Rehabilitation and maintenance planning of Burapawithi's approach ramp, Bangkok-Chonburi expressway

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Abstract : Burapawithi is the 55 km elevated expressway which connects between Bangkok and eastern seaboard. After almost 9 years of service, some highway ramps suffered the large deformation that caused the rotation of the transition boxes and question about its safety. Extensive investigation and analyses have been done including 26 soil borings, structure damage investigations, installation of instrumentations, analysis of structure and foundation safety and prediction of the affect of future settlement. It's found that only the ramps that located over the thick soft clay show the serious condition from the excessive of ground settlement. Most of the damages are not critical to the structural and foundation safety. However, the analyses show that the unappropriate repair and maintenance such as resurfacing of the pavement, might cause the failure of the transition piles. Furthermore, it's also found that the large deformation occurred in the middle of the transition zone where the pile tip of transition piles are above the stiff clay layer and float in the medium stiff and soft clay. These piles also clearly show that their deformation is strongly influenced by the changing of underground piezometric pressure. Maintenance scheme including appropriate repairing method, ramp condition grading system, limitation of resurfacing thickness, instrumentation reading and database management are suggested for Expressway Authority of Thailand.

Keyword : *Elevated highway, transition piles, ground subsidence*

1. INTRODUCTION

Even thought the infrastructure systems in Bangkok are still under developing, however much have been done. The maintenance of those structures is pretty much related to the characteristic of soft Bangkok clay. The building foundations and underground basement, tunnel and underground pipeline, road and highway, elevated highway, flood protection and retaining structures are all affected by high compressibility of soft Bangkok clay. The large long term settlement due to consolidation process of clay can be well predicted using available consolidation theory. However, the changing in effective stress due to the changing in underground piezometric pressure caused by ground water pumping effect can cause not so well predicted long term settlement or reducing the stability of Geotechnical engineering structures. Figure 1 shows the contour depth of soft Bangkok clay that analyzed from almost 4,000 boreholes based on soil database of Geotechnical engineering research and development center (GERD), Kasetsart University.

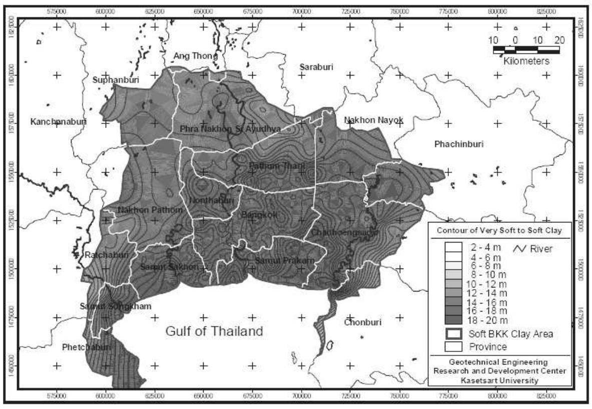

Fig. 1 Thickness contour of soft Bangkok clay (GERD, 2009)

This paper presents the example of the affect of the high compressibility of soft Bangkok clay and changing in peizometric level due to ground water pumping that influenced the maintenance scheme of the elevated highway. Burapawithi expressway is the elevated highway that connecting between Bangkok and Chonburi province. This highway is one of the most important highways in term of economic stability of Thailand since it connects between eastern seaboard and Bangkok. In 1969 highway number 34, which is now below this elevated highway, was constructed without any foundation improvement and then later facing serious excessive settlement problem. Within less than 10 years, this 55 km long highway found some part of the highway has settled almost 2.5m (N.D. Lea et al., 1998). In 1997 the highway was rebuilt and used soil-cement column as a foundation improvement and at the same time, to ensure the economic stability and serve large traffic volume during holiday periods, the elevated highway, Burapawithi, was built over highway 34.

The construction of Burapawithi completed in 2000, it was one of the largest elevated highway in the world with 6 traffic lanes to accommodate the traffic. The highway consists of 27 ramps and 20 payment toll stations. Figure 2 show the plan view of the highway.

