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Behavior of Reinforced Light-Weight Concrete Sections Under Eccentric Loads

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Abstract*—Due to technology and research development on concrete compressive strength over the last years, the use of light-weight concrete (LWC) has proved to be most popular in terms of economy, superior strength, stiffness and durability. However, strength and ductility are generally inversely proportional. Light-weight concrete is a brittle material causing failure to occur suddenly under excessive applied loads. It is also well known, that axial compression concrete elements (i.e. axially compressed) rarely occurs in practice. The stress concentrations caused by eccentric loading, further reduce the strength and ductility of high- strength concrete columns. This paper presents an experimental-theoretical andanalytically (Ansys 14.0) study to investigate the general deformational behavior of eccentrically loaded light-weight reinforced concrete (LWRC) columns. Six medium scale LWRC columns with 150 mm width, 250 mm depth, and 1200 mm height connected with two end cantilevers were tested under eccentric loads. Different types of light-weight materials were used. The experimental study includes also testing of one medium scale LWRC beam with cross section (150 x 250) mm, 1200 mm length and span 1100 was tested under the effect of two vertical concentrated loads. The obtained experimental results were combined with some other available data, in order to formulate some recommendations for designers and researchers concerning the analysis, design and construction of LWRC elements. Ansys 14 has provided useful insight for future application of a finite element package as a method of analysis. To ensure that the finite element model is producing results that can be used for study, any model should be calibrated with good experimental data. This will then provide the proper modeling parameters needed for later use.

***Key words*—Light-weight concrete, Columns, Eccentric loading, Strains, Beams, Codes.**

I. INTRODUCTION

Most of current concrete researches focus on using high-strength concrete mixes, by which is meant a cost effective material that satisfies demanding performance requirements, including durability [1]. Light-weight concrete (LWC) is very important to the construction industry due to its cost effective and numerous advantages. The primary advantage of using LWC is to reduce the dead load of the concrete structure, which allows the structural designer to reduce the size of carrying columns, footings and other load bearing elements [2]. Furthermore, the reduced mass will reduce the lateral load that will be imposed on the structure during earthquakes, hence simplifying and reducing the lateral load carrying system [3]. Structural light-weight concrete mixes can be designed to achieve similar strengths as normal weight concrete. The same is true for other mechanical and durability performance requirements. Structural lightweight concrete provides a more efficient strength-to-weight ratio in structural elements. In most cases, the marginally higher cost of lightweight concrete is offset by size reduction of structural elements, less reinforcing steel and reduced volume of concrete which result in lower overall cost [4]. Light-weight foamed concrete is a new kind of Lightweight concrete, which combines the advantages of normal density concrete, cellular concrete and self-compacting concrete through partially replacing the normal weight aggregates with polystyrene foam, hence, leading to concrete unit weight reduction while maintaining adequate strength. The latter material can therefore be produced using standard methods familiar to the construction industry with a dry unit weight of 18.5 kN/m3, which in turn leads to dead load reduction of 15 – 20 % and the associated decrease in the structure's overall cost, hence, providing a feasible challenge to normal density concrete (NDC) [5].

II. EXPERIMENTAL PROGRAM

The experimental program includes testing of three types of columns in order to perform five stages of loading from pure axial load up to pure bending moments. The details of tested columns are as follows:

A. Column Group No. (1)

Columns (C1-C3) of effective cross section 15 x 25 cm, overall length 120 cm, and 25 x 35 cm heads of height 20 cm, and effective loading length of 70 cm, with longitudinal reinforcement 4 ϕ 10 mm in corners and 5 ϕ 8/m closed stirrups with spacing 20 cm and the additional reinforcement. Details are given in figure (1).

B. Column Group No. (2)

Specimens (C4-C6) of effective column cross section 15 x 25 cm. overall length 120 cm, and 25 x 35 cm heads of height 40 cm, and effective loading length of 40 cm, with longitudinal reinforcement 4 ϕ 10 mm in corners and 5 ϕ 8/m closed stirrups with spacing 20 cm and the additional reinforcement. Details are given in figure (2).

C. Beam Test

A flexural loading beam (C7) is of dimensions 15 x 25 cm, longitudinal reinforcement 4 ϕ 10 mm and 5 ϕ 8/m closed stirrups with spacing 20 cm. The effective span is 110 cm and the overall length is 120 cm. Details of the beam are given in figure (3).
The seven specimens were made from lightweight foam concrete.

III. EXPERIMENTAL DETAILS

I. *Characteristics of used materials*

The properties of the materials used for preparing ordinary and lightweight concrete composites tested in this

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study are: aggregates, cement, silica fume, water, foam, super-plasticizer, and reinforcement steel [6].

Aggregates:

The fine aggregates used in this work were all of siliceous graded natural sand. It has a fineness modulus of 3.35 and apparent specific gravity of 2.62. Course aggregates used were all composed of siliceous gravel and having a general particle shape of a combination of round and sub –angular with max nominal size 10 mm and the surface texture is more or less smooth and uniform.

Cement:

The cement used in all of the experimental work was ordinary Portland cement of physical and chemical properties in compliance with E.S.S. 373, 1984.

Water:

Clean drinking fresh water free from impurities was used for mixing and curing.

Silica fume:

The silica fume used in all experimental work was ordinary silica fume.

Super plasticizer:

A high water reducer or a super-plasticizer was added to the concrete composites to improve the workability of the fresh composite and at the same time converse its compactness without increasing the water content. The super-plasticizer used in this study was of a liquid form under trade Name, ADDICRETE BVS which is in compliance with ASTM C494, 1982 of type V with doses about 2.8%. It permits a reduction of 24% of the water content in concrete mixture when used in these doses.

