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2019

This article was originally published at:

https://doi.org/10.1016/j.cscm.2019.e00240

Case Studies in Construction Materials 11 (2019) e00240

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case study

Applicability of GPR and a rebar detector to obtain rebar information of existing concrete structures

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ARTICLE INFO

Article history:
Received 6 January 2019
Received in revised form 9 April 2019
Accepted 11 April 2019

Keywords:
Rebar characteristics
Non-destructive testing
Accuracy
Ground penetrating radar
Electromagnetic field
Rebar detector

ABSTRACT

Much of Canada's existing infrastructure was constructed during 1950s, 1960s and 1970s. These include all transportation infrastructures such as bridges, highways, tunnels, etc. It is important to know the condition of these aging infrastructures in terms of their load carrying capacity to ensure their safety and serviceability. There are several old reinforced concrete slab bridges within the network of Ministry of Forests in B.C. Canada that have unknown rebar spacing, cover and diameter. This research paper discusses the application of Ground Penetrating Radar (GPR) and a Rebar detector in obtaining valuable information about rebar diameter, spacing and cover depth required to determine the structural capacity (load rating) of bridge decks. For this, GPR and the rebar detector have been applied on an existing bridge deck, a precast bridge girder and a reinforced concrete test slab panel available in the materials lab at the Facility for Innovative Materials and Infrastructure Monitoring (FIMIM) at the University of Victoria (UVic). To assess the applicability of GPR and Profoscope (Rebar Detector) in obtaining rebar information, the results obtained using both the techniques were compared in terms of their errors in determining all three parameters of rebar; diameter, spacing and cover depth. The results were validated by measuring the actual diameter, spacing and cover depth of the rebar in the reinforced concrete test slab available in the lab at UVic.

1. Introduction

A large part of Canada's infrastructure was constructed between 1950–1970. This includes water mains & Sewers but also includes bridges and overpasses. In Canada bridges have a mean service life estimated at 43.3 years and in 2007, they passed 57% of their useful life already [1]. It is important to know the condition of these aging infrastructures in terms of residual load carrying capacity to ensure the safety and serviceability of the structures and people using them. The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRO) currently maintains over 6000 bridge structures across British Columbia [2]. There are several old bridges under the network of MFLNRO of British Columbia that have unknown rebar spacing, cover and diameter due to the non-availability of their structural drawings. Information on rebar diameter, spacing and cover depth is essential in determining the load rating (Structural Capacity) of bridge decks. The present research uses two different non-destructive testing techniques to determine rebar diameter, spacing and cover

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https://doi.org/10.1016/j.cscm.2019.e00240

depth in reinforced concrete sections. The principle of both the techniques along with the previous research work is described here in this section separately for ease of reading.

2. Ground penetrating radar (GPR)

GPR's popularity is due to its advantages over the other techniques. Benedetto et al [3] describes the advantages of GPR and the major GPR strengths for its use in the field of civil engineering. These include the non-destructive nature, lower costs compared to the traditional methods, and higher reliability in the measurement.

The most common and wide use of GPR for concrete analysis has been found for mapping delamination in Reinforced Concrete (RC), detecting pipes, finding steel rebar and identifying thickness of pavements [4,5]. Apart from identification of the defects in RC, GPR is also being used for verifying design plans by mapping the true rebar grid layout and prestressing tendons [6].

Although many researchers have published their work related to identifying rebar diameter [7–9], the signal processing techniques they proposed, have been proven to be difficult and time consuming.

It should be noted that GPR does not directly measure the diameter of a rebar, cable or conduit [10]. GPR when used with the larger diameter of rebar, can produce a stronger reflection of the radar wave. Due to signal wavelength, any object under 2″ (5 cm) in diameter is a "dot" with no visible size [10]. It should be noted that the reflection strength depends on several factors such as depth of the slab, area of slab and properties of concrete and steel. Thus, it is very difficult to obtain an accurate measurement of diameter of rebar in concrete.

Rudimentary estimations of rebar diameter can be made, if the rebar is stacked perpendicularly, by subtracting the cover of the top rebar from the cover of the bottom rebar. This method can be accurate up to 3 mm, but can only estimate the top rebar diameter [11]. The present research uses this methodology. However, this is not helpful in most Ministry applications, as the top rebar is typically shear stirrups which are almost exclusively 10 M (11.3 mm) rebar.

The GPR equipment normally consists of two antennas; transmitter and receiver antenna, a radar control unit, data acquisition system and display devices. GPR technique detects the changes in electromagnetic properties of the material from the reflected Electro Magnetic (EM) waves that are sent into the material's subsurface. It uses high-frequency-pulsed EM waves (from 10 to 3000 MHz) (often called radar waves) to acquire subsurface information. The present research uses a GPR (Model Name- Structures Scan Mini) that utilizes 2600 MHz electromagnetic waves transmission antenna to detect the subsurface features.