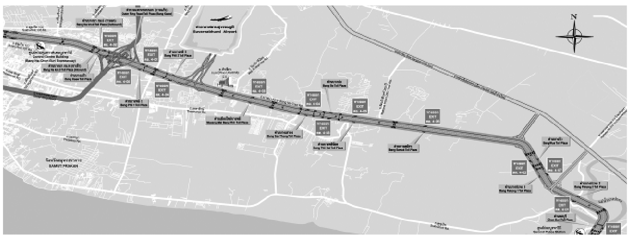

Fig. 2 Route map of Burapawithi expressway

2.EXCESSIVE SETTLEMENT PROBLEMS

In geotechnical point of view, this highway situates on soft Bangkok clay and half way of the rout it passes over the deepest area of soft Bangkok clay where soil moisture content is more than 120% and undrained shear strength is less than 1.5t/m2.

Since the highway is elevated, therefore the load from the highway structure is transferred through piles to the firm layer of dense sand underneath. However, some part of enter and exit ramps have to construct directly over the soft clay layer without any deep pile foundation for load transfer. Even though, the transition piles system is used to reduce the excessive settlement and to force the ramp to smoothly settle but sudden change of settlement in ramp still found especially where the ramp locates over the deepest area of soft Bangkok clay. Figure 3 show typical schematic of the ramp structure.

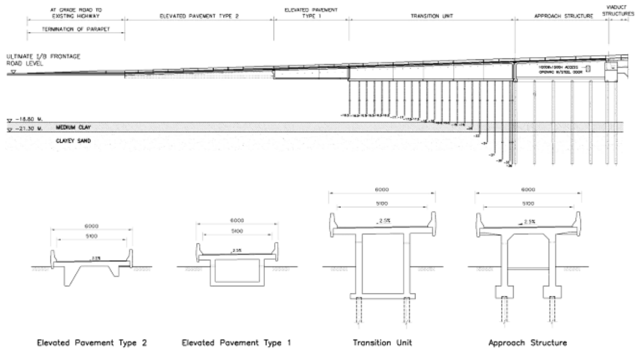

Fig. 3 Construction drawing of highway ramp

In 2008, Geotechnical research and development center (GERD) under civil engineering department, Kasetsart University is appointed by Expressway Authority of Thailand(EXAT) to investigate the problem and propose maintenance and repair plan for the highway ramps and the connecting stairs to the toll booths. The investigation found several flaws which are 1. Series of vertical cracks on the wall of approach structure, the crack width is mostly less than 0.2 mm. 2. Rotation of transition box causing the separation of contraction vertical joint and crack of ramp pavement 3. Cracking of parapet wall caused by the rotation of transition boxes 4. Flooding of elevated pavement type two from excessive settlement of this section. Figure 4 summarized the problems as described. As for the problem of the connecting stairs to the toll booths, since the stairs structure is supported by the shorter pile comparing to the supporting pile of the elevated highway, therefore the differential settlement between these two structures causing the simple span of connecting bridge section to move out of its support (Figure 5). The support have to be extended to accommodate the movement, the largest movement is about 20 cm. It also found that the ramps and staircases that have serious problem as explained are all located over the deepest area of soft clay layer which is between KM 24 to 37.