Reinforcing steel:

The longitudinal reinforcement of columns of diameter 10 mm was of high grade steel while and the 8 mm were of mild steel.

Mix Composition

The quantities required by weight for one cubic meter of fresh concrete for the L.W.C columns are as given in table (1).

Table (1): Material quantities the L.W.C columns

Materials	Cement (kg/m^3)	Sand (kg/m)	Gravel (kg/m)	w/c ratio	Plasticizer ($liter/$)	Silica fume (kg/m^3)	es Foam ($liter/m$)
Quantity	450	630	630	0.308	13.5	40	330

IV. PREPARATION OF SPECIMENS

Forms:

Wooden forms were designed and prepared to allow for simple and correct placing of concrete. The steel bars were tied with the stirrups forming reinforcement cages corresponding to that required for columns. Electrical strain strains gauges of 10 mm length and 120 ohm resistance were fixed on the steel bars, in order to follow the reinforcement strains during loading. The strain gauges were covered with silicon sealant to protect them during casting and consolidation of concrete. The forms were coated with a thin layer of oil to facilitate their removal after hardening of concrete. The reinforcement cages were then placed in the forms and lifted by small blocks to permit appropriate concrete cover.

MIXING AND CURING

Dry materials were mechanically mixed in a drum mixer for two minutes then water and super-plasticizer were added to the mix and cast in the forms just after mixing. The batch consisted of 34 kg cement, 9.5 kg water, 48 kg sand, 48 kg gravel, 1 liter super-plasticizer and 0.38 kg foam with approximately three batches to cast each column. The cast concrete was then vibrated with an electrical needle vibrator and hence, the final concrete surface was smoothed. The forms were removed after 24 hours from casting and columns were moistened continuously with water for 7 days and kept in laboratory atmosphere until they were tested after 4 to 6 weeks. Standard specimens were prepared during casting columns to obtain the mechanical properties of the used concrete. These specimens consisted of 12 cube specimens (15.8 cm side) and 2 cylindrical specimens (15 cm diameter and 30 cm height). The specimens were cast in layers and each layer was compacted by rod. After 24 hours, the specimens were demoulded and kept under water until they were tested. Six cubes were tested in compression to get the 7 days strength while the other cubes were tested to get the 28 days compressive strength. One cylinder was tested in uniaxial compression to determine the cylindrical strength and the compressive modulus of elasticity while the other cylinder was tested to obtain the splitting tensile strength of concrete. All cylinders were tested after 28 days from casting and all tests were carried out in accordance with the standard Egyptian specifications. Table (2) shows the average values of the obtained results.

Table (2): Mechanical properties of L.W.C columns mix (kg/cm^2)

Cube strength		Cylindrical compressive strength
7 days	28 days	
175	240	190

A. LOADING OF COLUMNS

Two sides of each column are white painted, one day before testing, to facilitate the tracing of cracks during loading. At the day of testing, the column was mounted and adjusted in machine. The columns were all loaded in increments up to failure.

The tested columns were instrumented to measure their mechanical behavior after each load increment using the following tools, see Fig. (4).

a. Strains: The concrete strains were measured using mechanical strains gauges (extensometer) of 50 mm gauge and 0.01 mm accuracy. The distance between demec points mounted on the painted sides of the specimen was measure in three rows. The main reinforcement strains were measured with the electrical strain gauges fixed on them.

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The electrical strain gauges were coupled to a strain indictor.

b. Lateral deflections: They were measured using 5 LVDT 100 mm capacity and 0.01 mm accuracy and were arranged to measure the deflection distribution through out the column height.

C. Cracks: After each load increment the cracks are traced and marked on the painted sides of the specimen according to their priority of occurrence.

B. Behavior of the Tested Specimens

The seven tested models behaved in a different manner and the following remarks were noticed:

- ***Cracking, Crack Pattern and Failure Load***

For the tested columns, the first crack for the first three columns appeared at a load level about 0.8 of the ultimate load (the failure load) while for the other columns the first crack appeared at a load level about 0.5 of the ultimate load. Table (3) shows the load at which the first crack appeared, the failure load and the eccentricity used for all specimens. Figures (5) to (10) show the crack patterns of the tested columns. Figure (11) shows the interaction (Load-Moment) diagram.

Specimen No.	Eccentric (cm)	Cracking load (ton)		Cracking Moment (m.t)		Failure Load (ton)		Failure Moment (m.t)	
		Ans	Exp	Ans	Exp	Ans	Exp	Ans	Exp
C1	0	50	60	0	0	70	80	0	0
C2	4.4	30	50	1.3	2.2	60	70	2.6	3.0
C3	6.9	25	45	1.7	3.1	53	60	3.6	4.1
C4	9.4	25	22	2.3	1.8	50	48	4.7	4.7
C5	13.5	15	18	2.0	1.3	40	38	5.4	5.1
C6	26.4	8	6	2.1	1.5	15	13	3.9	3.4
B	0	4	5	0.7	.83	6	8	1	1.3

Table (3): Results of column loading tests.

From the previous table and the mentioned figures the following marks can be included.

1-The ratio of first crack load to failure load for small eccentricity columns is more than for big eccentricity columns and this can be attributed to the difference of the behavior of light weight concrete due to compression only and due to compression and moment.

2-Increasing the eccentricity for the columns (C2-C6); the main cracks get higher near the middle, then as the load increased the cracks propagated in a diagonal manner until they reached the other side of column.

3-For the first three columns (C1-C3) the first crack appeared in the lower middle of the columns and as a load increased, the cracks propagated upwards in almost a vertical manner and For the next three specimens (C4-C6) the first crack appeared in the lower middle of columns and as a load increased, the crack propagated upwards in a diagonal manner with an inclination angle of about 55-65 degrees approximately. This may be attributed to the effect of increasing the loading eccentricity.

