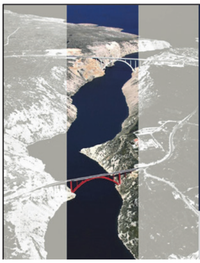

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# DETECTING THE DEFECTS IN CONCRETE COMPONENTS WITH IMPACT-ECHO METHOD

**Jing Liu*, Xiaoyu He*, Yushan He*, Jiahui Zhong* & Jun Xie***

* Research Institute of Highway Ministry of Transport
jing.liu@rioh.cn

**Keywords:** Prestressed concrete, pipeline grouting, imperfection, impact-echo method.

**Abstract:** *With the large-scale application of the prestressed concrete structure, the quality of the concrete component defects and pipeline grouting has increasingly become the focus of attention. In this paper, the development process of impact-echo method is described, the achievements made by the method are summarized, and the engineering applications of the impact-echo scanner is expounded. The impact-echo scanner uses the nature of wave, which pass though different media at different velocities, to distinguish internal defects of concrete, pipe filling density and so on. In this paper, using the impact-echo method to detect the concrete block with prefabricated defects of shape, location, and size explores the effect of defect properties, parameter settings and detection environment to impact-echo preliminarily, and also explores the relationship of pipeline filling status and impact-echo image. Based on this study, the article raised the problem met during this non-destructive testing methods applied to engineering, and accumulated a certain amount of available engineering data. The experiment results show that using the impact-echo method to identify the defects of concrete components and to test the quality of pipeline grouting is a more convenient and effective non-destructive testing method. Especially, with the radar method in the pipeline grouting quality inspection which complement each other to make up for the shortcomings the lightning wave in case of the metal medium total reflection phenomenon, cannot detect metal pipe grouting plumpness. This paper is useful to make impact-echo method further applied to the actual detection and also accumulates a certain amount of experience in engineering.*

# 1 INTRODUCTION

In recent years, the highway traffic infrastructure construction was developed rapidly, and great investments have last for a long time. By the end of 2011, there are a total of more than 689,400 highway Bridges in China, and the unsafe bridge number rises to more than 90,000 since 2007. Most of these unsafe bridges need repair, reinforce and reconstruct emergently. And especially, more than 90% of the unsafe bridges are concrete structures.

In the process of pouring concrete, some degrees of damage would happen to the concrete structure under the action of load and the external environment. These internal cracks and expansions, hollows, porosity can make concrete strength decline and eventually lead to the destruction [1]. In addition, for a prestressed concrete bridge, prestressed reinforcement is one of the most important element affecting safety and durability of the structure, which directly determines the structure performance in resisting compression, resisting shear, anti-seismic and shock resistance. At present, the bridge structure pipe grouting quality cannot be guaranteed, which lead to serious corrosion of prestressed tendons, and bring potential safety hazard to the bridge. Some important fact was found in the bridge strengthening process. For example, there are a large number of vertically prestressed reinforcement where pipe quality cannot be guaranteed. Some bridge pipes even have no grouting, which leaded to water flow backward into the pipe, and prestressed concrete soaked in water for a long time. Therefore, how to effectively, accurately and non-destructively detect the imperfection, such as holes and pores existing in concrete structure, and determine the pipe grouting state of the in-service prestressed concrete bridge, have been the most important issues and must be addressed for the department of research, design and management. In a word, grouting imperfection is a worldwide problem in bridge maintenance and management, and it is one of the hot research topics now.

# 2 DEVELOPMENT OF THE IMPACT-ECHO TECHNOLOGY

The impact-echo method was developed in the 1980s. As it came, this method was applied to detect all kinds of defects in concrete, and it was used in masonry structure defect detection recently[2]. In the detection of grouting tendons pipeline, post-tensioned prestressed structure, this method was early applied by the USA National Bureau of Standards. An ongoing research project including detailed digital, laboratory and field was initiated by Cornell University in 1993[3-5]. In the late 1990s, the basic standard of experiment with impact-echo was cooperatively made by NIST (The National Institute of Standards andTechnology) and Cornell, which was adopted by ASTM in 1998 in [ASTM C 1383].

