

INVESTIGATION OF CRACKS IN SELF COMPACTING CONCRETE BY USING ULTRASONIC PULSE VELOCITY

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This paper describes the reliability of Ultrasonic Pulse Velocity (UPV) method in detecting horizontal cracks and flaws inside self compacting concrete (SCC) and also to know more about if ultrasonic pulse velocity effective for measuring horizontal cracks in SCC.

Thirty beams was prepared in order to study the results of this research, sixteen beams for crack examinations for indirect UPV method and eight beams for detecting compressive strengths of beams with horizontal construction joint by direct method of UPV and by fracture methods also. Horizontal cracks were simulated using lower acoustic impedance material (plastic sheet) inserted at a known distance while casting the specimens. Three mixes of SCC were designed in order to prepare a new calibration curves for ultrasonic pulse velocity for detecting the compressive strength of SCC with horizontal cracks.

Results indicated that horizontal cracks induced to SCC may be detected by UPV if the transducers were in limited distance depending on the position and direction of readings and also the position of the cracks. In addition, compressive strength of SCC with one and two horizontal cracks was detected and a new calibration curves were prepared for detecting compressive strength of SCC with horizontal cracks.

Results indicated that UPV is reliable for investigation the horizontal cracks and flaws of SCC in addition to the compressive strengths of the defected SCC which helps the investigators in repair works but with some limitations of the distances and positions of receiver and transmitter. Experimental results also indicated that taking care should be taken into consideration for construction joint erection of SCC where a reduction of compressive strength of SCC with a construction joints was reduced by (9-14%) whereas the reduction was about (10-17%) for cracked SCC.

KEYWORDS: *Self compacting concrete (SCC); ultrasonic pulse velocity; horizontal cracks; construction joint; multiple reflections.*

1. INTRODUCTION

One of the principal objectives of the development of NDT techniques is a reliable assessment of defects of concrete members even when they are accessible only from a single surface. Especially on reinforced concrete structures such inspections could in the past only be solved by means of radiography (for concrete thickness less than 0.6 m) or by using more or less destructive methods. When some of the established

methods used in other areas of materials testing are applied to concrete testing, certain difficulties are encountered as concrete is an inhomogeneous, porous building material. There are mainly three ways of non destructive testing using ultrasonic techniques viz. Impact echo method, Pulse echo method and Pulse velocity method [1].

Ultrasonic pulse velocity is used to determine the crack depths in concrete. The test instrument consists of a means of producing and introducing a pulse into the concrete (pulse generator and transmitter), a means of accurately measuring the time taken by the pulse to travel through the concrete. A pair of piezoelectric sensors is placed at opposite ends of the test member. In one of the sensors, electronic pulses are generated and the time it takes for the pulse to propagate through the concrete is measured by the other sensor. Knowing the distance traveled, propagation velocity is calculated and based on the velocity, condition of the concrete is determined. Depending on the locations of the sensors, the procedure is divided in to three categories: direct (sensors at opposite ends), indirect (sensors on the same sides), and semi-direct (sensors at right angles) transmission. Indirect measurement is used in this study to assess the crack location in concrete [2].

Ultrasonic testing can be used not only for concrete quality control but also for determining the presence of the cracks, in a very efficient and sufficiently accurate way, and for defining how deep they are [3, 4, 5].

Concrete structures as many other engineering structures are subjected to deterioration that affect their integrity, stability and safety. Faced with the importance of the damages method on the structures, the current choice is directed towards the repair of existing structures rather than towards the demolition construction of new ones. But before any repair work being done, it is common practice to determine the causes of the deterioration so that successful repair can not be done. Many repair works fail because the exact cause of the deterioration was not adequately identified. This identification process comprises many methods including non destructive testing methods. Non destructive testing is usually undertaken as part of the detailed investigation to complement the other method. Sometimes, the conclusions of the investigation are based on these tests [6]. First developed steel, it has not been easy to transfer the NDT technology to the inspection of concrete. Because of the characteristics of reinforced concrete, the nondestructive testing (NDT) of concrete is more complex than NDT of metallic materials [7]. In order for the NDT to better achieve its role in structural assessment there must have agreed standard and guidelines on how to do the survey in the field and interpret the data obtained [8]. Unfortunately until now the choice of the best fitted technique for a specific case is not simple. The relevance of the measurements process not guaranteed, and the question of how to cope with measurement results and how to finally assess the structure properties remains unanswered [9].

Various NDT methods have been developed and applied in engineering with different degrees of success [10, 11, 12, 13, and 14]. Over the years, Non Destructive Testing (NDT) methods based on seismic waves propagation have gained increased use and popularity. Current wave-based NDT methods such as ultrasonic pulse velocity, impact echo, and spectral analysis of surface waves (SASW) have been used for the in-situ evaluation of material properties. However, there are some limitations in each of these NDT methods when they are used individually. These limitations have not been fully studied and understood. For example, the ultrasonic pulse velocity

(UPV) method is one of the most commonly used wave-based methods in NDT. Yet, its potential for assessing the quality of materials is limited because of the different variables that affect the relationship between strength and velocity. This may be the reason why a poor correlation between the wave propagation parameters determined from the standard pulse velocity test method (ASTM C597) and the field rutting was reported by the FHWA, NCHRP Report 465 [15]. Improved techniques for processing the output signals such as the spectral analysis of attenuation are necessary to complement the strength-velocity data.

The main objective of this paper is to present preliminary results of an experimental program carried out to address the current deficiencies of the UPV method limitations for detecting cracks in both NC and SCC to improve the reliability.

2. EXPERIMENTAL PROGRAM

A total of twenty four concrete beams which represented 6 groups with dimensions 150x200x800 mm and 150x400x800 mm were cast with a certain procedure in order to simulate the horizontal cracks with limited positions. First group of beams was 6 beams (3 beams with 200 mm depth and 3 beams with 400 mm depth) with induced plastic sheet of dimensions 150x300 mm for the all groups in the mid-span with different positions from the reference top surface, (70mm, 100mm and 130mm) for beams with 200 mm depth and (100mm, 200mm and 300mm) for beams with 400 mm depth. The second group was 2 beams one of them was 200 mm height and the second was 400 mm height but the induced sheets were two layer in this group (70 mm and 13 mm) for beam with 200 mm height and (100mm and 300 mm) for beam with 200 mm height. Groups 3 and 4 were the same of groups 1 and 2 respectively but the sheets were induced in the edge of all beams. All four groups were examined for detecting crack depths by three procedures indicated as case 1, case 2 and case three.

- *Case 1:* the transmitter fixed at 50 mm from edge of the beam surface and receiver moved 50 mm intervals up to the end 700 mm from transmitter.
- *Case 2:* the transmitter and receiver were positioned at the mid span of the beam surface at a distance 100 mm then the two poles moved away to the edge direction with 100 mm intervals up to 700 mm.
- *Case 3:* the transmitter fixed at mid span of the beam surface and the receiver moved to the edge towards the induced crack with 50 mm intervals up 350 mm.

Group 5 and 6 represented eight beams of dimensions 150x400x800 mm were prepared for detecting compressive strengths by direct method of UPV of both induced cracked beams with plastic sheet and also beams with the construction joint which had a time period 1 day between each separation. In order to estimate the fracture compressive strengths of these groups, beams of were cut by introducing a cut perpendicular to the axis of the beam using a diamond tipped concrete cutter to prepare eight prisms of cross section 150x400 mm and 150 mm breadth included one or two layers. In addition 2 prisms (one and two layers) from beams of designed compressive strength 400 kg/cm² from groups (1-4) were prepared.

Group 5 included four beams represented the induced cracked beams with designed compressive strengths 300 and 500 kg/cm² (chosen in addition to the beams

with 400 kg/cm^2 in groups (1-4) were induced with one and two plastic layers of breadth 150 mm and 300 mm length.