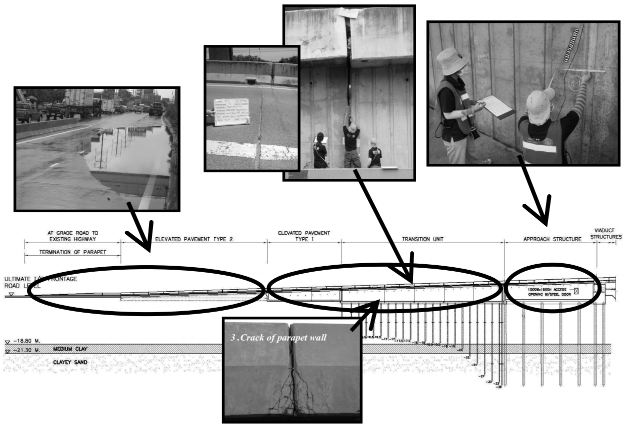

Fig. 4 Damage scenario of ramp structure

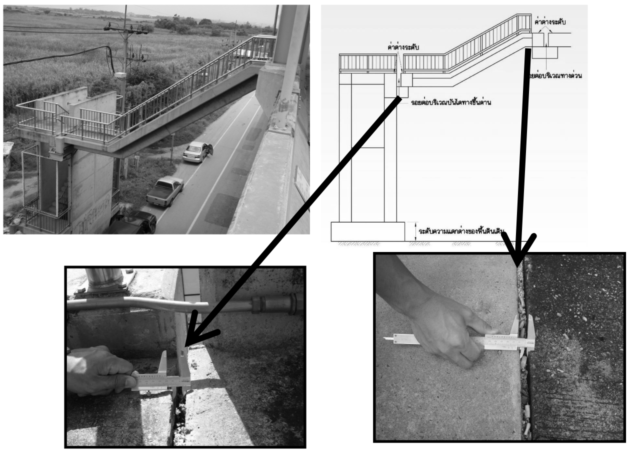

Fig. 5 Damage scenario of staircase

3. SUBSOIL CONDITIONS

In order to understand the subsoil condition, 20 of 30m deep boreholes and 2 vane shear tests were done. 4 of 60m deep boreholes were also done in the most critical ramps. Figure 6 shows the subsoil layers from bore holes data. It can be seen that the ramp and staircase structures that found to be in serious condition are located where the soft clay later is the thickest. Also the compression index(C_c) between KM 24 to 37 is found to be in a high value of 1.2-3.0 and the coefficient of consolidation(C_v) value is found to be 10^{-6} to 10^{-4} cm^2/sec where other section C_c is found to be about 0.2-1.0 and C_v is about 10^{-4} to 10^{-2} cm^2/sec (Figure 7). Furthermore, to see the effect of consolidation from the elevated pavement and at grade section, boreholes were drilled near the elevated pavement and outside the highway where undisturbed soil shall be found. Figure 8 clearly shows the consolidation effect in the upper soft clay layer where water content of the soil under elevated pavement is squeezed out causing lower in water content and higher in undrained shear strength comparing to the undisturbed zone.

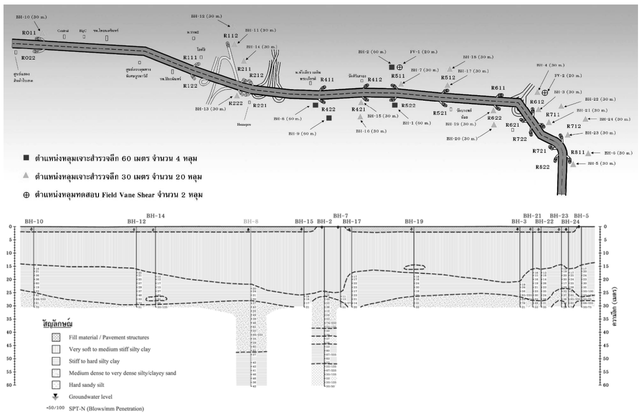

Fig.6 Subsoil layers along the elevated highway

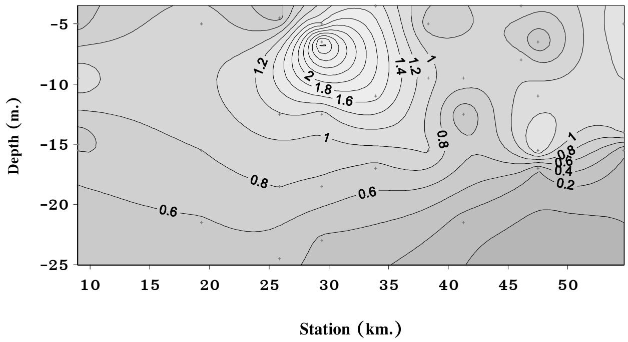

Fig.7 Compression index of soft to medium stiff clay layer along the highway

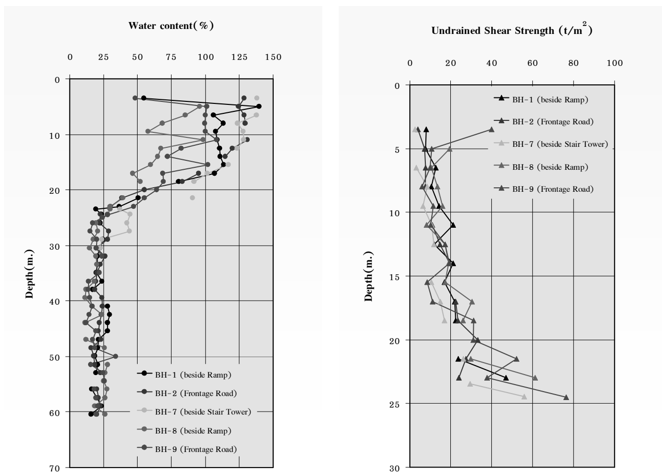

Fig.8 Soil moisture content and undrained shear strength beside and outside the ramp

