CHAPTER 3: EXPERIMENTAL WORK

3.1 Introduction

The main objective of this experimental investigation was to study the behavior and strength of reinforced concrete slabs with lap splice of headed bar tension steel reinforcement. Nine simply supported reinforced concrete one way slabs of dimensions (2400 mm x 1000 mm x 120 mm) were tested to achieve this objective. The effects of lap length, confinement at the splice zone, debonding of the spliced bars, and applying repeated loading were studied through this experimental program. This chapter contains details of properties of the used materials, concrete mix, steps of manufacturing the tested specimens, instruments, measurements, and test procedure.

3.2 Preparing of Headed Bars

Headed bars were fabricated locally since their commercial use is still limited in Egypt. Headed bars were manufactured by fixing a steel plate with dimensions (25 x 25 x 10 mm) to the main reinforcement bar by welding. Bars with 10 mm diameter high strength steel agrees with grade 400/600 were used as tension reinforcement. Table (3-1) gives the mechanical properties of the used steel. Headed bars used in the present experimental work were fabricated by drilling a hole with a diameter 12 mm in the center of a steel plate. Then, the bar was passed through the hole and extended 10 mm from the other face of the plate. After that, the bar was welded from the two faces of the plate as shown in Figure (3-1). Three trial specimens were tested to ensure that the welded connection between the bar and the head does not fail before the bar reached at least the yield strength. These trials are shown in Table (3-2). Specimens were tested by using direct tension test; Figure (3-2) shows the test setup for direct tension test and Fig.(3-3) shows the relation between stress and strain for headed bars were used as tension reinforcement. Specimen test results are given in Table (3-2). This type of connection shows that failure occurred after yielding of the bar just outside welding zone. Figure (3-4) shows the shape of failure for this specimen. Plain bars of 6 mm diameter agree with grade 280/450 were used for confining the splices zone and plain bars of 8 mm diameter agree with grade 280/450 were used for transverse reinforcement.

3.3 Concrete Mix

One concrete mix was used throughout this experimental program. The concrete mix consisted of ordinary portland cement, harsh sand, and crushed limestone with 1/2" maximum nominal size. The concrete mix design for one cubic meter and the mix proportions by weight are given in Table (3-3), while Table (3-4) gives the values of constant parameters in all specimens. This concrete mix was designed to achieve 100 mm slump and the required characteristic cube compressive strength of 35 N/mm^2.

3.4 Test Program and studied variables

Nine simply supported reinforced concrete slabs were tested in the present study. The dimensions of the tested slabs and full details of reinforcement are shown in Figs (3-5) to (3-7). All specimens' details are given in Table (3-5) through Table (3-9). The values of concrete strength, bar diameter, clear concrete cover from bottom, side cover, relative head area, and reinforcement percentage are given in Table (3-4). The tested slabs were grouped into four groups according to parameters investigated. The main studied parameters were:

3.4.1- Length of lap splice; Group 1

Four values of lap splice length were investigated; zero or no lap splice **Slab** (**AS-1**), 45 times the bar diameter **Slab** (**AS-2**) without headed bars, 15 times the headed bar diameter **Slab** (**AS-3**), and 27 times the bar diameter **Slab** (**AS-7**). The cut off ratio for all slabs in this group were constant as 100% except for the reference **Slab** (**AS-1**). The lap length of 450 mm (45 d_b) without headed bars represents the value approximately recommended by the Egyptian code ECP203-2007. A lap length of 150 mm (15 d_b) represents the value approximately recommended by the ACI 318-2014 for headed bar. Finally, a lap length 270 mm (27 d_b) was chosen according to Yassin [34] for deformed headed bar lap splice in reinforced concrete wide beams. No lap splice confinement (confinement of concrete around the tension spliced bars) was used for the slabs in this group. **Slab** (**AS-1**) with no splice was considered as a reference slab for all groups. Figure (3-5) shows the details of slabs in this group, while Table (3-6) gives the properties of the slabs.

3.4.2- Confinement in the lap splice zone; Group 2

In this group, two slabs were tested to study the effect of confinement in the lap splice zone. **Slab AS-5** was confined with two transverse embedded beams. The embedded beams consisted of two bar of 10mm diameter at both top, and bottom surfaces with closed stirrups of 6mm diameter, spaced at 50mm. **Slab AS-6** was confined with stirrup circular spiral around the spliced bars. The diameter of the spiral stirrup was 6 mm. The lap splices length, which was 15 times bar diameter (i.e., 150 mm), in this group. Figure (3-7) shows the detailing of slabs of this group. Table (3-7) gives the properties of the slabs of the group2.

3.4.3- Effect of debonding; Group 3

One slab was tested to study the effect of debonding on lap splice behavior and to evaluate the efficiently of the head .

Slab AS-4, the lap splices length (l_{dt}) was equal to 150 mm (about 15 times the splice bar diameter). The bond between concrete and steel bars in the splice zone was prevented by wraping an elastic tape around the bars in the lap zone. The objective was to study the behavior and to evaluate the efficiency of the head. Figure (3-6) shows the details of this group, while Table (3-8) gives the properties of the slabs in this group.

3.4.4- Effect of applying repeated gradually increased loading; Group 4

Two slabs with confinement in the spliced zone were tested to study the effect of applying repeated loading on slabs having head spliced bars. Slabs **AS-8** and **AS-9** were identical to slabs **AS-5** and **AS-6** except the application of repeated loads to **AS-8** and **AS-9**. Figure (3-7) shows the detailing of slabs in this group. Table (3-9) gives the properties of the slabs in this group.

3.5 Preparing of Tested slabs

3.5.1 Molding

Wooden molds were prepared casting. Each time, two slabs were casted in adjacent wooden molds except the specimen **AS-7** was casted only. Reinforcement bars were properly positioned in the forms using plastic chairs to obtain a 20 mm, and 60 mm clear concrete cover at the bottom and sides of the forms respectively. Figure (3-8) shows the photos of the specimens before casting.

3.5.2 Casting, de-molding, and curing

The concrete components were mixed for five minutes using a concrete mixer of 1/6 cubic meter capacity. Concrete was homogenous and the slump was kept constant of 100 mm. A hand vibrator was used to compact concrete. One day after casting, the curing of specimens and control cubes were kept for two weeks.

3.5.3 Quality Control Specimens

For each slab, three control cubes 150 x 150 x 150 mm were prepared using the same concrete mix, and were cured in the same conditions of the tested slabs.

3.6 Instrumentation

3.6.1 Loading Test Setup

The details of the test setup for the specimens are shown in Figure (3-9). The test frame was prepared in the Concrete Research Laboratory. The load was applied using a calibrated hydraulic jack of 200 kN capacity. The load was measured using a calibrated load cell. A strong spreader beam was used to transfer the vertical load to the tested slab through two concentrated loads 800 mm apart. As shown in Figure (3-9-b).

