Rehabilitation Design and Construction of PCC with AC Overlays Pavement of G328 Yizheng Section in China: a Case Study

H.Li, R.J.Cao, H.Zeng, Y.Lu
Jiangsu Transportation Research Institute, Nanjing, Jiangsu, China

ABSTRACT: The design and construction of pavement rehabilitation projects is one of the greatest challenges afforded today's pavement engineers especially for those PCC with AC overlays. Case study of G328 Yizheng Section rehabilitation in China is provided in this paper. The G328 Yizheng Section was overlaid with 12cm asphalt concrete in 1998 on the original 24cm PCC slabs constructed in 1980. Due to serious pumping and faulting of the lower PCC slabs and drainage design defects, severe distresses like reflective transverse crack, longitudinal crack, water bleeding and pumping appeared in the AC overlays which influenced the driving safety and quality heavily. On the basis of comprehensive pavement evaluation and traffic analysis, the rehabilitation design with rubbilization of PCC slab combined with cold central plant recycling (CCPR) of old asphalt overlay using foamed asphalt with new AC overlays was recommended. Combination of the two "recycling" technologies-rubbilization and cold recycling-is successfully used together the first time in China for PCC with asphalt concrete overlays, and may be used as reference for similar projects. The PCC slabs after rubbilization with similar characteristics to graded crushed rock, worked as the sub-base layer and provided good drainage pass, and the cold recycling layer worked as a flexible base course. Three design schemes are adopted according to different section conditions and environments, and are used in different sections to achieve long-term performance and for comparison with long time observation. The construction process is presented briefly as well.

KEY WORDS: Rehabilitation, cold recycling with foamed asphalt, rubblization, PCC with AC overlays, case study.

1 INTRODUCTION

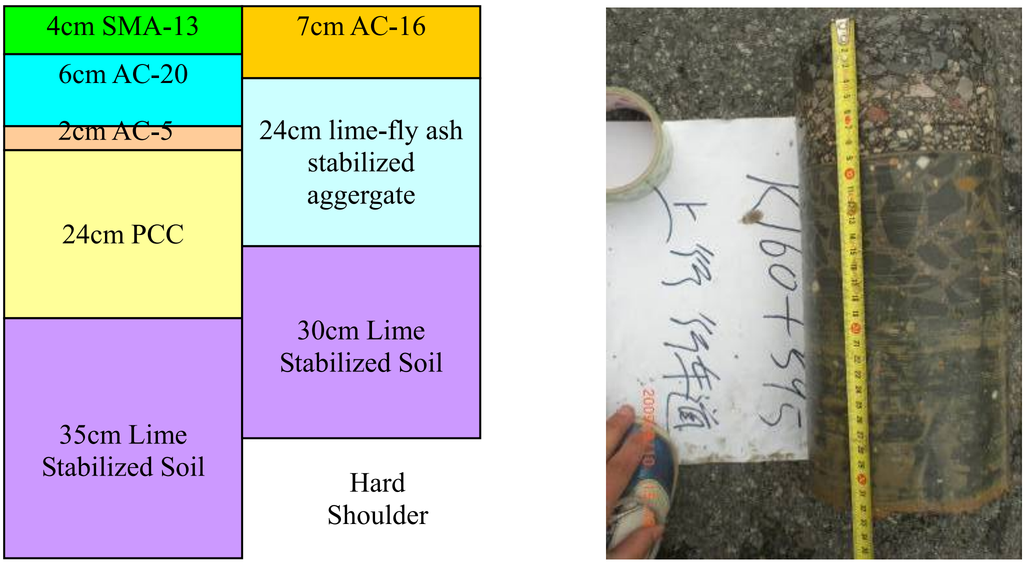
From early 1980s many concrete pavement was build in China, and many of those were rehabilitated with one or two layers of thin asphalt concrete overlays over the concrete slabs since late 1990s. These composite pavements serve near 10 years to today and some deteriorate severely due to pumping and faulting of the lower PCC slabs and heavy traffic, severe distresses like reflective transverse crack, longitudinal crack, water bleeding and pumping appeared in the AC overlays which influenced the driving safety and quality heavily, hence are facing "Second Rehabilitation". How to treat the lower slabs and use of the old asphalt overlay become the greatest challenges afforded today's pavement engineers in rehabilitation design and construction.