4-It was the observed that all the columns tested have low ductility and this may be attributed to the high cube strength fcu of the concrete used.

- ***Deflections***

As mentioned before, central lateral deformations of the tested models were measured on each model to predict the deflected shape of the tested model.

The experimental load central deflection curves, on tension side of all tested specimens, are shown in figures (12) to (17).

From these figures, the following remarks could be concluded.

1- The load-deflection curves for models (C1-C6) were nearly linear at the early stages of loading (from zero up cracking of concrete), after which there was a bigger increase in deflection because of the great decrease in stiffness due to excessive cracking.

2- For all models, it was noticed that increasing eccentricity causes increase of central deflection and this can be attributed to the increase in moment acting on the models.

- ***LONGITUDINAL STEEL STRAINS***

The curves in Fig. (18) to (23) Show the load steel-strain variations, at mid span section, through the load history for the seven tested models. From these curves, it is clear that before cracking, the behavior of steel strain was almost linear. Also, just before failure of the models, all the steel strain gauges were damaged so they did not give readings to be recorded.

- ***Longitudinal Concrete Strains***

The concrete strains were measured through the columns lengths to determine the strain distribution through the each column length from zero up to failure load.

The curves in Fig. (24) to (29) Show the longitudinal concrete strains near mid span section of all the tested models at different load levels.

From these curves the following remarks can be included:

1. The moment-longitudinal concrete strain curve was almost linear, before cracking, for all models.

2. For columns from C1 to C6 the failure concrete strain was almost 0.0042 (more than normal strength concrete) and this may be attributed to the low cube strength fcu of the concrete.

V. CONCLUSIONS

1. The observed value of the first cracking loads for all values of load eccentricity (e/t) almost same with theoretical analysis.
2. The observed value of the failure loads for load eccentricity (e/t) = 0 to 0.276 were greater than those obtained from the theoretical analysis about 13%, for load eccentricity (e/t) = 0.376 to 1.056 were greater than those obtained from the theoretical analysis about 5% and for (e/t) = ∞ was greater than those obtained from the theoretical analysis about 25%.
3. For load eccentricity (e/t) = 0 to 0.276, the steel strain values are greater than those obtained from the theoretical analysis about 25% and for load eccentricity (e/t) = 0.376 to 1.056, the steel strain values obtained from the theoretical analysis are almost same before cracking and smaller than that measured experimentally about 13% after cracking.
4. For load eccentricity (e/t) = 0.0 to 0.176, the concrete strain values obtained from the theoretical analysis were smaller than that measured experimentally about 3%, for load eccentricity (e/t) = 0.276 to 0.376, the concrete strain values obtained from the theoretical analysis were smaller than that measured experimentally about 12% and for load eccentricity (e/t) = 0.54 to 1.056, the concrete strain values obtained from the theoretical analysis were smaller than that measured experimentally about 20%.

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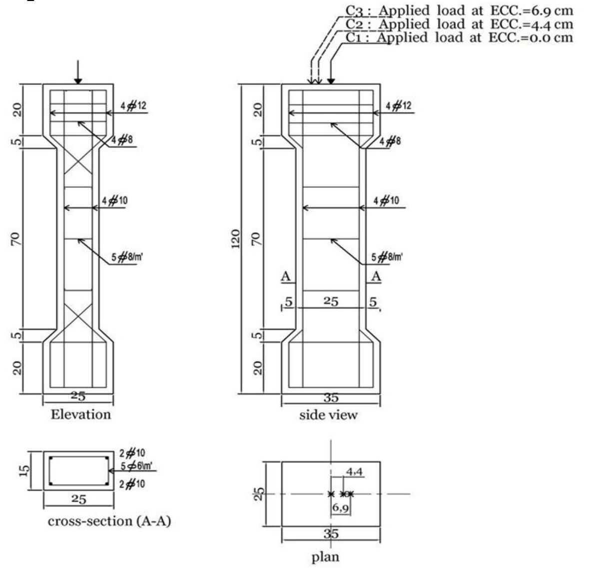