3.6.2 Displacement gauges

Four dial gauges of 0.01 mm accuracy were used to record deflection in the specimens **AS-1**, **AS-2**, **AS-3**, **AS-4**, and **AS-6**; two dials were placed at the center and edge of the mid span of the tested slabs. While two dials were placed under the position of the two concentrated loads as shown in figure (3-10-a).While five Linear Variable Displacement Transducers (LVDTs) with accuracy of 0.01 mm were used to record deflection in the specimens **AS-5**, **AS-7**, **AS-8**, and **AS-9** as shown in figure (3-10-b).

3.6.3 Strain gauges

For each slab, at least two electrical strain gauges of 10 mm length and 119.6 ± 0.4Ω gauge resistance were used to measure strains of the steel reinforcement bars. Figure (3-11) shows the distribution of strain gauges along longitudinal headed bars and the transverse stirrup used for confinement for slabs **AS-5**, **AS-6**, **AS-8**, and **AS-9**.

3.7 Test Procedure

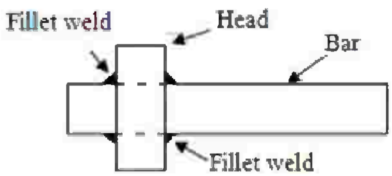
After the curing period, the specimen was moved from the form and placed centered and leveled on the test frame. The slab was painted with a white paint to facilitate the crack detection. The reinforcement layout within the lap zone was drawn on the surface of the specimen to facilitate the interpretation of the cracking behavior and for recording the position of cracks. Then, the electric strain gauges and the load cell were wired and connected to the strain indicator as shown in Figures (3-10-c) and (3-10-d). The dial gages or LVDTs were placed in about their positions. The load was applied in increments equal to 2.5 kN and at each increment deflection, and steel strain readings were recorded. The duration of each increment was about three minutes. The total duration of test was about 90 minutes. The dial gauges were removed just before failure occurred. Test was stopped as soon as crushing in the compressive zone appeared. However, failure of some slabs was brittle and sudden failure took place. In the case of the repeated loading were applied loading on the specimens gradually and divided to eight or nine of repeated loading when appear the failure in the compression zone.

Table (3-1): Properties of used steel

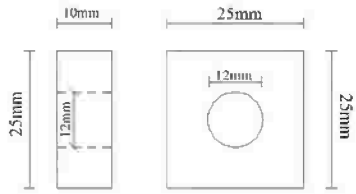
Bar diameter (mm)	Bar surface	Yield stress (f_y) (N/mm^2)	Tensile strength (f_u) (N/mm^2)	%age of Elongation	Equivalent grade
10	Deformed	435.86	697.56	18.33	400/600
8	Plain	330.42	460.72	23.41	280/450
6	plain	335.74	462.94	27.32	280/450

Table (3-2): Direct tension test results of the headed bars

Specimen	Failure load (kN)	Yield stress (f_y) (N/mm^2)	Tensile strength (f_u) (N/mm^2)	(f_u/ f_y)	Mode of failure
TR1	54.00	437.12	683.54	1.56	failure occurred in the bar near welding
TR2	53.50	436.21	677.22	1.55	failure occurred in the bar near welding
TR3	54.50	439.38	689.87	1.57	failure occurred in the bar near welding



Section elevation of the used connection specimens (TR1, TR2, and TR3)



Headed plate used in this study

Table (3-3): Concrete mix design (one cubic meter of concrete)

Component	Weight (kg/m^3)	% of mix (by weight)
Portland cement	400	1.0
Coarse aggregate	1040	2.6
Sand	640	1.6
Water	192	0.48

Table (3-4): Values of constant parameters in all specimens

Average concrete compressive cube strength	35 N/mm^2
Bar diameter (main reinf.)	10 mm
Clear concrete cover from bottom	20 mm
Clear concrete cover from both sides	60 mm
Relative head area (A_h / A_b)	6.91
Reinforcement percentage %	0.413%

Table (3-5): Details of tested slabs

Specimen	Average concrete compressive cube strength f_{cu} (N/mm^2)	$(L_o/d_b)^*$	Special reinforcement in the lap zone	Loading	Debonding of lap bars
AS-1	34.7	No splice	--------	Monotonic	Bonded
AS-2	36.7	45(without headed bars)	--------	Monotonic	Bonded
AS-3	37.0	15	--------	Monotonic	Bonded
AS-4	34.9	15	--------	Monotonic	Debonded
AS-5	35.9	15	2Embedded beams confinement	Monotonic	Bonded
AS-6	31.7	15	Spiral stirrup	Monotonic	Bonded
AS-7	42.1	27	--------	Monotonic	Bonded
AS-8	30.7	15	2Embedded beams confinement	Repeated loading	Bonded
AS-9	31.0	15	Spiral stirrup	Repeated loading	Bonded

* L_o: lap splice length, and d_b: bar diameter
Cut off ratio in all slabs-except AS-1 was 100%
Repeated loading was used to investigate effect the confinement in headed lap splices

Table (3-6): The properties of specimens of GROUP 1

Specimen	Average concrete compressive cube strength f_{cu} (N/mm^2)	$(L_o/d_b)^*$	Special reinforcement in the lap zone	Loading	Debonding of lap bars
AS-1 (reference)	34.7	No splice	-----	Monotonic	Bonded
AS-2	36.7	45(without headed bars)	-----	Monotonic	Bonded
AS-3	37.0	15	-----	Monotonic	Bonded
AS-7	42.1	27	-----	Monotonic	Bonded

* L_o: lap splice length, and d_b: bar diameter
Cut off ratio in all slabs-except AS-1 was 100%
Repeated loading was used to investigate effect the confinement in headed lap splices

Table (3-7): The properties of specimens of GROUP 2

Specimen	Average concrete compressive cube strength f_{cu} (N/mm^2)	$(L_o/d_b)^*$	Special reinforcement in the lap zone	Loading	Debonding of lap bars
AS-1 (reference)	34.7	No splice	-----	Monotonic	Bonded
AS-5	35.9	15	2Embedded beams confinement	Monotonic	Bonded
AS-6	31.7	15	Spiral stirrup	Monotonic	Bonded

* L_o: lap splice length, and d_b: bar diameter
Cut off ratio in all slabs-except AS-1 was 100%
Repeated loading was used to investigate effect the confinement in headed lap splices

Table (3-8): The properties of specimens of GROUP 3

Specimen	Average concrete compressive cube strength f_{cu} (N/mm^2)	$(L_o/d_b)^*$	Special reinforcement in the lap zone	Loading	Debonding of lap bars
AS-1 (reference)	34.7	No splice	--------	Monotonic	Bonded
AS-4	34.9	15	--------	Monotonic	Debonded

* L_o: lap splice length, and d_b: bar diameter
Cut off ratio in all slabs-except AS-1 was 100%
Repeated loading was used to investigate effect the confinement in headed lap splices

Table (3-9): The properties of specimens of GROUP 4

Specimen	Average concrete compressive cube strength f_{cu} (N/mm^2)	$(L_o/d_b)^*$	Special reinforcement in the lap zone	Loading	Debonding of lap bars
AS-1 (reference)	34.7	No splice	-----	Monotonic	Bonded
AS-8	30.7	15	2Embedded beams confinement	Repeated loading	Bonded
AS-9	31.0	15	Spiral stirrup	Repeated loading	Bonded

* L_o: lap splice length, and d_b: bar diameter
Cut off ratio in all slabs-except AS-1 was 100%
Repeated loading was used to investigate effect the confinement in headed lap splices

Figure (3-1-a): The head.

