Objective-Oriented Approach to Fulfilling the Need for PMS Pavement Structure Survey Data in Japan

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The pavement management system (PMS) is considered to be of significant value in the effective management of road systems. Large amounts of data related to road surface condition, pavement structure, mechanical properties, and such must be stored in the PMS to establish and render the system useful. The common methods used to determine pavement structure—trial digging and large-diameter boring—are destructive methods that supply only local information about the pavement structure. A rapid and wide-ranging survey system is required in order to add functional value to the PMS. An integrated system using a combination of ground penetrating radar (GPR) and the borehole camera (BHC) has been developed in Japan by focusing sharp attention on how such a system must perform. GPR supplies overall pavement structure information, and the BHC provides an accurate image of layer thicknesses and pavement material composition at a broader range of points. By combining the GPR overall data and the BHC specific location data into a single vehicle-mounted survey system, an accurate profile of the pavement structure can be successfully created. The system proved useful after evaluation of the trial period in terms of survey functionality and practical accuracy. Introduction of the system is considered to increase the accuracy of the PMS and thus of the formation of pavement management decisions.

It is a fact of life that roads, after construction, must be periodically repaired to maintain a suitable traffic flow condition. Because maintenance records are often inaccurate or hard to find, the maintenance history is likely to be an ineffective repair strategy development tool. Knowledge of a pavement's structure is necessary for designing a repair strategy. Accurate structure information is also needed to evaluate the increasingly popular falling weight deflectometer (FWD) data, to calculate future failure curves, and to add accuracy to a pavement management system (PMS) (*1*).

Recently, the importance of a PMS, which provides pavement surface and structure information for intelligent pavement decisions, has been growing worldwide (*2*). Current methods used to determine pavement structure are trial digging and core boring, but these methods give only limited information. To ensure the integrity of the PMS, a large amount of data taken over the road network must be acquired in a short period. For this purpose, the development of a more effective and convenient method has been anticipated in the industry. The Japanese government confronted the problem by designing a system that met certain predetermined objectives.

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OBJECTIVES IN SYSTEM DEVELOPMENT

During the development of the new system, the following priorities and objectives were established: the system must

- Be minimally destructive,
- Cause minimal interference with traffic flows,
- Provide a high degree of accuracy in the determination of layer thickness and material identification, and
- Be able to collect a large amount of data in a short period.

DESCRIPTION OF SURVEY SYSTEM

The survey system was created by combining ground penetrating radar (GPR) and a borehole camera (BHC) in a vehicle. The vehicle (Figure 1) was designed to use these two technologies conveniently as one operation (*3*). GPR meets the objectives of being a nondestructive tool for surveying a large area as quickly as possible, and the BHC was chosen to provide pinpoint accuracy in determining layer thickness and composition. Mounting the survey equipment on a vehicle was necessary in order to avoid obstructing traffic flows and increase efficiency.

GPR

In a GPR system, an electromagnetic pulse is radiated through an antenna to the pavement surface, where it continues to travel underground (*4*). It is partially reflected at the boundary between two layers, whose dielectrical properties are a little different from each other. This boundary is called an interface. The remaining radar energy propagates through successive layers, showing signals of interface as it strikes each boundary.

From this process the antenna receives a series of reflected pulses that represent each boundary. The pulses are repeatedly transmitted through the pavement. While the survey vehicle travels over the pavement, these pulses, which reflect interfaces, create a constant stream of radar reflection profiles. The vehicle drives at 30 to 40 km/hr. At this speed, the

FIGURE 1 Survey vehicle.

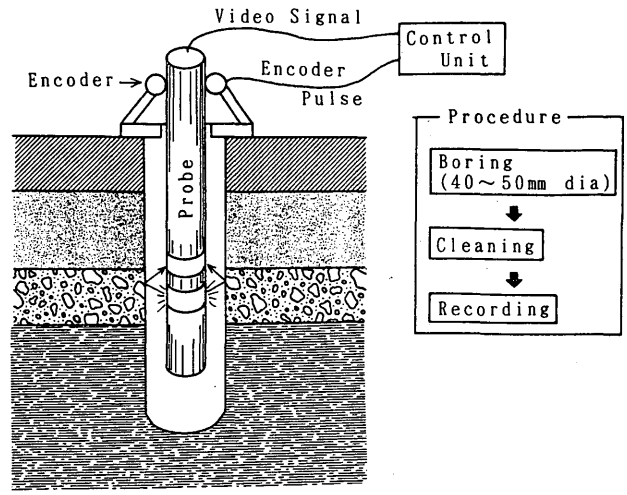

FIGURE 2 BHC acquisition drawing.

operators can cover a substantial length with minimal traffic obstruction.