2.1. Post processing of GPR data and development of 3-Dimensional maps

2-Dimensional line scans collected by Structures Scan Mini is post processed using the control unit's post processing software. The post processing includes time zero correction (set ground surface), background removal (remove horizontal banding), band pass filtering (remove high/low frequency noise), and Range Gain (normalize gain curve across depth range). It also performs automatic depth calibration. Once a depth measurement is obtained, the signal velocity and dielectric constant can be calculated using the two-way travel time (2WTT) from the radar data. This can always be done manually (Velocity = 2 x (Depth/ 2WTT)), but the authors have used StructureScan (GPR)'s automated depth Calibration feature that performs the calculations and adjusts the depth scale. If several layers are present between the surface and the measured target, the calculated velocity or dielectric is the average of these layers at the calibration point.

In-order to convert 2D profiles into 3D maps, a 3-dimensional mapping function integrated within the Structure Scan Mini's control unit was used in this research. This function performs a fairly linear interpolation between adjacent profiles on a grid to map subsurface features as a function of the depth of slab. The 3D gridding process itself does not introduce significant errors. The major source of errors in 3D datasets are inherited from data collection, such as incorrect distance encoder calibration, position of the antenna on starting/ending grid baselines, improperly configured survey grid, local topographic irregularities, and other variables [10].

It should be noted that one of the most important elements of post-processing of GPR data is calibration of depth. Calibration of depth is achieved using a process/algorithm called migration. Structure Scan Mini uses Kirchoff's migration algorithm [12] to remove hyperbolic tails by collapsing them into dots representing the actual targets (in this case rebar). Also, data with hyperbolic reflections need to be migrated in order to achieve a quality 3D display [10]. The migration process is very useful (it reduces clutter in the image) when identifying rebar that are close to each other in a concrete slab.

3. Rebar detector (profoscope)

Unlike GPR, the Profoscope uses the magnetic field to identify rebar layout in concrete. It uses electromagnetic pulse induction technology [13] to detect metallic object beneath the concrete surface. As can be seen in Fig. 1, the pulse induction technology has coils that are charged using the current pulses to generate magnetic field around the electrically non conductive concrete surface. The magnetic field generated by coils is opposite in the direction which creates the difference in voltage that can be used for the measurement. Using signal processing techniques, the rebar detector determines the various characteristics such as cover depth, diameter and spacing of rebar.

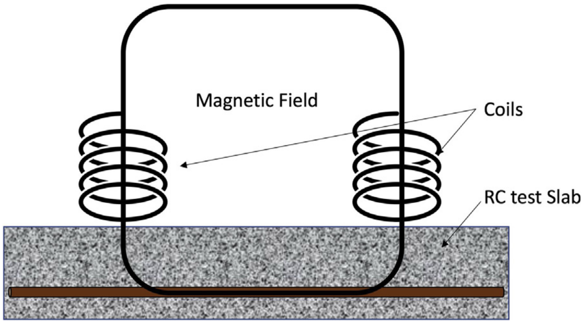

Fig. 1. Measurement Principle of Profoscope (Rebar Detector).

There are several research articles that describe the effectiveness of a rebar detector for its use in detecting rebar embedded in RC sections [14–17]. This particular paper describes the use of a Profoscope from Proceq, in determining rebar diameter, cover depth and spacing in concrete sections. It is suggested that before testing, the Profoscope must be calibrated, and all metal must be removed from the area. The calibration of Profoscope is performed on site right after turning on the equipment using the test jig provided by the supplier. All the metallic objects (rings, watches, keys, tool box etc.) are kept at least 3 m away from the calibration setup. When a rebar is passed under a Profoscope, crosshairs travel across the screen. When the cross hairs are in the middle of the screen, a light illuminates to indicate the Profoscope is over a target. The nature of this technique makes it difficult to know what the orientation of the rebar is. A method to determine the orientation of the rebar is to move the Profoscope around this target, until the target light remains constant, meaning the rebar is parallel to the line of movement. This method can be difficult to perform if there is a high concentration of rebar in the slab. Rebar diameter can be accurately measured when the rebar is spaced 150 mm apart and the cover is less than 65 mm [18]. Measuring range and standard resolution of Profoscope depends on the rebar diameter. The charts showing the effects of rebar diameter on measuring range and standard resolution are given in [15].

3.1. Research significance

The present research demonstrates the applicability of the Profoscope and GPR to determine rebar information such as diameter, cover and spacing in existing RC bridge decks. Past research shows that the Profoscope and GPR both could be used to detect and characterize the features of sub-surface metallic objects in concrete sections. However, research conducted in the past on comparison of both the methods in terms of accuracy in determining rebar information is very limited. This information would be very valuable to the infrastructure owners (e.g. MFLNRO) in making necessary decisions for managing their structures. The paper also highlights the key challenges of both the techniques that were faced during the experiments.

