Performance of Dowels in Direct Shear

Heba Ali Abdel Rahman / Searcher, Housing and Building National Research Center, Cairo, Egypt
Email: hebaali1985@yahoo.com

ABSTRACT

Dowels are used at construction joints to resist shear forces. The shear resistance takes place between existing and new reinforced concrete elements. In this study the shear friction behavior of concrete section reinforced by dowels is experimentally investigated. Twenty – one models were tested. The specimens were divided into seven groups. Each group consisted of three specimens of same characteristics to reduce the effect of unintended variability in test. Specimens have dimensions of 300 * 300 * 150mm. Specimens have equal shear and flexure reinforcement. The test specimens varied in dowel length, diameter, and shape. The lengths of dowels as multiplier of bar diameter (ϕ) varied from 10ϕ, 15ϕ, 20ϕ, to 30ϕ. The diameters of dowels were between (ϕ) 8mm and10mm. The variation in shape of dowels included L shape and straight shape.

The test results include among the general behavior the characteristics of load- deflection relationship, the load –steel strain relationship, load slip characteristics of dowel, dowel strain, and failure load. Based on the experimental results, the effect of the variables, being the length, the diameter and the shape assessed. Recommendations toward achieving maximum efficiency of dowels are given.

Keywords : Dowels, Concrete, Reinforcement, Direct, shear

1 INTRODUCTION

Efficiency of dowels in resisting shear between interfaces of old and new concrete surfaces has been the subject of many researchers. M. H. Arslan studied the performance of the RC shear walls-RC weak frame connected by steel anchor dowels .The performance depends on some parameters such as compressive strength of the existing RC frame concrete, diameter and embedment length of anchored rebar, type of rebar, yielding stress of bar, properties of used chemicals, position of the anchor bars in RC. The application problems of the steel anchor dowels had been checked. The anchorage strength varied according to several factors. The factors were the quality of the epoxy material, the composition, and the type of the epoxy to be used before the anchorage placing.

J. Shafaie studied bond-slip models between steel rebar and concrete using finite element program. It was found that stress distribution in the steel bar and concrete of pull-out tests may principally be influenced by the properties of the interface.

- The finite element analyses of pullout tests with a short embedment length (local bond conditions) showed relatively good agreement between experimental and numerical results.
- It was also concluded that cohesion layer is able to transfer adequate bond stresses from reinforcement into concrete.

Ghauch Studied the performance of traditional round dowels in concrete floors and attempts to optimize the shape of dowel bars through Finite Element analysis. A new type of Double-Tapered Round (DTR) dowels was proposed, and the performance of DTR dowels was compared to that of traditional cylindrical dowels. The results indicated that the use of DTR dowels can reduce bearing stresses at the face of the joint by as much as 2.2 times as compared to traditional cylindrical dowels.

While adequate load-transfer is a crucial part for the proper performance of pavement structures, the load-transfer capacity of DTR dowels was found to be more effective over cylindrical dowels by as far as 16%. In the inelastic range, even after significant concrete degradation and steel yielding, DTR dowels maintained a higher load-transfer capacity than traditional cylindrical dowels, and also presented lower amounts of differential deflections across concrete floors. Finally, damage in the concrete matrix below the dowel was relatively more confined for the case of DTR dowels, as compared to traditional cylindrical dowels.

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Different searchers studied improved technique of strengthening. S. S. Ravala investigated various methods of jacketing for RC beams.

The experimental results clearly demonstrated that:

- Jacketing can enhance structural properties for the RC beams.
- ¬For smooth surface jacketed beams, highest load carrying capacity has been observed using jacketing technique of combined dowel connectors and bonding agent with micro-concrete as compared to other jacketing techniques.
- Higher displacement at higher load has been observed for smooth surface jacketed beams using jacketing technique of combined dowel connectors and bonding agent with micro-concrete as compared to other jacketing techniques.
- For roughened surface jacketed beams, highest load carrying capacity has been observed with jacketing technique of using only micro-concrete as compared to other jacketing techniques.
- Higher displacement at higher load has been observed for roughened surface jacketed beams with jacketing technique of using only micro-concrete as compared to other jacketing techniques.
- Implementation of various jacketing methods has proved more beneficial for RC beams with chipped surface as compared to that for beams with smooth surface.