In 2003, the stressed wave propagation path in concrete slab was studied and analyzed by Italian researcher including three classic cases with grout pipe, no grout pipe and part grouted pipe. And, the modifier formulas to calculate concrete thickness were proposed, which limited the deviation of the calculated value into 5%.

After many years of research, based on a lot of theoretical research and field testing, many valuable theoretical results and test experiences were got by the researchers. Most of them concluded that the impact-echo method can determine the grouting pipes and no grouting pipes effectively. But for part grouting pipes, only the existence of gaps could be judged, while the size and form of the gaps could not be determined. There are a lot of factors affecting the thickness imaging, not only the concrete duct but also other factors such as layered grout, concrete density of the beam are not filled enough. All of these factors will lead to erroneous judgement for the duct. So, in order to detect the grouting degree of the concrete duct more correctly, it is necessary to combine with the construction technology of pouring and grouting.

With the deepening of the research on the impact-echo method, a new result was got by some researchers in 2000. That was, when the test plane parallels to the defect interface, in the case of pipe diameter exceeding 1/5 thickness of the slab, the defect of more than 50% of the size of the pipe area can be detected with impact-echo method. In the case of pipe diameter exceeding 1/3 thickness of the slab, the defect of more than 20% of the size of the pipe area can be detected. And, in the case that pipe interval is greater than 4 times the pipe diameter, the frequency domain image of the impact-echo is not affected by pipe interval. [6-7]

# 3 THE ENGINEERING APPLICATION BASE OF IMPACT-ECHO METHOD

## 3.1 The theory of impact-echo(IE) method

IE test method is as followed. Firstly, knock the concrete surface with a small impactor or a pulse hammer, and then determine the reflected wave energy by the displacement sensor or the acceleration sensor that installed at the concrete surface nearby the impact point(within 50mm). If using a small hammer, record the output force of the hammer and the responsive displacement or acceleration. In time-domain, the resonant echo usually is not very clear, but in frequency-domain the resonant echo is recognized much more easily. Therefore, convert the test datum in time-domain to those in frequency-domain with Fast Fourier Change to recognize the frequency value in the echo peak. Utilize the receiver's displacement spectrum, which is the relation between the receiver's output displacement or the small hammer's input force and the frequency, and transfer function to determine resonance peak value. By analyzing the reflected stress wave in time-domain and in frequency-domain, determine the defect deepness and the construction member's thickness in the structure.

If the thickness of the test component is known, the compression wave velocity Vp can be get with the relation:

$$V_p = 2 * d * f / \beta \tag{1}$$

where, *d* is the thickness of the test component, and *f* is the resonant frequency of the peak.

Corrects with the correction factor β, for wall and plateβ is 0.96.

Analyzes the impact-echo as follows:

1) Time-domain analyzing: determine the travel time of the reflected wave of the defect or construction bottom with recorded echo signals, tR=1/FT, in accordance with the propagation velocity of stress wave in concrete $V_P$, calculate the thickness of the concrete or the deepness of the defect with the followed expression.

$$T = \frac{\alpha_s (V_p T_R)}{2} = \alpha_s V_p / (2F_T) \tag{2}$$

Where, T delegates the thickness of the concrete or the deepness of the defect, tR delegates the coefficient associated with the geometry shape of the component section, $V_P$ is the propagation velocity of the P wave in concrete, and tR expresses the travel time of reflected wave.

2) Frequency-domain: convert the data signal recorded into frequency-domain with FFT (Fast Fourier Transform) to analyze, and get the amplitude spectrum. The obvious peak in Figure 1 is caused by the transient resonance that generated by multiple reflections between impact surface and defects or other surface, which can be recognized to calculate the concrete structure thickness and the deepness of defects. The expression is as follows:

$$T = \alpha_s \cdot V_p /(2f) \tag{3}$$

where, f expresses the resonant frequency of the stress wave. [8]