Case study of G328 Yizheng Section rehabilitation in China is provided in this paper. On the basis of comprehensive pavement evaluation and traffic analysis, the rehabilitation scheme using rubbilization of PCC slab combined with cold central plant recycling (CCPR) of old asphalt overlay with foamed asphalt overlaid by new AC overlays was recommended. Combination of the two “recycling” technologies-rubbilization and cold recycling-is used together the first time in China for PCC with asphalt concrete overlays, and may be used as reference for similar projects.

2 PAVEMENT INVESTIGATION

2.1 General

The rehabilitation project is G328 Expressway Yizheng Section (Chainage:K158+300~ K163+819), with a total length of 5.519km.The G328 is an east-west bounded national trunk highway with dual 4 carriageways, and Yizheng Section was overlaid with 12cm asphalt concrete in 1998 after grouting treatment or replacing of bad slabs of the original 24cm PCC slabs constructed in 1980.The designed overlay structure of the 2 carriageways is 4cm SMA-13(SBS modified, wearing course) + 6cmAC-20C (binder course) +2cmAC-5(leveling course and stress absorbing) over the PCC slabs as show in Figure 1 and confirmed by coring. It also should be noted that structure of the hard-shoulder is different with the carriageways as shown in Figure 1 as well.



Carriageway

Core of Carriageway

Figure1: Pavement structure before rehabilitation

2.2 Main Distresses and Pavement Condition Survey

The main distresses includes severe reflective transverse cracks，water bleeding and pumping due to serious pumping and faulting of the lower PCC slabs, and the longitudinal crack appeared between the carriageway and hard-shoulder caused by the rigidity difference of the different structure of the carriageway and the hard-shoulder as given in Figure 1. Though many of the distress had been repaired or patched during routine maintenance, the pavement condition deteriorated rapidly and influenced the driving safety and quality heavily after 10 years service bearing growing traffic, and need rehabilitation and reconstruction.

(a) Transverse Crack (Patching)

(b) Longitudinal Crack

(c) Water bleeding and pumping

Figure2: Main distresses before rehabilitation

The pavement surface distress is also surveyed and evaluated by crack degree (CD) which is the crack length of every $1000m^2$. It can be found in Figure 3 the highest crack degree up to $230m/1000m^2$, which shows a very sever crack condition.

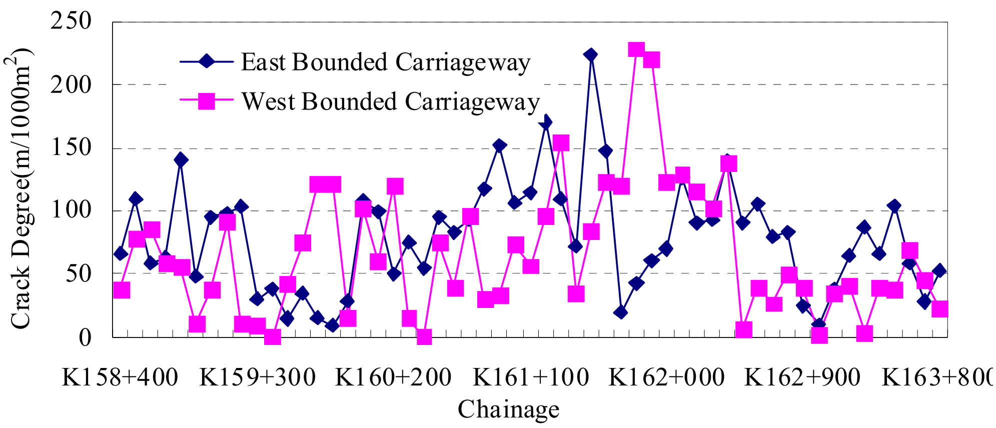


Figure 3: Crack degree of every 100 meters sections

2.3 FWD Test

FWD (Falling Weight Deflectometer) has been used in the investigation of PCC and flexible pavement extensively, but for the composite structure, the use of FWD is rarely reported. In this project FWD is conducted similarly to PCC pavement to evaluate the pavement bearing capacity, bond condition between slab and base, joint load transfer capability.

FWD test was performed at 50m spacing on asphalt surface corresponding to the slab center and two adjacent slab corners of the both directions carriageway only. Figure 4 shows deflections of each slab center. It's easy to find that the deflections of slab center are between 5~50(0.01mm) and most are between 5~30(0.01mm) except few are over 30(0.01mm), which means the pavement still keep somehow good bearing capability. Also it can be founded that west bounded carriageway has better bearing capacity than east bounded carriageway, especially in the section K161+500 to K163+819 which corresponding to the sever distress and poor pavement condition as shown as an example in Figure 2 (a).