2 CODES PROVISIONS

The design method to assess the shear strength of concrete interfaces has changed throughout the continuous development of codes. The majority of design codes have adopted expressions based on the shear-friction theory. Although all codes equations are based on one theory but different design expressions have been proposed to estimate the shear strength at concrete –to-concrete interfaces. In this paper, the following design, Codes were considered. Egyptian Code (ECP 2018), American Code (ACI-318), Canadian Code (CSA), and British Code (BSI-8110).The relevant equations and coefficients given by the different codes are listed in table (1).

Table (1): The relevant equations and coefficients given by the different codes

Code	Formula	μ Friction coefficient	Shear strength ϕ 8 (ton)	Shear strength ϕ 10 (ton)
ECP (2018)	$Q = \mu_f A_{sf}$ fy	1.2	4.4	6.8
ACI-318 (2017)	$Un = \mu A_{vf}$ fy	1.4	5.1	7.7
CSA (2018)	$Un = C + \mu A_{vf}$ fy	1.4	6.4	9
BSI-8110 (2017)	$Un = \mu A_{vf}$ fy	1.6	5.8	8.7

Where Un and Q represent shear strength. fy is the reinforcement yielding stress, μ is friction coefficient which assumes the following values referring to ACI :1.4λfor monolithic construction, 1.0λ for joints with the surface roughened artificially and0.6λfor joints not roughened ,0.7λ for concrete to steel.λ is modification factor reflecting the reduced mechanical properties of light weight concrete, relative to normal weight concrete of same compressive strength=1.C is cohesion factor=1.25.

3 EXPERIMENTAL PROGRAM AND TEST SETUP

An experimental program was carried out to investigate the behavior of dowels with emphasis on the effect of dowels, the effect of embedment length, shape of dowel and diameter of dowels. Twenty-one specimens were tested. The specimen dimensions were 300 * 300 * 150mm as shown in Figure (1). Specimens have approximately same shear and flexure reinforcement as shown in Figure (2). The test specimens varied in dowel length, diameter, and shape. The lengths of dowels varied as multiplier of bar diameter between 10ϕ , 15ϕ , 20ϕ , and 30ϕ . The diameters of dowels varied between ϕ 8mm and ϕ 10mm. The shape of dowels varied between L shape and straight shape. Table (2) gives data for dowel shape and reinforcement. The designed cube compressive strength of the concrete was 30 N/mm2 after 28 days. The proportion of concrete mix was 1 (Portland cement): 3 (coarse aggregate): 2 (fine aggregate) by weight. Water / cement ratio was 0.5. Six concrete cubes with dimensions 150*150*150mm were used for concrete quality control. The type of steel was of yield strength 360 N/mm2 and ultimate strength of 520 N/mm2 (grade 52).

The specimens were supported at bottom surface and subjected to concentrated test load applied at top surface. The specimens were instrumented to record deflection and strain of dowel. In addition to these measurements the applied loads were recorded. Strains in dowel were measured by electrical strain gauges. Deflections were measured by linear variable deferential transducers LVDT of length 100mm. Two LVDT were mounted vertically under top flange and above bottom flange. The Specimen dimensions & reinforcement are shown in Figure (1). The test set-up is shown in Figure (2).