Figure (3-1-b): The bar.

Figure (3-1-c): The headed bar.

Figure (3-1): Shape of the manufactured headed bar after welding.

Figure (3-2): Test setup of direct tension for the headed bar.

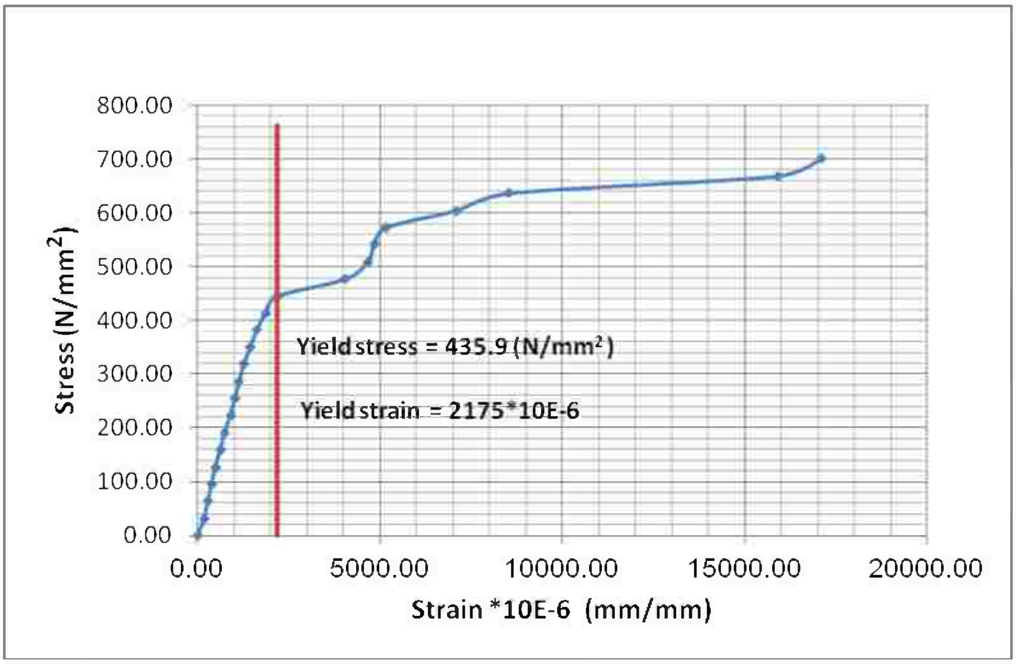
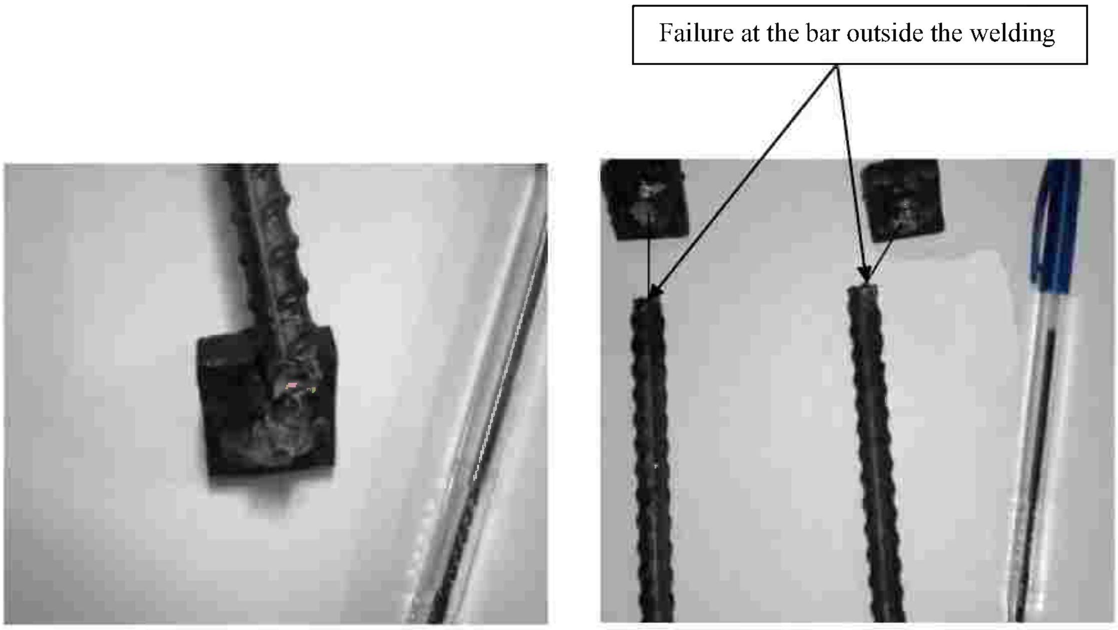


Figure (3-3): Relation between stress and strain for headed bars.

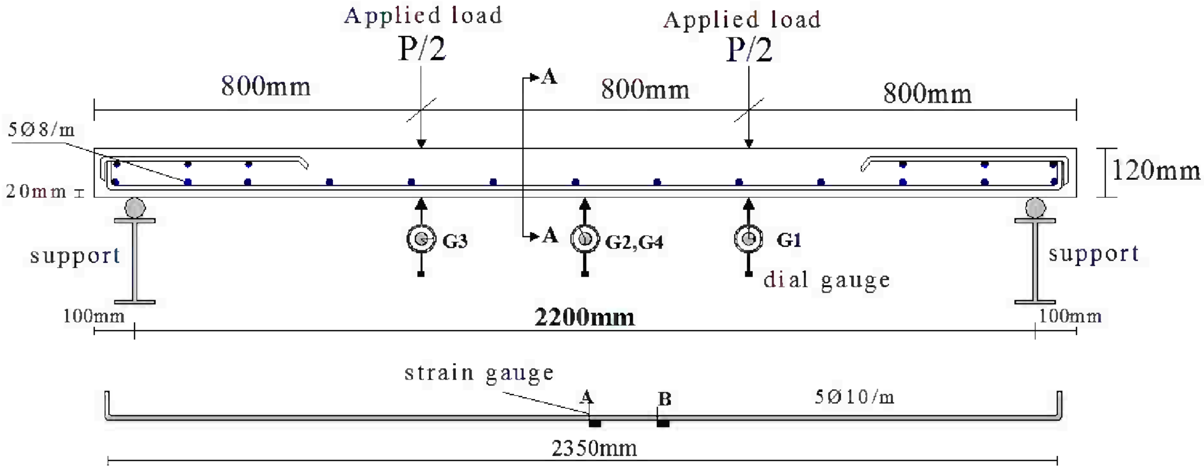
Figure (3-4-a): Shape of failure for specimen TR1 outside the welding.