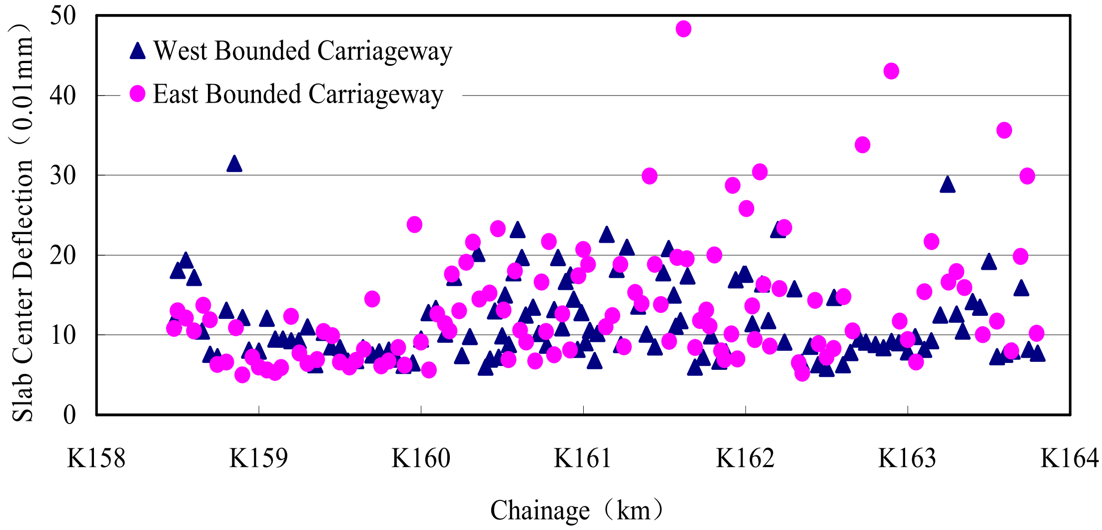


Figure 4: Deflection of each slab center

Bond condition between slab and base (lime treated soil) was evaluated by FWD test on slab corner. For ordinary PCC slabs the bond condition was evaluated by the following widely accepted criteria for FWD test results:

- Slab Corner Deflection>20(0.01mm): good bond condition
- 40>Slab Corner Deflection⩾20(0.01mm): poor bond condition
- FWD Slab Corner Deflection⩾40(0.01mm): unbonded condition

To verify whether the above criteria are applicable or valid for composite pavement of this project, we use coring according to different slab corner deflection to evaluate the bond condition.

Table 1: Bond condition relation between coring and FWD

Core No.	Chainage	Location	Deflection(0.01mm)	Bond condition
1	K158+850	West bounded carriageway	31.5	poor
2	K160+046	West bounded carriageway	12.8	good
3	K160+595	West bounded carriageway	23.2	poor
4	K161+145	West bounded carriageway	22.6	poor
5	K163+246	West bounded carriageway	28.9	poor
6	K158+860	East bounded carriageway	10.9	good

Core No.	Chainage	Location	Deflection(0.01mm)	Bond condition
7	K159+960	East bounded carriageway	23.8	poor
8	K160+475	East bounded carriageway	23.3	poor
9	K160+744	East bounded carriageway	16.6	good
10	K161+410	East bounded carriageway	29.9	poor
11	K161+619	East bounded carriageway	48.3	unbonded
12	K161+921	East bounded carriageway	28.7	poor
13	K162+770	East bounded carriageway	53.9	unbonded
14	K162+867	East bounded carriageway	69.4	*unbonded*
15	K163+199	East bounded carriageway	87.5	unbonded
16	K163+595	East bounded carriageway	35.6	poor

Table 1 shows the criteria to evaluate bond condition of PCC pavement seems to be valid for composite pavement (PCC with thin AC overlay) except 1 core (No.14). And the bond condition was evaluated in this project by above criteria.

Table 2 shows the statistical results of the carriageways, near 20 percent of the concrete slabs has poor bond condition with the overlying base, with near 30% of the PCC slabs of the east bounded carriageway and 10% of the west bounded has poor and unbonded condition, which shows the bond condition of the east bounded carriageway is much worse than that of west bounded carriageway, which also explains why the east bounded carriageway has poorer pavement condition than the west bounded carriageway.