3.2. Experimental investigation

Experimental work was carried out at three different site locations: a) Stocking Creek Bridge Site (SI-3006A) in Duncan, BC, Canada b) Surespan Structures precast facility and c) Civil Engineering Materials lab at University of Victoria. GPR and Profoscope were applied on three different RC sections at different site locations. A smaller area of the slab examined at Surespan was measured due to time constraints, which means fewer assumptions can be made for the rest of the section of the bridge. It should be noted that during the experiments conducted at the bridge site and at the precast site, the weather conditions included cloudy skies with a few showers and ambient air temperature of about 7 °C. The experiments were conducted right after the showers. At the Civil Engineering Materials Lab, the test slabs were in a controlled environment (ambient air temperature 15 °C) isolated from the outside weather. Procedure of conducted non-destructive testing at all three locations is described here separately.

4. Reinforced concrete Bridge deck at site Si-3006A

The reinforced concrete precast bridge deck at Site SI-3006A (Fig. 2) located at 10675 S Watts Rd. Ladysmith, BC, Canada (48.947040, −123.785428) was assessed from the bottom side using GPR and Profoscope. Record drawings were not reviewed prior to proceeding with experiments to simulate assessing a bridge with unknown reinforcement. To perform the Profoscope and GPR tests, a 2′x 2′ (610 mm x 610 mm) grid (169 data points) was drawn on the bottom side of the bridge deck. The location of the grid was measured relative to the edge of the structure for reference.

In order to calibrate the Profoscope, all metal was removed from the testing area. The diameter input of the Profoscope was estimated to be 20 mm, as the rebar diameter was not known. No spacing adjustment was made, as the spacing of the rebar was a parameter to obtain from the test. To detect lateral rebar, the Profoscope was placed on the y-axis of the grid and moved in the positive x-direction until the Profoscope indicated the location of a rebar with a constant beeping sound with

a) b)

Fig. 2. GPR and Profoscope tests on the bottom of the bridge deck slab; a) Test grid, b) Test Site SI-3006A.

red light. The coordinates, cover, and diameter of the rebar were marked on the grid. The Profoscope was then moved in the x direction until all lateral rebar which were located on the x-axis within the grid were identified. This process was done a total of two times, increasing the y-value each time. To detect transverse rebar (rebar running in the x-direction), similar methodology was used. GPR data was collected using the same 2′x 2′ (610 mm x 610 mm) grid used previously. The GPR was run along each of the grid lines, totaling 26 different passes with the GPR (13 vertical lines, 13 horizontal lines).

5. Precast Bridge girder at surespan structures

The procedure undertaken for performing non-destructive testing at Surespan Structures was similar to the procedure prepared for the testing at the bridge site. The girder tested at Surespan Structures was a 12 m concrete interior slab. Instead of a 2′x 2′ (610 mm x 610 mm) grid size, a 1′x 1′(305 mm x 305 mm) paper grid was used due to closely spaced rebar. The actual (design) rebar spacings are given in Table 1.

The grid paper was taped to the top surface of the concrete girder as can be seen in Fig. 3. The location of the grid paper was measured relative to the edge of the structure for reference.

6. Reinforced concrete test slab panel at the university of Victoria

Reinforced Concrete slab panel was tested at the University of Victoria using both GPR and Profoscope. Testing was performed on one of the 914 × 914 × 140 mm (thick) concrete slabs with a single layer of 10 M (11.3 mm) reinforcement. This slab was further destructively tested to validate the rebar cover and spacing obtained by GPR and Profoscope.

In order to collect the data using GPR and Profoscope, a 2′x 2′ (610 mm x 610 mm) paper grid was taped to the top surface of the concrete slab, as seen in Fig. 4. Fig. 5The location of the grid paper was measured relative to the edge of the concrete sample in order to identify the exact location of the test results. Guidelines of the grid were traced onto the slab for use

Table 1
Comparison of Profoscope and GPR average estimates versus drawing values.

Rebar Parameters (Average values in mm)		Site SI-3006A			SureSpan Structures			Materials Lab at University of Victoria		
		NDTs		Actual	NDTs		Actual	NDTs		Actual
Type	Direction	Profoscoe	GPR		Profoscoe	GPR		Profoscoe	GPR	
Cover	Lateral	33	34	40	84	95	65	77	93	112
	Transverse	28	24	30	83	74	75	86	106	123
Spacing	Lateral	120	73	75	104	148	125	218	236	229
	Transverse	187	150	125	255	204	200	227	234	229
Diameter	Lateral	40	Could not be determined	30	Could not be determined	Could not be determined	16	9	13	11.3
	Transverse	30	10	11.3		22	11.3	Could not be determined	Could not be determined	11.3
Cover (Difference)	Lateral	−7	−6	–	19	30	–	−35	−19	–
	Transverse	−3	−6	–	8	−1	–	−37	−17	–
Spacing (Difference)	Lateral	45	−2	–	−21	23	–	−11	7	–
	Transverse	62	25	–	55	4	–	−2	5	–
Diameter (Difference)	Lateral	10	Could not be determined	–	Could not be determined	Could not be determined	–	2.3	1.7	–
	Transverse	19	−1.3	–		10.7	–	Could not be determined		–

Fig. 3. GPR and Profoscope tests on the top the precast girder at Surespan Structures.