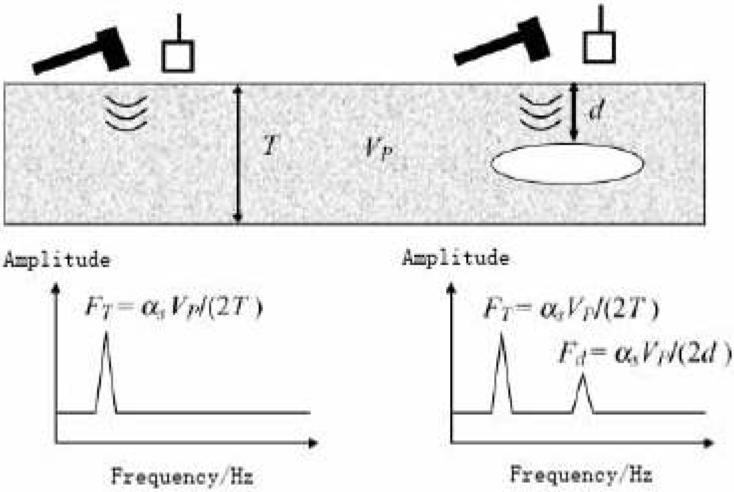


Figure 1: The theory of detecting concrete defects with impact-echo method

### 3.2 Basis of the impact-echo method applying to concrete member

Applying mechanical shock on the surface, the instant stress waves will be excited inside include longitudinal wave(P), horizontal wave(S) and surface wave(R). Beneath the impact-point, because the P-wave amplitude is the largest and the S-wave amplitude is the smallest, R-wave is mainly the P-wave.

The phenomena of reflection and diffraction happen when the mechanical wave meets some obstacles. Based on the classic propagation law of the two types of mechanical wave, the distance and size of defects can be judged in theory. For reflection phenomenon, when the mechanical waves encounter some obstacles or poles, the mechanical wave is reflected if its size is much larger than the wavelength. The distance of defects can be calculated by detecting reflected wave with the transducer placed on the surface. For diffraction phenomenon, in accordance with Huyghens Principle, when the wave encounter an obstacle during the propagation it can spread around the edges of the obstacle to move on. The diffraction phenomenon is significant or not, which is related to the ratio of the wavelength and the size of the obstacle. If the the size of the obstacle or the hole is much smaller than the wavelength, the wave is not spreading along a straight line but rather change the direction to bypass obstacles or holes, and then arrives at the shadow place if it spread in line. Continuing spread, reflection occurs after arriving at bottom, and so the travel time increases. In theory, based on the extension of wave travel time the size of the defect can be determined.

In practical engineering, concrete medium is complicated heterogeneous structure, which is composed together with aggregate, cement, steel, and holes. The thickness of concrete bridge member structure is usually in the range of 40cm-100cm, with prestressed steel, prestressed wire and regular reinforcement inside. In addition, the complicated structure such as honeycomb and irregular cavity is also created by construction. Therefore, some complicated phenomena like reflection, refraction and diffraction will be emerged during mechanical wave transmission. In theory the location and size of defects can be detected by monitoring these phenomena, while because of the complexity of the actual situation a lot of practical experiences are still needed to be accumulated.

## 4 THE RESEARCH TEST ON LOCATING DUCT AND STEEL WITH IMPACT-ECHO METHOD

Precasting the concrete test piece embedded with steel duct preinstalled defects and 32mm diameter coarse thread steel, which was used to test and verify the capability of locating ducts and imperfect steel bars with impact-echo technology.

### 4.1 Manufacting test piece

The distribution of corrugate pipes and thick steel bars was as shown in Fig. 2. Four corrugate pipes 2#, 4#, 6# and 7# were all penetrated with steel strands, and all of strands in the corrugate pipe were not tensioned. 6# and 7# were both set hollow and watering defects. Here, 5# was a diameter of 32mm thick deformed steel bar.

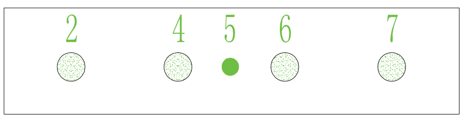


Figure 2: Cross-section figure

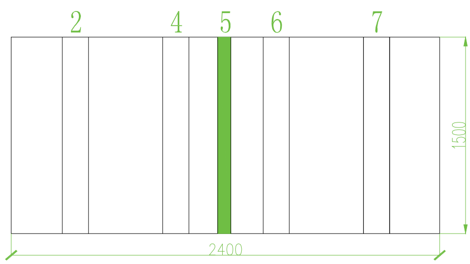


Figure 3: Plane figure

### 4.2 Equipment

The equipment used in this test was IES the scanning type impact-echo test system provided by Shenzhen Monite Corp, the main characters of which was 2% test precision after calibrating at the known thickness. And its roll sensor measures once each inch. There were two parts in IES, one is Freedom Data PC the data acquisition unit, another is IE Scanner the scanning impact receiving unit.
As shown in Figure 4 and Figure 5.