In addition, group 6 was as the same of group 5 but with a horizontal construction joint along the length of the beams instead of the plastic sheets in order to simulate the nature of separation of SCC if it cast in multi layers. All eight beams of groups (5-6) in addition to four beams from groups (1-4) with induced crack depths were examined by UPV device in order to estimate the compressive strengths by UPV device. The results of the compressive strengths of the sixteen samples induced by horizontal cracks gave unrealistic values of compressive strengths so it is very vital and important to estimate the actual compressive strengths of the cracked beams (with induced plastic sheets). Three mixes of SCC were designed as 300, 400 and 500 kg/cm^2 in order to examine different qualities of SCC. Direct method was carried out for each mix for different cross section dimensions 150x200, 150x300 and 150x400 mm. That is mean nine specimens with cross section dimensions 150x300 of three mixes were prepared for each of three types (control, one crack at 100 mm depth and two cracks with two depths 100 mm and 200 mm). Another nine beams as the same was prepared but with a natural crack as a construction joint while the age between each separation was 24 hours.

The following parameters were studied according to its tests as follows:

- 1) Depth of horizontal cracks (70, 100 and 130 mm) for beams with 200 depth and (100, 200 and 300 mm) for beams with 400 mm depth.
- 2) Position of horizontal cracks(edge and middle)
- 3) Number of horizontal cracks (one and two)
- 4) Position of ultrasonic pulse velocity transducers (case 1, case 2 and case 3)
- 5) Concrete compressive strength (300, 400 and 500 kg/cm^2)

3. MATERIALS

Normal Portland cement was used (specific gravities: 3.15). The fine aggregate was river sand (specific gravity: 2.61, water absorption: 1.61%, FM: 2.51). The coarse aggregate had a maximum size of 19 mm. Gravel batches employed were clean, free from impurity matter. The main properties of gravel were measured according to Egyptian standard specifications (ESS 1109-1971). The specific gravity of silica fume and lime stone powder were 2.15 and 2.68 respectively and its chemical proportions was shown in Table (1). F type of high range water reducers (HRWR) superplasticizers based on polycarbocylate was used according to ASTM C494. The type of segregation reducing agent or viscosity enhancement admixture VEA was used by weight of cement.

4. EXPERIMENTAL PROCEDURE

The slump tests were carried out according to BS (1881): PART 102: 1983. All destructive tests were carried out on 150x150x150 mm cubes and according to the British Standard BS 1881: Parts, 2 and 116:1983. Non destructive testing were carried out according to BS 1881: Part 205: 1986. Also, all tested specimens were completely dried before both destructive and non destructive testing. The scheme of the experimental work and the number of samples were illustrated in Tables (2 and 3).

Table (1) Chemical compositions of SF and LSP

Powder type	Percentage of SF and LSP chemical structure														
	SiO ₂	C	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	R ₂ O ₃	K ₂ O	SO ₃	Cl	LOI	TiO ₂	CaCO ₃	MgCO ₃
Silica fume SF	96.0	0.6	0.25	0.6	0.3	0.6	0.2	-	0.65	0.18	0.02	0.6	-	-	-
Lime stone LSP	7	-	2.53	1	48.8	1.15	0.5	-	-	0.19	-	38.9	-	-	-

5. DISCUSSION OF RESULTS

Actually, the importance and vital results are shown in figures 1 to 14. the portions for mixes used in this research results are shown in Table (4). Moreover, value of the results for both destructive and non destructive testing after 28 days for SCC are illustrated in Tables (5 and 6). On the other hands, fresh concrete tests were carried out for all mixes used according to ASTM C1611.

5.1 Detecting Of Horizontal Cracks by UPV (Case 1)

Figure (1) to Fig.(4) reported the experimental results of the crack depths detected by ultrasonic pulse velocity for SCC beams with induced definite horizontal cracks by inserting a thin plastic sheet at the edge of the beams or at mid-span at different height of the beams depth. This case (Case 1) was set up where the receiver was fixed far from the edge of the beam by 50 mm and the receiver was movable with 50 mm intervals up to the end of the beam (far from edge by 50 mm). Equation (1) used to investigate the crack depth

$$Y=0.5(V^2T^2-X^2)^{0.5} \tag{1}$$

Where:

X= distance between transmitter and receiver

Y= depth of horizontal crack

V= velocity of the compression wave through the concrete

T= transit time

5.1.1 Case 1: beams with cross section 150x200 mm

Figures (1 and 2) represented the relations between the crack depths induced to edge or to the center of the beams (B1-B8) and its corresponding span between transducer and receiver of UPV device.

Induced crack depth to center (Cross sec. 150x200 mm)

Figure (1) represented the crack depths of the beams B1-B4 with induced crack depth at the center of beams with 150x200 mm cross section. Crack depth of B1 can be

detected if the distance between the fixed transducer and receiver between (300-350 mm) i.e. approximately at mid span where the position of the crack depth was 70 (66-72 mm recorded). For B2 which a crack depth of 100 mm induced recorded a crack depth of (91-105 mm) where the distance were (300-400 mm). B3 with a crack depth of 130 mm recorded a crack depth of 126 mm if the distance was 350 mm. Increasing the distance more than 350 mm, unrealistic crack depths were recorded. This may be due to multi-reflections of the pulses from transducer to the receiver due to the long span. On the other hands, B4 with with two cracks was difficult to record the crack depths because the short distance between the 2 cracks (60 mm) may lead to a multi reflections and hence, crack depth was difficult to be detected.

Table (2) Scheme of the experimental procedure of UPV indirect test

Total of 16 SCC beams with induced cracks prepared for indirect test of UPV (design compressive strength=400 (Kg/cm ²))	8 Beams have 150x200 mm cross section	2 beams with induced crack at 70 mm height	Middle crack	B1
			Edged crack	B2
		2 beams with induced crack at 100 mm height	Middle crack	B3
			Edged crack	B4
		2 beams with induced crack at 130 mm height	Middle crack	B5
			Edged crack	B6
		2 beams with induced 2 cracks at 70 and 130 mm height	Middle crack	B7
			Edged crack	B8
	8 Beams have 150x400 mm cross section	2 beams with induced crack at 100 mm height	Middle crack	B9
			Edged crack	B10
		2 beams with induced crack at 200 mm height	Middle crack	B11
			Edged crack	B12
		2 beams with induced crack at 300 mm height	Middle crack	B13
			Edged crack	B14
		2 beams with induced 2 cracks at 100 and 300 mm height	Middle crack	B15
			Edged crack	B16
1 beam	150x200 mm	Control	B17	
1 beam	150x400 mm	Control	B18	
Total=18 beams*				

*Each beam was tested by UPV indirect method by 3 methods (case 1, case 2 and case 3)

Table (3) Scheme of the experimental procedure of UPV indirect test

Designed compressive strength (Kg/cm ²)	Case of induced horizontal crack		Case of construction joint		control
	One crack at mid-height	Two cracks	One crack at mid-height	Two cracks	
300	B19	B20	B21	B22	B23
400	B11*	B15*	B24	B25	B18*
500	B26	B27	B28	B29	B30

*Beams taken from UPV indirect test (3 beams)
Beams required for direct test = 12 Beams

Table (4) SCC components by weight for one cubic meter

Mix	F _{des}	OPC (Kg.)	Sand (Kg.)	Gravel (Kg.)	LSP (Kg.)	SF (Kg.)	HRWRA(Kg.)	VEA (Kg.)	W/C	F _{cu}
M1	300	350	1108	739	52.5	35	7	0.35	0.33	304
M2	400	400	1064	709	60	40	8	0.40	0.3	405
M3	500	500	962	642	75	50	10	0.50	0.27	506

F_{des}=Designed compressive strength
 OPC=Ordinary Portland Cement
 C/F=Coarse to Fine aggregate
 LSP=Lime stone powder
 SF=Silica Fume
 HRWRA=High Range Water Reducer Admixture
 VEA= Viscosity Enhancement Admixture
 W/C=Water to Cementitious ratio
 F_{cu}=Fracure compressive strength at 28 days age

Table (5) Results of compressive strengths of horizontal cracked SCC beams.