Table 2: Bond condition evaluation between PCC slab and lower base

Slab Corner Deflection		West bounded carriageway	East bounded carriageway
＜20	(%)	89.71	70.46
[20，40）	(%)	10.29	18.18
≥40	(%)	0	11.36

Table 3 gives the results of load transfer capability evaluation using the criteria given in Chinese specification (Ministry of Communications, 2002). It shows the load transfer load is somehow good and needn't to be take into account as an emphasis during rehabilitation design.

Table 3: Load transfer capability evaluation

Section		West bounded carriageway	East bounded carriageway
Excellent	(%)	72.06	72.73
Good	(%)	19.12	9.09
Mid	(%)	8.82	11.36
Poor	(%)	0	6.82

2.4 Coring Survey

A coring survey was carried out to identify the pavement thicknesses, material condition, bond condition as given above and to provide samples for laboratory testing. The results show on average 109mm asphalt layer overlying the PCC slabs of an average thickness 239mm.

2.5 DCP Test

DCP (Dynamic Cone Penetration) test is also conducted to evaluate the subgrade bearing capacity. The subgrade CBR value ranges between 4.7% and 33.8% with a minimum resilient modulus at approximate 48MPa, which represents the unevenness of the subgrade stiffness, and most of the bearing capacity of the subgrade can meet the requirements for rubbilization.

2.6 Laboratory Testing

Splitting test was performed on the concrete samples extracted from the pavement, in order to get the flexural-tensile strength of the PCC slabs. The flexural-tensile strength ranges between 4.5MPa and 5.3MPa with an average value of 4.8MPa, which means the concrete slabs still keep good strength.

3 TRAFFIC ANALYSIS

Traffic data was collected through the toll and Average Annual Daily Traffic (AADT) from 2001 to 2008 increases from 15000 to 20000 vehicles per day with 33% trucks.

The predicted accumulated traffic loads in the next 5 years is 3.0 msa (million standard axle load, in 100KN) using the traffic calculation method given in Chinese specification (Ministry of Communications, 2006) with a rehabilitation design period of 5 year assuming the traffic growth rate at 5% each year.

4 REHABILITATION DESIGN

4.1 Forensic Analysis of Pavement Distress

Before rehabilitation design, it's important to find out the causes of the pavement distress to adopt a proper design scheme, and the main causes are summarized below:

(1) The transverse cracks are most reflective cracks of underlying PCC slab joints due to serious pumping and faulting of the lower PCC slabs.

(2) The longitudinal cracks appeared between the carriageway and hard-shoulder are caused by the different pavement structures of the carriageway and hard-shoulder as illustrated in Figure 1, which caused the rigidity difference, and clogged the horizontal drainage path of the carriageway asphalt layer at the same time.

4.2 Design Consideration

Several important aspects or requirements need to be considered in the selection and decision of design schemes:

(1) Eliminate or mitigate the reflective cracking of the underlying PCC slabs to achieve long term performance of the rehabilitation.

(2)Try to get full use of the existed pavement material including PCC slabs and AC overlays, taking into account the environment concerns and economics aspects. Thus recycling technology should be considered.

(3) Resolve the drainage and rigidity difference problem between the carriageway and hard shoulder.

(4) Develop suitable and potential solutions according to different pavement condition and compare different solutions' long term performance with long term observation.

4.3 Design Scheme

(1) Solutions to the underlying PCC slabs

Reflection cracking can occur at any PCC joint or crack. A variety of techniques have been used over the years in an attempt to eliminate reflection cracking in HMA overlays (TRB, 2006) and rubblizing has proven to be one of the most economical and successful ways to eliminate reflection cracking of HMA overlays placed on existing PCC pavements (NAPA, 1997).The rubbilization can also be treated as a "recycling" technology for PCC pavement.

In this project, rubblization is recommended to eliminate the reflective crack, provide good drainage pass, and improve the bond condition between slabs and the original base for the PCC slabs of east bounded carriageway due to its severe deterioration and unbonded condition. For west bounded carriageways, use of thick HMA overlays while reserving the existed PCC slabs are used in the design for economical concerns and better slab conditions.

(2) Recycling of the existed AC overlays

To reuse the existed AC overlays above the PCC slabs, Cold Central Plant Recycling (CCPR) as defined by Asphalt Recycling and Reclaiming Association (ARRA, 2001) with foam asphalt is recommended as the preferred solution for its high content use of RAP materials and the advantage to get better quality control. And the recycling material is used as flexible base above the rubbilized surface or cement treated materials in the rehabilitation structure.