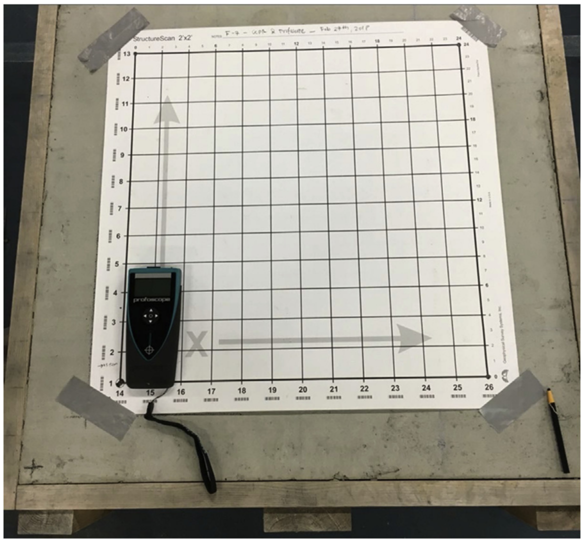

Fig. 4. GPR and Profoscope tests on the top the reinforced concrete slab panel at the University of Victoria.

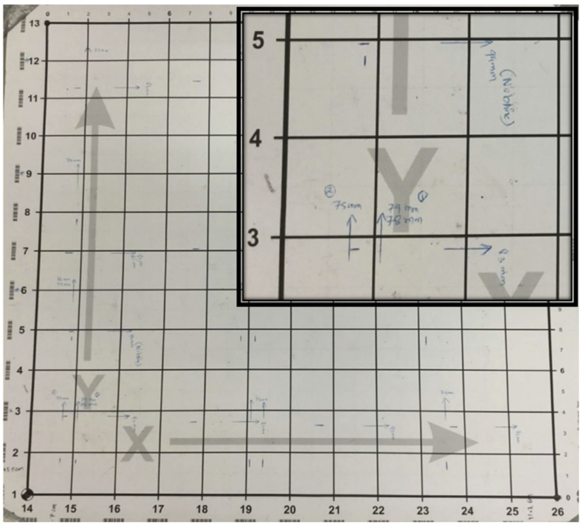

Fig. 5. Mapped Profoscope data on the 2′ X 2′ grid (610 mm x 610 mm) (Arrows in the zoomed view indicate the direction of the rebar; the numbers indicate the cover of the rebar. No diameter was obtained as the cover was over 65 mm).

during future destructive testing. To identify rebars in both the directions, Profoscope and GPR was moved in both the directions. For Profoscope, measurements were taken along the lines y = 3, 6, 9, and 12 respectively when detecting lateral rebars. For transverse rebar detection using Profoscope, measurements were taken along the lines x = 16, 19, 22, and 25 respectively. Please note that each line on the grid is spaced at 50.8 mm.

GPR data was collected using the same 2′x 2′ (610 mm x 610 mm) grid. The GPR was run along each one of the grid lines, for a total of 26 different passes with the GPR (13 vertical lines, 13 horizontal lines).

7. Results and discussions

The collected results from both techniques are discussed separately for the ease of understanding.

8. GPR

The collected GPR data was modelled in the GSSI software called RADAN. In order to compare the GPR data with the record drawings, the GPR data points (in-terms of x–y co-ordinates) were exported as a csv file and modelled into AutoCAD software. RADAN uses specialized module- StructureScan to map reinforcement over large areas in large structures. Prior to the depth calculation, the concrete surface is automatically located into the software. RADAN software locates the points of maximum amplitude within the slab layers or rebar [10]. The software extracts coordinate and amplitude information into a numerical database which is then exported into a csv file as mentioned earlier.

In Figs. 6–8, the GPR data points were modelled in red while the record drawings (design rebar grid) were modelled in black. It can be seen that the modelled GPR results do not exactly match the record drawings. However, in the data from all the experiments, the shapes of the grids were reflective of the designs as can be seen in Figs. 6–8. The error in determining the spacing at the University of Victoria was minimum for both directional (lateral and transverse) rebar. In addition the lateral rebar spacing at Site SI-3006A was 73 mm compared to 75 from the drawing and the transverse rebar spacing at