Fig (1): Typical dimension and reinforcementof columns C1,C2,C3

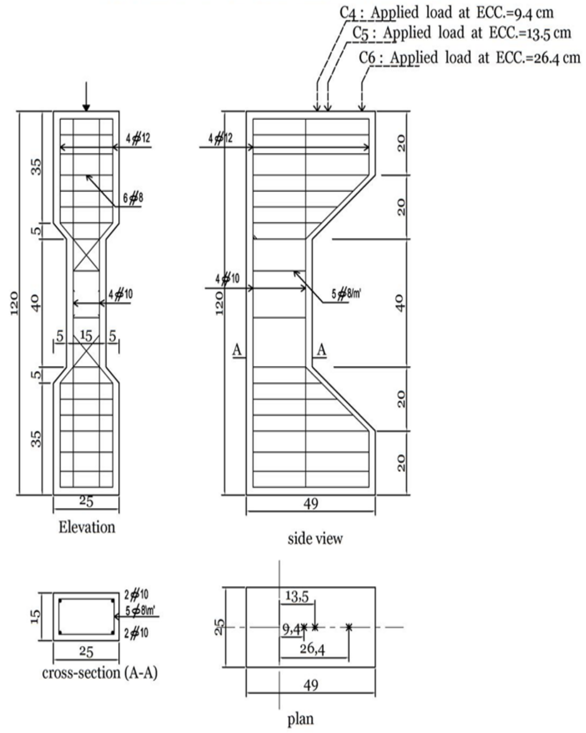

Fig (2): Typical dimension and reinforcementof columns C4,C5,C6

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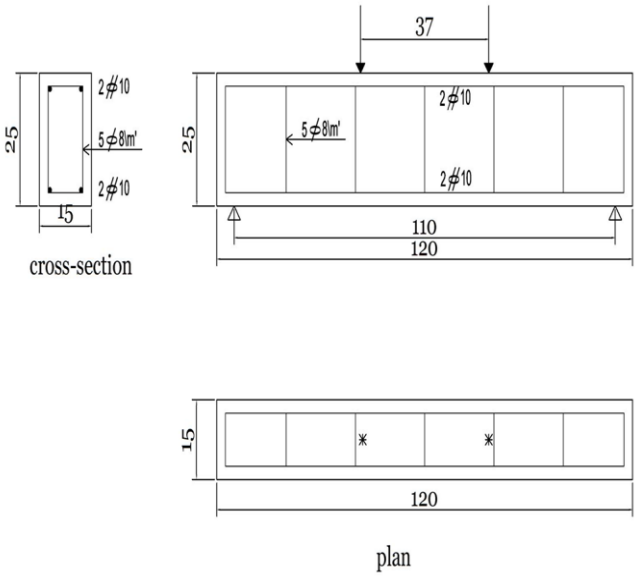