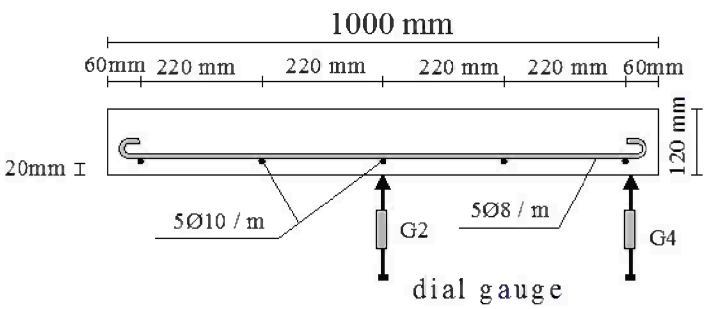
TR2 TR3

Figure (3-4-b): Shape of failure for specimen TR2 and TR3.

Figure (3-4): Shape of failure of specimens TR1, TR2 and TR3 direct tension test.



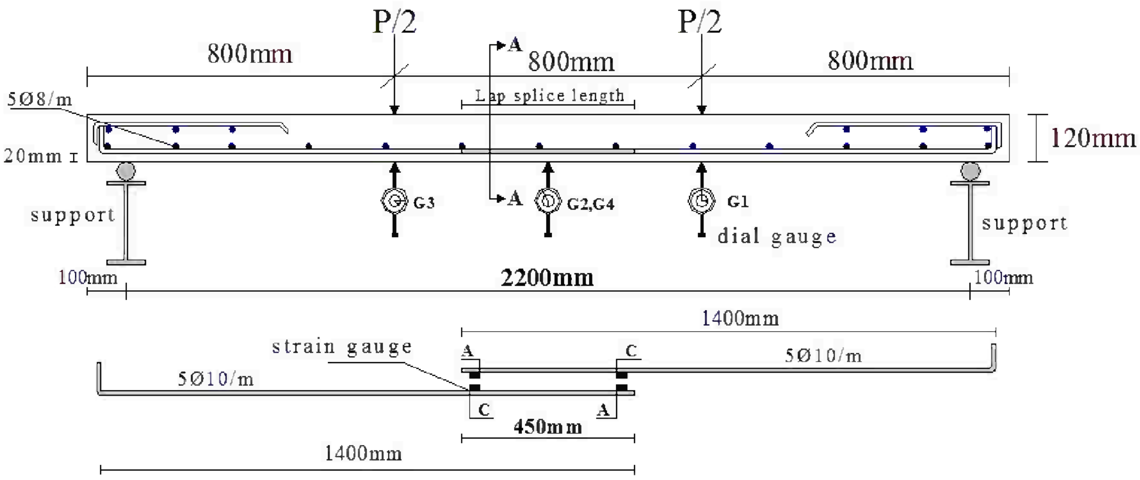
Detailing of reference slab (AS-1)



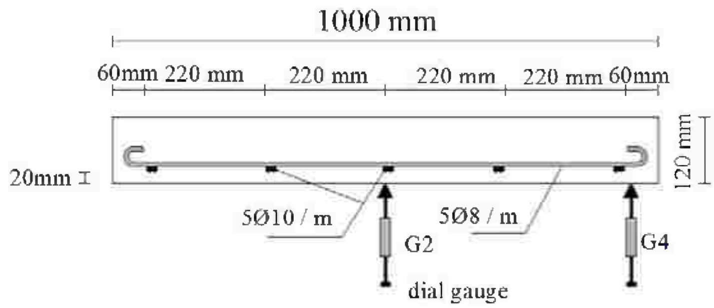
Cross section A-A of reference slab (AS-1)

Reinforcement of reference slab (AS-1) before casting

Figure (3-5-a): Reference slab (AS-1).



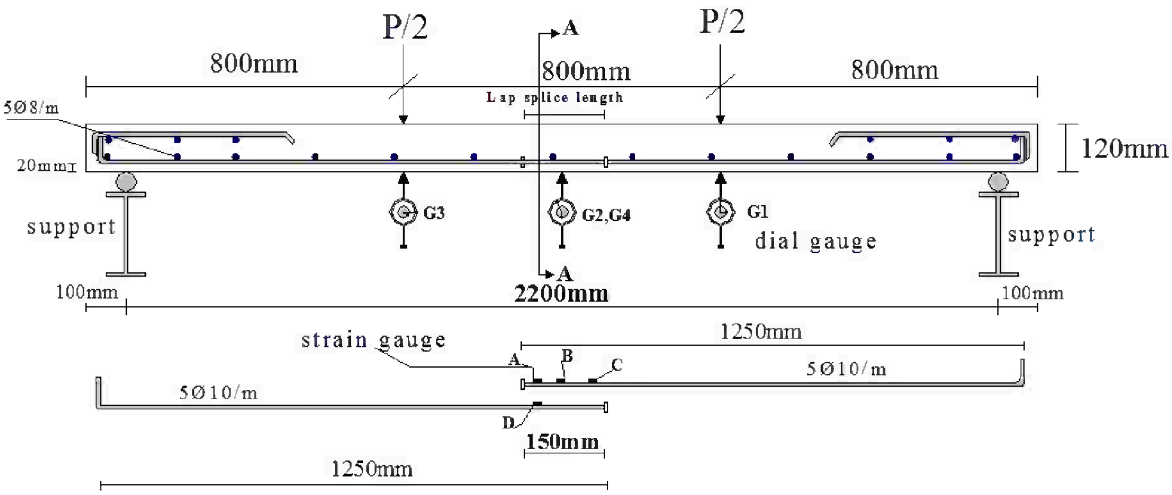
Detailing of slab (AS-2) with lap splice



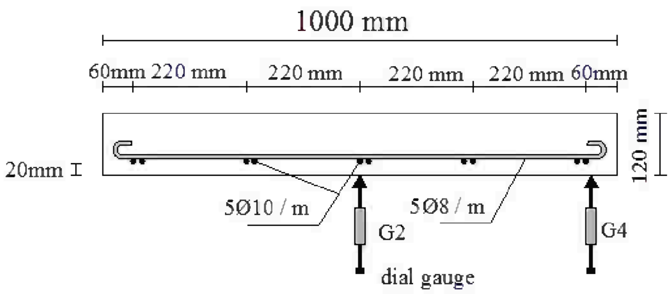
Cross section A-A of slab (AS-2)