The pulse length has been adopted as 1 nsec to obtain both the best available resolution and sufficient penetration. GPR, however, cannot measure the absolute layer thickness and it cannot determine material composition, because the velocity of an electromagnetic wave in a medium depends on the dielectric constant of the material. GPR cannot determine its own dielectric constant, so that constant must be determined by another method.

Borehole Camera

To supplement the limitations of GPR, the BHC has been introduced (*5*). The data acquisition process requires a borehole, which is destructive, but because of the small diameter of the probe, the borehole is limited to no more than 4 cm in diameter. Such small-diameter borings are considered minimally destructive to the overall pavement structure.

The hole reaches into the pavement subgrade, which in most cases in Japan is approximately 1 m from the surface. Before inserting the probe, the wall of the hole must be cleaned by a heavy-duty vacuum cleaner wand insertion using a water flush to remove any mud generated by the boring process; this provides a clean target for the image acquisition process. The diameter of the probe is 2.5 cm.

A full-angle view (360 degrees) of the wall is taken by the video probe, and this NTSC (National Television Standards Committee) image is digitized and recorded on magnetic tape. Figure 2 shows a sketch of the BHC data acquisition portion of the survey. BHC survey allows the thickness and the composition of the layers to be determined visually. After taking the BHC record, the hole is repaired with a fast-cure concrete and epoxy-mixed asphalt.

EVALUATION OF FIELD TRIALS

The suitability of this system needed to be proved in several actual pavement structure survey trials. In the evaluation period, three items were carefully evaluated.

Speed of Survey Vehicle

The survey vehicle travels at 30 to 40 km/hr. Profile information, which is derived from the displayed chart paper data, is made with every 10-m plot. However, plotting accuracy may decrease at higher speeds. To determine the effect of speed on the plotting accuracy, a test was carried out on Road 8 in Tokyo.

Six cases were investigated, at speeds of 0, 5, 10, 20, 30, and 40 km/hr; these speeds were considered in the comprehensive trial. Layer thickness observed under each survey speed has been compared with the stationary vehicle mode. The results are shown in Figure 3, which indicates the correlation of layer thickness between the moving vehicle versus zero speed. The allowable range of thickness deviation is practically established at ± 2.5 cm for asphalt and at ± 5.0 cm for subbase and others. The result shows that 100 percent of asphalt and 95 percent of crushed stone subbase are within allowable limits when surveyed at speeds under 5 km/hr, as are 92 percent of asphalt and 95 percent of crushed stone subbase under 40 km/hr. A slightly greater accuracy was obtained at slower speeds. It is believed that positioning accuracy is mainly related to this phenomenon. The results also showed better accuracy on shallower layers and an increase in thickness error in direct proportion to the depth of the medium. It is thought that this occurs because the subbase is not as smooth as the asphalt layers.

Material Properties

Layer thickness is calculated by a calibration method using a selected dielectric constant. The dielectric constant is 1.0 for air, and average values appear to be approximately 5.0 for asphalt and 8.0 for subbase in actual experience. These values usually experience a range of deviation to some extent. If deviation is quite large, GPR would not be used effectively for this purpose.