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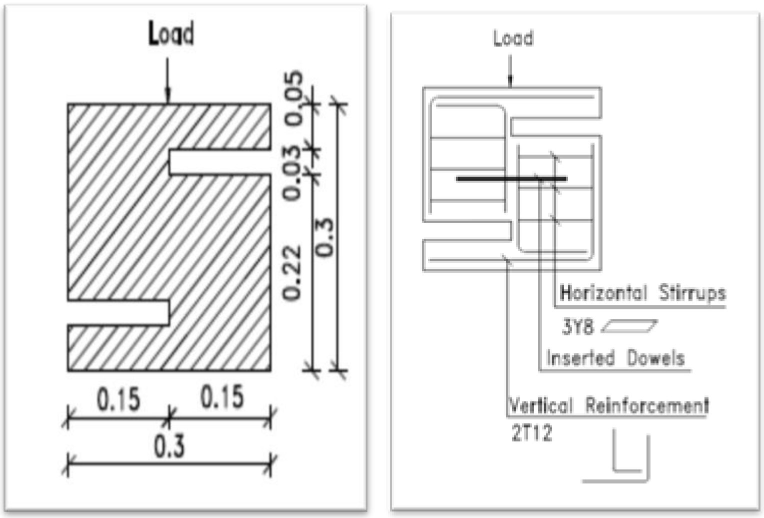
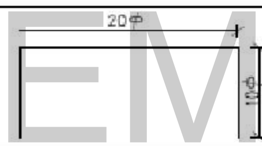
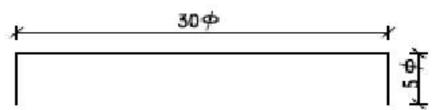
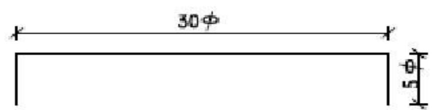
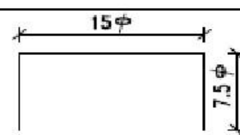
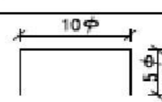
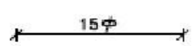
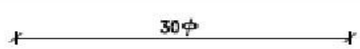


Figure (1): Specimen Dimensions & Reinforcement

Figure (2): Test Setup

Table (2): Specimens' schedule

Group label	Specimen no.	Dowel diameter	Embedment length	Dowel shape
Group (A)	SP1,SP2,SP3	T8	20 ϕ =160mm	
Group (B)	SP4,SP5,SP6	T10	20 ϕ =200mm	
Group (C)	SP7,SP8,SP9	T8	20 ϕ =160mm	
Group (D)	SP10,SP11,SP12	T8	15 ϕ =120mm	
Group (E)	SP13,SP14,SP15	T8	10 ϕ =80mm	
Group(F)	SP16,SP17,SP18	T8	7.5 ϕ =60mm	
Group (G)	SP19,SP20,SP21	T8	15 ϕ =120mm	

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4 TEST RESULTS

The behavior is examined through investigating the following characteristic failure load, deflection, maximum strain and ductility.

4.1 FAILURE LOAD AND CRACK PROFILE

The crack profiles of specimens are shown in Figures (3) to (9).The maximum loads and the first crack loads for specimens are plotted in Figure (10). Crack profile was observed during the test to identify the failure mode for the dowel. The ratio between crack load and failure load for group (A) is 0.55. The ratio between crack load and failure load for group (B) is 0.52. The ratio between crack load and failure load for group (C) is 0.55. The ratio between crack load and failure load for group (D) is 0.44. The ratio between crack load and failure load for group (E) is 0.375. The ratio between crack load and failure load for group (F) is 0.46. The ratio between crack load and failure load for group (G) is 0.41.

The test failure load values of group (A) relative to the code estimated value are 234%, 201%, 160%, and 178% for codes ECP, ACI, CSA, and BSI respectively. The test failure load values of group (B) relative to the code estimated value are 213%, 188%, 161%, and 167% for codes ECP, ACI, CSA, and BSI respectively. The test failure load values of group (C) relative to the code estimated value are 227%, 196%, 156%, and 172% for codes ECP, ACI, CSA, and BSI respectively. The test failure load values of group (D) relative to the code estimated value are 204%, 176%, 140%, and 155% for codes ECP, ACI, CSA, and BSI respectively. The test failure load values of group (E) relative to the code estimated value are 181%, 157%, 125%, and 138% for codes ECP, ACI, CSA, and BSI respectively. The test failure load values of group (F) relative to the code estimated value are 148%, 127%, 100%, and 112% for codes ECP, ACI, CSA, and BSI respectively. The test failure load values of group (G) relative to the code estimated value are 193%, 167%, 133%, and 147% for codes ECP, ACI, CSA, and BSI respectively.

Group (F) was the lowest load capacity indicating the negative effect of the short dowel length. The failure of specimens of group (E) and (F) were associated with large displacement. The values of shear strength calculated by codes were less than the test results expect for group (F), where the embedment length was 7.5 ϕ

Splitting cracks were developed just before reaching the maximum dowel strength. After the maximum dowel force was reached, the applied force decreased as concrete splitting cracks occurred under the dowel rebar. According to the failure mode displayed through the test, it was evident that the maximum dowel force can be increased by controlling concrete splitting cracks. It can be concluded from these profiles that the shear resistance capacity due to the dowel behavior of the rebar is significantly influenced by the strength of the concrete that supports the rebar.