Figure 4: Freedom Data PC data acquisition unit

Figure 5: Receiver unit

1) Freedom Data PC data acquisition unit.
- 16 channel analog/digital PCI data acquisition card.
- National Instruments short-form PCI 12 bit A/D card.
- Sampling rate: each channel 1 m/s, and 16 channels are the same.
- Gain margin: ×1 to ×8000.
- Frequency range: DC-500000Hz.

2) IE Scanner the impact receiving unit
- Built-in solenoid impactor.
- Roll sensor testing wheel with six displacement sensors.
- Integrational impactor unit and receiver unit, which makes the test very quick.

### 4.3 Testing progress

1. Setting survey lines. In 10 cm spacing, 14 survey lines were drawn vertical to the direction of corrugated pipe and reinforcement known, and the lines should cover all corrugated pipes and steel bars that to be tested.
2. Setting service parameters. It can be carried out in accordance with the equipment operating instructions.

It is worth to note that the mechanical wave speed setting in the concrete is important. The impact-echo speed should be set accurately to guarantee the program correctly calculate the thickness of the structure under test. Supposed that thickness is known and the concrete structure under test is basically uniform, record the crest wave frequency in the frequency-domain window, and calculate the wave speed with the expression VP=2*d*f. In addition, before the formal test, repeating line continually is necessary to set gain appropriate multiples and make the waveform displays basically at the 2/3 position in time-domain window.

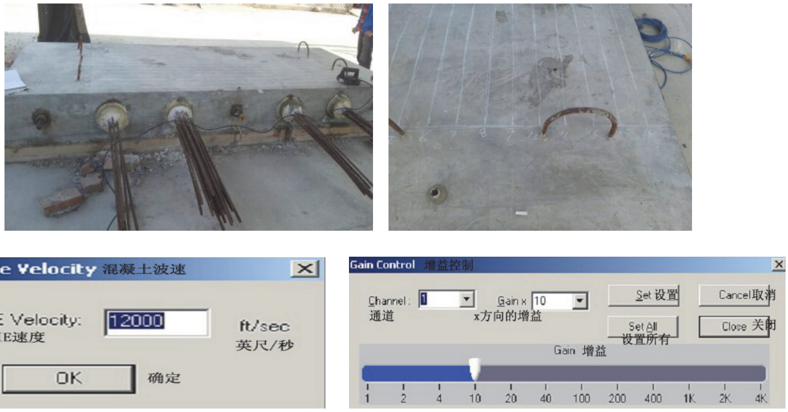


Figure 6: Parameter setting

## 4.4 The image results and analysis

1. Image results

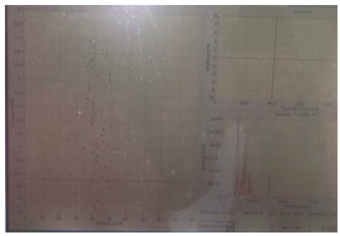

Figure 7: Surficial laitance and crack Figure 8: Data points collected at the scene

