# Chapter 5 - Conclusions

## 5.1 PERES data and analysis using pattern recognition

This study used a new GPR system, PERES, to collect data from concrete bridge decks that were subsequently analyzed using a pattern recognition algorithm developed for the study. The performance of PERES and the algorithm were closely linked because good quality data was a prerequisite for analysis methods to be applicable. The algorithm was designed to overcome limitations of the data to the greatest extent possible, but the performance of the algorithm was also limited by the data. The algorithm was designed to analyze PERES data to determine a bridge deck's mean concrete cover depth, detect and locate reinforcing steel and detect and locate delamination distress.

The specific results from the algorithm are presented in Chapter 4 and some important trends can be observed in them. First, the concrete cover depth is accurately determined (within error bounds) for bare concrete bridge decks with cover depths that do not exceed 9 cm. For bare decks with cover depths greater than 9 cm (deck sections R11 and R10 in the FHWA inventory), attenuation of the signal is too great for the pattern recognition algorithm to make an accurate assessment. A threshold was used to automatically reject data that was inappropriate for cover depth determination based on the expected maximum spacing of reinforcing steel from standard design specifications (Section 4.3.1). Second, position and orientation of the reinforcing steel is determined for decks where the cover depth could be determined. The accuracy of the position and orientation assessment varied between deck sections, but typically followed the reinforcing steel along its length more than 80% of the time. Error rates for false detections of reinforcing steel went up noticeably for the lower layer of the top reinforcing steel mat relative to the upper layer of the top reinforcing steel mat. This was attributed to artifacts in the radar data (in the lower layer of the top reinforcing steel mat) produced by the upper layer of the top reinforcing steel mat (Section 4.3.2). Third, delamination distress (and simulated distress) is detected by the algorithm for the cases where it is observed in PERES data by an expert. Two simulated distress areas were not detected by PERES in bridge deck R13 and it was therefore impossible for the algorithm to detect them. For decks from the FHWA inventory that had asphalt overlays, features of interest (such as delamination distress and reinforcing steel in the concrete) were not detected in PERES data based on expert interpretation. This assessment and trials of the pattern recognition algorithms on this data showed that improvements needed to be made to PERES to produce data that contained meaningful information about asphalt covered decks.

The promising results obtained in this study show that PERES and the pattern recognition algorithm developed for it may have practical applications for field use in the future. However, a variety of important options for improving PERES (Section 4.5) must be explored and implemented before the potential of PERES and the algorithm can be fully realized. In addition, adjustments to the algorithm will be required to obtain appropriate responses to the improved PERES data. These adjustments will predominantly involve the use of new training data that reflects the improved PERES system. Changes will also be made to make the algorithm more versatile for detecting deck features, such as reinforcing steel, for less common geometric deck designs (Section 4.4). Section 5.2 will review comparisons between PERES and current inspection techniques to clarify where improvements are needed for efficient, working inspections to be conducted with PERES.

## 5.2 Comparisons of PERES (using a pattern recognition algorithm) and current bridge deck inspection techniques

The primary purpose of PERES is to detect delaminated areas below the surface of bridge decks, providing bridge inspectors with valuable condition assessment information (although other information, such as concrete cover depth, can also be obtained using PERES). The pattern recognition algorithm developed for this study is intended to automate the interpretation of the PERES data to the greatest extent possible. Current inspection techniques have deficiencies (Section 1.1.2) that make PERES technology an attractive option if adequate performance can be achieved. The current technique in most common use for delamination detection, chain drag, requires bridge or lane closures and also requires the subjective judgment of a technician (Section 1.1.2).

PERES produces data that can be interpreted by an automated pattern recognition algorithm, which may improve the consistency of the results. Unfortunately, the current PERES and pattern recognition algorithm produce significant false positive results (Sections 2.3.2 and 2.3.3). In addition, PERES is not sensitive enough to detect distress areas with profiles that are too thin (Section 2.2.1) or too deep beneath the concrete surface (Section 4.2). This precludes using PERES as a practical field assessment tool in its current configuration, although it has shown capabilities for detecting delaminations with thick profiles, distinguishing them with high cross-range accuracy (Section 2.2.1). The false positives result from phenomena related to clutter and noise while the sensitivity limitations result from inadequate range resolution (Section 4.5) signal attenuation (Section 4.2) and other radar issues (Section 4.2). With appropriate improvements (Section 4.5) PERES may be able to compete with the chain drag test, in terms of detection capabilities. PERES has inherent advantages over the chain drag test that would make it a very attractive choice for bridge deck assessment if the improvements can be made. Specifically, PERES is noncontact and uses the same technology that can be implemented in a data collection platform that travels at highway speeds (HERMES). This could eliminate the need for bridge closures for testing. PERES has capabilities to provide additional information about the locations of reinforcing steel in the bridge deck, including concrete cover depth (Sections 4.3.1 and 4.3.2). In addition, PERES is objective when it is used with a pattern recognition algorithm, eliminating the human inconsistencies inherent in the chain drag test.

Many competing bridge deck inspection technologies are currently available other than the chain drag test but, with the exception of the impact-echo test and GPR, they do not directly measure bridge deck distress. Impact-echo results are often complicated to interpret, and the high costs of extended bridge or lane closures in addition to testing costs that are prohibitive. A variety of techniques exist to measure either the corrosion of bridge deck reinforcing steel at a point in time or a corrosion rate (Section 1.1.2). All of these tests can provide useful information, but they do not measure concrete damage, with the exception of impact-echo that has drawbacks already noted. No method except GPR (which PERES implements) has the potential to obtain information about features in concrete beneath an asphalt overlay, which is a critical need for bridge engineers and inspectors. Based on results from testing of FHWA bridge deck sections, PERES will need to be modified to achieve this capability. All currently available alternatives to PERES testing require bridge or lane closures and most do not assess concrete damage. PERES and the pattern recognition algorithm developed for it could fill a vital role by providing this kind of information for aging bridge decks in the future.

## 5.3 Future applications of PERES with pattern recognition analysis

The results from the pattern recognition algorithm show that expert interpretations of PERES data from bare concrete decks can be modeled using a pattern recognition algorithm that determines concrete cover depth, locates reinforcing steel and locates delamination distress. The accuracy of this algorithm has been summarized in Section 5.1 and quantified in Section 4.3. Based on these results, it is clear that improvements in accuracy will be needed before PERES data and the pattern recognition algorithm developed in this study can be used for practical application to real world bridge decks. However, the current PERES prototype data and the pattern recognition algorithm provide a significant framework that may be built on to improve the system for real world applications. The pattern recognition algorithm will be particularly useful for evaluating improvements to PERES. Section 4.5 describes some of the key improvements that may be made to PERES (which are also valid for the HERMES system). These improvements and continued refinement of the pattern recognition algorithm may make a useful PERES and HERMES possible in the future.