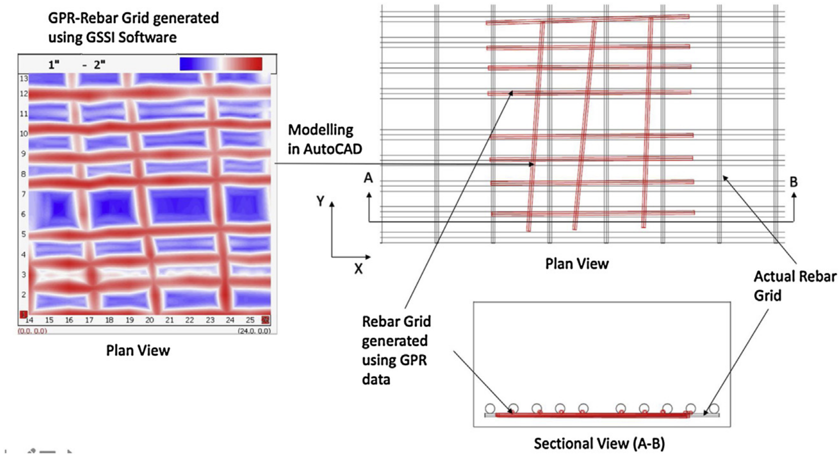

Fig. 6. Rebar Grid generated using GPR data (RC Bridge Deck Slab at Site SI-3006A).
Note: The rebar co-ordinates from the GPR rebar grid are reversed in the AutoCAD model.

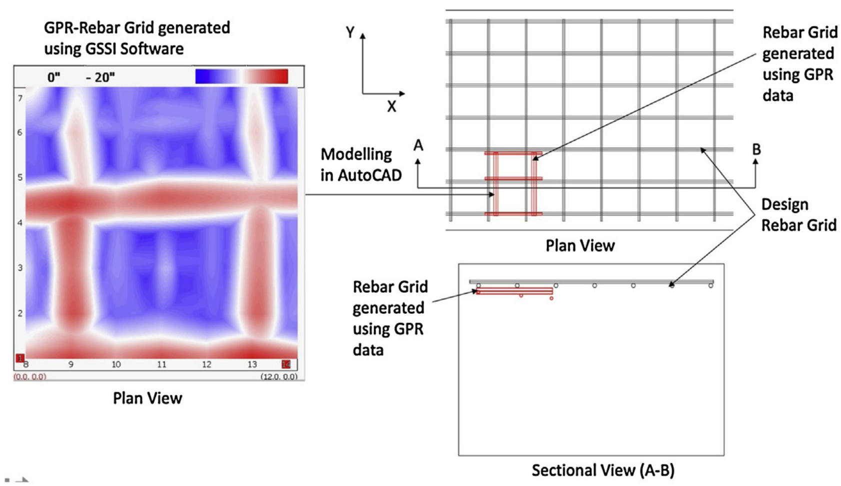

Fig. 7. Rebar Grid generated using GPR data (RC Precast Girder at Surespan Structures).

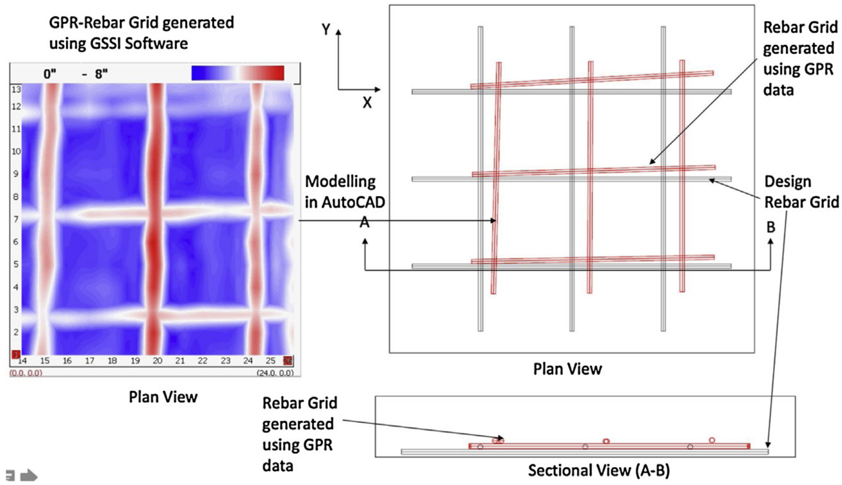

Fig. 8. Rebar Grid generated using GPR data (RC slab panel at the University of Victoria).

SureSpan Structures was 204 mm compared to 200 mm from the drawing. The other two instances, transverse rebar spacing difference at Site SI- 3006A and lateral rebar spacing difference at SureSpan Structures were very high as can be seen in Table 1.

The covers were found to be within 30 mm of the design drawings. The diameter of the rebar could only be obtained for the first rebar from the surface. The rebar diameter measured for the slab located at Surespan was estimated to be 22 mm when it is actually 11.3 mm (10 M), which is a significant error. The possible reasons for this could be the closely spaced rebar and/or the thickness of the girder. The diameter values obtained using GPR at other locations (at Site SI-3006A and the lab) were close (difference of 1.3 mm (at SI-3006A) and 2.3 mm (at the lab)) to the design values.

