Long-life repair method for road based on soundness evaluation of embankment and pavement

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\textbf{ABSTRACT}

Although the maintenance work of pavement is often planned based on MCI and FWD data, the repeated damages of pavement are observed at many places. This surface damage of pavement is partly originated by the weakness of subgrade, damage of the filled up ground and ground water. In order to avoid repeated maintenance works of pavement, the condition of earthfill structure should be evaluated by an easy logging technique from pavement surface. The automatic technology for surveys and evaluations of pavement and embankment by using surface wave logging and electric resistivity logging has been proposed. In this study, we tried to improve the pavement life by reinforcing the base course using geosynthetics for degraded pavement on the low embankment with multiple box culverts.

\textbf{Keywords:} long-life repair, pavement, embankment, geosynthetics, optical fiber

\section{1 INTRODUCTION}

A pavement inspection guideline was established with the aim of implementing efficient remedial action such as extending the life of road pavements and reducing life cycle costs (Ministry of Land, Infrastructure and Transport, 2016). In this guideline, the concept of remedial measures appropriate to the level of pavement damage is defined based on the results of pavement inspection and diagnosis.

For example, when the years of service of the surface layer exceeds the target years, easy remedial measures such as cutting overlay. On the other hand, if remedial interval is getting shorter or it is judged that remedial measures only for the surface layer are not appropriate, countermeasures will be taken for the pavement including the base course and subbase course, replacement of subbase, reinforcement of subbase by cement stabilization, change to concrete pavement and composite pavement after conducting a detailed survey to confirm the soundness of the pavement and subgrade.

The soundness of pavement structure is often evaluated by MCI (Maintenance Control Index) and FWD (Falling Weight Deflectometer) in Japan. The MCI is evaluated based on roughness, cracking and rutting of pavement. This MCI varies in the range from 10 to 0. The larger value of MCI indicates that the pavement condition is better. MCI, however, only reflects damages in surface and binder courses. FWD data is most often used to calculate stiffness-related parameters of a pavement structure. The process of calculating the elastic moduli of individual layers in a multi-layer system (e.g. asphalt concrete on top of a base course on top of the subgrade) based on surface deflections. The damage indices are also obtained based on the measured surface deflection of pavement (Kawan et al., 2013, Ishita et al., 2014). It is very difficult to investigate the lower part of subgrade and the stability of embankment and natural ground.

Yashima et al. (2018) has developed the automatic technology for surveys and evaluations of pavement and embankment by using surface wave logging and electric resistivity logging. In order to improve the inspection speed and operability of a current geophysical survey technique (Inazaki and Hayashi, 2010), we proposed a newly designed automation logging system. In order to achieve the stable movement of towed accelerometers, the carrying carts for accelerometers were designed and manufactured. The photographs and schematic figures of equipment are shown in Photo 1. A cart for the receiver has been also newly designed for electric resistivity logging system as shown in Photo 2. The operability on a curved road was significantly improved.

The remaining problem on the 2-dimensional surface wave logging is the noise induced by cars passing by. The very quiet environment is usually needed to measure an impact signal by the hammer accurately.

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However, the measured acceleration signal by the hammer is not large enough compared to the noise induced by cars passing by. We have to increase the signal/noise (S/N) ratio to obtain sufficient surface wave signals.

In order to overcome the traffic noise problem, we decided to use the impact power from the FWD test vehicle, which was found to be sufficient. Photo 3 shows the FWD vehicle towing the carrying carts for accelerometers and electric resistivity receivers and transmitter. The proposed system can speed up the integrated geophysical survey technique by using the 2-dimensional surface wave method and electric resistivity method. This proposed system can also evaluate the pavement and subgrade stiffness by the FWD test and the stiffness and stability of the subgrade and embankment body by the 2-dimensional surface wave logging and electric resistivity logging at the same time.

In this study, we tried to improve the pavement life by reinforcing the base course using geosynthetics for degraded pavement on the low embankment with multiple box culverts. First, we introduce the efficiency of the surface wave logging for better understanding the soundness of the road embankment. Then we outline the remedial test construction, the performance of hybrid measurement before and after the test construction and the long-time monitoring system for the base course with a built-in optical fiber in the geogrid.

2 EXAMPLE OF SURFACE WAVE LOGGING

The 2-dimensional surface wave logging was carried out for the embankment and cut sections of the pre-opened Tokai-Hokuriku expressway in the area indicated by an arrow in Photo 4. The shear wave velocity distribution between the road surface and GL -16m for the embankment and cut sections is shown in Fig.1. The fast shear wave velocity is observed in cut section. On the other hand, the much slower shear wave velocity is observed in the embankment. The quite low shear wave velocities are recognized in particular around the boundary between embankment and cut section. The low shear wave distribution is also observed around the underground box culvert. It is well known that the densification of the fill materials is very difficult not only around the boundary between embankment and cut section but also around the boundary between embankment and stiff structure such as box culvert by the vibrating compactor.

There will be a possibility of the seepage of groundwater around the boundary between embankment and cut section in the future. The groundwater and soft fill material easily accelerate the decrease in the strength of fill material. This will lead to the instability of road embankment. These accumulated data will be utilized as the initial reference ones for understanding the change in the internal mechanical condition of the embankment by future inspections.