(3) Design scheme

Three schemes had been adopted in the rehabilitation design for different sections as presented in Figure 5 and Figure 6.

For east bounded carriageway, the PCC slabs were rubbilized after milling the AC overlays, for section A (K161+800~K162+000), 31cm cold recycled materials with foamed asphalt (in two layers) was used as the flexible base with 6 cm Sup-20 binder course and 4cm Sup-13 wearing course, thus formed a fully flexible structure, and for section B (the rest of the east bounded carriageway), 20cm cement treated materials laid over the rubbilized slabs, underlying the 11cm cold recycled materials and 10cm surface course as section A, thus composed a structure of semi-rigid base with thick asphalt layers. The use of 20cm CTB in scheme II arises from two aspects: to improve the foundation strength and to be economical compared with scheme I.

For west bounded carriageway, the PCC slabs was repaired by replacing the cracked slabs without rubblization, because the PCC slabs condition and bond condition are much better than that of the east, and there are some buildings very close to the expressway which restrained the use of rubblization. And then 20cm cement treated material and 11cm mixture of cold recycling with foamed asphalt was laid as base course over the slabs to mitigate the reflective cracking, overlaid by 10cm asphalt surface course.

For east bounded hard shoulder, 30cm of graded crushed rock was placed with the top level the same as the rubblized PCC pavement to get a more even foundation and form a good drainage channel for both scheme I and II.

For west bounded hard shoulder, the hard shoulder hadn't been treated and 20cm CTB was used to mitigate the stiffness difference for scheme III.

The three schemes are used in different sections to achieve long-term performance and for comparison with long time observation.