Reinforcement of slab (AS-2) with lap splice

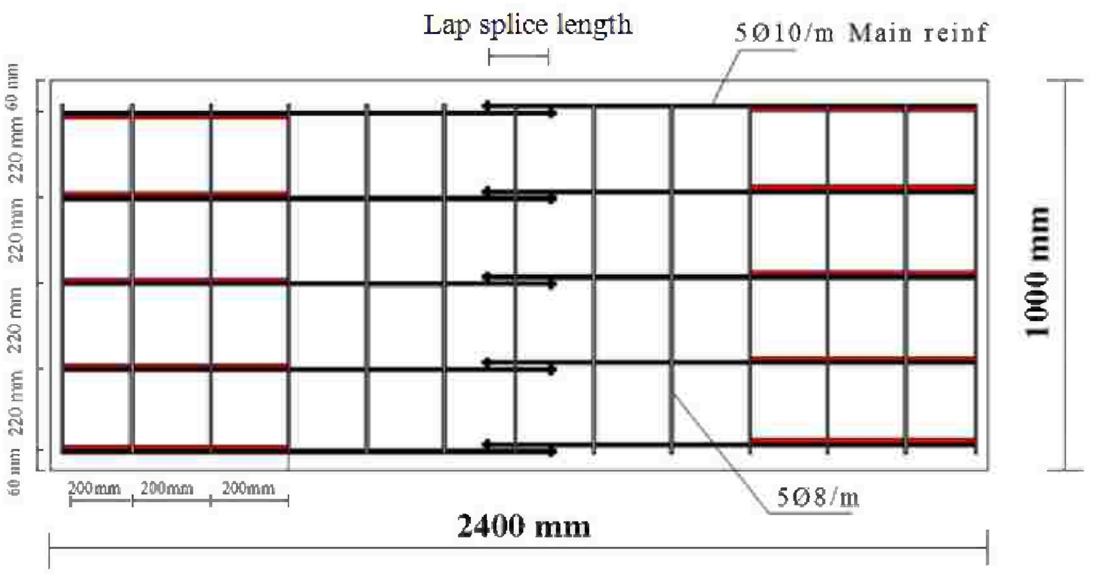
Figure (3-5-b): Slab (AS-2) with lap splice.



Detailing of slab (AS-3) with lap splice

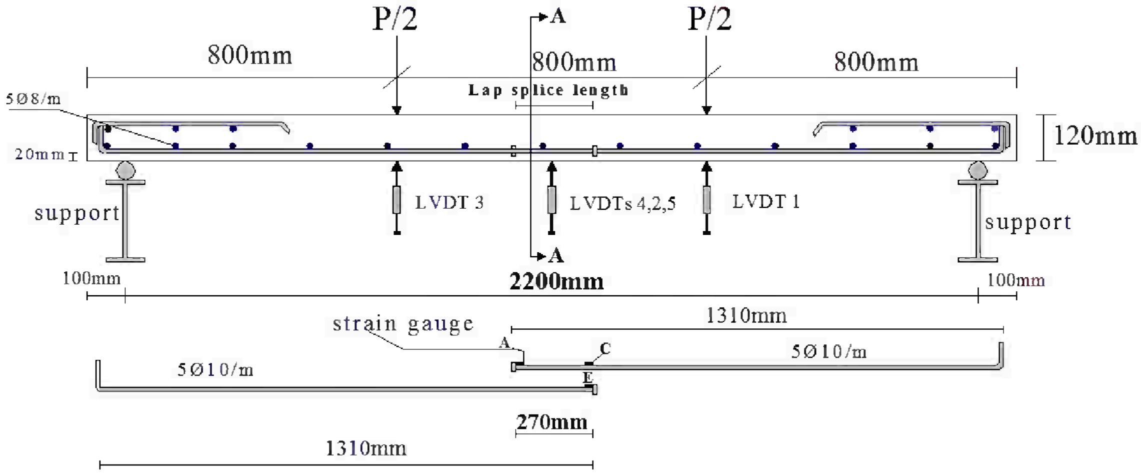


Cross section A-A of slab (AS-3)

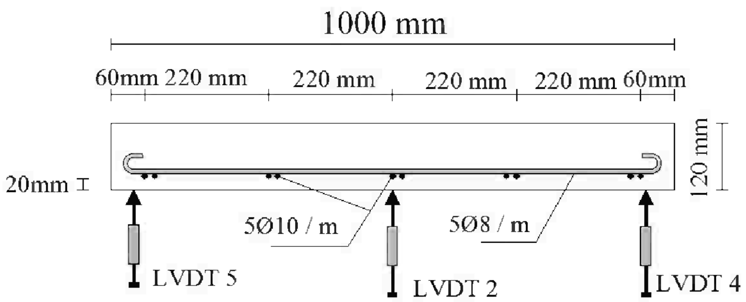


Reinforcement of slab (AS-3) with lap splice

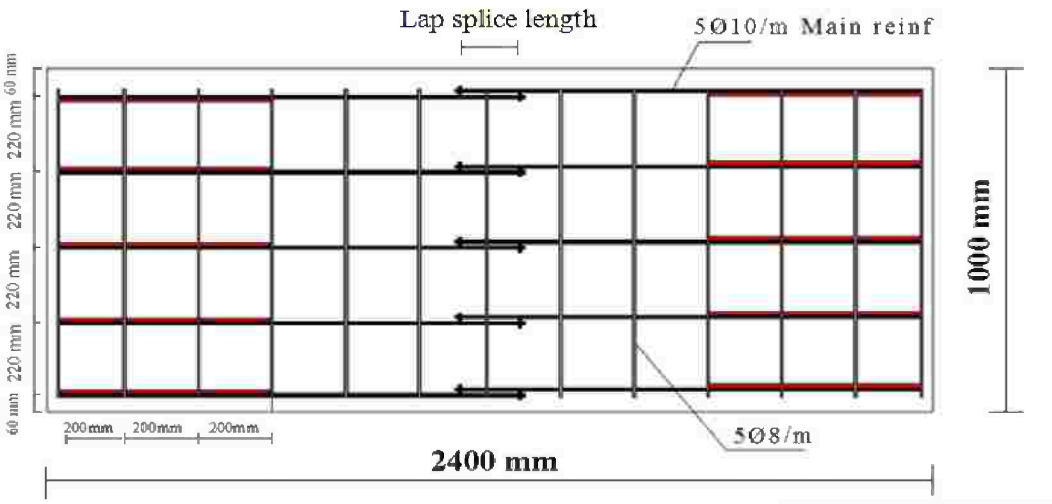
Figure (3-5-c): Slab (AS-3) with lap splice.



Detailing of slab (AS-7) with lap splice



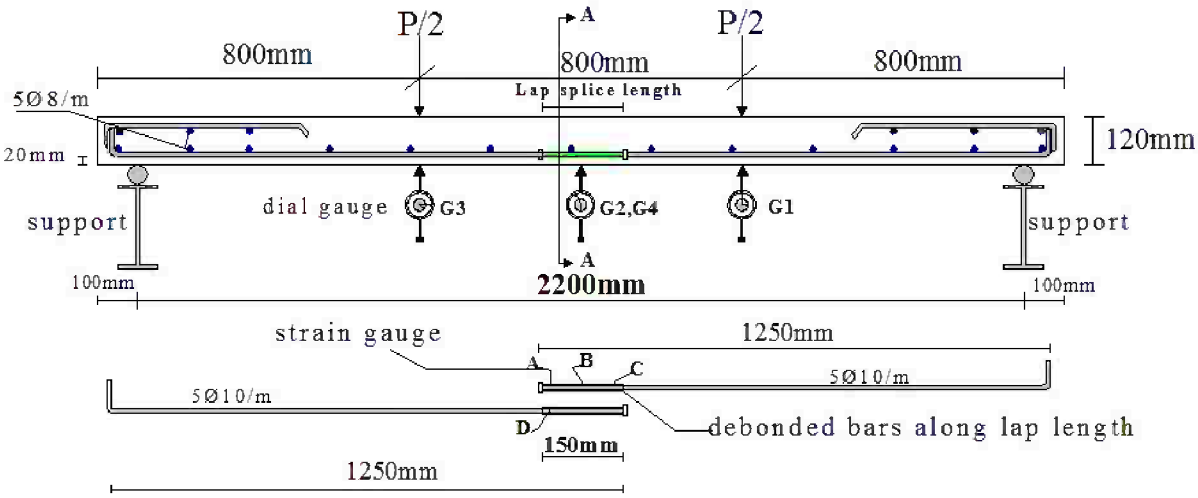
Cross section A-A of slab (AS-7)