Fracture strength, F _{cu} (kg/cm ²)			F _{cu} cracked/F _{cu} control (%)	
Control	One crack	Two cracks	One crack	Two cracks
304	287	254	94.4	83.6
404.7	353	316	87.2	78.1
506	448	439	88.5	86.8
Average (F _{cu} cracked)/(F _{cu} control) (%)			90.0	82.8

Table (6) Results of compressive strengths of SCC beams with construction joints

Fracture strength, F_{cu} (kg/cm^2)			F_{cu} cracked/ F_{cu} control (%)	
Control	One crack	Two cracks	One crack	Two cracks
304	285	260	93.8	85.5
404.7	360.7	339	89.1	83.8
506	457.3	448.7	90.4	88.7
Average (F_{cu} cracked)/(F_{cu} control) (%)			91.1	86

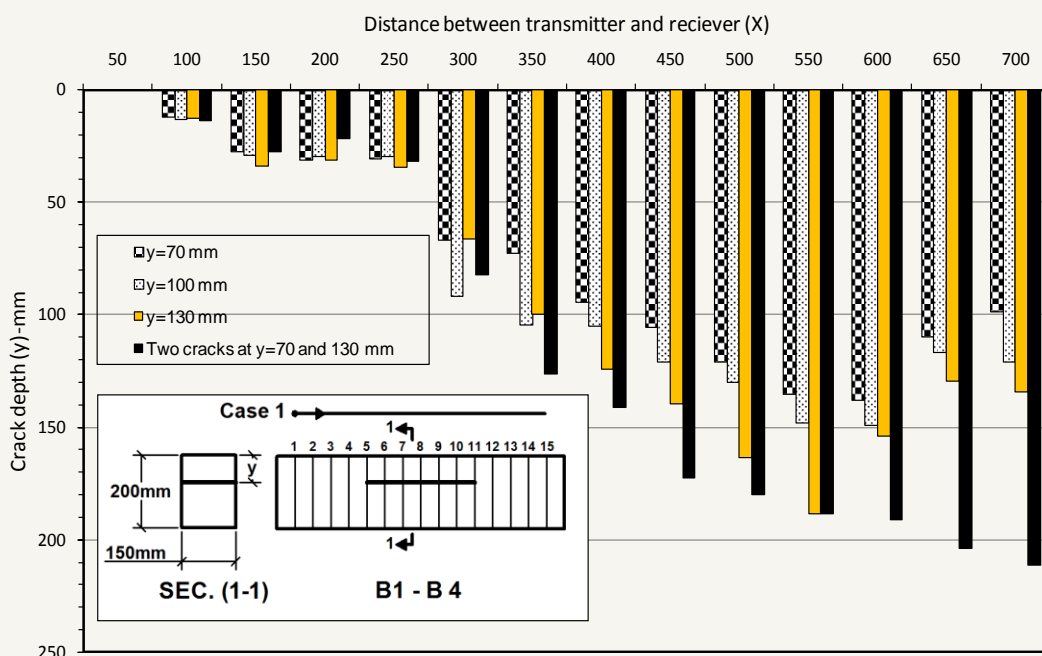


Fig. (1) Crack depth of Case 1-induced crack to center (C.S. 150x200 mm)

Induced crack depth to edge (Cross sec. 150x200 mm)

Figure (2) showed the crack depths of the beams B5-B8 with a 200 mm depth but the cracks were induced at the edge of the beams. Crack depth of B5, with induced crack depth 70 mm, may be detected if the distance was (150-200 mm) where the recorded cracks were in between (65-69 mm). B6 with induced crack depth of 100 mm also gave a crack depth of (91-92 mm) if the distances were in between (150-200 mm). B7 with an induced crack depth of 130 mm can be detected as a crack depth of 108 mm for a distance of 100 mm. Figure showed also that UPV cannot detect the crack depths of beams have two cracks (B8) where it can detect only the top crack (69 mm) when the distance was 150 mm. If the distance between the transducer and receiver were more than (100-200 mm), unrealistic crack depths were detected as shown in Fig. (2). This may due to the multi reflection of the pulsed due to the long span.

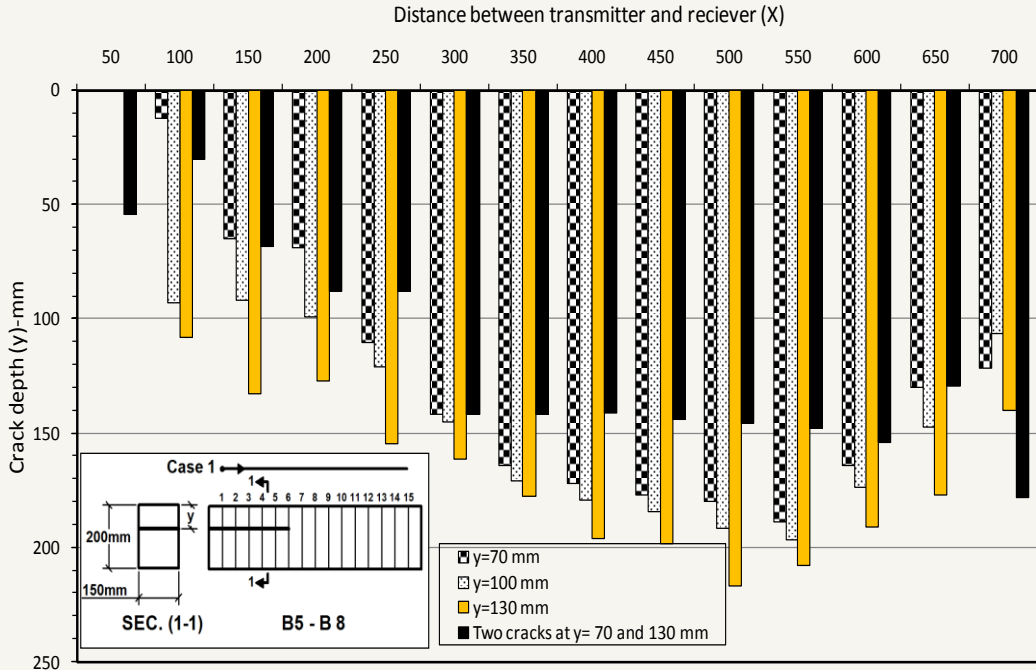


Fig. (2) Crack depth of Case 1-induced crack to edge (C.S. 150x200 mm)

5.1.2 Case 1: beams with cross section 150x400 mm

Figures (3 and 4) illustrated the crack depths of the beams B9-B16 with a cross section of 150x400 mm and cracks were induced to the center or to the edge of the beams with different induced crack depths 100, 200 and 300 mm as one crack in addition to two cracks with a depths of 100 mm and 300 mm from top to surface of beams.

Induced crack depth to center (Cross sec. 150x400 mm)

Figure (3) exhibited the detected crack depths for B9 with a crack depth of 100 mm. results showed that the crack depth may be detected if the distances between the transducer and receiver were in between (400-500 mm) with a detected crack depths between (94-110 mm). B10 with an induced crack depth of 200 mm can be detected only if the distances were (450-550 mm) which gave crack depths of (195-200 mm). B11 with induced crack depth of 300 mm can be also detected as (296-306 mm) if the distances were (450-500). B12 with induced two cracks can be detected only by the top crack depth which receive the pulse before the deeper crack hence top crack only may be detected if the distances were (400-450mm) which detected the crack depth of (100-104 mm).