Fig (3): Typical dimensions and reinforcement of beam C7

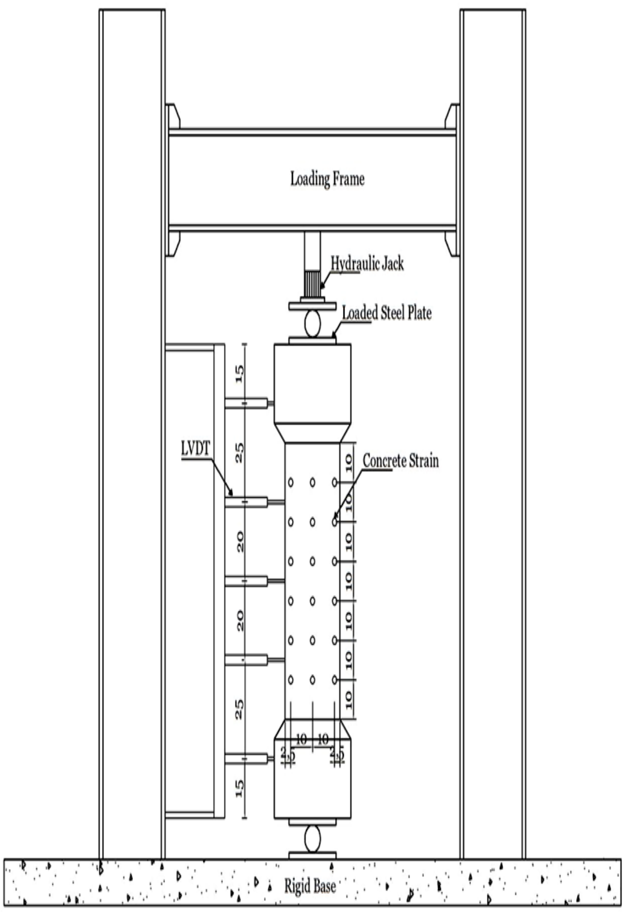

Fig.(4): Schematic Arrangement of the Test Set-up

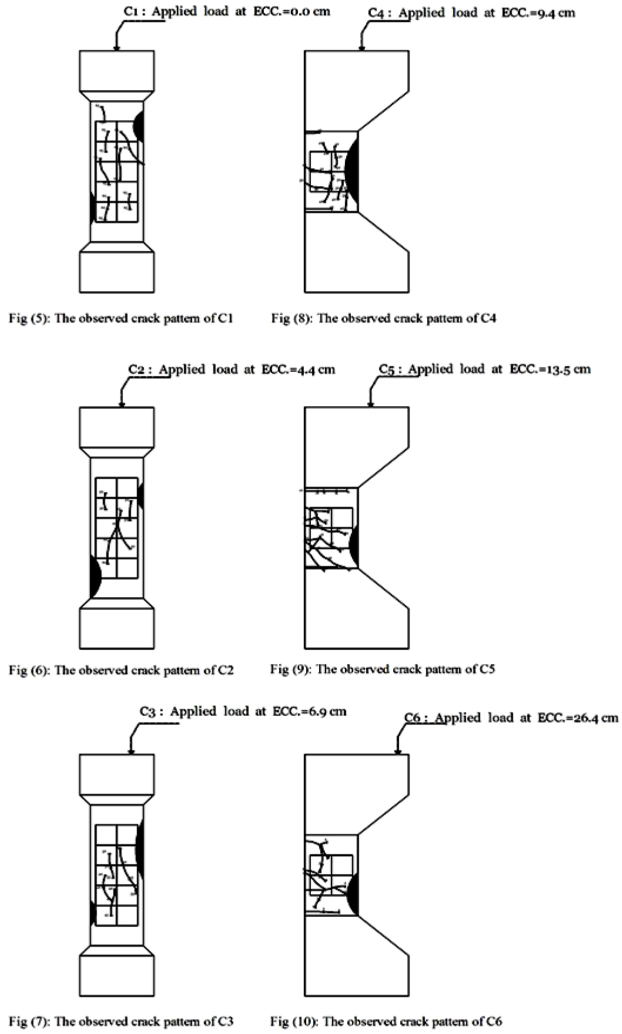

Fig (5): Failure pattaerns of columns C1 to C6

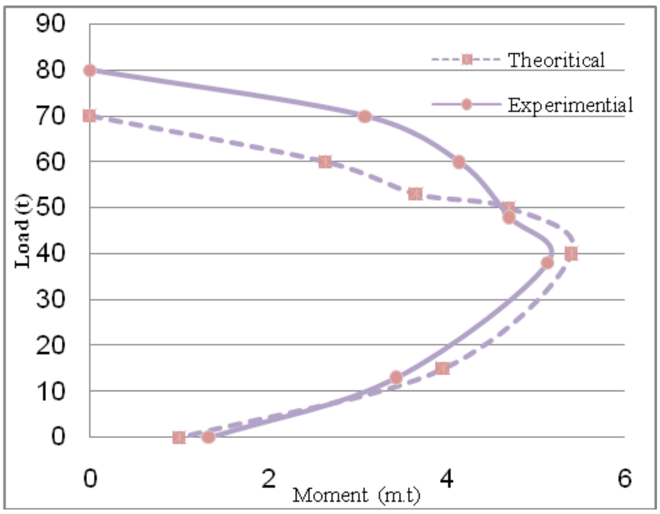

Fig (6): Load-Moment diagram for tested columns

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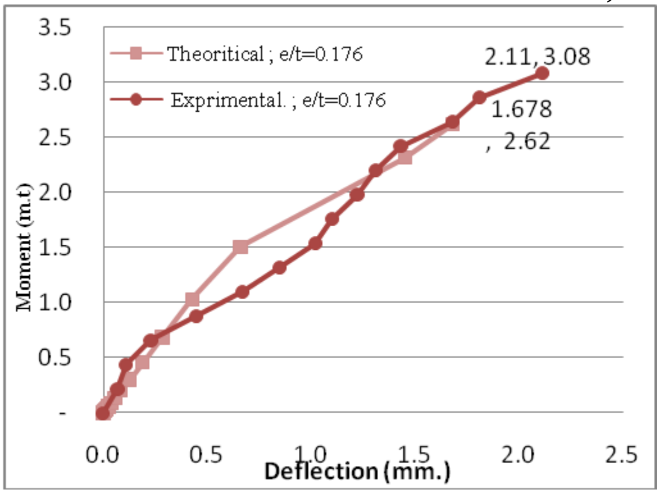

