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Research paper

Air-Coupled Impact Echo Test with Acoustic Shield

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Abstract

The ability of air-coupled impact-echo technique to retrieve data in a short time is the main advantage of this technique. However, there are some external factors, especially noise disruptions arising from surrounding sound where the test is performed causing some error to the data collected. Therefore, the use of acoustic shield is introduced. This paper presents the performance of air-coupled impact echo testing in detecting concrete flaws depth and effects of different acoustic shields on the estimated flaws depth. Testing is performed on concrete slab designed to have four defects at different depth and size. Acoustic shield are made from egg crate foam, aluminium sheet, polyvinyl chloride (PVC) pipe and polypropylene (PP) plastic. Recorded data in time domain is transformed to frequency spectrum by fast Fourier transform (FFT) to obtain the peak frequency for each defect zone. Estimated depth error obtained without acoustic shield is 10.0%. The value was higher compared to the use of acoustic shield from egg crate foam, aluminium sheet, PVC pipe and PP plastic with 3.3%, 3.3%, 8.3% and 3.3% error respectively. Data analysis shows that the use of acoustic shield has reducing the effects of noise and other acoustic waves measured by error percentage. The use of egg crate foam as an acoustic shield is the most effective shield followed by aluminium sheet, PP plastic and PVC pipes.

Keywords: *Air-coupled impact-echo testing; acoustic shield; concrete flaws; nondestructive testing.*

1. Introduction

Impact-echo is a widely used nondestructive method that can be used to detect the voids [1], honeycombing [2] and cracking [3]. When a disturbance is imposed at a point on a solid surface such as an impact, the disturbance through the solid is categorized in two types of waves which are body waves and surface waves. The body waves will be disseminated through the internal medium by compression or medium particle pressure (P-wave) or shear movement to the left and to the right or top and bottom (S-wave). In addition, surface waves (R-wave) are produced when the medium has a free surface such as a ground surface [4]. P-wave moves the fastest among other waves and associated with normal stress. When the P wave passes through a certain point, the particle vibrates in parallel with the direction of the propagation which is located along the radius taken from the point of impact to the location. S-wave is moving at slower speed and is associated with shear pressure.

One of the challenges in applying an impact-echo test using conventional sensor, accelerometer is to ensure the sensor coupled perfectly to the surface of structure [5]. Sensor is coupled to concrete surface by commercial glue and gel couplant [6]. However, for impact-echo test, several testing point may be required for scanning larger structure. Therefore, attaching and detaching sensor is a main disadvantage of the test. To overcome this problem, air-coupled sensing using microphone was introduced. The ability of air-coupled sensing in retrieving data in a short time shows the advantages of this technique. Subsequently, recorded data can be analyzed rapidly and demonstrated the deflection of voids in concrete structures. However, there are some external factors, especially noise disruptions arising from wind, traffic and machinery will also be considered by the microphone and cause signal reduction to the data noise ratio. Thus, the use of acoustic shield was introduced [7]. With the use of this acoustic shield, it can reduce the effect of direct acoustic waves and other noise effects.

When impact by using hammer is applied at a point on the surface of concrete, elastic waves propagate along the concrete surface and direct acoustic waves travel in air. The resulting motion at each surface point of the solid causes an acoustic wave to "leak" into the surrounding air. The result of the movement on the surface of the concrete structure causes the acoustic wave to be free to the air surface before moving towards the sensor. The use of air-coupled sensor, microphone is the same as the conventional impact-echo testing using accelerometer; however, no contact occurs between the sensor and the concrete surface [8].

In this study, the performance of impact-echo test using air-coupled sensor, microphone in estimating concrete flaws depth will be determined. In addition, the effect of different acoustic shields to determine the depth of void/delamination will be highlighted. The data will be recorded by microphone sensor located near the point of impact. With the aim, monitoring the surface spacing produced by the presence of pressure waves reflected by the void defect and the outer boundary of the concrete structure. The data will be analyzed using the appropriate FFT algorithm. Time domain wave signals that have been recorded to the frequencies and frequency reflections will be analyzed. The obtained time domain signal is transformed to the frequency domain (frequency spectrum) where the frequency value at the maximum amplitude (peak) is monitored. The thickness or depth of void, d is related to P-wave velocity V_p and peak frequency, f_{max} of the frequency spectrum as in (1).

$$d = 0.96\frac{V_p}{2f_{max}} \quad (1)$$

2. Experiments

Reinforced concrete slab with artificial defect and acoustic shields are prepared for the experiment. This experiment is performed completely indoor.