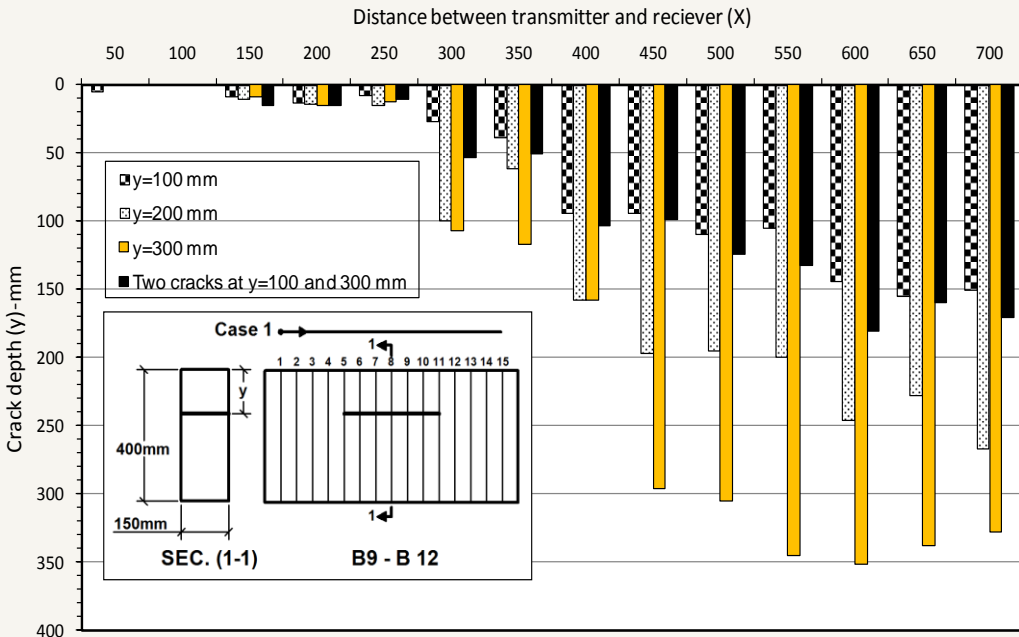


Fig. (3) Crack depth of Case 1-induced crack to center (C.S. 150x400 mm)

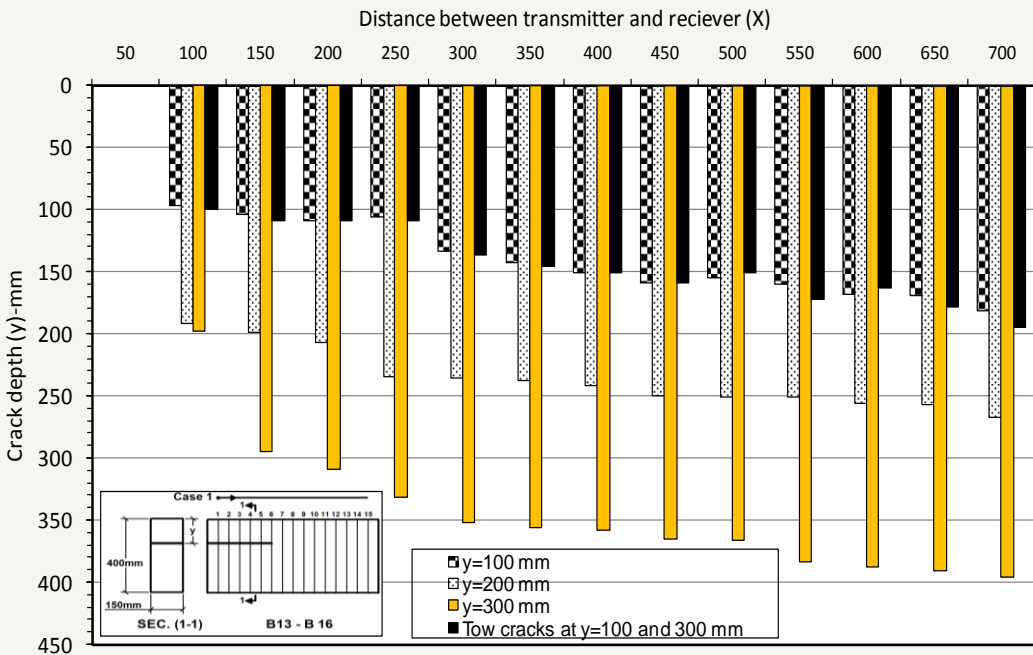


Fig. (4) Crack depth of Case 1-induced crack to edge (C.S. 150x200 mm)

Induced crack depth to edge (Cross sec. 150x400 mm)

Figure (4) reported the results of the crack depths induced to the edge of the beams (B13-B16). Figure indicated that B13 with an induced crack depth of 100 mm can be

detected if the distance were (100-250 mm) where the detected cracks were (97-109 mm). B14 with induced crack depth of 200 mm indicated crack depths of (198-207 mm) if the distanced were (100-200 mm). Induced crack depth of 300 mm in B15 can be detected if the distances were (150-200 mm) which indicated a crack depth of (295-309 mm). on the other hands, B16 with an induced 2 crack depths cannot be detected because the top crack only receive the pulses and hence the cracks detected were (100-109 mm) if the range of the distance were (100-250) as B13 with one top induced crack depth.

5.2 Detecting Of Horizontal Cracks by UPV (Case 2)

Figures (5 to 8) exhibited the experimental results of the crack depths detected by ultrasonic pulse velocity for SCC beams with induced definite horizontal cracks by inserting a thin plastic sheet in the edge of the beams or at mid-span at different height of the beams depth. Case 2 of UPV device was setup as the transducer and receiver were centered at a distance of 100 mm (each pole far from 50 mm from the center) and moved together towards the edge at intervals 100 mm up to a distance of 700 mm.

5.2.1 Case 2: beams with cross section 150x200 mm

Figures (5 and 6) represented the results of the detected crack depths with the distance between the transducer and the receiver for the beams B1-B8 with the cross section 150x200 mm.

Induced crack depth to center (Cross sec. 150x200 mm)

Figure (5) illustrated the crack depths of beams with induced cracks in the center of the beams. B1 with 70 mm induced crack depth can be detected if the distances were (100-200 mm) with a detected crack depth of (69-75 mm). B2 with induced crack depth of 100 mm can also be indicated if the distances were (100-200 mm) with a detected crack depth of 92 mm. B3 with induced crack depth of 130 mm was detected if the distances were (100-200 mm) with a detected crack depth of 124 mm. on the other hands, B4 with 2 cracks layers cannot be detected because of the small cross section with a short distances between the two cracks (6 mm).

Induced crack depth to edge (Cross sec. 150x200 mm)

Figure (6) illustrated the detected crack depth by UPV of beams with induced crack at edge of beams which can be detected where B5 with induced crack depth of 70 mm can be detected if the distance were 100 mm which gave a detected crack depth of 73 mm. B6 with induced crack depth of 100 mm represented a detected crack depth of (94-99) if the distances were (100-200 mm). B7 with 130 mm induced crack depth can be detected if the distances were (100-200 mm) with a detected crack depth of (129-133 mm). On the other hand, crack depths cannot be detected if the beams B8 contains two cracks that is may be due to the small cross section with a small depth between the two cracks (6 mm).

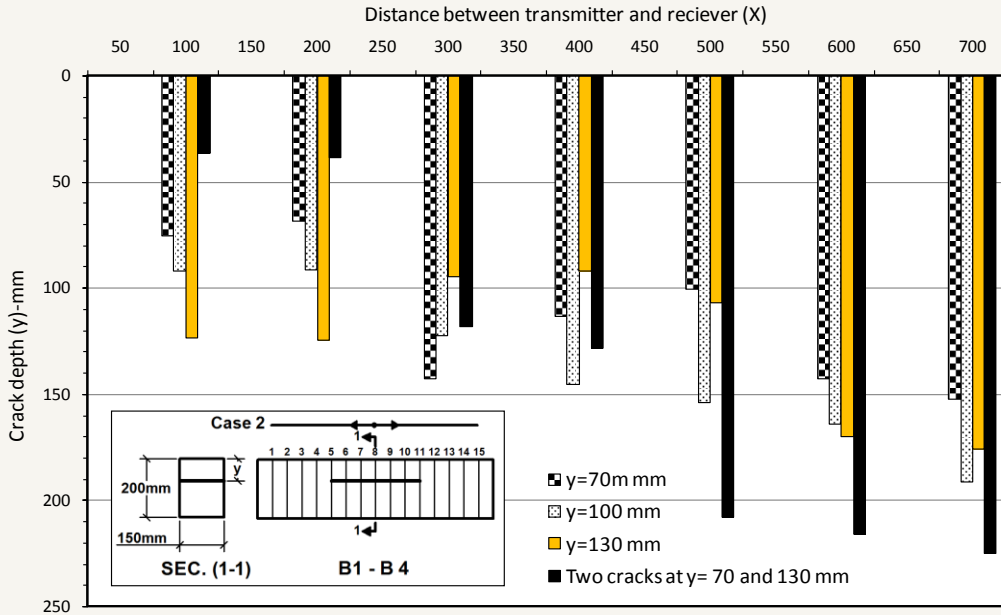


Fig. (5) Crack depth of Case 2-induced crack to center (C.S. 150x200 mm)

