Multi-technology Inspection for Increased Productivity in PPVC Construction

Abstract

Prefabricated Prefinished Volumetric Construction (PPVC) is increasing in popularity in Singapore and is even imposed on selected Government Land Sales sites. PPVC offers several advantages including enhanced productivity, which is now an even higher priority because of the pandemic. Inspection is required to ensure the structural integrity of PPVC structures but inspection is often considered a non-value adding, time-consuming process. This paper will illustrate how the use of a multi-technology inspection approach can ensure integrity, and how digital inspection tools can add value and enhance productivity.

Introduction

Offsite construction methods are growing in popularity in many countries including Singapore, UK and Japan. One such method is Prefabricated Prefinished Volumetric Construction (PPVC). PPVC involves fabricating and finishing 3D modules (usually rooms) off-site. At the construction site they need to be assembled together to form the complete building e.g. a block of flats. In dual wall design, the gap between the two prefabricated concrete walls is grouted, by injecting liquid grouting on site. By moving a lot of the work off-site, there are several advantages including improved productivity, better construction environment, improved site safety and tighter quality control. Some examples of completed PPVC projects in Singapore include the NTU Hall of Residence and Clement Canopy.

Although a main reason for employing PPVC is to increase productivity, this has not been fully realised because of several challenges, many around quality control. There are various inspection requirements on PPVC structures including (i) Quality control of precast concrete elements; (ii) Quality control of in-situ casting concrete elements; (iii) Grouting quality control and (iv) Structural defect inspection on existing/old PPVC projects.

Several non-destructive testing (NDT) methods are applicable to PPVC. These will be introduced in turn in the 'Materials and Methods' section, and their relevance for PPVC will be described. Results from Ultrasonic Pulse Echo (UPE), together with data representation on a digital inspection platform, will be presented and discussed in the 'Results and Discussion' section. It will be shown that the use of different inspection techniques coupled with the use of advanced software can increase the productivity and reliability of PPVC.

Ultrasonic Pulse Echo is the focus of this paper, since this is the most advanced NDT method applied to PPVC. The Proceq Asia team has worked closed with PPVC pioneers in Singapore to apply UPE to grouting quality control.

Materials and Methods

The rebound hammer is a common NDT instrument for estimating compressive strength quickly and without the need for coring. The operating principle is that a spring-loaded mass impacts the concrete surface and its rebound is measured and correlated to compressive strength. Ultrasonic Pulse Velocity (UPV) is similarly used for estimating compressive strength quickly and without the need for coring. However, the operating principle is very different. With UPV an ultrasonic signal is sent into the concrete using a transducer, and received using a second transducer.

The thickness of concrete through which the ultrasound has travelled must be known. The travel time is determined based on the send and receive times from the transducers. The velocity of the ultrasonic pulse can then be calculated. Since ultrasound is a mechanical wave, its velocity through a material depends on the mechanical properties of said material. Therefore, it is possible to estimate the concrete strength once the ultrasonic pulse velocity is computed. These two techniques can be used to measure the compressive strength of the precast PPVC concrete elements, at the fabrication site.

The combination of rebound hammer and UPV testing is referred to as the SONREB ("sonic rebound") method and gives a more accurate compressive strength estimation. This is another option for precast concrete elements.

An important inspection requirement is to check that grouting between concrete elements has been conducted properly. This is obviously done at the construction site itself. An option is to use UPV since the speed of the ultrasound can give an indication of the quality of the grouting. However, this does not provide the inspector with much information. They will only know that a particular volume of grouting probably has some defects, but their size and exact location will not be known.

Offsite data analysis is required to get further understanding so immediate evaluation is impossible. The coverage from UPV is limited so multiple measurements must be taken to cover a large area of concrete. A preferred option is Ultrasonic Pulse Echo (UPE) since this offers an actual image of any defects, amongst other advantages discussed below. Evaluation is possible immediately on site, which contributes to enhanced productivity.