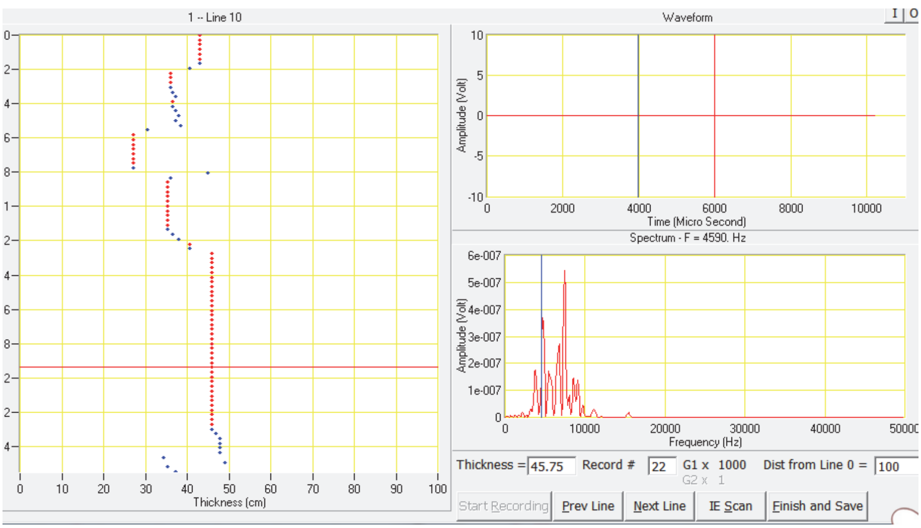


Figure 9: Playback image of the10th survey line

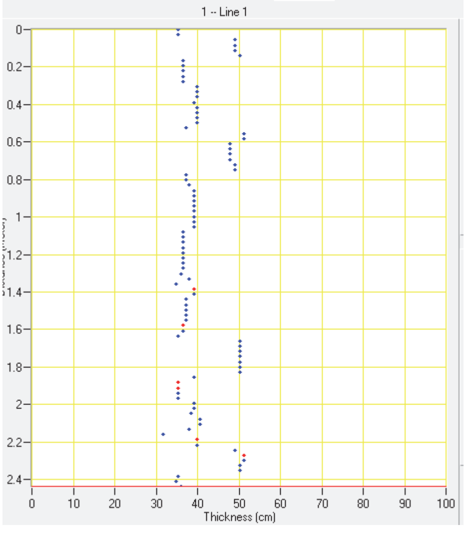


Figure 10: Pipe position

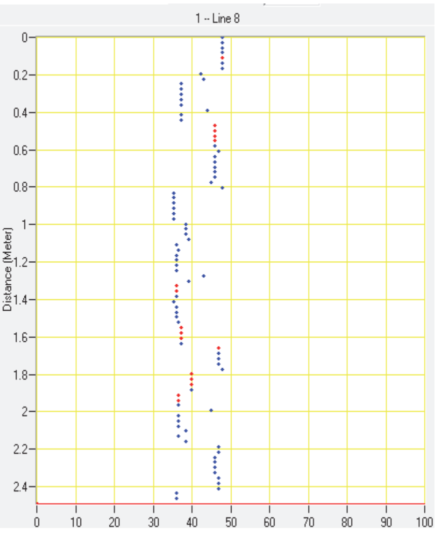


Figure 11: Steel position

The acquisition image and the 3D image in post-analysis software were shown in Figure 12. Some issues can be concluded as follows.

1) Image recognition in the process of acquisition

① The result of the test could be affected by the uneven and laitance surface. As figure showed, some local data points were messy and chaotic in the 10th servey line in the acquisition image, and many frequency peaks could be seen in the frequency -domain image.

② The result of the test could be certainly affected by surficial cracks. As figure showed, because of some surficial cracks the data points of that position in the next few survey lines were dispersed, and the frequency chart was irregular.

③ For the determination of pipe location, the coincide degree was ideal as collecting as comparing with the acquisition image, which was largely related to the relatively large pipe diameter near to 100mm.

④ The acquisition image of the 32mm diameter crude steel could also be recognized obviously. At the thick steel position, the data points were deviated from the position of normal thickness, and the degree of deviation was smaller than the corrugated pipe position.

⑤ The grouting state in pipe could not be recognized obviously in the acquisition image.

2) Image recognition in the process of analysis

① Surficial laitance, unflatness and crack were displayed with obvious different colors in the 3D analysis image and their scope was irregular, as Figure 12 shown.

② In Figure 12, four regular red humps were obviously the duct location. In addition, in the figure of the two ducts with defects, the display of the red ducts was slight white.

③ The thick steel with 32mm diameter was relatively obvious as shown in figure.