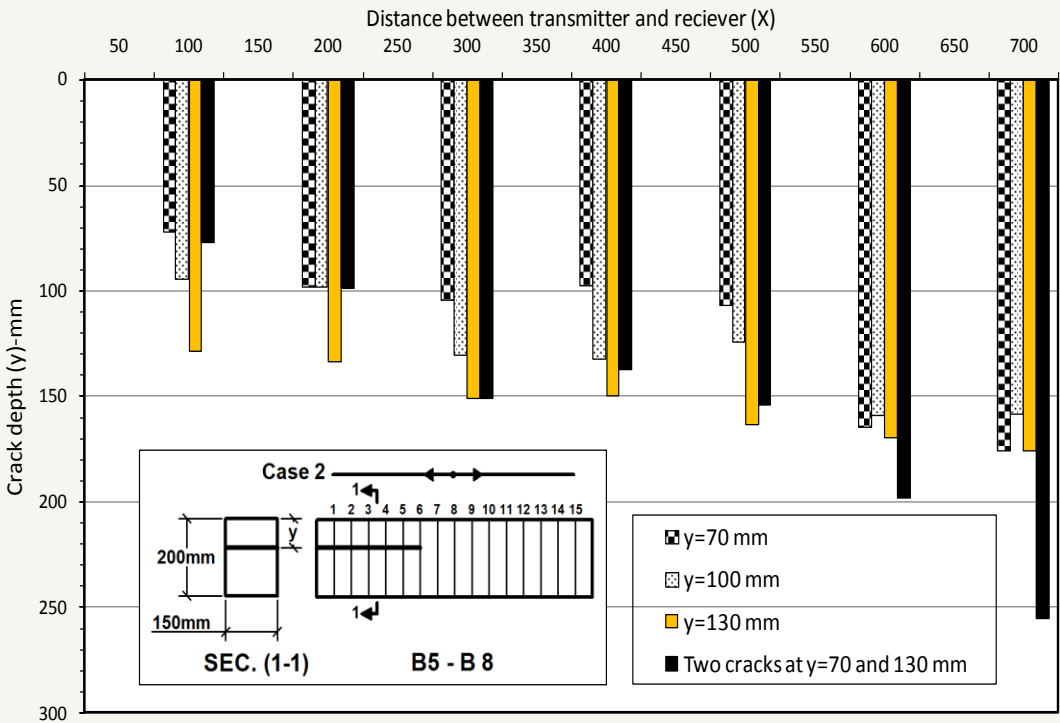


Fig. (6) Crack depth of Case 2-induced crack to edge (C.S. 150x200 mm)

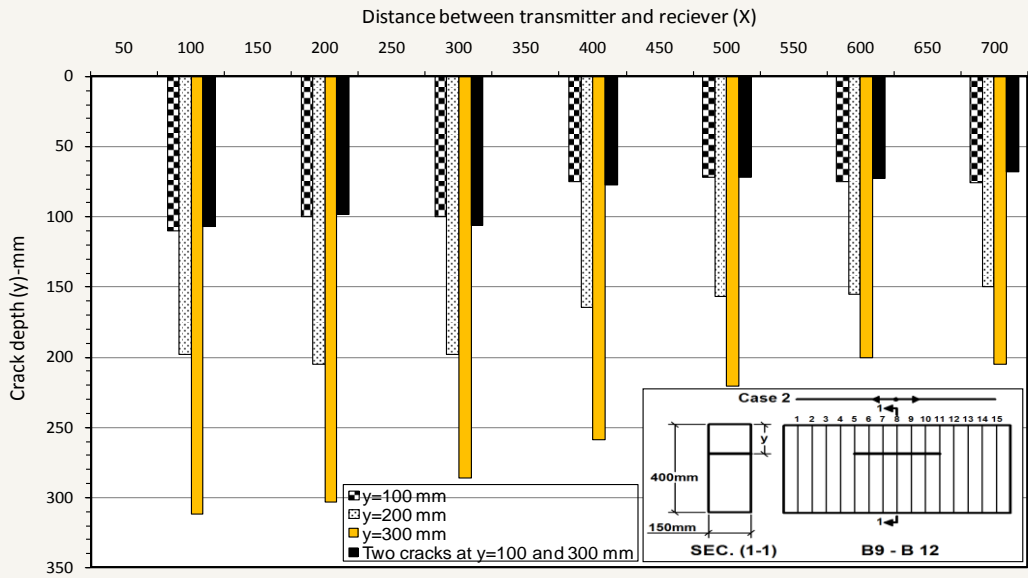


Fig. (7) Crack depth of Case 2-induced crack to center (C.S. 150x400 mm)

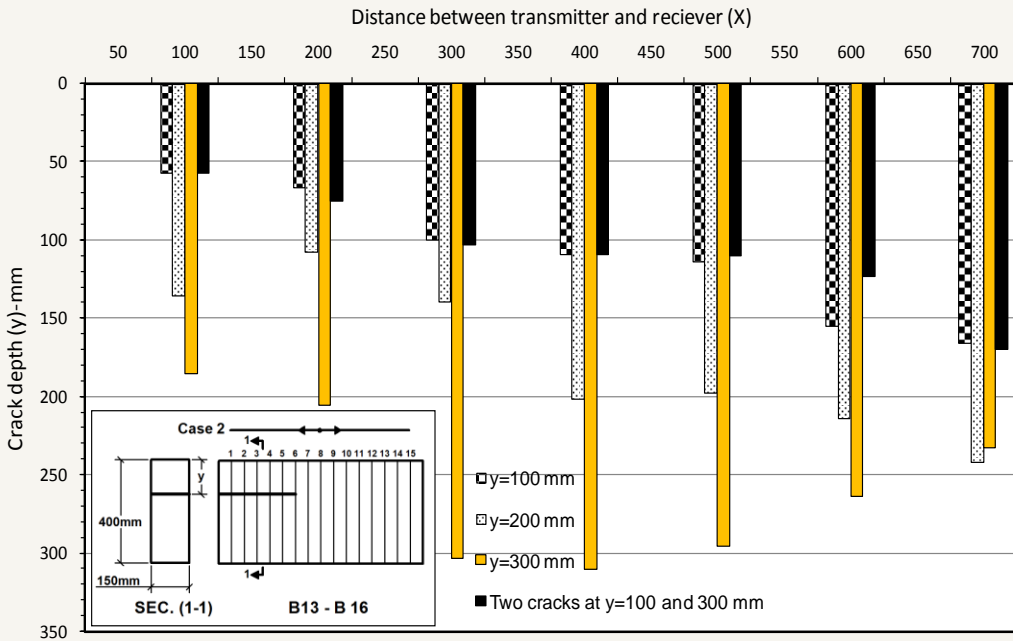


Fig. (8) Crack depth of Case 1-induced crack to edge (C.S. 150x400 mm)

5.2.2 Case 2: beams with cross section 150x400 mm

Figures (7 and 8) illustrated the detected crack depths of beams B9-B16 with induced crack depths in the center of the beams with cross section depth of 400 mm.

Induced crack depth to center (Cross sec. 150x400 mm)

Figure (7) showed the crack depths of B9-B12 with induced crack depths at center of beams which can be detected. B9 illustrated a crack depth of (100-110 mm) if the distances were (100-300 mm). B10 with 200 mm induced crack depth was detected if the distances were (100-300 mm) with a crack depth of (198-205 mm). B11 with 300 mm induced crack depth also can be detected if the distances were (100-300 mm) with (286-311 mm) induced crack depths. The two induced cracks of B12 detected the top crack only (98-106 mm) through distances of (100-300 mm). This may due to the reasonable distance between the 2 cracks which enable the top crack to receive the pulses before the down crack.

Induced crack depth to edge (Cross sec. 150x400 mm)

Figure (8) illustrated the detected crack depths of beams B13-B16 with induced crack depths at center of beams. B13 can be detected if the distance between transducer and receiver in between (300-500 mm) which gave a detected crack depths of (100-113 mm). B14 also can be detected if the distances were (300-500 mm) with detected crack depths of (197-202 mm). B15 can be detected the distances were (400-500 mm) which indicated a crack depths of (295-310 mm). Elsewhere, 2 layer cracks induced in B16 detected the top crack when the distances were (300-500 mm) which indicated a crack depth of (103-110 mm).