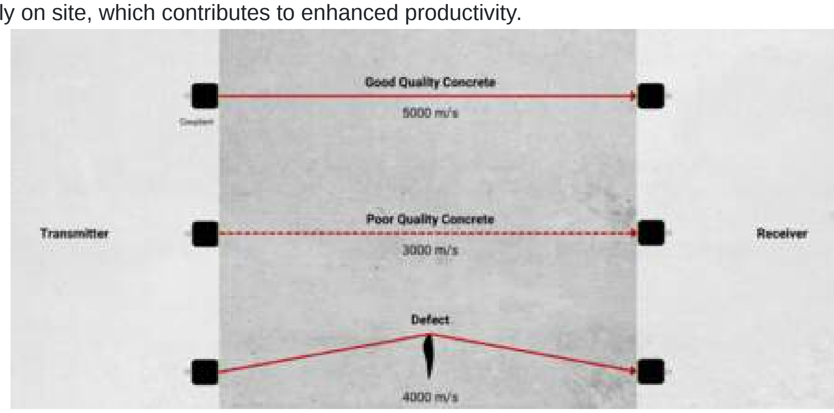

Figure 1 Ultrasonic Pulse Velocity (UPV) principle

With UPE, ultrasound is sent into the concrete and reflects off any boundaries or defects (Figure 2). The reflected ultrasound is received by the same instrument, therefore access only to one side is required, unlike with UPV. Another difference is that with UPE, typically an ultrasonic 'array' is used which means there are several transducers in one instrument which all transmit and all receive ultrasound. This generates a large number of signals which can be processed to get a cross-sectional 2D or even 3D image of the structure. A large area of concrete can be imaged with the instrument in a single position, and the instrument is moved along the concrete to generate many images which are automatically stitched together.

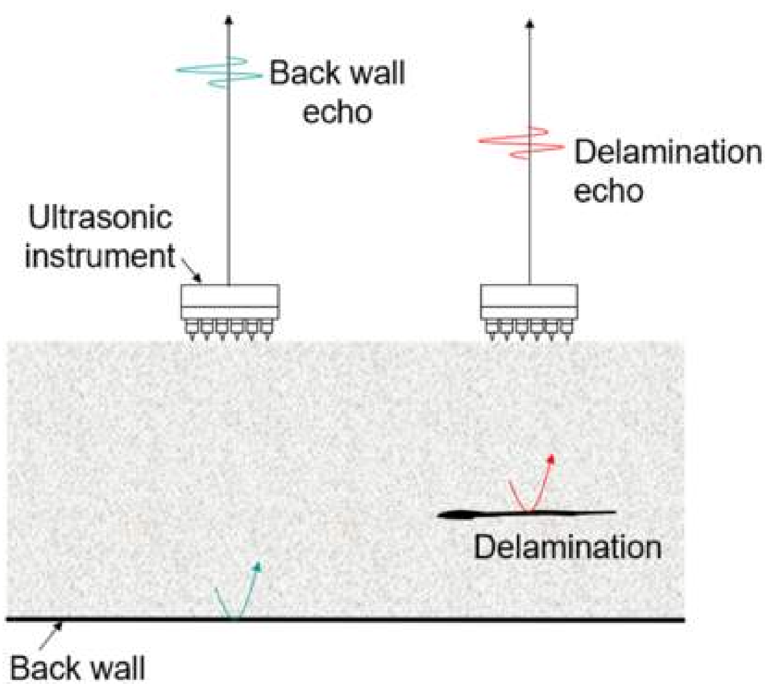

Figure 2 Ultrasonic Pulse Echo (UPE) principle.

On the left hand side of figure 2, a reflection from the total thickness (back wall) is shown. On the right hand side a reflection from a defect e.g. delamination is shown.

The principle of UPV and UPE are shown schematically in Figure 1 and Figure 2 respectively. Note that UPV requires ultrasonic couplant gel between the transducers and the surface, and UPE does not because Dry-Point-Contact (DPC) transducers are used. This is a further advantage of UPE especially for scanning large areas.

Over the years Proceq has developed several UPE array instruments, namely Pundit 250 Array, Pundit PD8000 and Pundit PD8050. The latter two are wireless instruments connected to internet-enabled mobile devices. A dedicate app on iPad is used. All data is backed up on a web server and can be accessed and processed securely from remote locations. The app allows users to generate reports on the field and also link automatically to other apps e.g. for inspection management.

Another NDT requirement for reinforced concrete is to detect the reinforcing steel bars (“rebars”). The two most popular methods for this are pulsed eddy current testing and Ground Penetrating Radar. Eddy current testing is a quick test which detects the presence of rebar and can also give an estimate of cover depth and diameter, but cannot detect any other objects. Ground Penetrating Radar (GPR) is an imaging technique, similar to UPE, but utilising radio waves instead of ultrasonic waves. These methods can be applied to precast reinforced PPVC elements.