The kinking effect takes place in groups (E) after the yielding of the dowel. This effect reduced the failure load and first crack load in group (E) when compared those of groups (A), and (C).For the specimen of group (F) the failure load and first crack loads occurred due to the shear slip mechanism.

4.2 DUCTILITY

Ductility is defined as the ability to sustain plastic deformation before fracture. Considering this definition, ductility has many indicators among which are the ratio between defection at failure load and deflection at cracking load.

$$\text{Ductility index} = \frac{\Delta ultimate}{\Delta crackingload}$$

Figure (11) shows the ductility index for each group.

Load deflection curves of each group are plotted in Figure (12.a), (12.b), and (12.c).

By comparing group (A), (C), (D), and (E). The results indicate that the behavior of specimen of group (C) is more ductile than that exhibited by others group. The 90 degree bent bar shape having relatively longer embedment measured perpendicular to the failure increase the ductility of the specimen when compared to other specimens having shorter length. This behavior indicates the positive effect of providing the 90 degree bent part of the dowel close to the end of the total embedment length.

4.3 STRAIN

Figure (13.a), (13.b), and (13.c) shows the dowel load strain responses for the groups. It is noted that the strain of the dowel was measured by electronic strain gauge attached on the rebar on the failure plane. At same level of load the strain of rebar in group (F) was the highest when compared to other groups. The strain in bar at same level of load was higher for small embedment length than the large embedment length.

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5 CONCLUSIONS

In this study, an experimental program was conducted toinvestigate the behavior of dowelsembedded in a small concrete member .In this experimental investigation; Twenty – one models were tested. The specimens were divided into seven groups. Each group consisted of three specimens of same characteristics to avoid the unintended error in testing. The results led to the following conclusions:

- The dominated failure mode took place in all specimens as splitting cracks under dowels were developed.
- The maximum capacity of dowel was attained when the dowel bar reached yielding state in the cases of long embedment length.
- The maximum capacity of the dowel was attained when kinking of bar as well as yielding state were developed for the cases of short embedment length having 90 degree bent.
- The bond slip failure mode was exhibited for the case of short and straight embedment length.
- Comparison between failure load and first crack load for the various specimens indicated the positive effect of increasing embedment length and using 90 degree bent bars.
- The high ductility was linked to 90 degree bent shape.
- The strain in bar at same level of load was higher for small embedment length than for the large embedment length.
- The (ECP, ACI, CSA, and BSI) codes predict lower failure loads than the measured values indicating conservation of these codes.

Figure (3): Crack Profile for Specimen in Group (A)

Figure (4): Crack Profile for Specimen in Group (B)

Figure (5): Crack Profile for Specimen in Group (C)

Figure (6): Crack Profile for Specimen in Group (D)

Figure (7): Crack Profile for Specimen in Group (E)

Figure (8): Crack Profile for Specimen in Group (F)

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Figure (9): Crack Profile for Specimen in In Group (G)