4. SETTLEMENT PREDICTION

From the damage investigation it's clearly shown that the settlement of the ramp is sudden increased at 2 areas 1. at the joint between approach structure and transition unit and at the middle of transition unit where pile tip of transition system is above the stiff clay layer and tip on the medium stiff or soft clay. This can be confirmed by Figure 9 to 11 where detail movements have been collected. Questions has arisen that whether the consolidation has been finished or what is the current degree of consolidation of soft clay due to the structure load. One dimensional consolidation analysis based on conventional Terzaghi's theory has been used to calculate the settlement behavior along the transition unit and elevated pavements. Piezometric drawdown effect due to ground water pumping was also considered for calculating the applied effective stresses for consolidation settlement. The evidence of ground subsidence due to ground water pumping can be seen everywhere along the highway as shown in Figure 12. The rate of average ground subsidence estimated from the previous figure is about 4.5 cm per year. Piezometric drawdown recorded from Suwanaphom airport which located near by the studied site was used.

The calculated profile grading of the most critical ramp, with and without considering the effect of piezometric drawdown is shown comparing with the current profile grading in Figure 13. The calculated profile grading is analyzed based on end of primary settlement. It can be seen that piezometric drawdown has less effect on the ramp section where longer pile which tip on the stiff clay or dense sand are used and also has less effect on the elevated pavement as well. However, it has a great effect on the ramp section where pile tip is in the medium stiff and soft clay. As for the rate of consolidation it's found from the analyses that at the present time, when the highway has been using for 9 years, the settlement has approached the end of primary consolidation stage (Figure 14).

Even though the evidence is clear, but the piezometric drawdown might not be the only factor that causes the additional settlement. Other factor such as cyclic loading or else shall be investigated in the future.

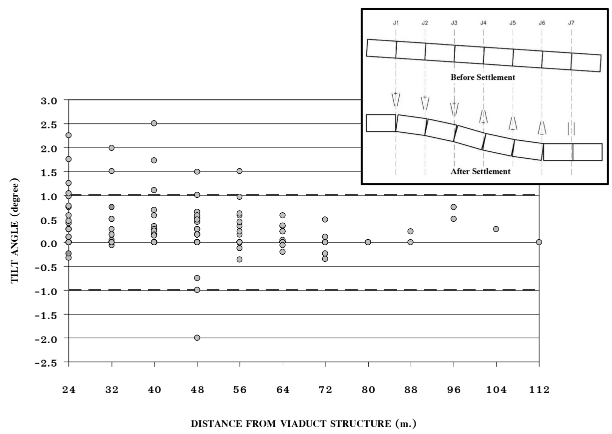

Fig.9 Tile angle of transition box from viaduct structure

Fig.10 Rate of grade changing and present grading profile

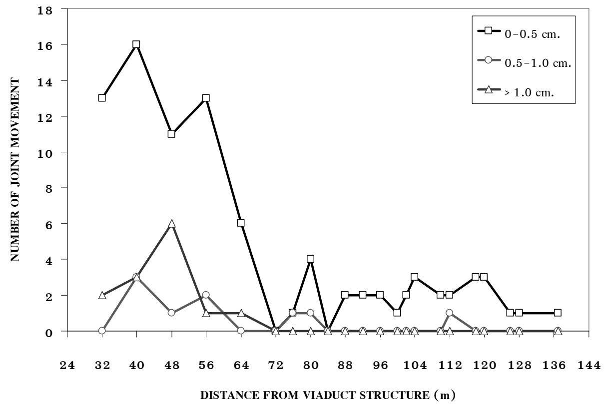

Fig.11 Number of joint movement in transition unit

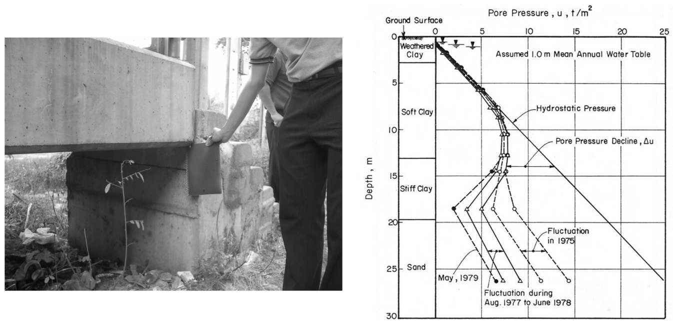

Fig.12 Evidence of ground subsidence near the staircase and record of piezometric drawdown in Suwanaphom airport (AIT, 1978)