2.1. Sample

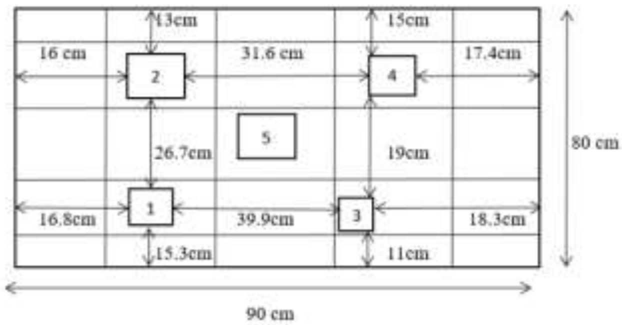


Fig. 1: Plan view of concrete slab showing the location of defects and solid area.

A 90x80x10 cm slab mould is used. The steel bar layer is placed inside the reinforced concrete to withstand the tensile force and also to help maintain the compressive strength in the structure. After the first steel bar layer is leveled with concrete then the second steel bar layer is laid. This is due to the second layer the steel bar has been placed 4 types of voids of different sizes at different depths. Then the concrete is inserted into the slab mold. The mixture is a grade 40 concrete. The sample then be left for 28 days for curing before experiment can be performed. Two types of defects are used in this experiment: polystyrene with size 15x15 cm and 10x10 cm and two plastic layers that have been attached together with size 10x10 cm and 5x5 cm with 1 cm thickness.

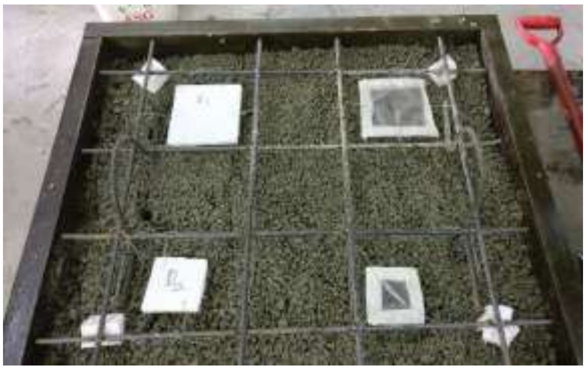


Fig. 2: Placement of artificial defects during sample preparation.

Table 1: Size and depth of artificial flaws based on zone number.

Zone	Material	Flaws	Size (cm)	Depth
1	Polystyrene	Void	10 x 10 x 1	6.0
2	Polystyrene	Void	15 x 15 x 1	5.0
3	Double-layer plastic	Delamination	5 x 5 x 0.3	6.0
4	Double-layer plastic	Delamination	10 x 10 x 0.3	5.0
5	Concrete	-	-	10.0

2.2. Design and procedure

This experiment will start by using sensor microphone without acoustic shield that act as reference point, to check whether the data generated by the microphone along with acoustic shield is relevant. CM-505B condenser type microphones are used in this experiment. This condenser-type microphone is more sensitive than the usual dynamic microphone, allows it to capture the finest waves. Based on the design of microphone condenser, it was built by thin diaphragm which able to respond quickly to low waves or travel waves away. While, the distance between impactor and sensor is 40% of the thickness of the defect. The microphone position is set at a distance of 1.0 cm above the surface of the concrete structure.

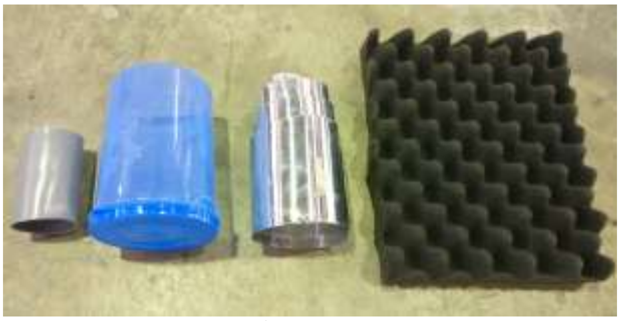


Fig. 3: Acoustic shield adopted in testing. From left, PVC pipe, PP plastic, aluminium sheet and egg crate foam.