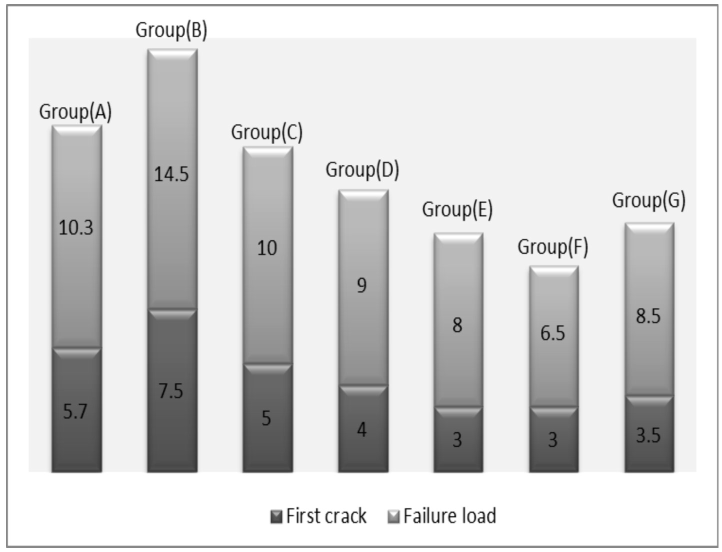

Figure (10): First crack load and failure load for specimens

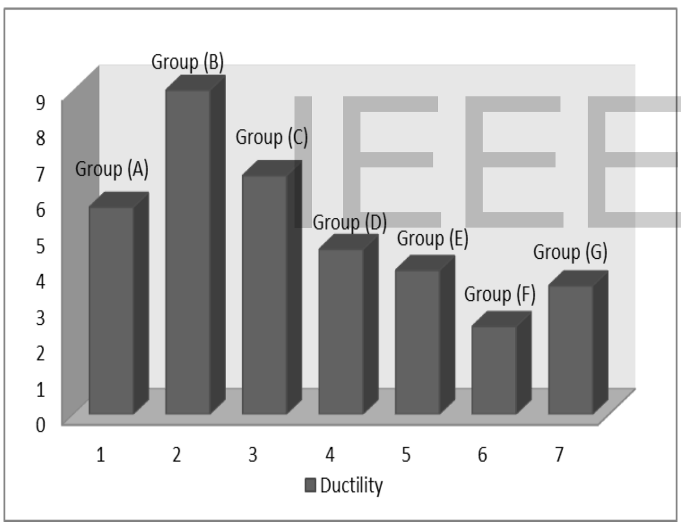

Figure (11): Ductility for specimens

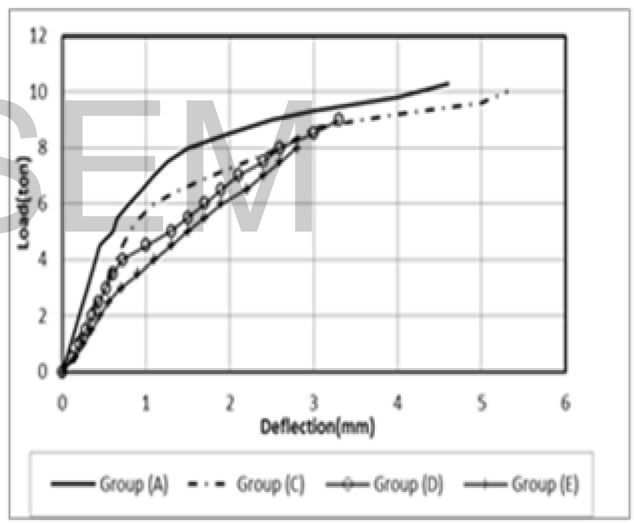

Figure (12.a): Load- deflection curve for groups (A), (C), (D), and (E)

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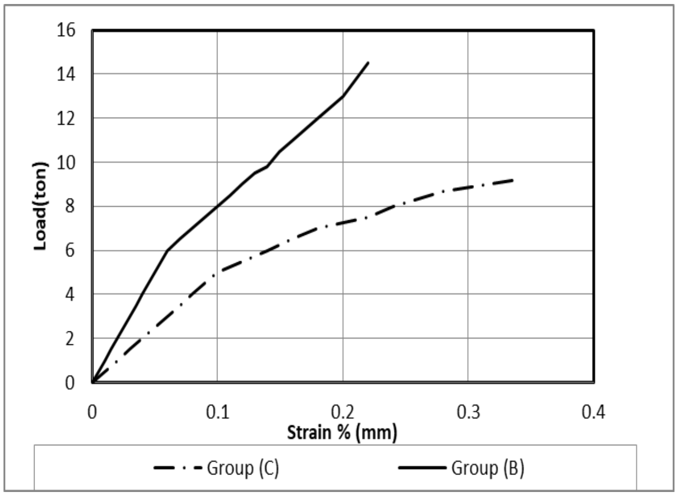

Figure (12.b): Load- deflection curve for groups (B), (C)