The relationship between the GPR data and the BHC data was investigated. It should be noted that zero-speed GPR data was used to eliminate the speed effect, as indicated in

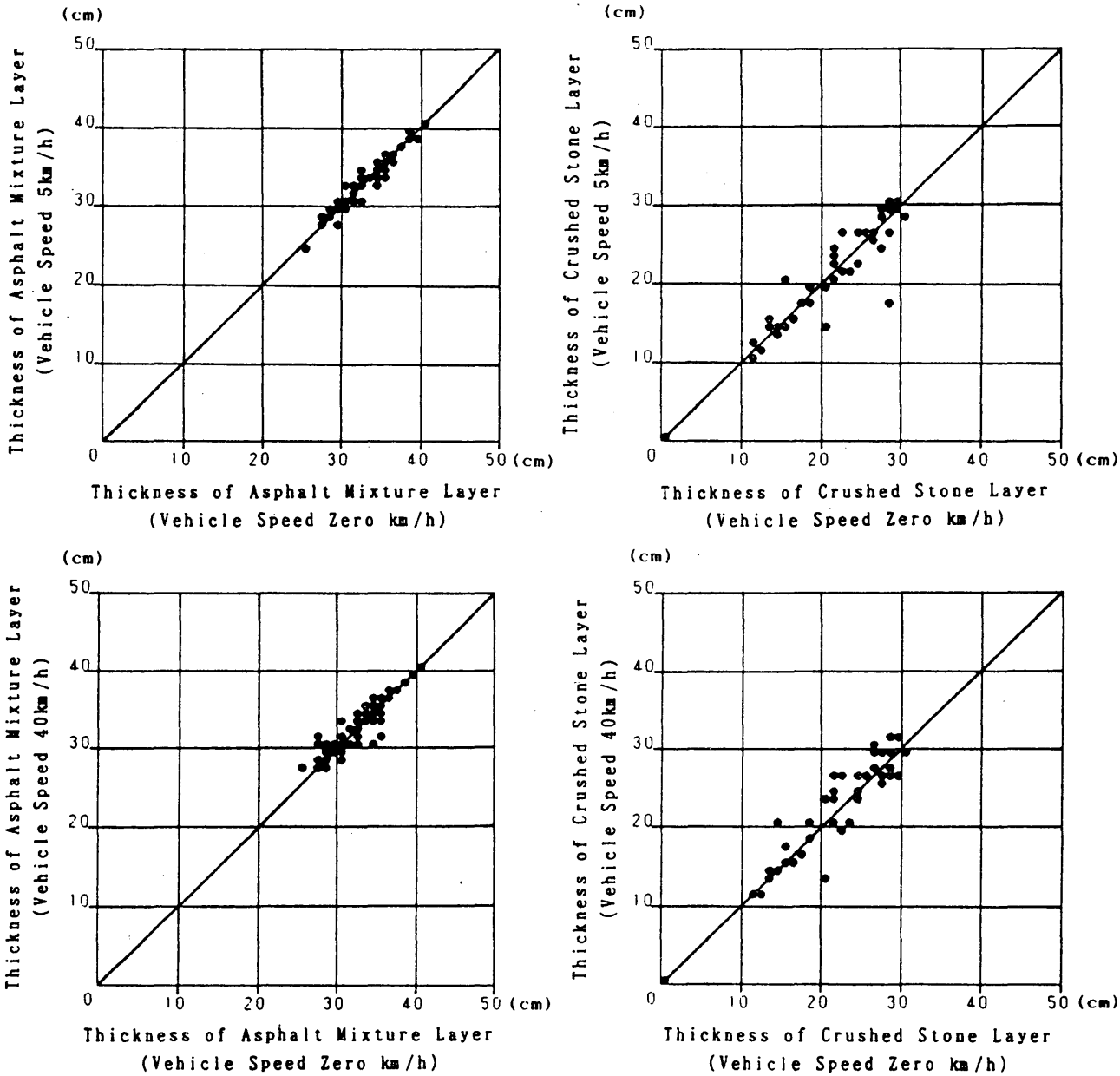

FIGURE 3 Correlation between vehicle speed and system accuracy.

the preceding section. The results are shown in Figure 4, which indicates that 91 percent of asphalt and 82 percent of subbase are within allowable limits. Deviation of material properties is not considered to have a practical effect on the result.

Combined Accuracy

In an actual investigation, layer thickness will be observed as a result of the combined condition of speed and material property effects. Though these effects occur at the same time, a simply combined value is considered to determine the minimum value. The result is that 84 percent of the asphalt and 78 percent of the subbase were within allowable limits. It shows that the system is practically suitable for application to the pavement structure survey.