2.3. Acoustic shield

Figure 3 shows four types of acoustic shield adopted in this study which are; egg crate foam, Aluminium sheet, PVC pipe and PP plastic. The thickness of PVC pipe is 20mm. It is an absorbing porous material which allows air to ventilate inside the pipe. The thickness of the pipe plays an important role in sound absorbing properties, more thickness means more acoustic noise can be reduced. Aluminium sheet is a good heat and electric conductor. Rigid and fire retardant properties of aluminium make it one of the best sound insulators. While egg crate foam is a good acoustic absorber due to its porous properties. Acoustic absorber is used to control airborne which reduces sound reflection. Zhu [7] shows that the use of acoustic shield improves data collected in term of noise.

3. Results and discussion

3.1. Air-coupled impact-echo test without acoustic shield

Table 1 shows thickness of each zones depicted in Fig. 1. It can be observed that air-coupled impact-echo method is able to detect the depth of defects and depth of solid with acceptable error. Figure 4 shows frequency spectra for zone 5 that match the slab depth. Zone 5 is a defect-free zone on concrete structures that proves the use of a microphone sensor on impact-echo test is successful in obtaining depth of the slab structure. Likewise, with the defect depth in other zones. However, zone 1 has the biggest error value of 10% due to lack of consideration of material frequency. The content of the material frequency should be included in the expected resonance frequency [6].

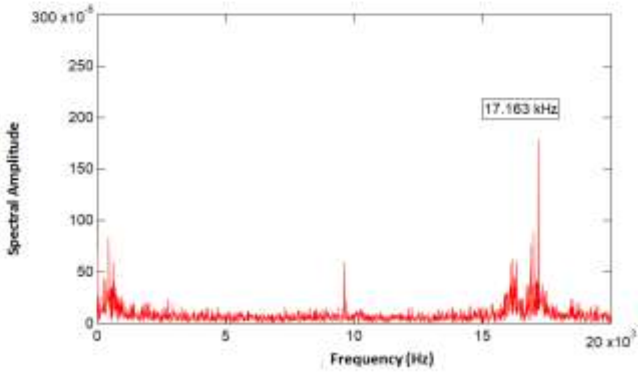


Fig. 4: The resulting frequency spectra analyzed from data recorded with microphone without shield for Zone 5.