Errors of measurement with the GPR were likely introduced when drawing and measuring the grid. Small skews in the alignment of rebar were likely caused by incorrectly measuring the squareness of the grid with relation to the slab. This error was likely to be most prevalent on the slab from SI-3006A, as the paper grid would not stay on the bottom surface of the bridge, so the grid had to be drawn by hand. Other misalignments with existing drawings could be due to variation in construction, such as adding additional rebar, or lap splicing. The two girders tested in the field may have had different surface moisture content. The variation of surface moisture on the slabs may have affected the accuracy of the GPR because the dielectric constant (an input of the GPR which effects signal resolution) changes with moisture within concrete. Different values of dielectric constants were assumed depending upon the type of concrete. Dielectric constant of 6 was chosen for moderately dry concrete and 9 for saturated concrete. A dielectric of 3 to 12 corresponds to radar velocities from 7 to 3.5 in. per nanosecond (or 18 to 9 cm per nanosecond), respectively. GPR determines the radar velocities depending upon the chosen dielectric constant.

8.1. Key challenges of using GPR (structurescan mini) in the field

Following is the list of some of the key challenges that authors have faced during the use of GPR,

1. While moving the equipment on the grid, it is very difficult to maintain the alignment. Any misalignment has a direct effect on the results produced.

2. StructureScan mini requires the concrete surface to be smooth as the wheel size are very small. Concrete surface irregularities may introduce error in rebar grid mapping. In addition, GPR will also detect any subsurface anomalies such honeycombing, delamination and voids due to difference in the dielectric constant. Any subsurface anomalies will be displayed in the 3D rebar grid map. It should be noted that any subsurface defects may not necessarily interfere the results of mapping rebar grid as the dielectric constant of steel is very different.

3. The equipment is very difficult to work with when used underneath (upside-down) or on the side of a slab or girder.

9. Rebar Detector-Profoscope

From the testing on three different types of RC slabs, it was found that the Profoscope tests were much more prone to error. The method used works well for slabs with largely spaced reinforcement that have drawings available due to the fact that the instrument requires estimated rebar diameter for higher accuracy. It was very difficult to identify rebar when testing a slab with unknown reinforcement, or tightly spaced rebar. Also, it is difficult to differentiate between a lateral and a transverse rebar, or if the measurement is being taken at an intersection between the two.

The test results from the bridge deck (Fig. 9) and the precast girder (Fig. 10) both poorly reflected the general shape of the rebar grid: missing rebar, large skews, and strange spacing. As noted, the results obtained by the Profoscope on RC slab panel at the University of Victoria reflected the layout of the grid well (Fig. 11), and rebar spacing was estimated to be within 7 mm of the design drawings. This is likely due to the larger spacing between the two rebars.

The average spacing for the Profoscope testing ranged from 2 to 62 mm of the design. The average cover was within 37 mm of the design, which is a large range. The Profoscope can only measure rebar diameter to a depth of 65 mm, as such, only the diameters of the slab at SI-3006A could be determined. Measured rebar diameter was within 10–19 mm (for lateral rebar: Profoscope result = 40 mm, and design value = 30 mm, for transverse rebar: Profoscope result = 30 mm, and design value = 11.3 mm) of the design drawings.

9.1. Key challenges of using Profoscope in the field

In addition to the limitations mentioned above, following is the list of some of the key challenges that authors have faced during the use of Profoscope,

1. The equipment requires a firm contact with the concrete surface in order to detect rebar in concrete. It is difficult to maintain firm contact when concrete surface is not smooth.
2. The sensitivity of the equipment in detecting rebar is quite low.

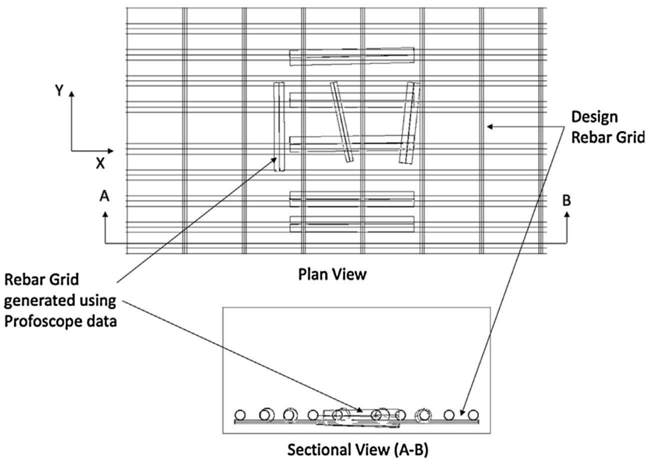

Fig. 9. Rebar Grid generated using Profoscope data (RC Bridge Deck Slab at Site SI-3006A).