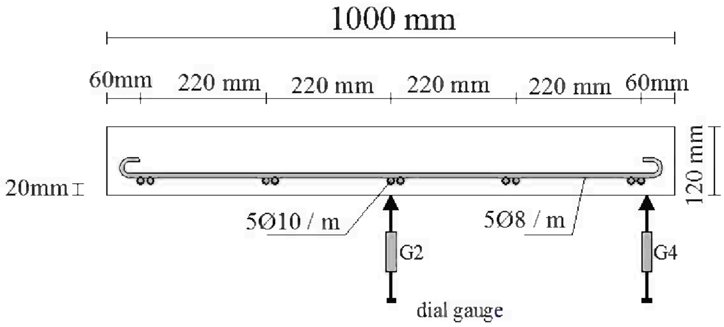
Reinforcement of slab (AS-7) with lap splice

Figure (3-5-d): Slab (AS-7) with lap splice.

Figure (3-5): Details of tested slabs of Group 1.



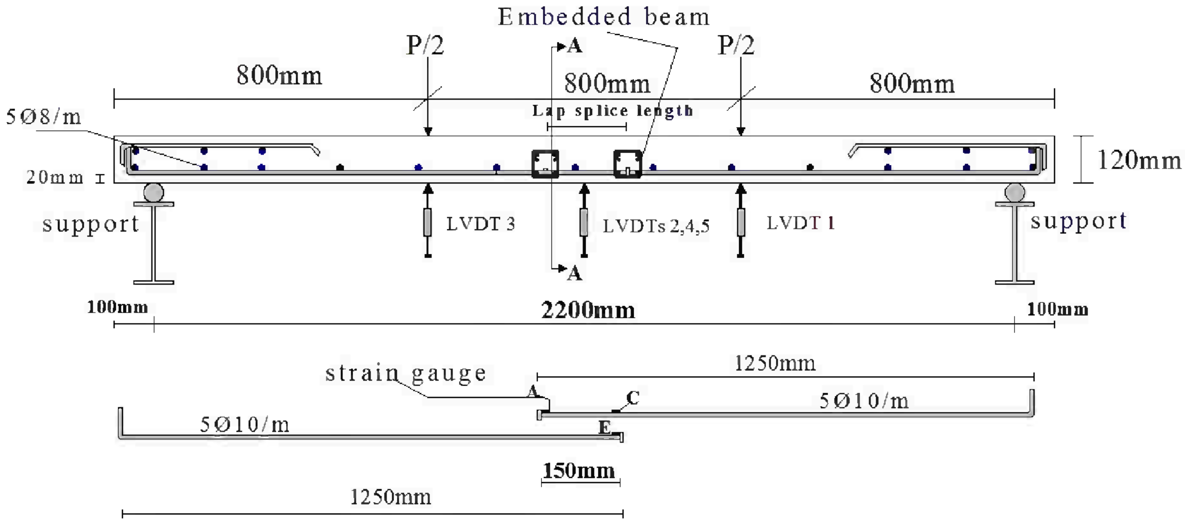
Detailing of slab (AS-4) with debonded lap splice



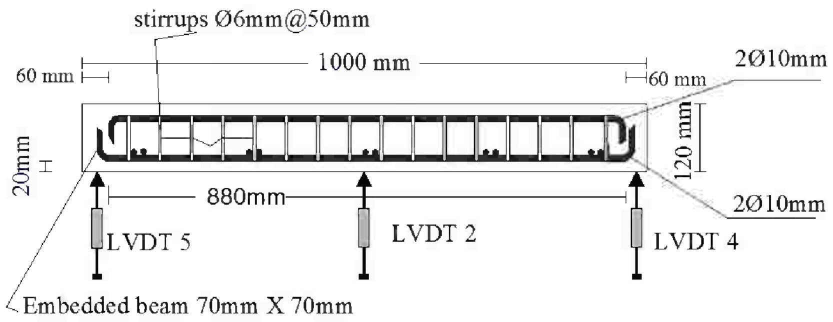
Cross section A-A of slab (AS-4)

Reinforcement of slab (AS-4)

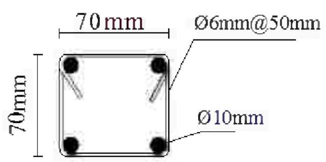
Figure (3-6): Details of tested slab (AS-4) with debonded lap splice of Group 3.



Detailing of slabs (AS-5) and (AS-8) with confinement lap splice



Cross section A-A of slabs (AS-5) and (AS-8)



Cross section of the used embedded beam

Figure (3-7-a): Slabs (AS-5) and (AS-8) with embedded beams at the both ends of the lap splice zones.