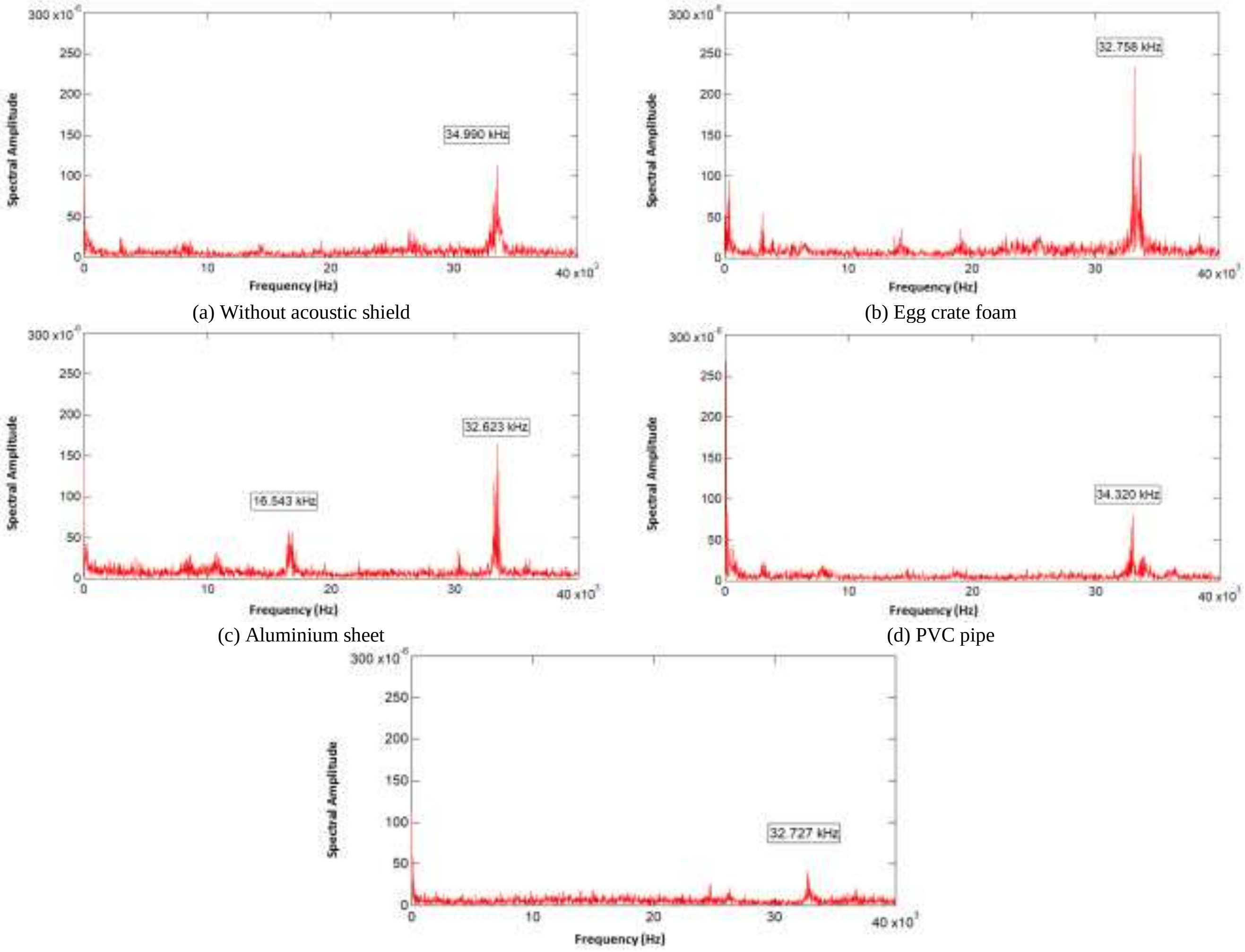
Table 2: Flaw depth estimated by air-coupled impact-echo test on concrete slab.

Zone	Actual depth (mm)	IE (mm)	Error (%)
1	60	54	10.0
2	50	49	2.0
3	60	55	8.3
4	50	49	2.0
5	100	109	8.3

Zone 3 has a lateral dimension less than 1.5 times the depth, thus the depth is possible to be detected. Whereas for zone 1, zone 2 and zone 4 having a dimension greater than 1.5 times the depth, then the reaction of the test to the impact will be similar to the slab thickness that equivalent to the voids depth. Reaction of both voids and delamination is dependent on size and depth of delamination [9],[10],[11].

3.2. Air-coupled impact-echo test with acoustic shield

Acoustic shield is an external structure designed to protect objects from noise pollution. It reduces noise by preventing direct travel of sound waves from sources (impactors) to sensors. Effect of the use of microphone with four different types of acoustic shield which is foam, aluminum, polystyrene (PVC) pipe and PP plastic is analyzed. In order to determine whether acoustic shield is successful in reducing noise and others acoustic wave and obtaining the depth of the voids and delamination defect. Table 1 shows the artificial defect detail that was embedded inside the slab structure.