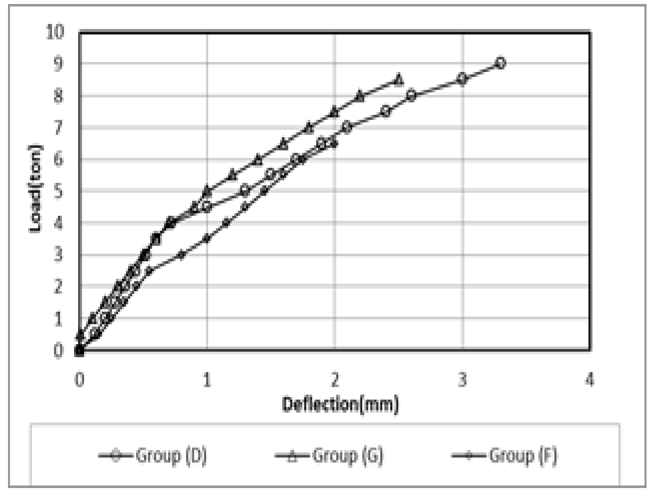

Figure (12.c): Load- deflection curve for groups (D), (F), (G)

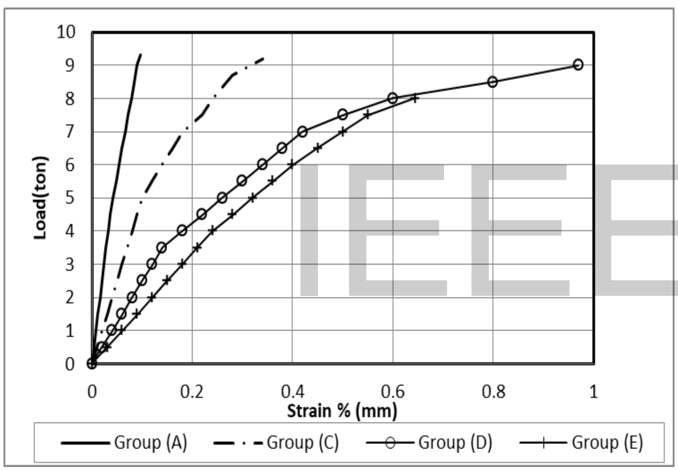

Figure (13.a): Load- strain curve for groups (A), (C), (D), and (E)

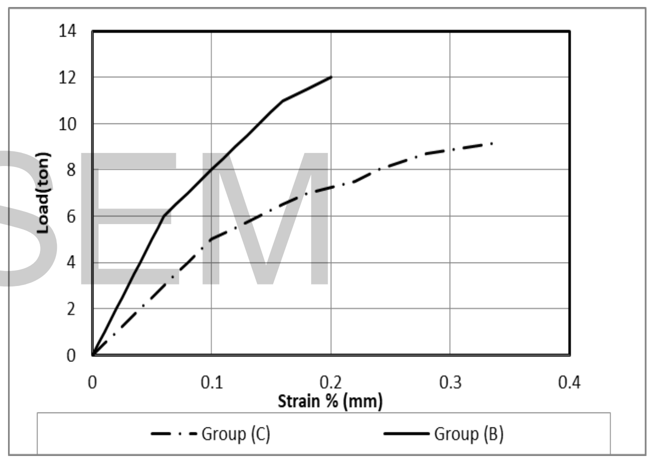

Figure (13.b): Load- strain curve for groups (C), and (B)

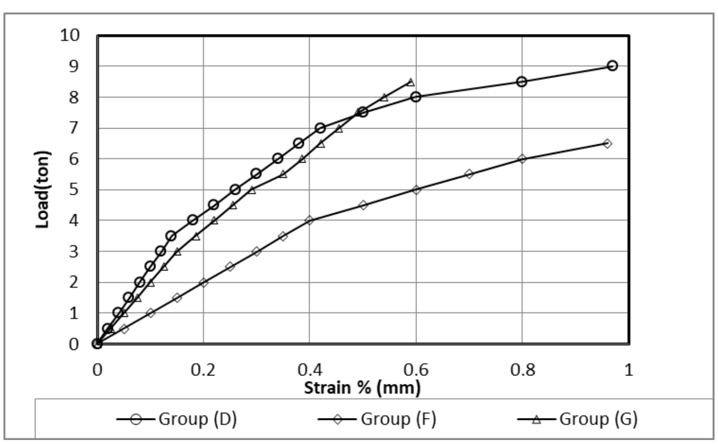

Figure (13.c): Load- strain curve for groups (D), (F), and (G)

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