5.3 Detecting Of Horizontal Cracks By UPV (Case 3)

Figures (9 to 12) reported the experimental results of the detected crack depths by UPV device which measure the beams from its center point to its edges where the transducer was fixed to the center of beams and the receiver was movable towards the edge with 50 mm intervals covering the area induced by horizontal cracks.

5.3.1 Case 3: Beams with cross section 150x200 mm

Figures (9 and 10) showed the crack depths of the beams with 150x200 mm cross section with the distances between transducer and receiver. Plastic sheets were induced to those eight beams from B1-B8 either in the middle of beams as B1-B4 or induced to edge as B5-B8.

Induced crack depth to center (Cross sec. 150x200 mm)

Figure (9) indicated the crack depths of beams B1-B4 which represented the detected crack depth for all beams with different crack depths. B1 with 70 mm induced crack depth was detected if the distances between transducer and receiver were (100-150 mm) which gave a detected crack depth of (66-74 mm). B2 with 100 induced crack depths also can be detected when the distances were (100-200 mm) with (96-98 mm) crack depths. The detected depths for B3 with 130 mm induced crack depth were detected by the same distances between transducer and receiver of B1 and B2 (100-150 mm) which represent a crack depth of (131-133 mm). Elsewhere, B4 with induced 2 crack depths at 70 mm and 130 mm from top of the cross section cannot be investigated because of small dimensions of the cross section with a short distance between the two cracks (60 mm) which may cause multi-reflections hence, unrealistic crack depths are shown in the figure.

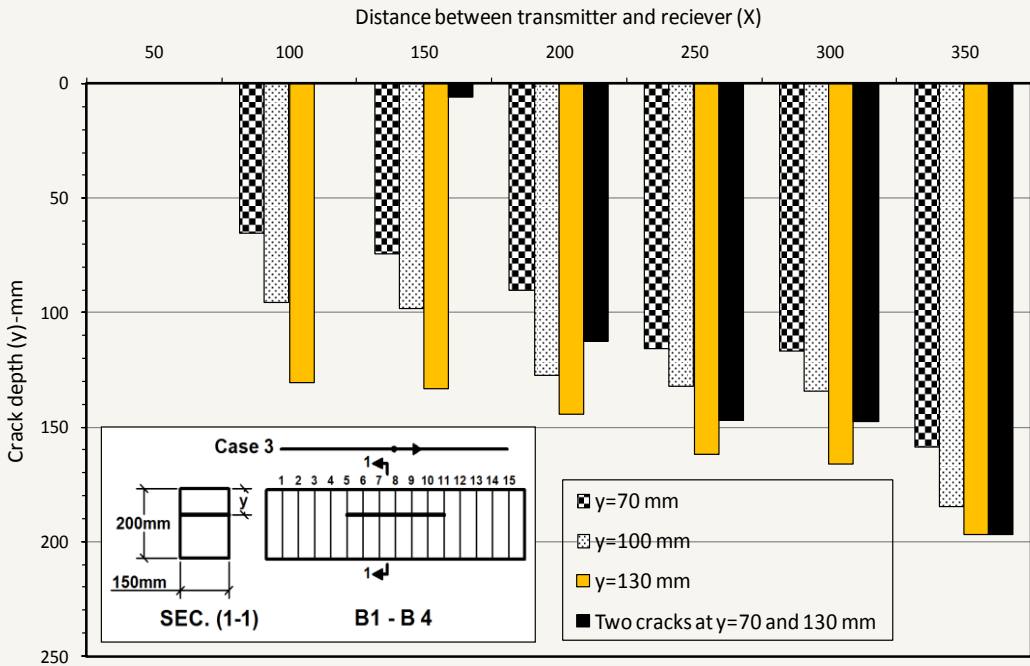


Fig. (9) Crack depth of Case 3-induced crack to center (C.S. 150x200 mm)

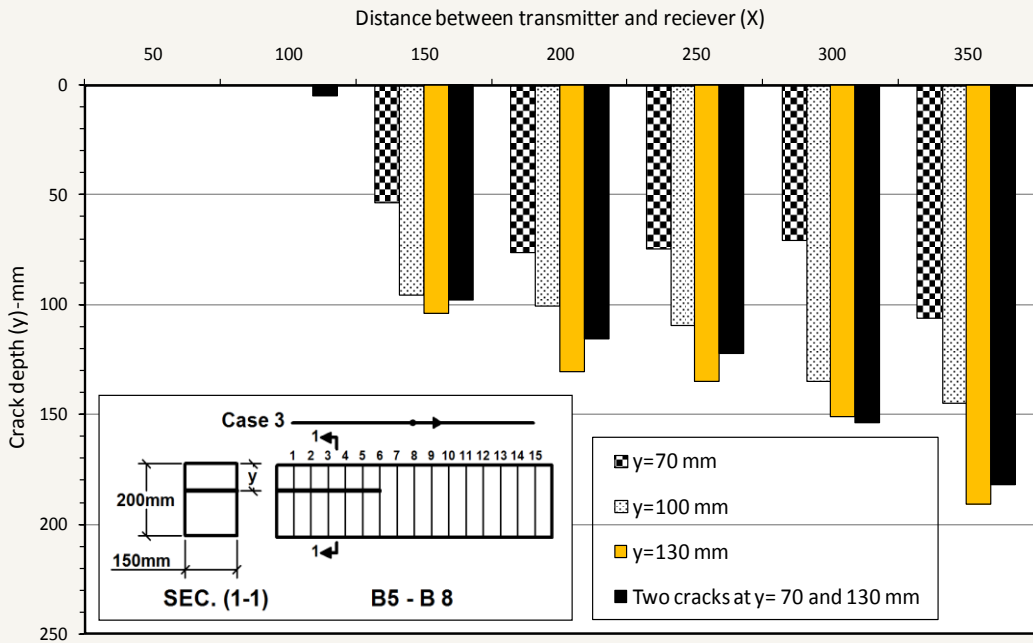


Fig. (10) Crack depth of Case 3-induced crack to edge (C.S. 150x200 mm)

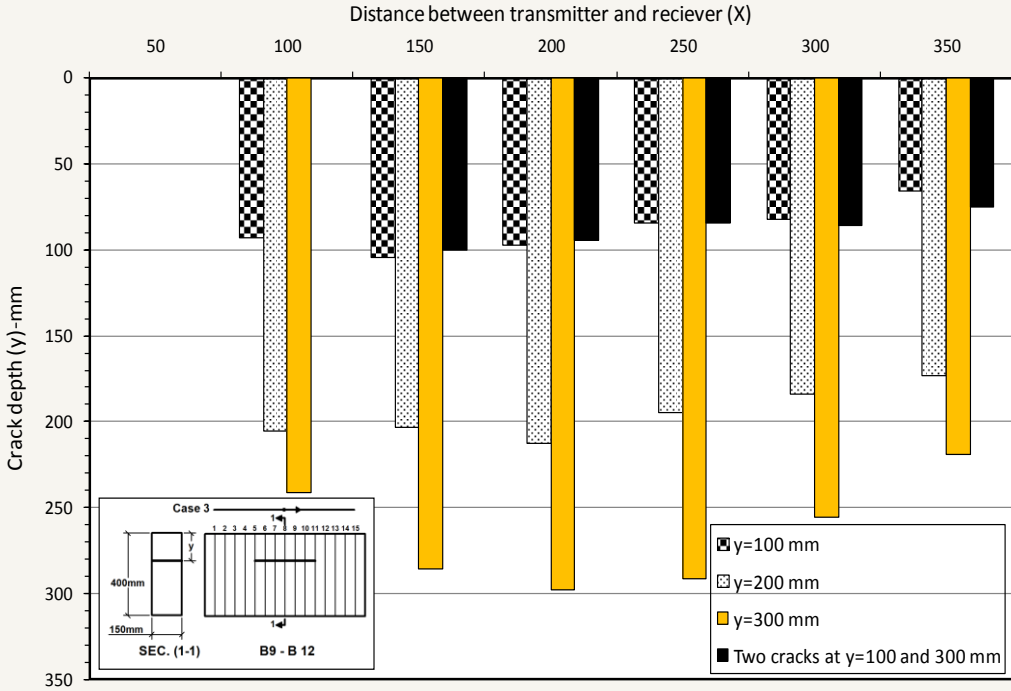


Fig. (11) Crack depth of Case 3-induced crack to center (C.S. 150x400 mm)