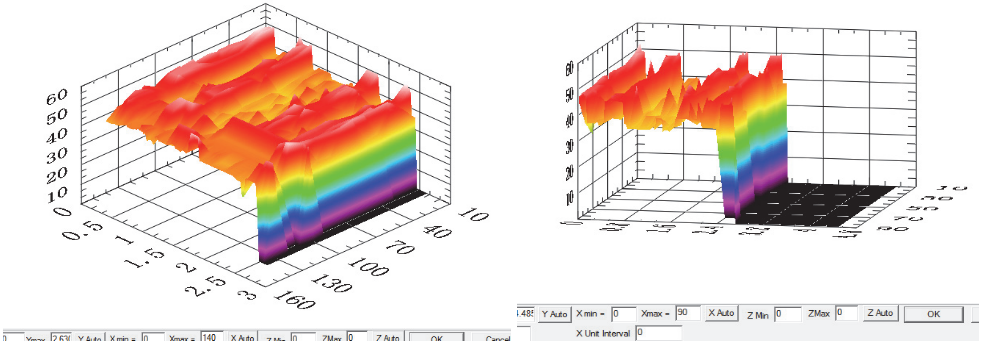

Figure 12: 3D display image

1. Analyzing

1) Analysis of the spectrogram

① For the spectrogram of normal concrete with no defects, the frequency curve is smooth and unimodal, and the frequency peak value follows the mechanical wave propagation law in concrete.

② For the spectrogram in the condition of well pouring concrete with tiny cavity and segregation defects, the frequency curve is smooth and unimodal, but the frequency peak value is smaller than that value of mechanical wave propagates in concrete, f1<f.

③ For the spectrogram in the condition of concrete with serious defects such as big cavity, the frequency curve is clipped and peak part is smooth, but a peak would be identified automatically by the instrument. Another fact caused clipping is that the concrete structure is very thick with on concentrated reflection energy, which is needed to be judged by the special situation.

④ For the spectrogram of prestressed components with plastic corrugated pipe and well grouted, the frequency curve turns up two peaks, the primary one is sharp and the subsidiary one is clipping.

⑤ For the spectrogram of concrete with defects, because of existing two reflecting surfaces the frequency curve turns up two obvious peak values, according to the position of the subsidiary peak the defects in concrete can be located.

2) Image analysis

Thus, pipelines and crude steel bars can be intuitively and effectively recognized. However, because of more steel bars in pipe and relative small defects in this test, only rough qualitative distinguish could be made based on the 3D images. Much more research work are needed to achieve quantitative results.

## 5 THE IMPACT-ECHO TECHNOLOGY FOR DEFECTS RECOGNIZATION

Adopting precast concrete test piece, in the piece simulating the actual need different defects of sizes, position, and shapes were preinstalled.

### 5.1 Making test specimens

The concrete grade was C50. The erection bars can be set for fixing the precast defects position, but cannot form a front occlusion to the defects. The specific locations of defects were shown as Figure 13. The materials of the prestressed ducts in test-piece IV were two types, plastic corrugated pipes and metal bellows.