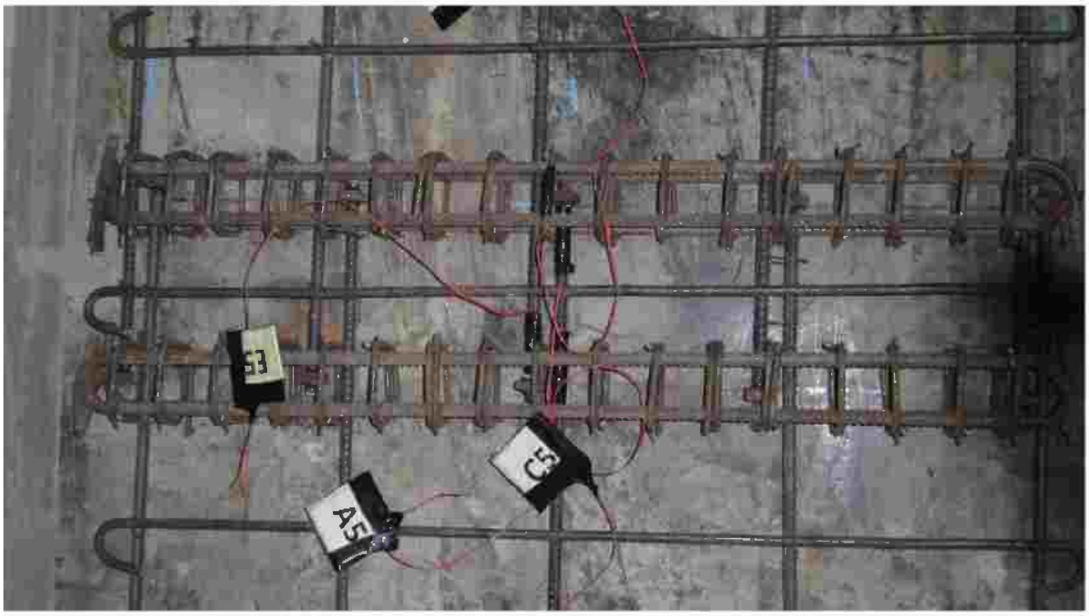
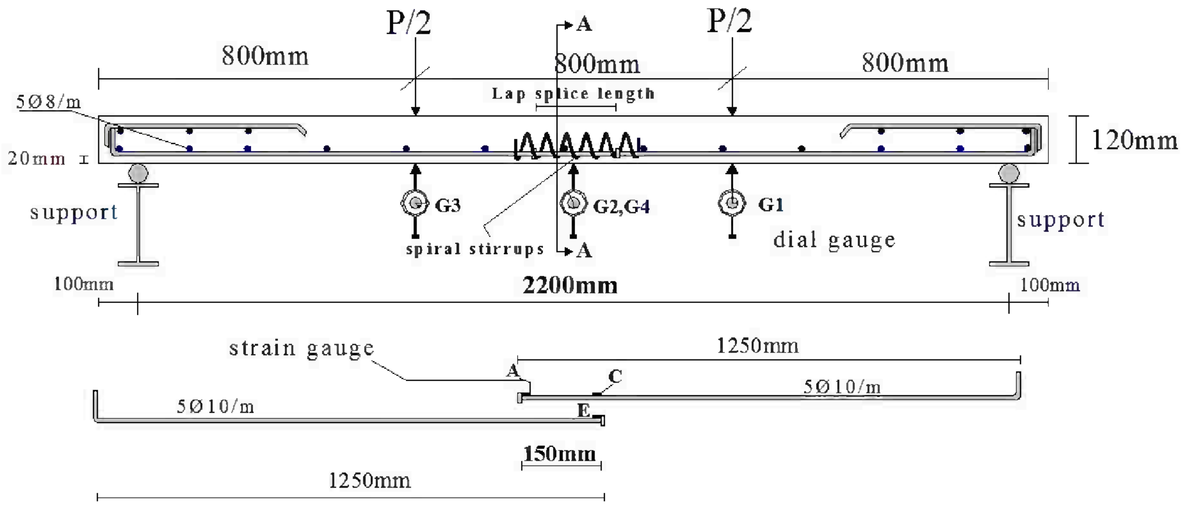


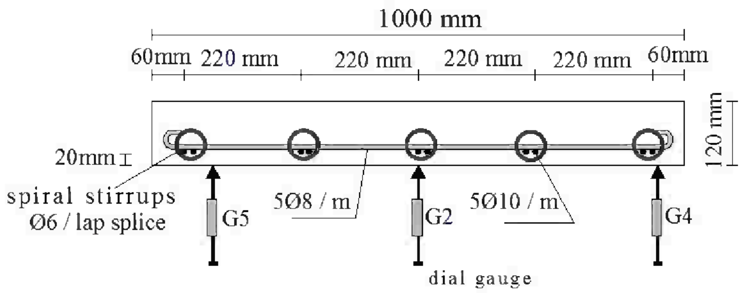
Photo of the lap splice confinement detail of slabs (AS-5) and (AS-8).

Reinforcement of slabs (AS-5) and (AS-8)

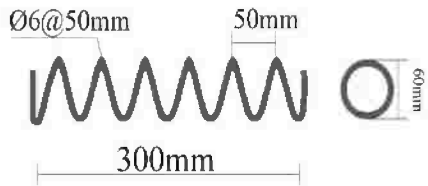
Figure (3-7-a): Slabs (AS-5) and (AS-8) with embedded beams at the both ends of the lap splice zones.



Detailing of slabs (AS-6) and (AS-9) with confinement lap splice



Cross section A-A of slabs (AS-6) and (AS-9)



Cross section of the used spiral stirrups around each splice bar

Figure (3-7-b): Slabs (AS-6) and (AS-9) with continuous spiral around each splice bar.

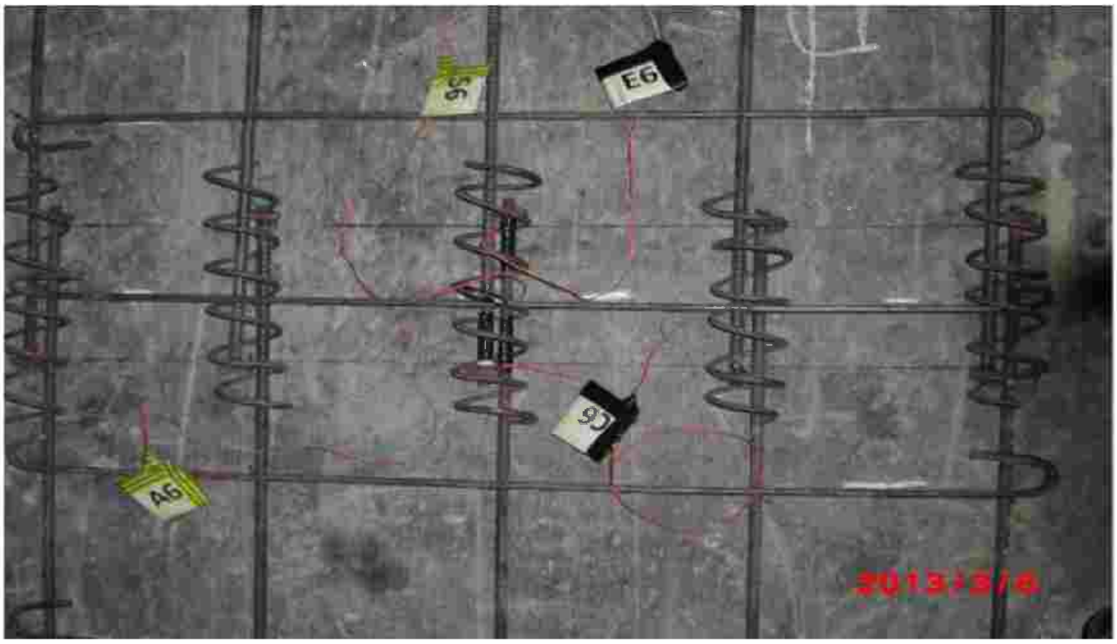
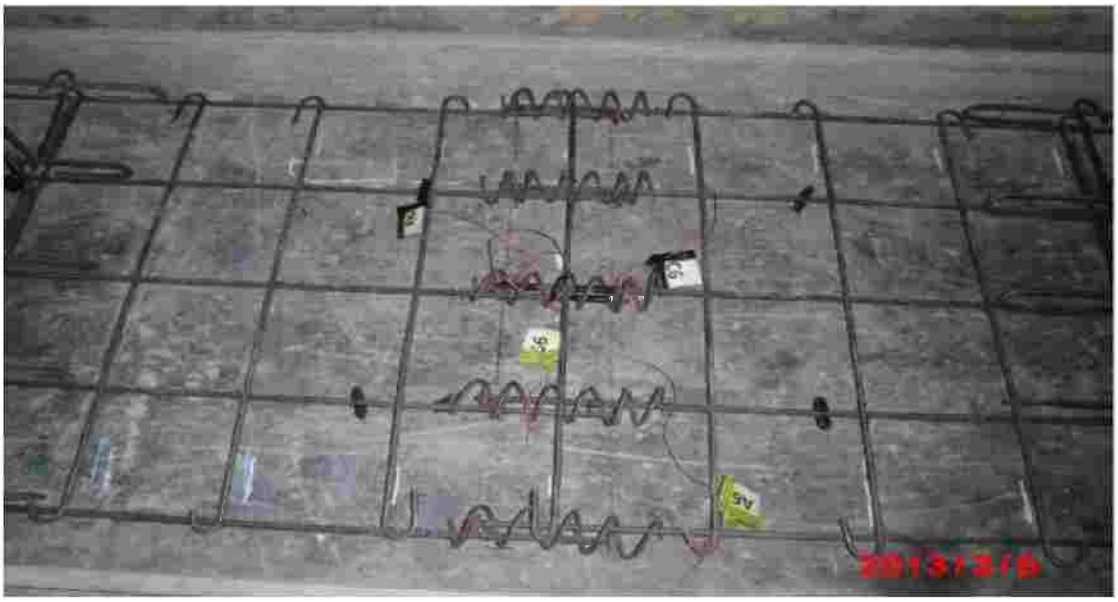