(a) Without acoustic shield

(b) Egg crate foam

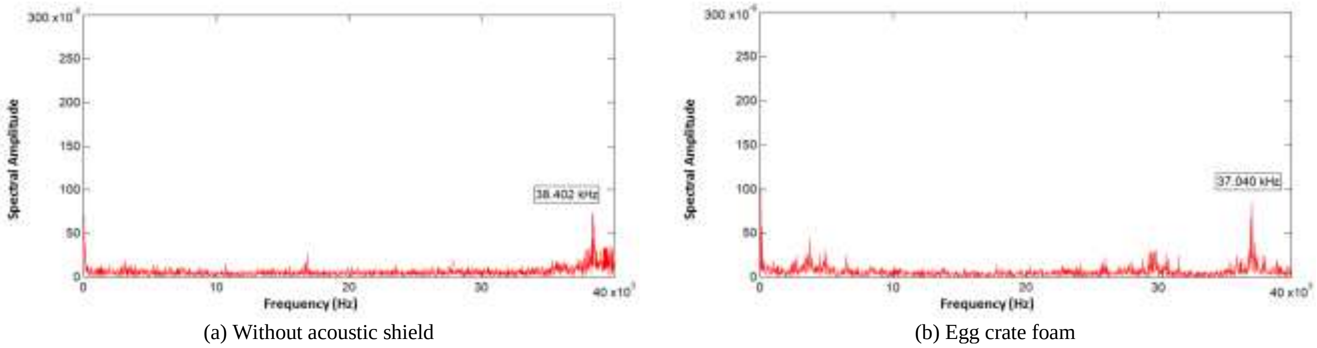
(c) Aluminium sheet

(d) PVC pipe

(e) PP plastic

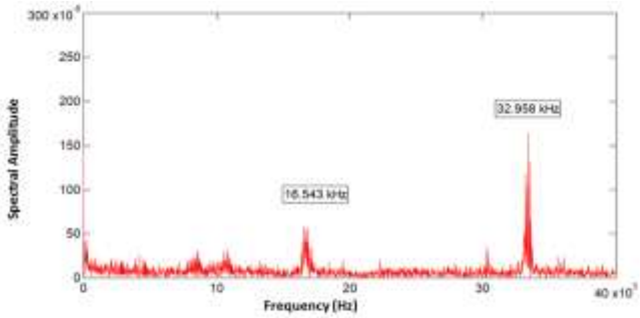
Fig. 5: The resulting frequency spectra analyzed from data recorded with microphone with and without acoustic shield for Zone 1.

Figure 5 shows zone 1 experiment result which is void defect with size 10x10 cm and 1.0 cm in depth. P-wave velocity is 3944 ms^{-1}, and the defect thickness from the surface is 6.0 cm. When the impact is applied on the top of void, the reflection from the surface of the void dominated the frequency response. Foam is used as acoustic shield because of its physical properties as sound absorption. It absorbs excess of acoustic energy that scattered into the air. It can be seen on Fig. 5(b) around the peak area of acoustic energy surplus is virtually absent because it is absorbed by the foam. Fig. 5(c) shows the use of aluminium as acoustic shield. There are two peak peaks that occur at 32.623 kHz and 16.543 kHz. The highest frequency peak indicates the depth of the void while the second frequency peaks show thickness of the concrete. Aluminium sheet is amplifying frequency peak corresponding to slab thickness more than other shield types. The use of PVC pipe shows the dominant peak of 34.320 kHz in Fig. 5(d). And the use of PP plastic which has a wide surface causes the released acoustic power to be reflected back to microphone and caused a lot of acoustic forces around the dominant area as can be observed in Fig. 5(e). These results is expected since the area of the delamination is greater than 1.5 times the depth the reaction of the impact-echo to the impact will be similar to the slab thickness equivalent to the voids depth.

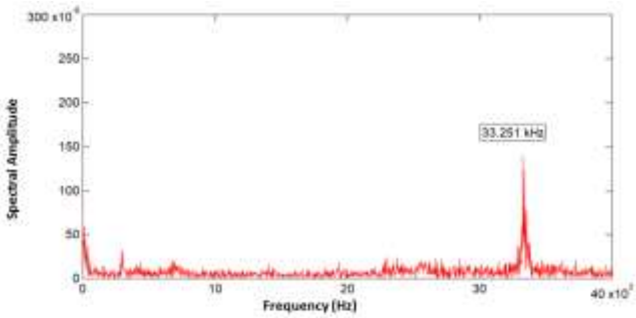


(a) Without acoustic shield

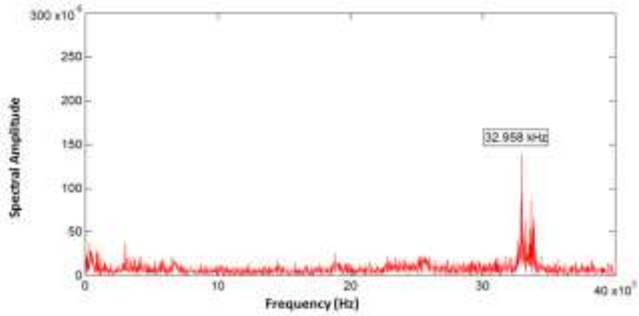
(b) Egg crate foam



(c) Aluminium sheet



(d) PVC pipe



(e) PP plastic

Fig. 6: The resulting frequency spectra analyzed from data recorded with microphone with and without acoustic shield for Zone 2.