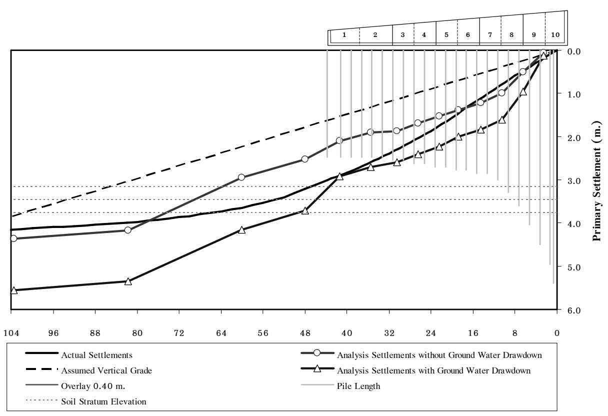

Fig.13 Calculated profile grading considering with and without piezometric drawdown effect comparing with present profile grading

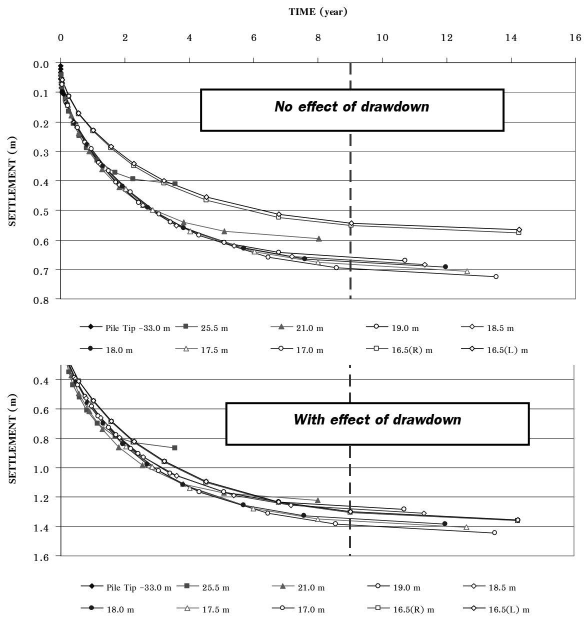

Fig.14 Rate of consolidation settlement with and without piezometric drawdown effect

5. MAINTENANCE AND REPAIRING SCHEME

Since it has been clear that the end of primary consolidation at this stage of loading has been reached, therefore appropriate maintenance and repairing plan shall be discussed. Various repairing methods have been proposed such as using jet grouting to grout underneath the pile tip, micro pile, vacuum consolidation and simply just overlay the pavement surface. It has been agreed that overlaying the pavement surface with bitumen to improve the profile grading is a suitable method for now. However, this method will be induced further settlement because of the bitumen load and also the factor of safety of supporting pile will be reduced as well. Analyses have been done to ensure this effect as shown in Figure 15 and 16. Moreover, the limitation of the overlaying thickness has been set for future maintenance as shown in Figure 17. Theses criteria have applied only for the ramps that are in the serious condition. Most of the ramps are in good shapes, however instrumentations including tile meter, joint meter, permanent bench mark, deep settlement plate and piezometer were installed to monitor the movement of the ramps, staircases, piezometric drawdown and ground subsidence behavior as shown in Figure 18.

All the data including damages, soil borings and instrumentations data are collected in custom made database system and available in the internal sever system of EXAT. Collected data is used to calculate the condition index of each ramp and staircase. New condition index will be automatically updated when new data is entered. The condition index is used by the decision maker for maintenance approach and budget. Improving the profile grading by pavement overlaying method is estimated to be appropriate and cost effective for at least 5 years from now. However, if the ground subsidence due to ground water pumping effect still went on, the overlaying thickness may exceed the limit. Therefore, more complicated and expensive solution might be required.