Photo of the lap splice confinement detail of slabs (AS-6) and (AS-9).



Reinforcement of slabs (AS-6) and (AS-9).

Figure (3-7-b): Slabs (AS-6) and (AS-9) with continuous spiral around each splice bar.

Figure (3-7): Details of tested slabs of Group 2 and Group 4.

Figure (3-8): Photo of the specimens before casting.

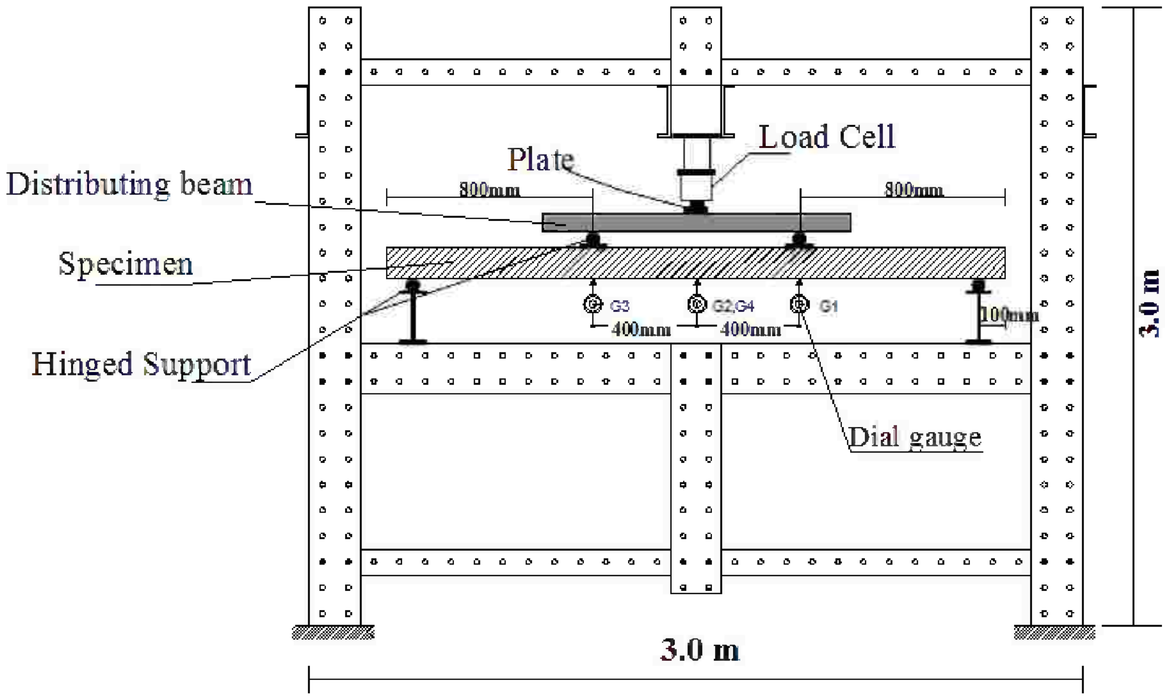


Figure (3-9-a): Test setup and Loading Rig.

Figure (3-9-b): Photo of tested specimen and setup before start of the loading.

Figure (3-9): Details of the test setup for the specimens.

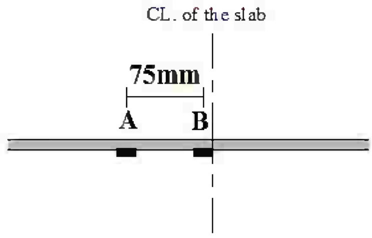
a -Dial gauges used for specimens; AS-1, AS-2, AS-3, AS-4 and AS-6.

b- LVDTs used for specimens; AS-5, AS-7, AS-8, and AS-9.

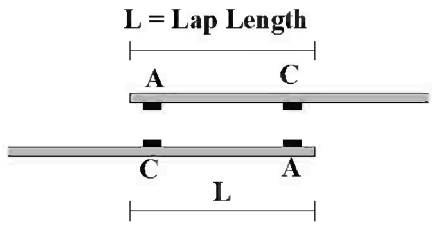
c -View of the strain indicator used for specimens; AS-1, AS-2, AS-3, AS-4, and AS-6.

d-View of the strain indicator used for specimens; AS-5, AS-7,AS-8,and AS-9.

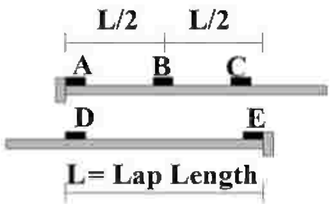
Figure (3-10): Instruments used of recording deflection and strains.



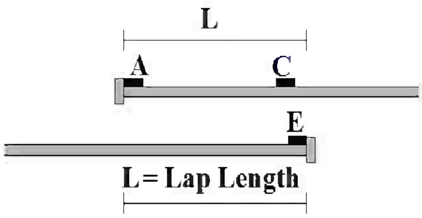
i. (AS-1).



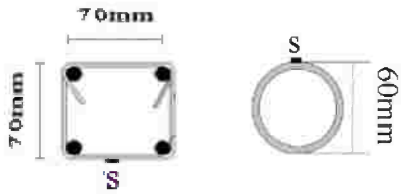
ii. (AS-2) bars without bar head.



iii. (AS-3) and (AS-4) bars with head.



iv. (AS-5), (AS-6), (AS-7), (AS-8) and (AS-9).



v. Stirrups of (AS-5), (AS-6), (AS-8) and (AS-9).

Figure (3-11-a): Distribution of strain gauges of tested slabs.

Figure (3-11-b): Position of strain gauges on the headed bars.

Figure (3-11-c): Position of strain gauges on the headed bars.

Figure (3-11-b): Placement of strain gauges on the headed bars.

Figure (3-11): Distribution of strain gauges along longitudinal headed bars.