Fig. (7) Moment – Maximum deflection curve of e/t=0.176

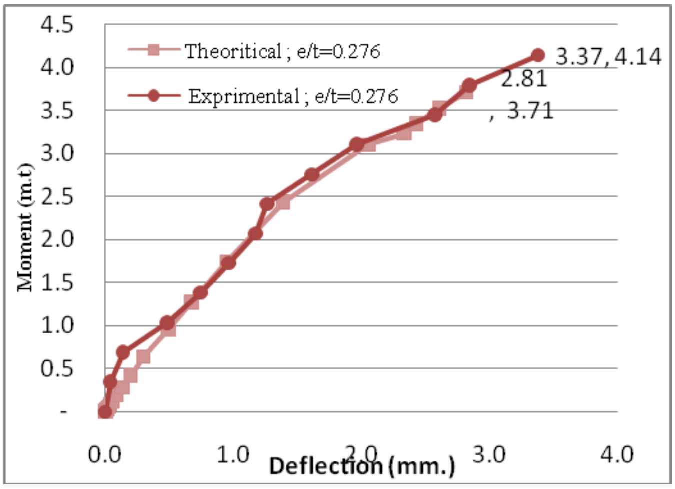

Fig. (8) Moment – Maximum deflection curve of e/t=0.276

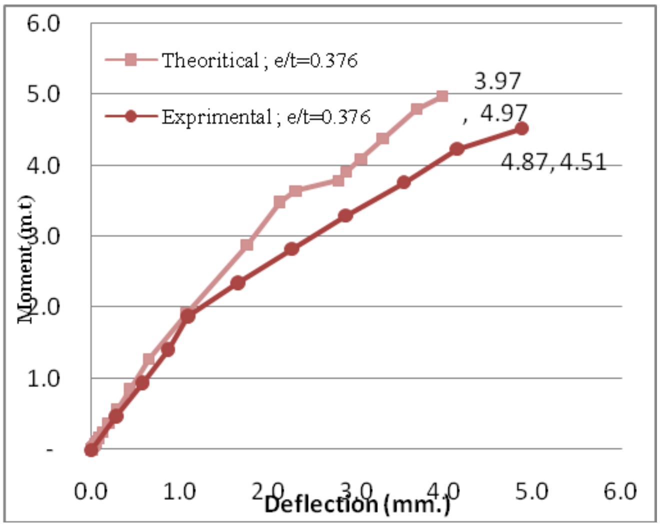

Fig. (9) Moment – Maximum deflection curve of e/t=0.376

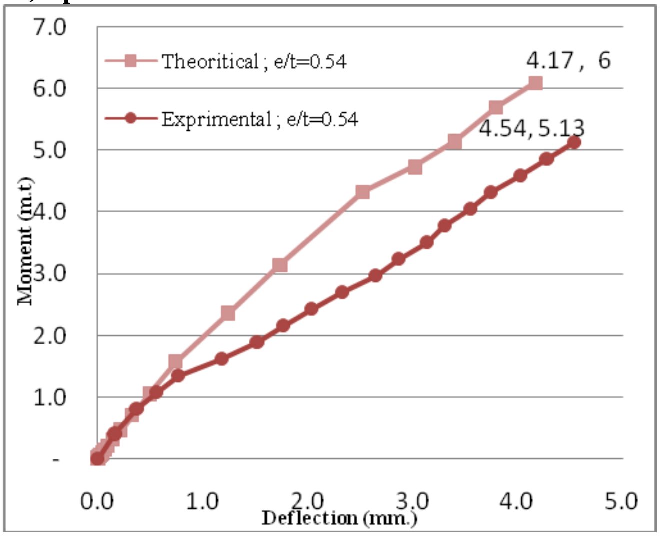

Fig. (10) Moment – Maximum deflection curve of e/t=0.54

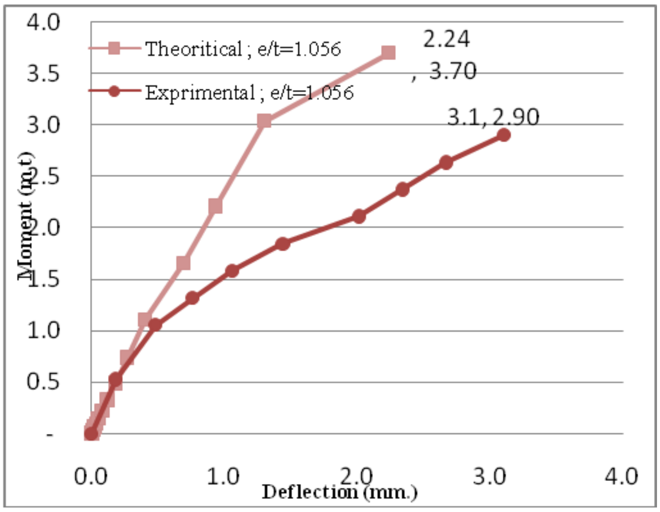

Fig. (11) Moment – Maximum deflection curve of e/t=0.1.056

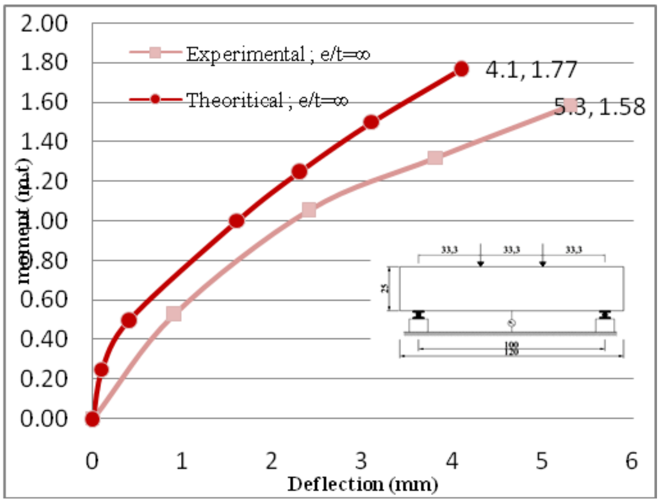

Fig. (12) Moment – Maximum deflection curve of e/t = ∞

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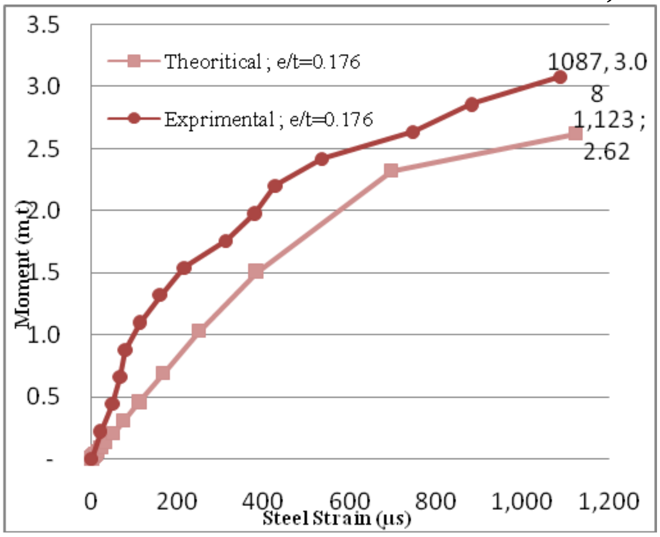