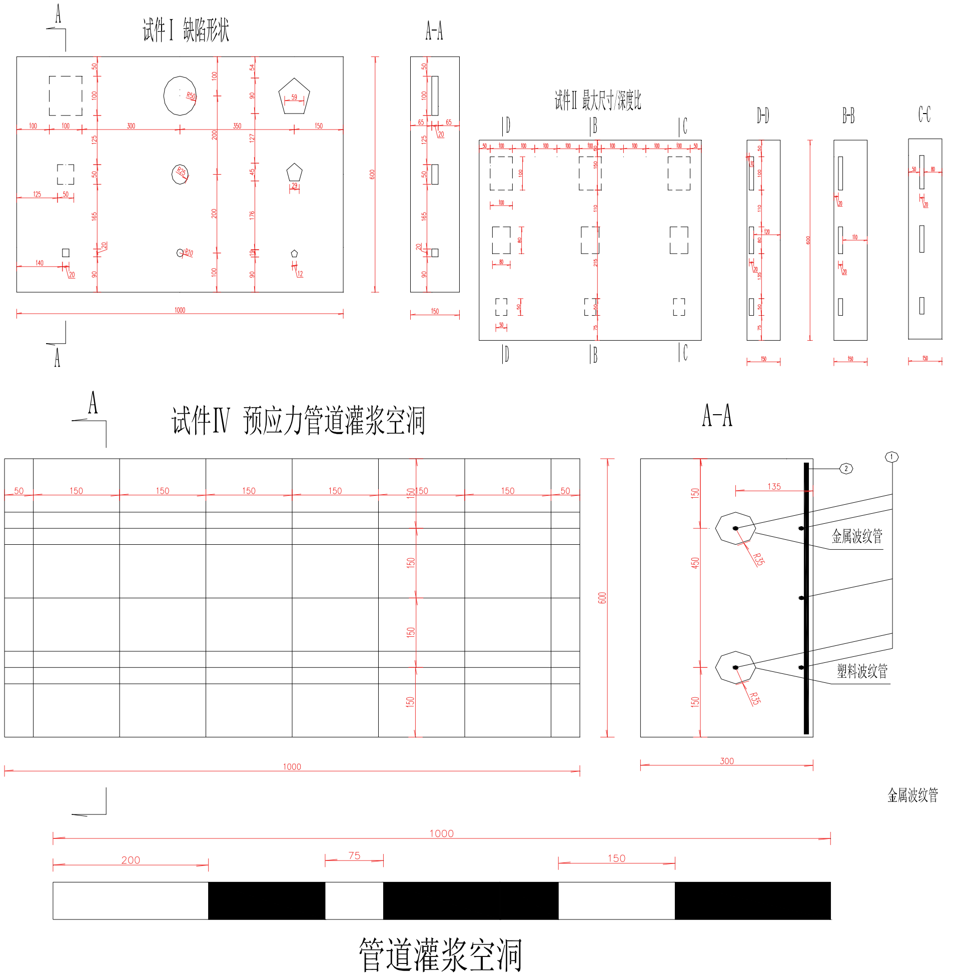


Figure 23: Defects arrangement

### 5.2 Equipment

The same with the equipment mentioned in Section 4.2.

### 5.3 Test Progress

Figure 34: Briquette 1

Figure 15. Briquette 2

Figure 46: Briquette 4

(1) According to the identification in the blueprint, determine the defect position.
(2) Set up measuring lines centering on the defect position. The measuring lines were all perpendicular to the long side of the test specimen, and covered all bellows and defect positions under test.
Seven measure lines were set in 1# test-piece, 5 measure lines were set in 2# test-piece, and six measure lines were set in 4# test-piece. The line directions of the receiver unit were all from top to bottom.
(3) Setting system parameters.

### 5.4 Image results and analysis

1. Image results
1) The image recognition in the acquisition process.

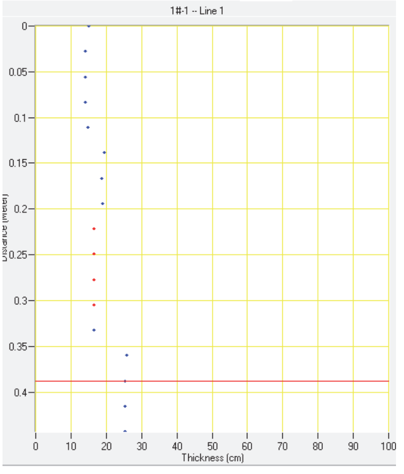


Figure 57: 1# test-piece

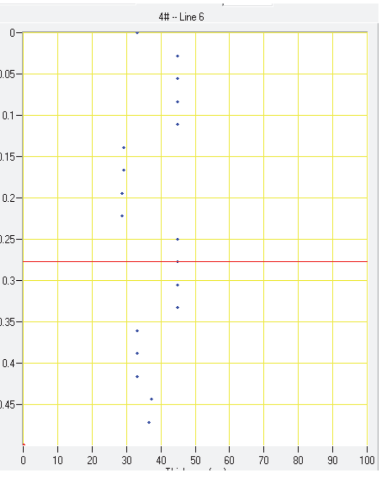


Figure 68: 4# test-piece

① For the thickness of 150mm 1# test-piece and 2# test-piece in the acquisition figure, the reaction of the large defect in the top were both obvious no matter what shape and position they were. At the position of the defect, data points were deviated and the deviated extent was the same.

② In the acquisition, the data points of the small defects in the lower position were hardly any deviation.

③ For different pipe materials in the 4# test-piece, there were no obvious different in impact-echo image. The pipe position could be determined, and the data points at the empty pipeline were deviated larger.

2) The image recognition during the analysis procedure.