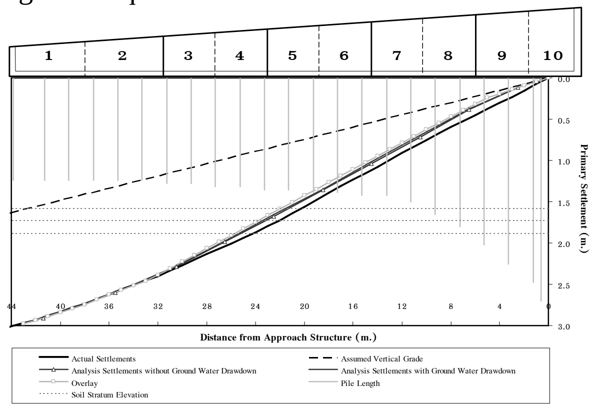

Fig.15 Predicted profile grading at end of primary settlement from pavement overlay loading

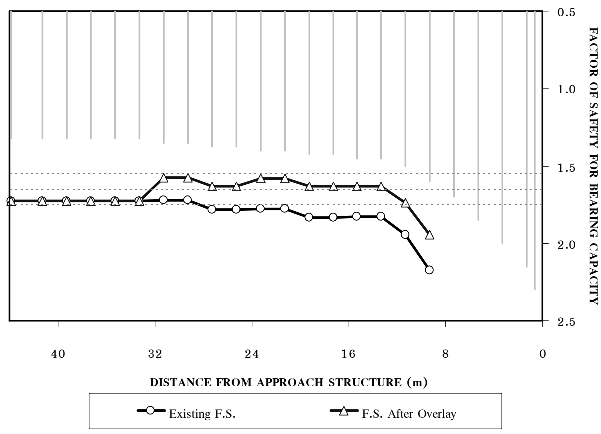

Fig.16 Estimated factor of safety of transition piles due to pavement overlaying load

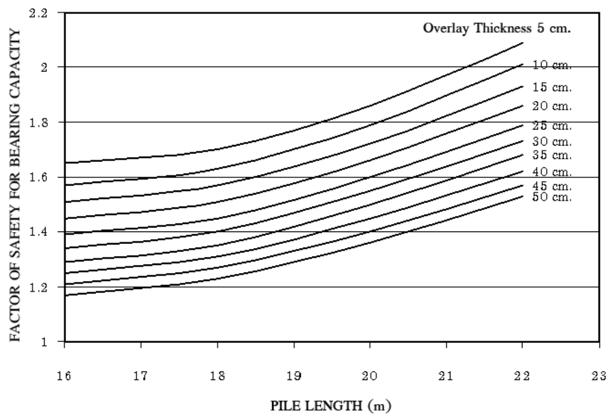

Fig.17 Limitation of overlay thickness based on factor of safety criteria

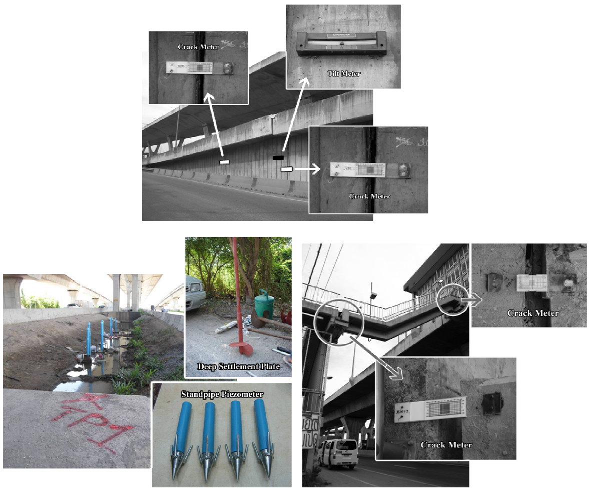

Fig.18 Instrumentation of ramp and staircase as well as piezometeric drawdown monitoring devices

6. CONCLUSIONS

The appropriate maintenance plan of Burapawithi highway ramps is directly related to the changing of underground piezometric pressure. The extensive of the repairing and maintenance scheme is limited by the bearing capacity of the transition pile. Meanwhile, the large magnitude of the future ground subsidence might force the repairing technique to be more expensive and sophisticated. Instrumentations, database system and effective grading system is the main key for decision makers to plan the appropriate future maintenance plan.

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