3 OUTLINE OF TEST CONSTRUCTION

Figure 2 shows the test construction location. There are two box culverts and one drainage box in the low embankment built on the soft ground at 0m above sea level. As shown in Photo 5, there are vertical gaps and cracks on the pavement adjacent to the box culvert, and repair works with overlays have been repeated.
Figure 3 shows the shear wave velocity, specific resistivity and stability index (Yashima et al., 2019) obtained by the automatic logging technology. The test construction site is located on the very soft ground with high ground water level. The stiffness of the embankment is found to be high enough. Fig.4 shows the maintenance control index (MCI) calculated based on the crack rate, rutting amount, and flatness before repair work. MCI shows a slightly high value around the box culvert shown by the mark of “□” in the figure due to several repairmen works. On the other hand, other parts show low values of 5 or less.

As effective repair methods for vertical gaps, cracks, etc. observed around the adjacent parts of the box culverts, test construction was planned and carried out. Four different repair methods were employed as shown...
in Fig. 5. For the east bound lane, base course was reconstructed by crushed stones. This is a general repair method that reconstructs the base course and the surface layer. In section B in particular, the geocell was used to strengthen the base course. On the other hand, for the west bound lane, a method of replacing the base course with the bitumen stable treatment layer was applied. In section D, the geogrid was used to strengthen the treated base course.

Figure 6 shows the geocell and geogrid used for reinforcement. The cell shape of the geocell is $320 \times 287$ mm and the height of the cell is 75 mm. The geogrid has the aramid fiber as a core material, and its surface layer is melted by the temperature of asphalt and is coated with low density polyethylene so as to be integrated with asphalt.

Photos 7 and 8 show the construction procedure for section A and section C. Crushed stones and bitumen stabilization treatment were squeezed with the finisher and compacted with a vibration roller and a tire roller. Since most works were carried out mechanically, the workability was excellent.

![Fig. 3. Shear wave velocity, specific resistivity and stability index.](image1)

![Fig. 4. MCI value before repair work (20m interval).](image2)

![Fig. 5. Four different repair methods.](image3)

![Fig. 6. Structure of geocell and geogrid.](image4)

![Photo 7. Construction procedure for section A.](image5)

![Photo 8. Construction procedure for section C.](image6)
crushed stones into the geocell was performed using a mini backhoe. Thereafter, the compaction was performed using a vibration roller and a tire roller. Because the construction of the geogrid and the installation of the geocell became manual work and a mini backhoe was used to spread crushed stones into the geocell, it took more time for construction than Sections A and C. Photo 10 shows the construction procedure for section D. After laying the geogrid on the subbase course, the bitumen stable treatment mixture was spread out, the mixture was compacted with a vibration roller and a tire roller. Then prime coat was sprayed, and the geogrid was laid in the same manner. Due to the process of laying two geogrids, it took more time to construct than sections A, B and C.

4 CONFIRMATION OF REPAIR EFFECT

4.1 Surface wave exploration and FWD test

Figure 7 shows the result of two-dimensional surface wave exploration conducted before and after repair work. The change rate of the shear wave velocity (ratio) was calculated by “(S wave velocity after repair / S wave velocity before repair) x 100-100”.

The shear wave velocity distribution before the repair shows almost no difference between the east and west bound lanes, and the embankment is located on the soft ground where the shear wave velocity is 200 m / s or less. The shear wave velocity distribution after the repair shows almost no change for the west bound lane. On the other hand, a large increase is seen in the surface layer for the east bound lane. We can also understand that there is the velocity drop of nearly 20% around the box culvert at the end of the west bound lane, which corresponds to the construction area used with the geocell. On the other hand, the east bound lane shows an increasing trend in general, and the velocity increase of about 20% is confirmed particularly in the surface layer portion.

Figure 8 shows the distribution of the deflection $D_0$ after the load and temperature correction, based on the FWD test results conducted before and after repair. Here again, the replacement with particle size-adjusted crushed stones did not improve the performance of the base course, and a significant decrease in the rigidity was confirmed in the section where the geocell was laid as a reinforcing material. This is thought to be because the particle size-adjusted crushed stone charged into the geocell could not be sufficiently compacted. On the other hand, in the replacement with the bitumen stable treatment layer, $D_0$ decreased significantly after the construction, and it was confirmed that the performance of the base course was greatly improved.
Measurement of strain by optical fiber

In order to confirm the repair effect of the pavement in this test construction, we tried to apply the sensing technology that incorporated an optical fiber in a geogrid which was originally applied as a reinforcement. Photo 11 shows the installation of the geogrid type sensor. In each repair section, a geogrid sensor with a width of 0.3m and a length of 30m was laid on the bottom of the base course at the center of the roadway. Strain measurement was carried out approximately once a month after the completion of repair work in August 2018. Clear strain change has not been observed yet. In order to confirm the efficiency of the repair works, it is necessary to continue measuring strains in the future.

CONCLUSIONS

In this study, test repair construction was performed for road pavement using geosynthetics where the service life of the surface layer was less than the target years and deterioration was very fast. The following conclusions were obtained.

1) The installations of the geogrid and geocell were carried out manually without using a machine. Therefore, those works took more time than the conventional replacement works for the base course. In the future, studies to improve workability are necessary.

2) The repair effect by the test construction was investigated by two-dimensional surface wave exploration and FWD test. The rigidity of the base course was lowered in the section where the geocell was installed because the filling material was insufficiently compacted. On the other hand, it was confirmed that the performance was improved in the section where the base course was replaced with the bitumen stable treatment mixture.

3) The strain distribution of the base course using a geogrid with built-in optical fiber was tried to monitor. Clear strain change has not been observed yet. In order to confirm the efficiency of the repair works, it is necessary to continue measuring strains in the future.

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