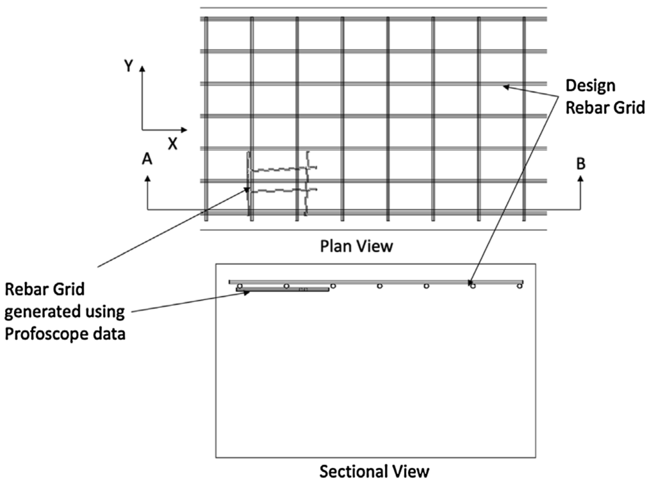

Fig. 10. Rebar Grid generated using Profoscope data (RC Precast Girder at Surespan Structures).

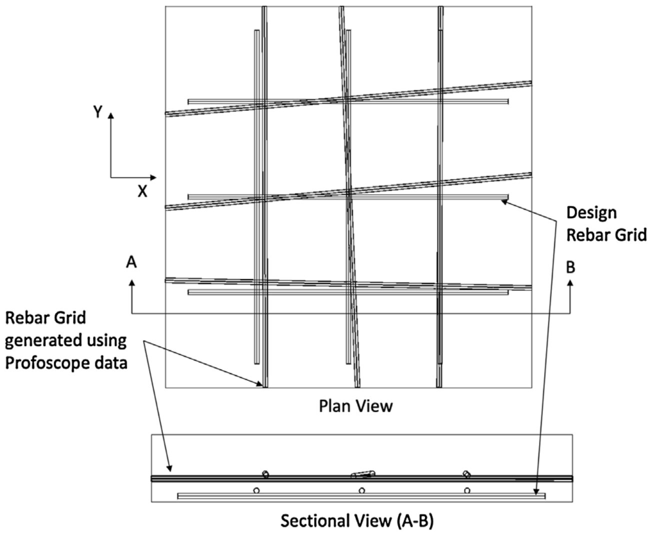

Fig. 11. Rebar Grid generated using Profoscope data (RC slab panel at the University of Victoria).

10. Destructive Testing

In order to validate the NDTs' results, the RC slab at the University of Victoria was destructively tested to expose the rebar using a chisel and hammer as shown in Fig. 12. This was the only way to confirm the results of the NDTs against a "real" value. It was found that the spacing and cover both were equal to the dimensions mentioned in the drawings. The results obtained from the NDTs were compared against the drawing dimensions as shown in Table 1.

It should be noted that the RC deck slabs at other two sites were not destructively tested due to restriction from the owner. However, both the slabs were constructed in a very controlled envirement at SureSpan Structures precast facility. It was assumed that the rebar grids were placed according to the design drawings.

11. Accuracy model of GPR and profoscope

In order to determine the measurement accuracy of both the techniques, the values obtained were compared against the true values given in the drawings. It is assumed (with the exception of the test slab at UVic) that the values in the drawings are the true values. The values compared in Table 1 were used to determine the percentage error in the measurements. Fig. 13 shows the calculated percentage error of both techniques at all three locations.

Percentage error from the rebar cover data collected from Profoscope was 14%, 20% and 31% at the Bridge site, at Surespan Structures and at UVic respectively. This shows that as the rebar cover increases the error from the data collected by the

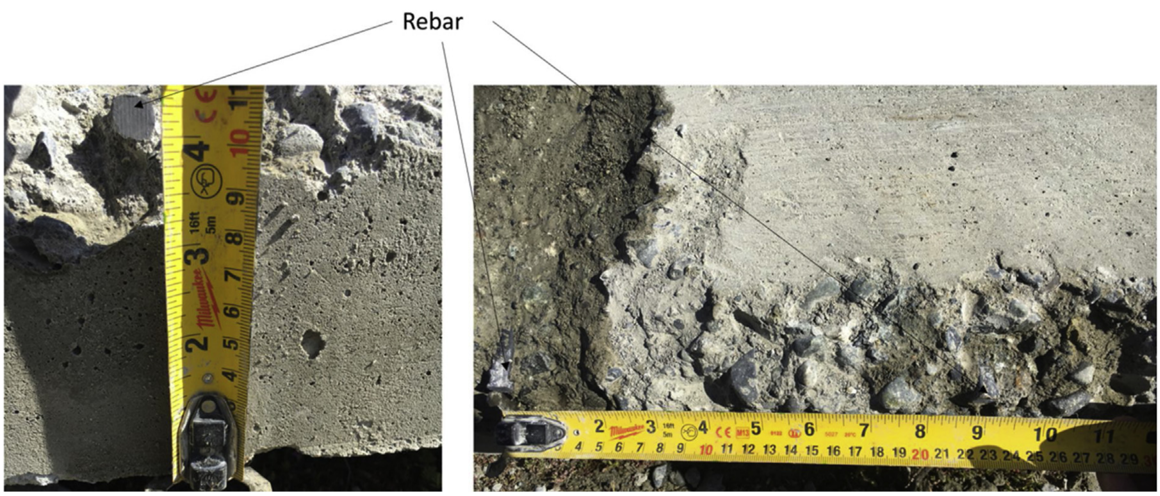

Fig. 12. Destructive testing of the Slab at the University of Victoria to locate the rebar spacing and cover.