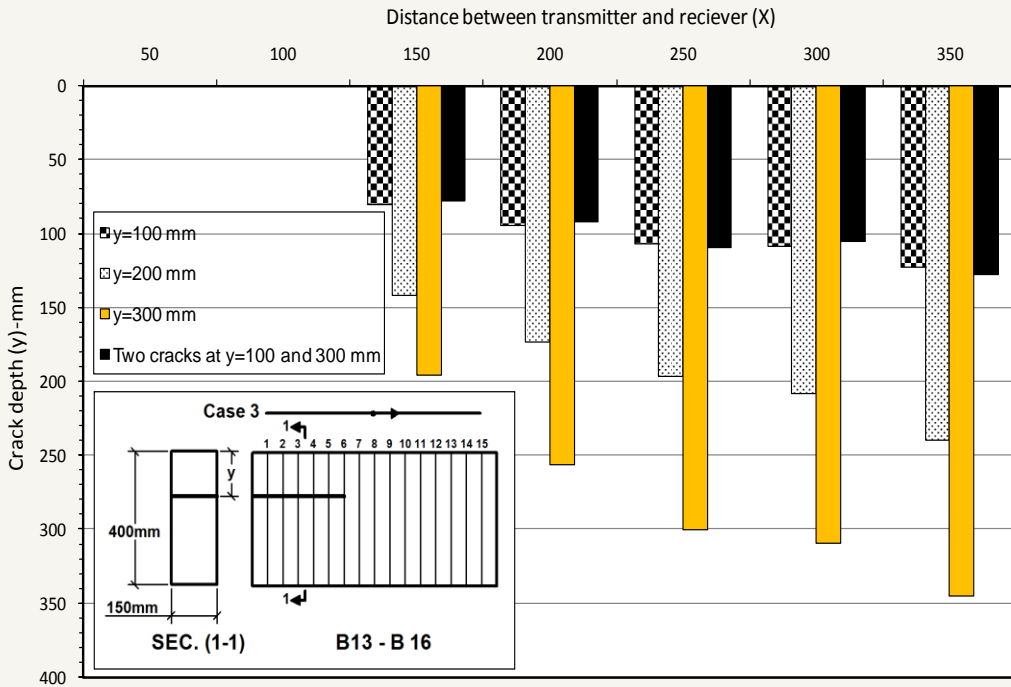


Fig. (12) Crack depth of Case 3-induced crack to edge (C.S. 150x400 mm)

Induced crack depth to edge (Cross sec. 150x200 mm)

Figure (10) represented the crack depths by UPV device for the beams B5 to B8 and which have induced crack depths to the edge beams. B5 with 70 mm induced crack depths indicated (70-75 mm) crack depth when the distances were (150-250 mm) whereas B6 with 100 mm induced crack depth represented (95-109 mm) crack depths when the distances were (200-300 mm). B7 indicated also the crack depths of (130-135 mm) when the distances were in the range (200-250 mm). On the hand, crack depths of the B8 with two induced cracks gave unrealistic values that are because of the multi-reflections of the pulses and small dimensions of the cross section.

5.3.2 Case 3: beams with cross section 150x400 mm

Figure (11 to 12) reported the results of the beams with 150x400 mm of the eight beams (B9 to B16) which measured as indicated in case 3 where cracks induced either center or edge of the beams.

Induced crack depth to center (Cross sec. 150x400 mm)

Figure (11) showed the crack depths of the four beams which have a crack depths induced to center of beams B9 to B12. Results exhibited that B9 of 100 mm induced crack depth may be detected through a distances of (100-200 mm) with a crack depths of (93-104 mm). B10 with 200 induced crack depths was investigated and the crack can be detected when the distances were (100-250 mm) which gave (194-212 mm) crack depths. B11 with 300 mm induced crack depth represented a detected crack depth of (285-298 mm) through the distances (150-250 mm). B12 with two cracks in levels 100 mm and 300 mm can be detected for its top crack only when the distances were (150-200 mm) where as the crack depths were (94-100 mm). The reasonable distances between the two cracks (200 mm) enabled the top crack to receive the pulses and reflect it to the receiver without any multi-reflections.

Induced crack depth to edge (Cross sec. 150x400 mm)

Figure (12) explained the relations between the crack depths of beams (B13 to B16) and the distances of the transmitter and receiver of the induced crack depths to the edge of beams. B13 with 100 mm induced crack depths may be investigated when the distances were (200-300 mm) which gave a crack depth of (94-108 mm). B14 with 200 mm induced crack depth indicated a detected crack depth of (196-208 mm) when the distances were (250-300 mm). It is clearly shown that B15 with 300 mm induced crack depth can be investigated through distances f (250-300 mm) where the detected cracks were (300-309 mm). On the hand, B16 with two cracks detected only the top crack with 100 mm depths at distances (200-300 mm) where the cracks were (92-109 mm).

5.4 Compressive strengths of SCC Have horizontal cracks by UPV

The vital and important calibration curves of the cracked SCC should prepared by direct method in order to estimate the compressive strengths of the cracked SCC that is because indirect method failed to detect the compressive strengths and gave unrealistic values. Results of group 5 showed that control sample of SCC can be investigated by

UPV by a calibration curve between UPV and fracture compressive strengths as indicated in Equation (2).

$$F_{cu} = 1361.1\text{Ln}(V) - 1670.4 \tag{2}$$

Where:

F_{cu} = Actual compressive strength of the control sample

V = Ultrasonic pulse velocity

Figure (13) also indicated the results of the compressive strengths of the group 5 with induced one crack depth which can represent also by Equation (3):

$$F_{cu} = 480.51\text{Ln}(V) - 43.118 \tag{3}$$

Results of investigation group 5 with induced two cracks depths illustrated in Fig. (13) and Equation (4):

$$F_{cu} = 788.37\text{Ln}(V) - 145.84 \tag{4}$$

It is shown from Fig. (13) that compressive strengths of the cracked SCC can be estimated by UPV device but with direct method.

Table (5) represented the fracture compressive strengths of SCC with induced cracks with related to the control SCC. Table showed that fracture strength of SCC with one crack was 90% whereas SCC with two cracks was about 83%.

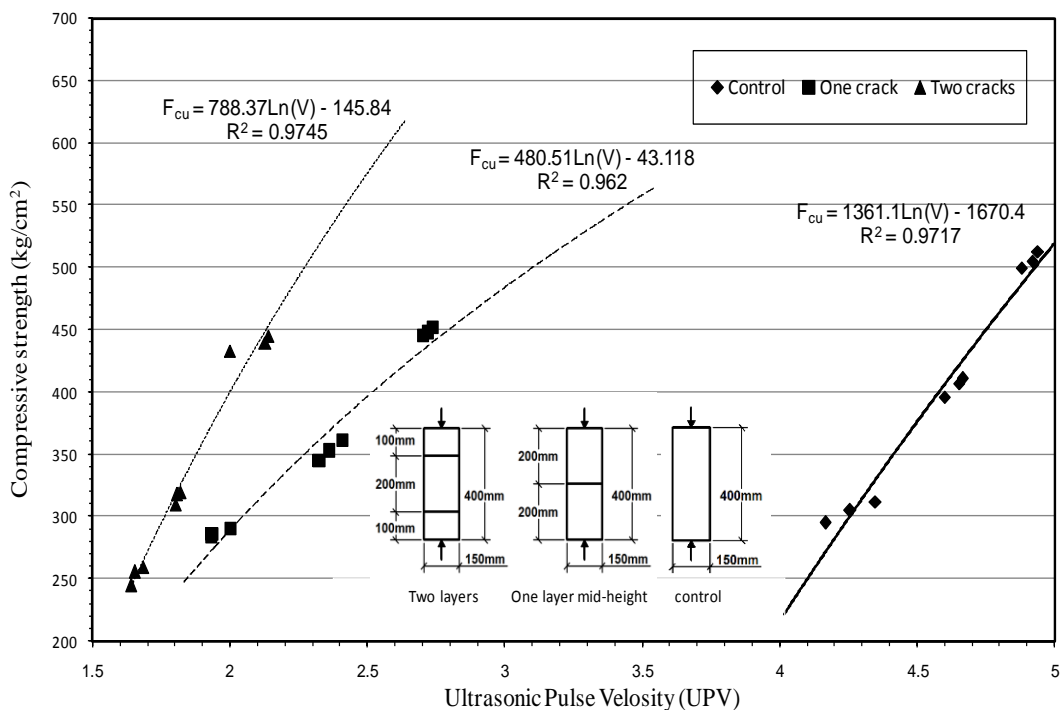


Fig. (13) Calibration curves for detecting compressive strength of SCC induced with horizontal cracks by UPV device