Dielectric constant determination sometimes turns out to be higher or lower than expected, probably because of material mixture at a boundary or local changes of thickness. The calibration constant should be determined carefully by averaging or by adopting regional values to cancel as much error as possible.

APPLICATION

The pavement structure survey was carried out in the Tokyo metropolitan area. The survey distance was approximately 60 km.

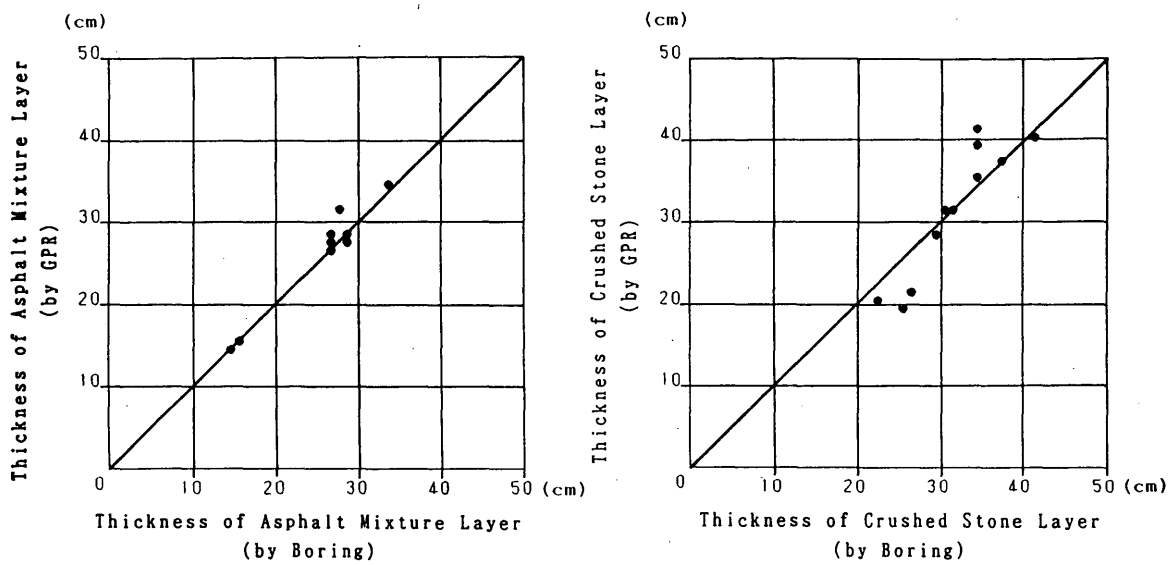

FIGURE 4 Relationship between BHC and GPR data.

Preparation

Within the target area, the locations of buried facilities such as water, gas, electricity, sewer, and communication lines must be identified so that they will not be damaged during the BHC portion of the survey.

GPR Survey

The GPR survey was carried out first. The vehicle speed was about 40 km/hr, because that speed proved sufficient to avoid traffic disruption. A sample of acquired GPR data is shown in Figure 5. After the site survey, all the data were divided into segments. Segmentation depends on the view of experts who distinguish some kind of critical pavement differences, such as the number of layers, relative layer thickness, and signal intensity. Distribution of segment lengths is illustrated in Figure 6. The average segment length was 440 m. It is preferable to bore one hole per segment, except for considerably similar segments. In this case, based on the segmentation, 50 BHC survey points were selected. To evaluate the result, 70 large-diameter boring survey points also were selected, some of which were at the same point as the BHC points.