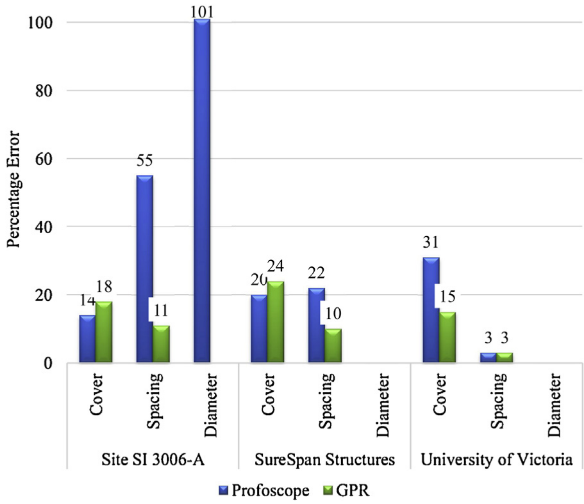

Fig. 13. Percentage Error Model of GPR and Profoscope.

Profoscope increases. For GPR, percentage error from the rebar cover data collected was 18, 24 and 15 at the Bridge site, at Surespan Structures and at UVic respectively.

Percentage error in determining the rebar spacing using Profoscope was 55%, 22% and 3% and using the GPR, it was 11%, 10% and 2% at the Bridge site, at Surespan Structures and at UVic respectively. It can be seen that the percentage error using both the techniques in determining rebar spacing at the bridge site was highest due to the fact that the readings were collected upside down (bottom part of the bridge deck).

From Table 1 and Fig. 13, it can be seen that the percentage error in determining rebar diameter using both the techniques was high (more than 100%) at some of the locations. It also includes some of the instances where the diameter could not be determined. It should also be noted that the GPR was unsuccessful in determining rebar diameter at all three locations.

Rebar spacing determined by GPR has the least error. Overall percentage error for the Profoscope is higher compared to GPR as expected. The overall percentage errors by the two techniques at the bridge site was found to be the highest compared to other locations.

12. Conclusions

Both GPR and the Profoscope may be used to assess in situ rebar detail, but users should be aware that both testing methods lack accuracy. Matching the results of both tests to record drawings with a high amount of confidence could be difficult without background information or destructive testing. The data collected suggests that GPR gives more consistent and accurate data with regards to spacing and cover. It should also be noted that the cost of the GPR equipment used in this study is $15,000 CAD while the cost of the profoscope is $5000 CAD. GPR took about 3 h in total to map the rebar grids while Profoscope took about 15 h in total to map the rebar grids at all three locations.

Following conclusions can be drawn from this research study,

1 The GPR was found to be much easier to use in the field. The data collection process was simple and easily repeatable, with very little chance for human error. The testing was fast, taking 10–15 min to do a 2′x 2′ grid at all three locations.
2 Data collection for the Profoscope was slow, difficult to repeat, and required many inputs which increased the chance of error occurring. The testing of a 2′x 2′ grid took more than 1.5 h at all three locations. In addition the authors took more than 2 h in mapping the rebar grid at each site location.
3 Percentage error (with respect to the design drawings) from the rebar cover data collected from Profoscope was 14, 20 and 31 at the Bridge site, at Surespan Structures and at UVic respectively. This shows that as the rebar cover increases the error from the data collected by the Profoscope increases.
4 For GPR, percentage error (with respect to the design drawings) from the rebar cover data collected was 18, 24 and 15 at the Bridge site, at Surespan Structures and at UVic respectively.
5 Percentage error (with respect to the design drawings) in determining the rebar spacing using Profoscope was 55, 22 and 3 and using the GPR, it was 11, 10 and 2 at the Bridge site, at Surespan Structures and at UVic respectively. It should be noted that GPR processed images shown in Figs. 6–9 has a slight skew in the rebar grid. This could be due to the construction error where the rebar might not be properly positioned as per the design drawing and the GPR data could be accurate.

Acknowledgments

The authors would like to thank MFLNRO and India-Canada Centre of Excellence (IC-IMPACTS) for their financial support. The authors acknowledge co-op students; George Hill and Victoria Gagnon at MFLNRO for their help in the project. The authors also acknowledge the help from Butler Brothers in providing ready-mixed concrete at the University of Victoria and Surespan Structures for letting the authors access their facility for testing.

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