Fig. (13) Moment – Maximum steel strain curve of e/t=0.176

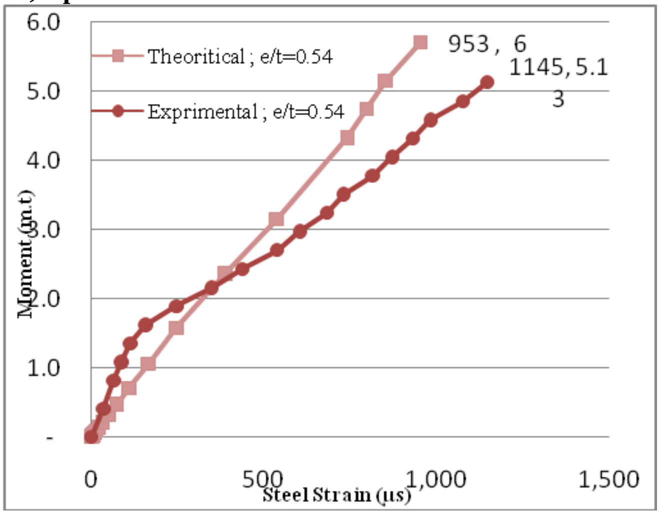

Fig. (16) Moment – Maximum steel strain curve of e/t=0.54

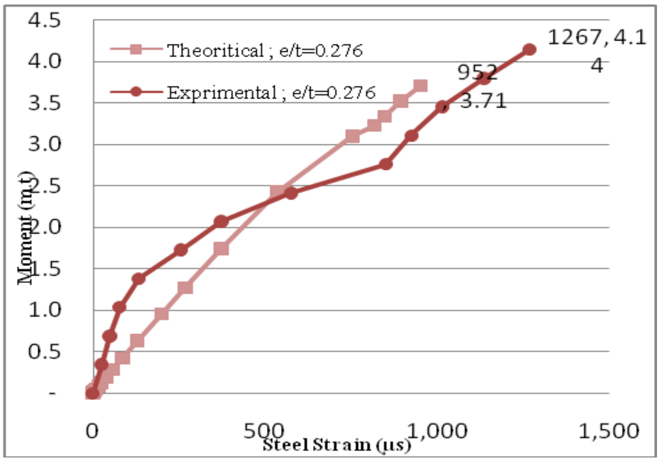

Fig. (14) Moment – Maximum steel strain curve of e/t=0.276

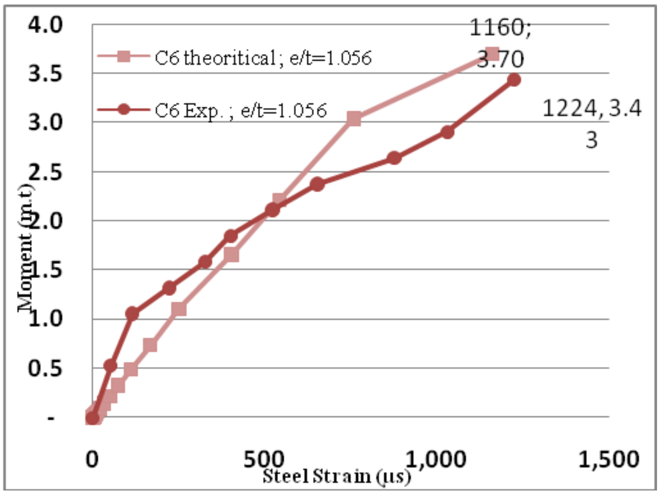

Fig. (17) Moment – Maximum steel strain curve of e/t=1.056

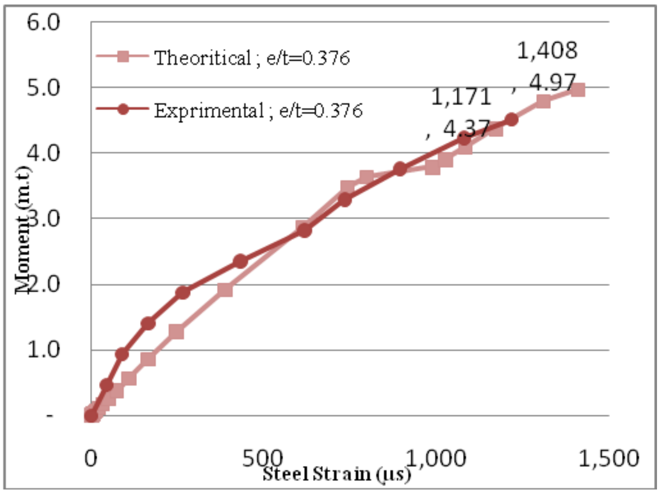

Fig. (15) Moment – Maximum steel strain curve of e/t=0.376

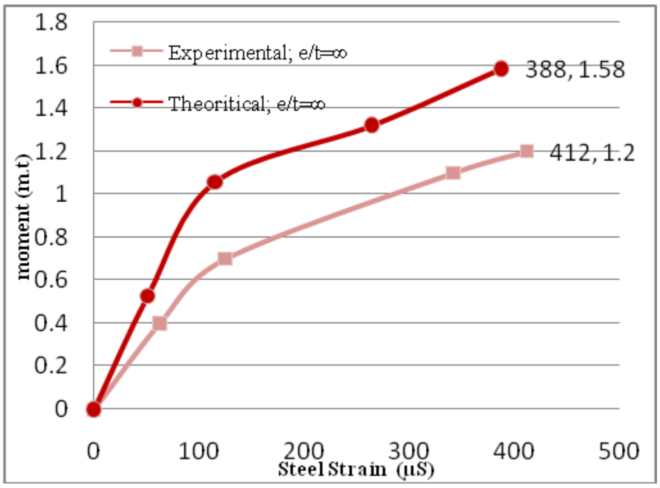

Fig. (18) Moment – Maximum steel strain curve of e/t=∞

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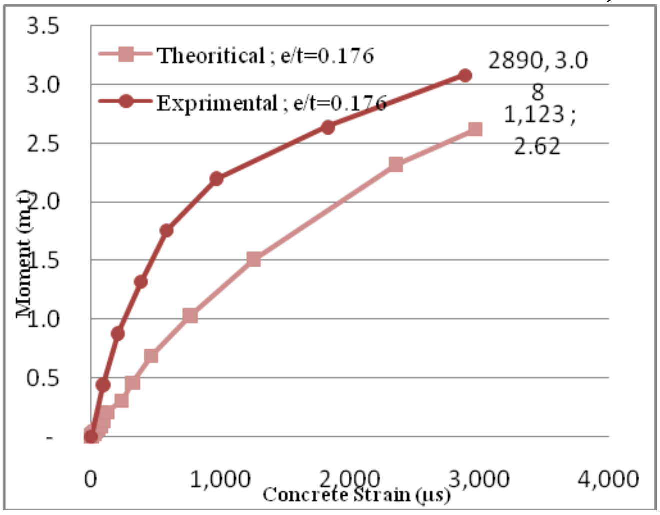