BHC Survey

Before the BHC survey, all the selected investigation points were marked with spray paint. It is considered good practice for the surveyor to ask the owners of the buried facilities whether it is safe to dig around the points. If they recognize

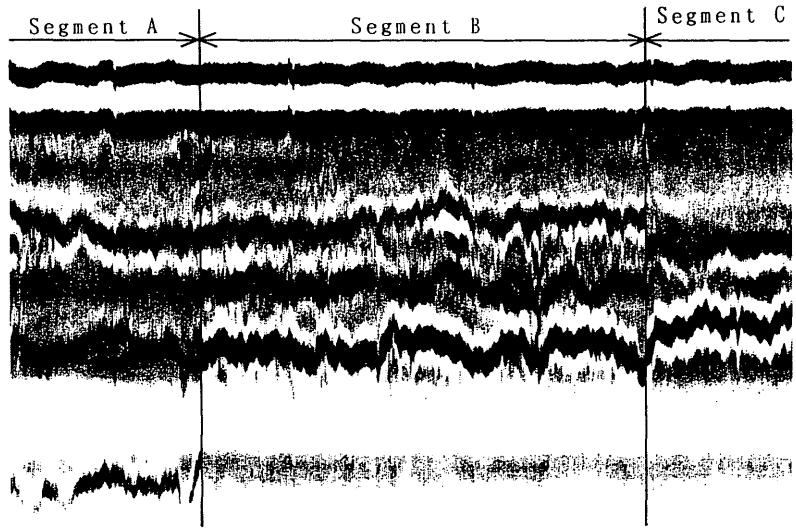

FIGURE 5 Sample of GPR data.

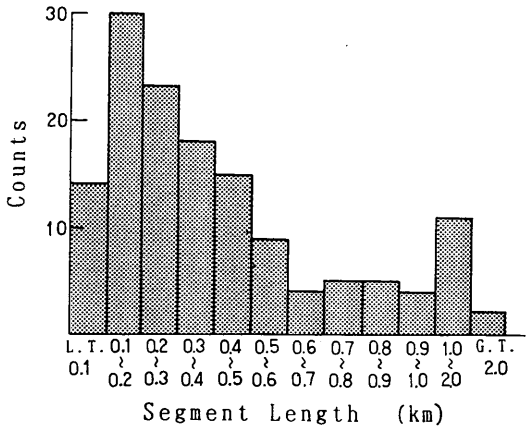

FIGURE 6 Distribution of segment lengths.

any problem, the boring point might be shifted a couple of meters.

When a BHC survey starts, traffic control must already be in place. After traffic control was in place in this survey, it took 30 min to bore the hole to a sufficient depth and 30 min to record the video data. Total work time per BHC record in the field was approximately 90 min, including the time it took to move to the next location. A record acquired by BHC survey is shown in Figure 7. Pavement structure is clearly observed in the picture. Figure 8 compares BHC survey results with large-diameter boring results. The thickness observed by both methods was very consistent. After the BHC record was taken, the hole was repaired by fast-cure concrete and epoxy-mixed asphalt.

Data Analysis

The GPR record was analyzed to make a profile in reference to the BHC record. A sample plot is illustrated in Figure 9. The upper part is the profile, and the lower part is the av-