Results and Discussion

In this section UPE results will be presented and discussed, including their integration with a digital inspection platform.

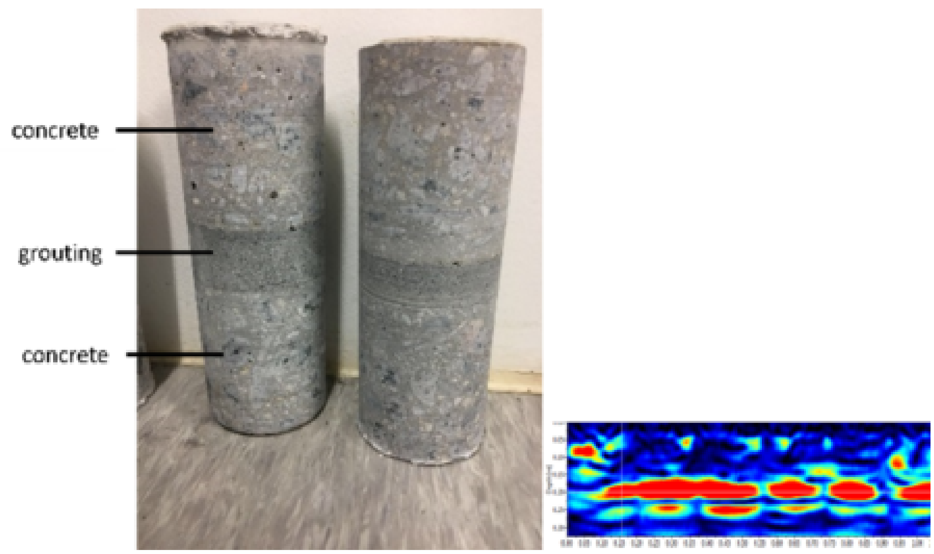

Figure 3 (a) and (b)

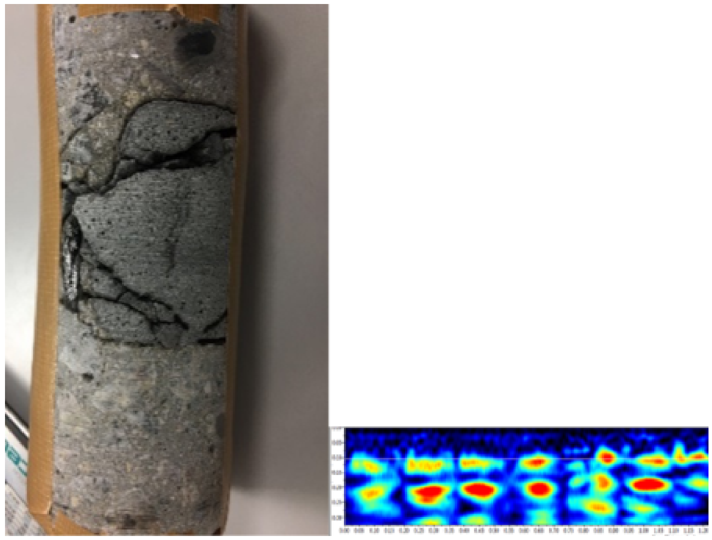

Figure 3 (c) and (d)

Figure 3 shows cores taken from a PPVC structure.

In (a) the cores consist of two layers of concrete with good quality grouting in between. The total thickness is approximately 20cm.

In (c) a single core is shown with defective grouting in between the two concrete layers. The total thickness of concrete-grouting-concrete is approximately 20cm but this time there are several defects in the grouting.

In (b) and (d) the UPE results taking with Pundit 250 Array are shown. In (b) there is a strong reflection (large red indication) at approximately 20cm which is what is expected from good quality grouting – the ultrasound passes straight through it and is only strongly reflected from the opposite wall. In (d) there is a strong reflection at approximately 10cm which refers to the depth of the grouting; this means that the ultrasound is being reflected from within the grouting so air (defects) must be present.