Fig. 6 shows zone 2 for shallow delamination with a distance of 5.0 cm from the concrete surface. It has a void defect size of 15x15 cm. This is the largest size of artificial defect used for this experiment. Fig. 6(b) shows the peak frequency of 37.040 when foam is used as shield. Fig. 6(c), microphone with aluminium shows two peak frequency, consistent with previous result presented for zone 1. These peaks are representing void depth and the slab depth which are 33.958 kHz and 16.543 kHz respectively. For microphones with PVC pipe and microphones with PP plastic, the dominant frequency peaks of 33.251 kHz and 32.958 kHz respectively are observed.

Depth of the void is calculated using equation 1. Table 3 shows summary of estimated depth of artificial defect that performed at each defect zone with different type of acoustic shield. Zone 1 for polystyrene depth 6.0 cm from the concrete surface with a sample size of 10x10 cm indicates that the use of acoustic shield of foam, aluminium and PP plastic is performing better with 3.3% error compared to PVC pipe with 8.3% error.

For void at zone 2 represented by polystyrene, the depth is 5.0 cm from concrete surface with the size of 15x15 cm. Zone 2 for microphones with foam, aluminium, PVC and PP plastic as acoustic shields give 2.2%, 12.0%, 14.0% and 14.0% error respectively. The depth detected for zone 2 for microphone with acoustic shield is more than the use of microphone without acoustic shield with only 2.0% error. This is because the peak frequencies in the area are lower than the microphone data without acoustic shield.

Table 3: Flaw depth estimated by air-coupled impact-echo test with acoustic shield on concrete slab.

Zone	Actual depth (mm)	Acoustic Shield	IE (mm)	Error (%)
1	60	-	54	10.0
		Foam	58	3.3
		Aluminium	58	3.3
		PVC Pipe	55	8.3
		PP plastic	58	3.3
2	50	-	49	2.0
		Foam	51	2.2
		Aluminium	56	12.0
		PVC Pipe	57	14.0
		PP plastic	57	14.0
3	60	-	55	8.5
		Foam	57	5.0
		Aluminium	57	5.0
		PVC Pipe	57	5.0
		PP plastic	57	5.0
4	50	-	49	2.0
		Foam	55	10.0
		Aluminium	57	14.0
		PVC Pipe	57	14.0
		PP plastic	57	14.0

There are several possible reasons for this: 1) very thick defect thickness, 2) errors during the concrete making process, and 3) unsuitable material selection to represent delamination defects. Previous studies show that the minimum value of the width of the delamination defect that can be detected by the impact-echo test is about 0.0025cm [3]. The artificial defect widths embeded in zone 2 is 1.0 cm. Thus, it appears that the void is too thick to be detected by the impact-echo test. Therefore, based on impact-echo test that have been performed, the use of acoustic shields has successfully reduced error in flaw depth estimation. The use of egg crate foams as acoustic shield is the most effective barrier to reduce the effect of other acoustic waves because of its nature which absorbs noise when the waves pass through it. Followed by aluminium sheet and PP plastic acoustic shields are the second effective acoustic shield because of its material properties as a sound reflector. This sound reflection principle can amplify the wave of the impact then used it to measure the thickness of the defect in the concrete structure. Finally, PVC pipes are the less effective acoustic shields.

4. Conclusions

The present study investigate the performance of air-coupled impact echo testing in detecting concrete flaws depth and effects of different acoustic shields on the estimated flaws depth. Testing is performed on concrete slab designed to have four defects at different depths and size. Different acoustic shield used together with microphone are foam, aluminium sheet, polyvinyl chloride (PVC) pipe and polypropylene (PP) plastic. The following conclusions were derived from the current study:

1) Air-coupled impact echo test is effective in detecting void and delamination of conrete slab with acceptable error.
2) Egg crate foam is the most effective acoustic shield followed by aluminium sheet, PP plastic and PVC pipe.
3) Acoustic shield made from aluminium sheet is capable to detect both frequency peak corresponding to slab thickness and flaw depth.
4) Material with sound absorber properties is more effective than material with sound reflector properties to be used as acoustic shield during air-coupled impact echo testing.

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