5.5 Compressive Strengths of SCC Have Horizontal Construction Joint by UPV Device

Figure (14) reported the results of compressive strengths by UPV device (direct method) for group 6 of SCC cast by stages (one and two construction joints) where the ages between each layer was 24 hours. Results indicated that fracture compressive strength of SCC with one separation was about 91% of the control SCC whereas SCC with two separations reached 86%.

It is shown from Table (6) the reduction of compressive strengths for SCC cast with multi-layers may exist especially when a construction joint do not carried out perfectly according to the specification and rules of the concrete industry limitations. So, it is recommended that take care should taken into consideration for separation erection and it is recommended, if possible, to cast the construction with SCC in one time.

The compressive strength of SCC with multi-separations can be detected by UPV device correctly if calibration curves were prepared as indicated in Fig. (14) where Equations (5 and 6) represented the compressive strengths by UPV device for SCC with one ore two separations respectively are :

$$F_{cu} = 1386.4Ln(V) - 1634.9 \tag{5}$$

$$F_{cu} = 601.5Ln(V) - 1886 \tag{6}$$

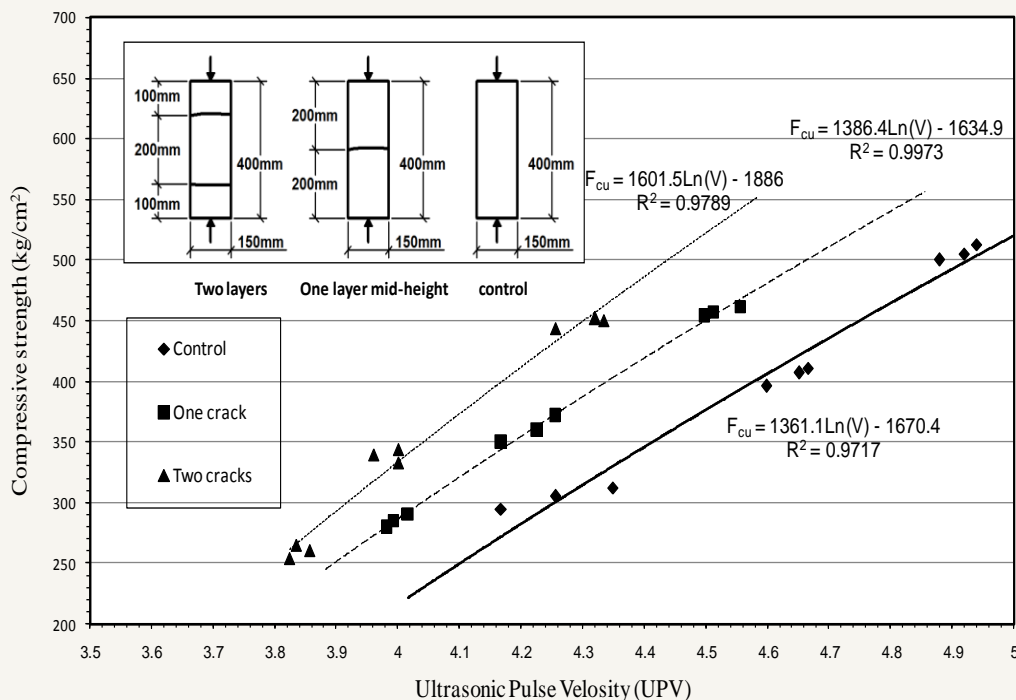


Fig. (14) Calibration curves for detecting compressive strength of SCC with horizontal crack joints by UPV device

6. CONCLUSIONS AND RECOMMENDATIONS

The results of the experimental work on different SCC mixes and dimensions in order to investigate the effect of horizontal crack and compressive strengths of SCC with horizontal crack or construction joint have been considered in this research. On the sound of results obtained in this paper, the following conclusions can be drawn:

- 1- Horizontal of SCC can be detected by UPV device with limited distances of transmitter and receiver according to the crack position and case of measuring.
- 2- Limitations of the distances of receiver and transmitter should be taken into consideration as minimum distances 100 mm and reasonable distances (100-300 mm) for the crack region.
- 3- Investigation can be detected easily if the UPV device was in the position of the crack such as case 1 with induced crack to edge and case 2 with induced crack depth to center in addition to case 3 with induced crack to center
- 4- Compressive strengths of cracked SCC by UPV was unrealistic and new calibration curves were carried out for cracked SCC and SCC with construction joints
- 5- Taking care should be taken into consideration for construction joint erection of SCC where a reduction of compressive strength of SCC was reduced by (9-14%) whereas the reduction of compressive strength was about (10-17%) for cracked SCC.

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الكشف عن الشروخ في الخرسانة ذاتية الدمك باستخدام الموجات فوق الصوتية

تتجه أنظار العالم اليوم إلى استخدام الخرسانة ذاتية الدمك في كثير من التطبيقات في مجال التشييد و من ثم ازدادت في الآونة الأخيرة الكثير من الأبحاث لدراسة خواص هذه النوعية من الخرسانة و حل لكثير من الصعوبات التي تعترضها. ولما كان كثير من المنشآت يصعب صبها في يوم واحد لكثرة كميات الخرسانة فإننا نلجأ للصب على أكثر من مرحلة مكونة فاصل أفقي أو أكثر من فواصل الصب مما تعرض الخرسانة لفواصل أفقية قد ينتج عنها عيوب أفقية قد تمتد إلى شروخ مستقبلا. و حيث أن الأبحاث التي تتعرض لهذه النقطة تكاد تكون قليلة و لا تغطي هذه الدراسة فأصبح من الضروري دراسة سلوك الخرسانة ذاتية الدمك في ظل وجود هذه الفواصل و ذلك بدراسة عدد 30 كمره من الخرسانة ذاتية الدمك تم فحصها بجهاز الموجات فوق الصوتية لاكتشاف الشروخ الأفقية و التي تم إدراجها عن طريق وضع طبقة بلاستيكية رقيقة أو طبقتين على أعماق مختلفة و أوضاع مختلفة من الكمرات بعدد 18 كمره و تم الكشف عن هذه الشروخ المعروف أماكنها بالطريقة الغير مباشرة لجهاز الموجات فوق الصوتية. و من ناحية أخرى تم دراسة عدد 12 كمرات بدون وضع طبقات بلاستيك و لكن تم عمل فاصل أو أكثر

كفواصل صب طبيعية و تم دراستها عن طريق فحصها بجهاز الموجات فوق الصوتية بالطريقة المباشرة لعمل منحنيات معايره جديدة سواء للخرسانة المحتوية على شروخ أفقية أو التي تحتوى على فواصل صب طبيعية. و على ضوء نتائج الدراسة فانه تم التوصل إلى اكتشاف الشروخ الأفقية عن طريق جهاز الموجات فوق الصوتية بالطريقة الغير مباشرة و لكن فى حدود مسافة معينة بين المرسل والمستقبل فد تفيد كثير من فاحصي المنشآت التي تحتاج إلى ترميم. و كذلك تم التوصل إلى أن فواصل الصب الأفقية قد ينتج عنها فقد فى إجهاد الخرسانة ذاتية الدمك قد يصل إلى 9-14% و فقد فى مقاومة الضغط الخرسانة ذاتية الدمك المحتوية على شروخ أفقية يصل إلى 10-17%.