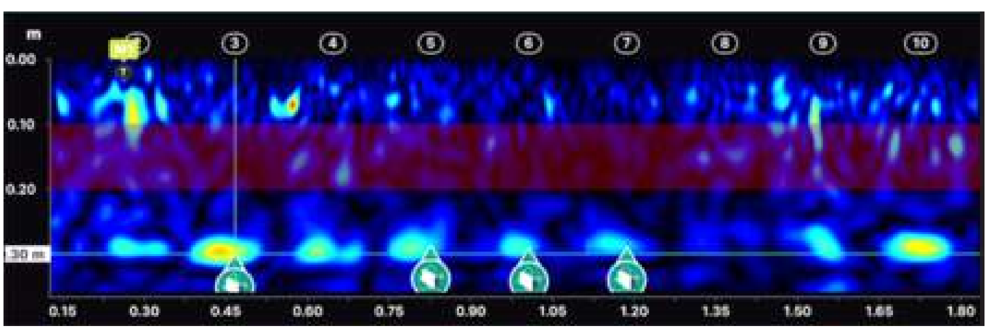

Figure 4 (a)

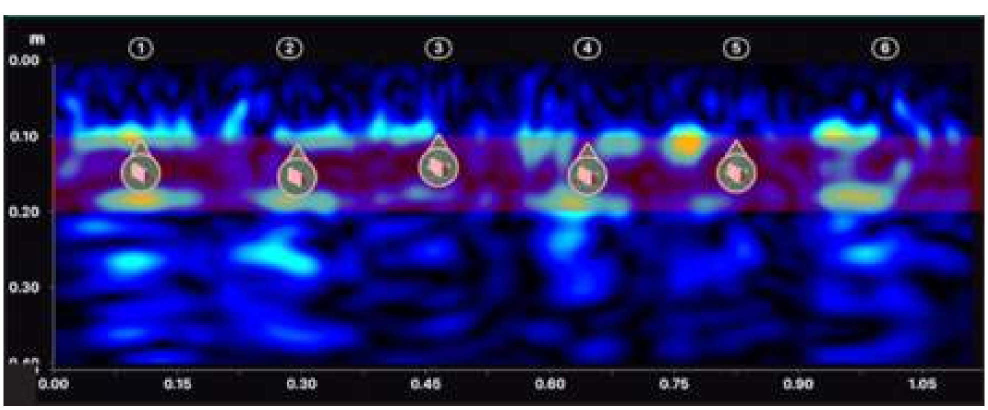

Figure 4 (b)

Figure 4 shows further examples of UPE data from PPVC structures; this time the total concrete-grouting-concrete thickness is 30cm and the grouting is Self Compacting Concrete (SCC). In (a) the grouting has been completed so a strong reflection is seen at 30cm. In (b) the grouting has not been performed yet so reflections are seen approximately midway, corresponding to the gap between the two concrete layers. This represents what really poor quality grouting (containing a lot of air) would look like with UPE.

Like most construction projects, PPVC involves large volumes of material that must be inspected, multiple work sites (both fabrication and construction sites), large volumes of inspection data and many stakeholders. It is therefore important that inspection data is stored digitally, and on secure cloud servers so that it can be accessed by the relevant stakeholders, even several years into the future. Ideally the data collection and web storage is seamless i.e. the data is collected directly onto an internet-enabled mobile device and automatically sent to the cloud. In this way the operator does not need to spend any additional time or effort saving the data.

Furthermore, it is important that location data is stored together with the inspection data. This should not just be a rough GNSS position, or a postal address, but an exact location against a floor plan of the project. Proceq engineers are now working with PPVC pioneers in Singapore to do this using their new software, Screening Eagle INSPECT.

INSPECT is a comprehensive, intelligent software platform with many functions for improving the productivity, quality and reliability of pre-inspection, inspection and reporting tasks. In the context of PPVC structures it allows users to assign NDT data, e.g. UPE data, to an exact location in a housing unit. An example is shown in Figure 5. Data from other inspection methods and inspection sites, e.g. rebound testing at the fabrication site, can also be included.

Conclusions and Recommendations

The use of PPVC has the potential to greatly improve construction productivity, yet poses several inspection challenges. Through good planning and the selection of the right inspection tools, it is possible to inspect a structure rigorously without expending much time or energy. As this article has shown, a multi-technology approach is required with different inspection technologies employed for different inspection requirements.

A further recommendation is to use internet-enabled mobile devices to collect the data and automatically send it to secure cloud storage. This will further increase productivity and reliability of PPVC structures. Furthermore, ideally the inspection data is stored together with its location e.g. exactly which part of which housing unit the ultrasonic data was taken from. The benefit of doing this will be most strongly felt several years in the future when inspection data of PPVC structures must be revisited, for example because of a failure of a similar structure, or when retroffiting/refurbishment is to be performed.