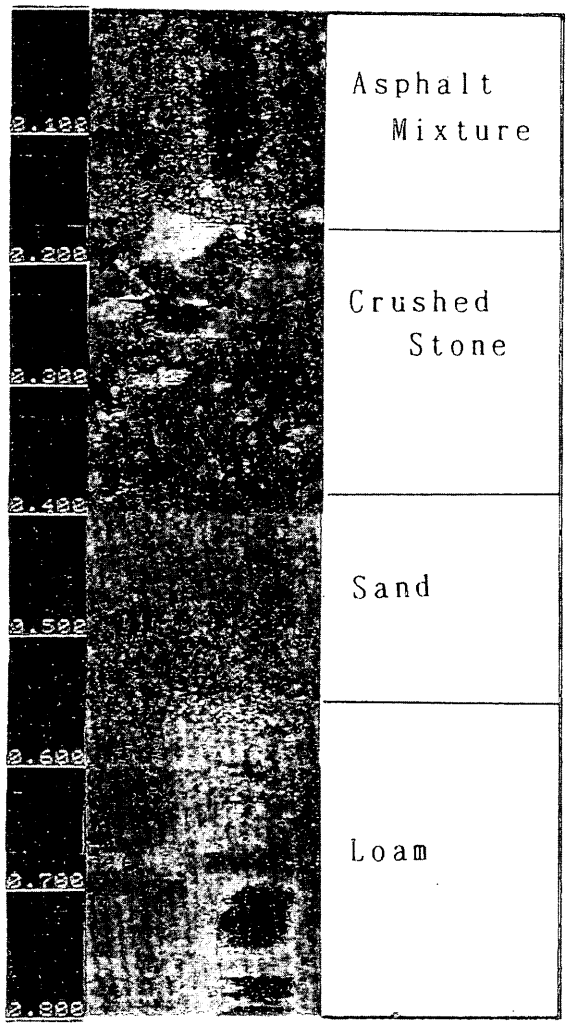

FIGURE 7 Sample BHC survey record.

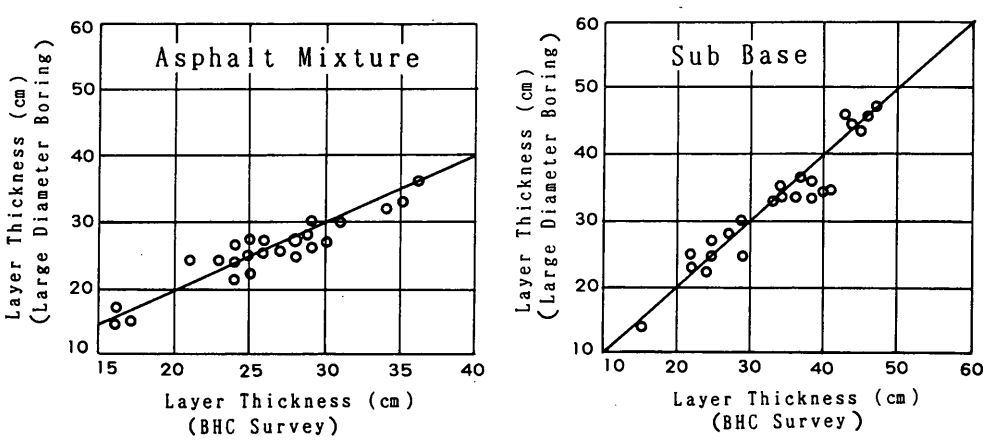

FIGURE 8 Comparison of BHC and core data.

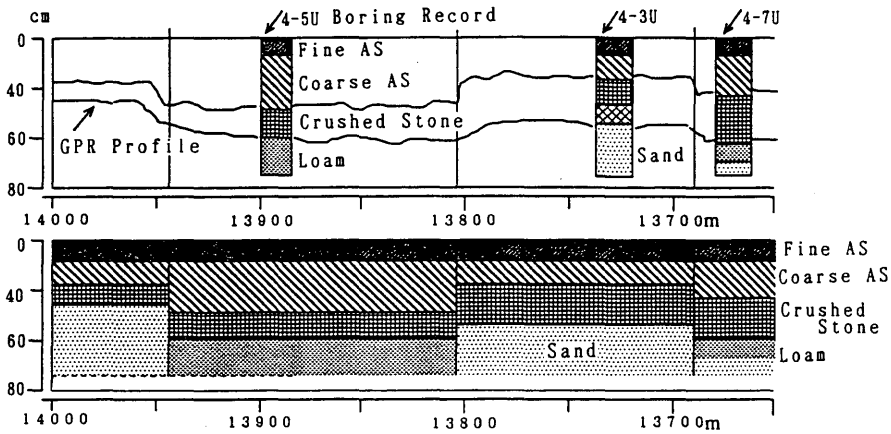

FIGURE 9 Software-generated profile of GPR and BHC data: *top*, profile of pavement structure; *bottom*, averaged profile.

eraged profile. Ultimately, the averaged profile is stored in the data base of the PMS.

CONCLUSION

The Tokyo metropolitan government is now establishing an extensive PMS. Various kinds of data are being stored: road surface condition survey data taken by the road surface observation vehicle, mechanical properties taken by FWD, and so on. A system was envisioned that would provide pavement structure data within certain operational parameters. The survey system of combined GPR and BHC mounted in a designed vehicle proved useful in determining the pavement structure. The advantage of this system is to add functionality that enables a wide-ranging survey to be performed in less time than the more common methods.

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