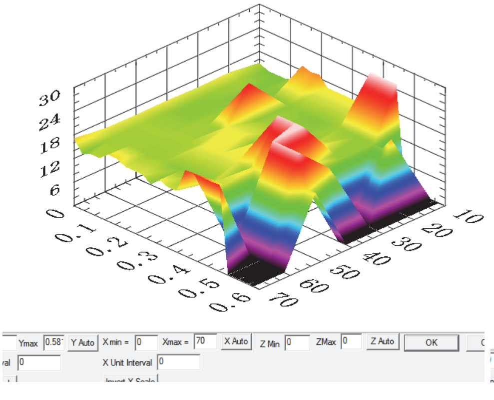

Figure 79: 1# test-piece

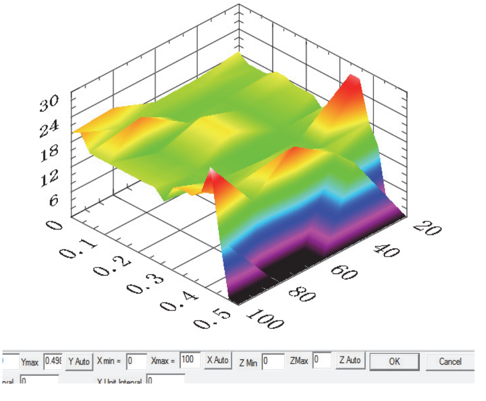

Figure 20: 2# test-piece

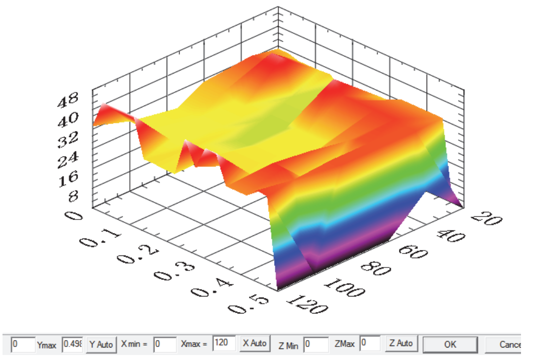


Figure 28: 4# test-piece

① In 3D image, for the 100mm diameter circular defect, the side length 100mm square defect and the side length 59mm regular pentagon big defect, the 3D images generated by impact-echo were very clear, but the original shape of the images could not be recognized.
② The recognition of ducts with impact-echo method will not be influenced by the material quality of the bellows.
③ For hollow pipes, it is easy to determine the grouting state based on the 3D figure, and the display images of grouting well duct are same with those of construction member.
2. Analyzing
Consequently, with the impact-echo technology large defects can be recognized easily and intuitively, while small defects are hard to be distinguished in acquisition image and can be barely found in 3D images. For no grouting corrugated pipes, the location can be detected accurately no matter what kind of materials it is made of. For well grouting pipes without steel, it is same with the surrounding materials in 3D image no matter during the acquisition or the post processing. In order to realize quantitative analysis, a lot of research work is still needed to do.

## 6 EXISTING PROBLEM

Each 2.54cm the impact-echo instrument travels, once an impact wave is sent. The frequency interval in this process will inevitably lead to some error. Furthermore, this kind of error will affect locating the boundary point in acquisition figure and confirming the image boundary in 3D figure, so that leading to inaccurate judging for defect size and grouting fullness. The key to solve the problem mentioned above is to establish the relationship between the concrete defect size with the graphic display with this method. That is, achieving the calibration of the defect figure, it will reduce the error effectively that recognizing the defect after amending image display by the result of the calibration.
In addition, nowadays the model test is too few for defect types in engineering, and the image library is still not established well. Accumulating the data is needed urgently in the future work.

# 7 CONCLUSION

The impact-echo method provides a very promising and convenient non-destructive testing method to identify defects and detect prestressed duct grouting quality in concrete bridge structures. Especially, this method can be complementary with the radar method in pipe grouting quality inspection. It makes up the shortcoming of the radar method which cannot detect the grouting plumpness in metallic conduit because of the total reflection of wave from metal medium. Some important experiences groped and some data accumulated in this paper are beneficial to the future engineering practice. Furthermore, before applying this impact-echo method to real projects in the future, a lot of research works are still needed.

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