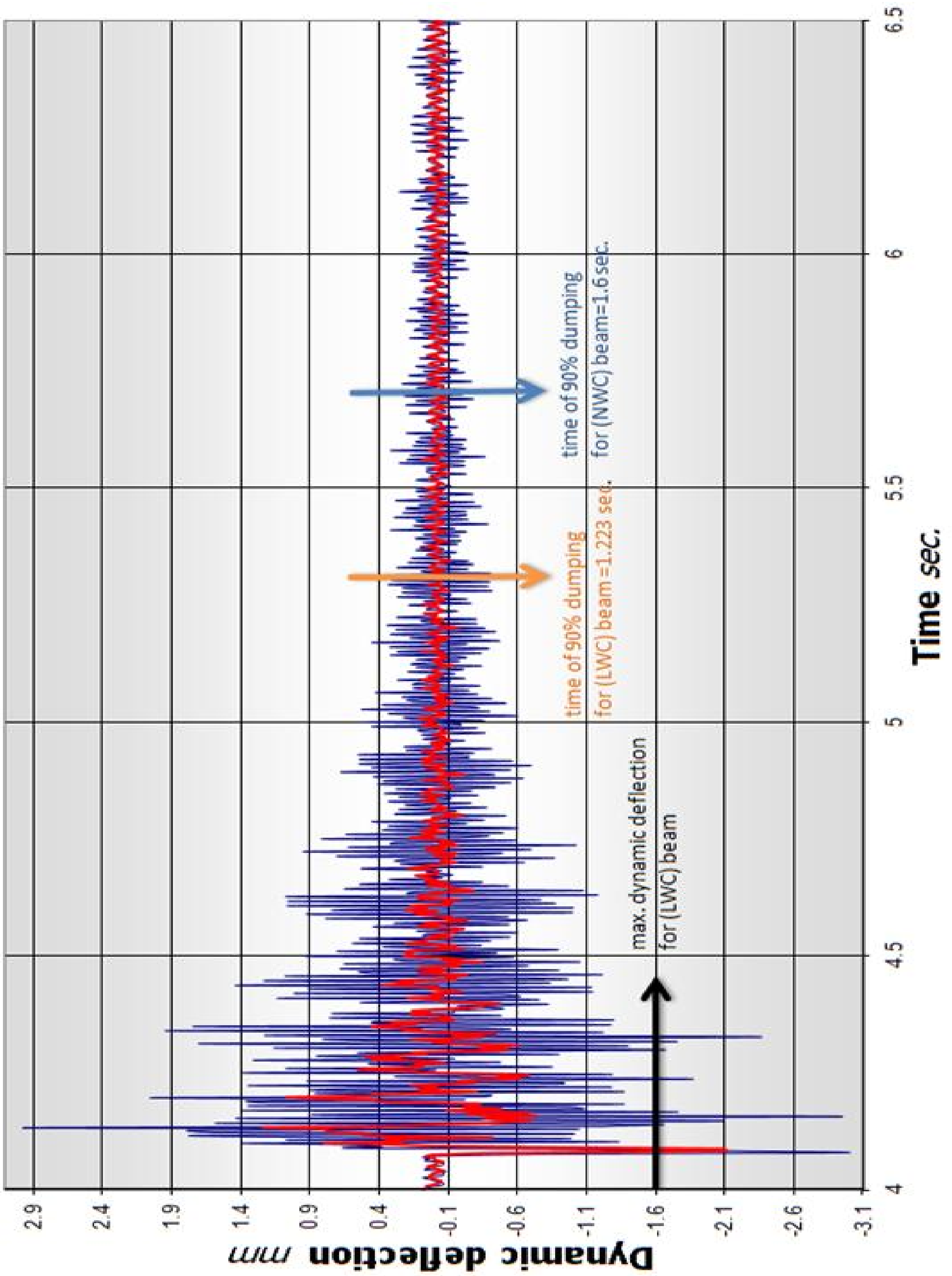

Figure (8) Dynamic response of normal weight R.C.Beam

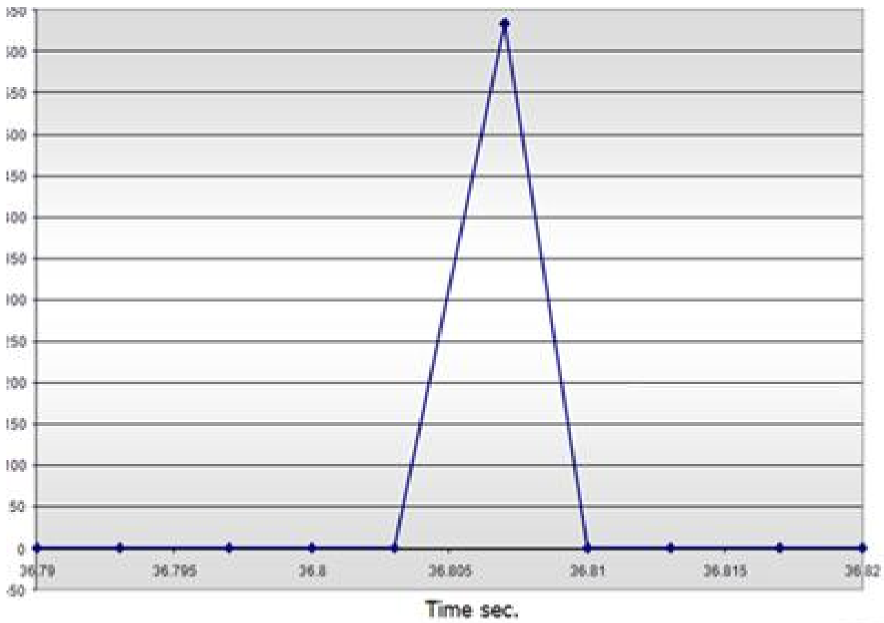

Figure (9) Impact load diagram for lightweight concrete beam

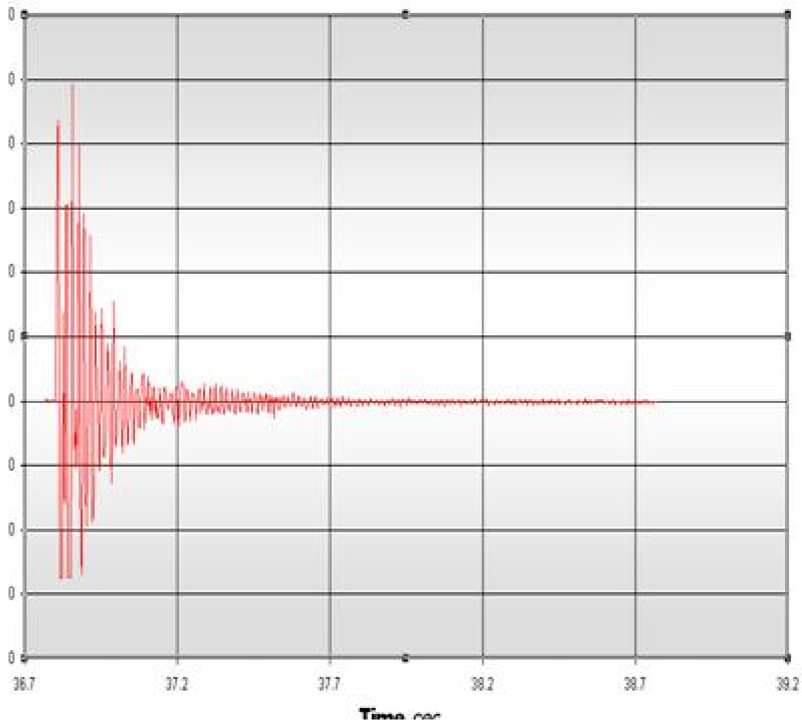

Figure (10) load under hinge support diagram for lightweight concrete beam

Figure (12) Number of blows from first crack up to failure for lightweight Concrete beam

Figure (13) Number of blows from first creak up to failure for normalweight concrete w beam