Fig. (19) Moment – Maximum concrete strain curve of e/t=0.176

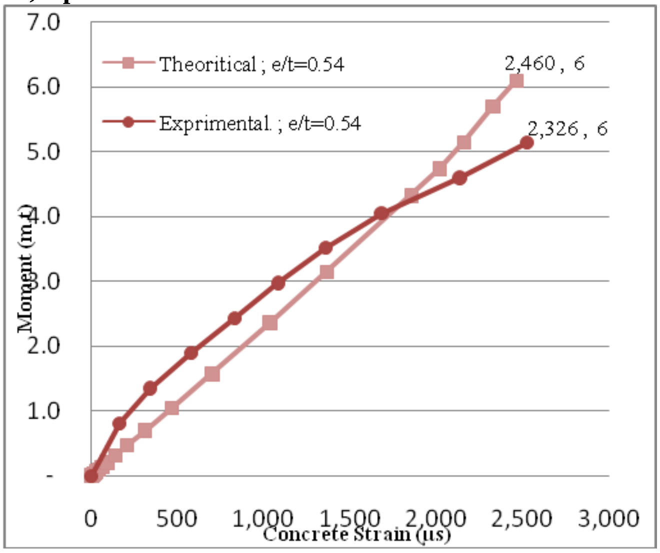

Fig. (22) Moment – Maximum concrete strain curve of e/t=0.54

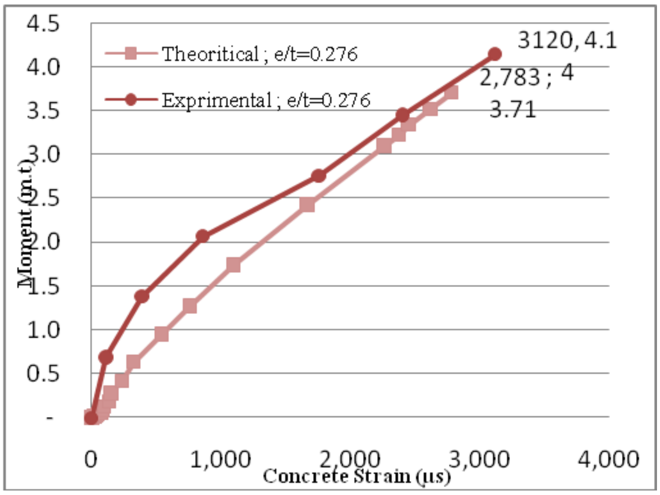

Fig. (20) Moment – Maximum concrete strain curve of e/t=0.276

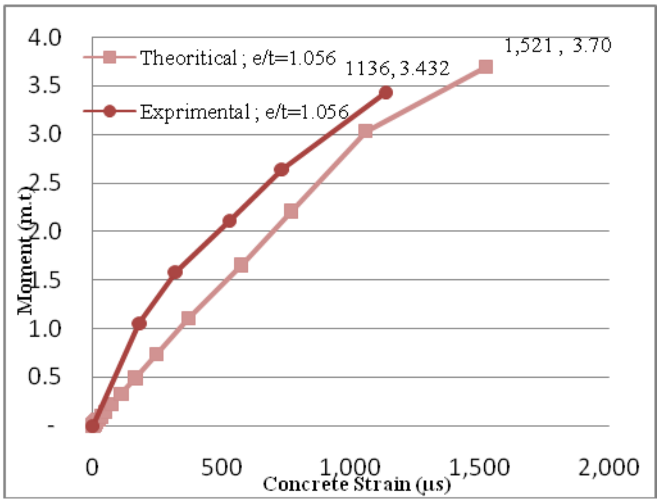

Fig. (23) Moment – Maximum concrete strain curve of e/t=1.056

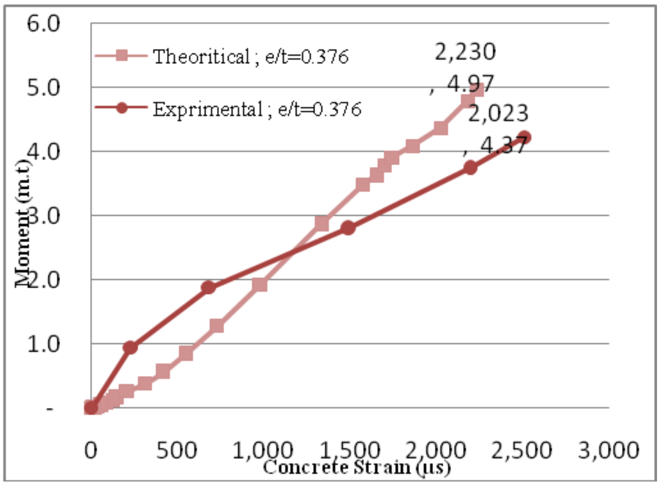

Fig. (21) Moment – Maximum concrete strain curve of e/t=0.376

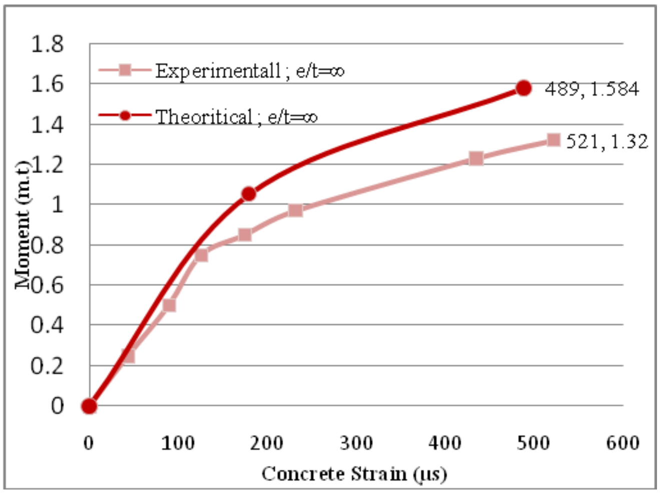

Fig. (24) Moment – Maximum concrete strain curve of e/t=∞