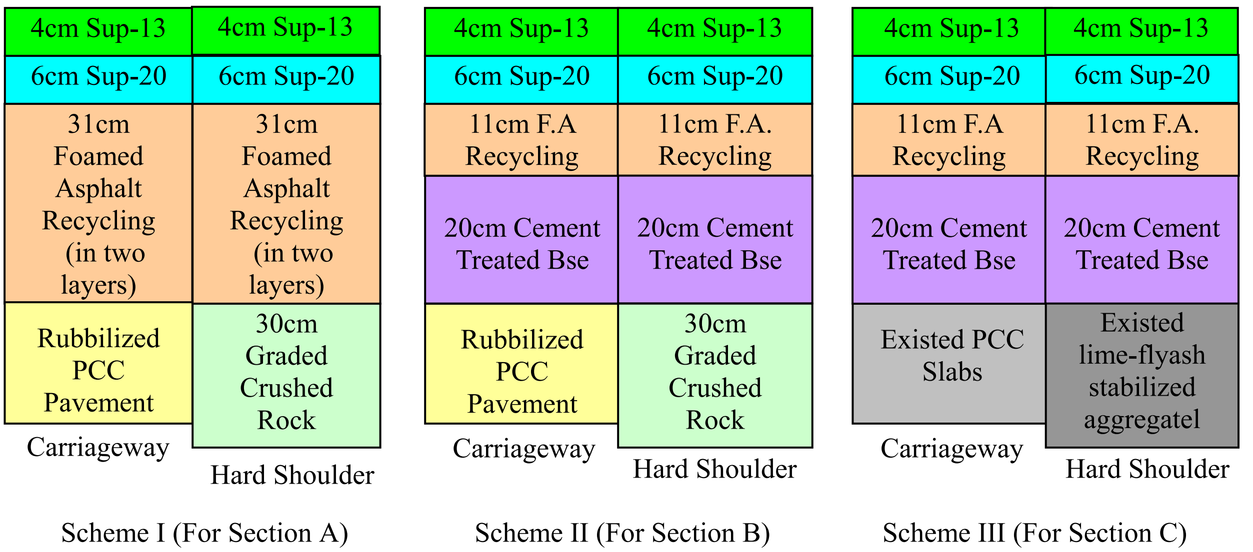


Figure 5: Rehabilitation design schemes

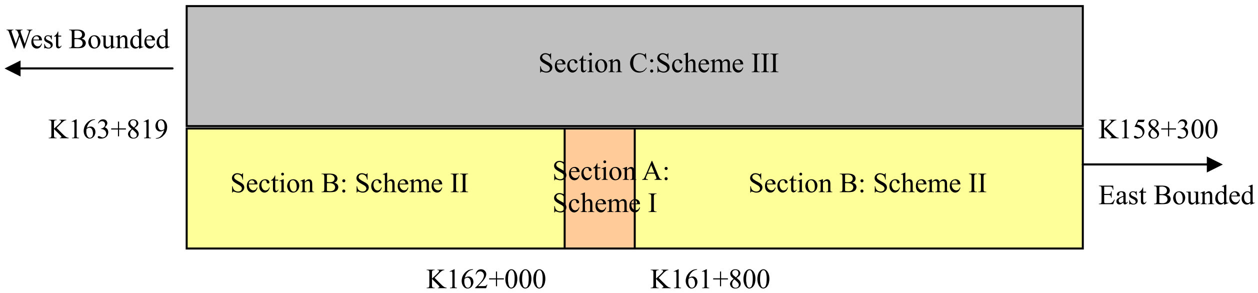


Figure 6: Sections for different schemes

5 CONSTRUCTION

5.1 Rubbilization

The Multi-Head Breaker (MHB) was used in this project for rubbilization.A 50m section from K162+650 to K162+700 of east bounded carriageway was selected as trial section before full construction.

The sieve analysis results after rubblization showed the rubblization has got good fracture size. Compaction of the rubblized surface by the MHB is accomplished using a vibratory roller that has been fitted with a “Z” grid and tack coat was performed after the compaction with high dosage of emulsions and 5~10mm aggregates and compacted using vibratory roller.

Benkelman Beam Test, FWD test and Plate Bearing Capacity Test are conducted as well to ensure the bearing capacity after rubblization and to find a quick and reliable test method for QC/QA. It can be seen in Table 4 that the back calculated modulus of BB and FWD has good correlation with the plate bearing capacity test results, and the deflection tests may be used as a quick test method foe QC/QA of rubbilization cause Plate bearing test is not convenient and time consuming. The resilient modulus ranges between 106 and 211Mpa which means the high variance and unevenness of the rubblization using MHB. General speaking, the resilient modulus are somehow lower than we had expected to be more than 150MPa and this mainly due to the weak subbase of the old pavement. The test results also reveal that the design of overlays after rubbilization should be adjusted timely according to the trial section.

Table 4: BB, FWD and PBT test results after rubblization

Slab No	BB		FWD		Plate Bearing Capacity Test
	Deflection	Back Calculated Resilient Modulus	Deflection*	Back Calculated Resilient Modulus	(Mpa)
	(0.01mm)	(MPa)	(0.01mm)	(MPa)	
4	119	138	116	141	106
9	108	152	106	155	156
11	84	195	78	210	187
16	80	205	85	193	211

*The deflection of FWD has been converted to BB deflections.

5.2 Cold Central Plant Recycling with Foamed Asphalt

Cold recycling with foamed asphalt may have the advantage of shorter curing period compared with the cold recycling with emulsions but maybe more susceptible to water damage. The two kinds of cold recycling are both attempted to use in China but for cold central plant recycling with foamed asphalt is performed the first time in Jiangsu Province.

5.2.1 Laboratory Formula Study

The target formula study of the cold recycling is conducted following the procedure below (Ministry of communications, 2008, Wirtgen Group, 2004):

- Select the parameter for foaming by expansion ratio and half time
- Select the proper gradation
- Determine the optimum water content through heavy compaction test
- Determine the optimum binder content through indirect tensile strength test
- Conducted other type test as Freeze-thawing splitting test and wheel track test

Two gradations, gradation A (70.5%RAP+28%New aggregates+1.5%cement) and gradation B (74.5%RAP+24%New aggregates+1.5%cement), both of which meets the gradation requirements, were proposed. Further test showed the tensile strength of gradation A is much better than gradation B, thus gradation A was chosen as the target gradation with a high RAP content more than 70% for further design and testing. The optimum water content is determined at 5.7% with the maximum dry density of 2.004g/cm^3 by heavy compaction. Cause there is no peak value of the tensile strength, and the optimum binder content was determined at 2.4% based on experience with a designed indirect tensile strength of 0.7741MPa which satisfied the requirement 0.5MPa in Chinese specification (Ministry of communications, 2008).

Wheel track test showed the designed mixture has an average dynamic stability of 11200 passes/mm and a TSR of 86.6% by freeze-thawing splitting test, reveals the mixture has good high temperature performance and resistance to water damage.

5.2.2 Trial Section Construction

Section from K161+850 to K162+000 after rubblization was chosen as the trial section for construction. The mixture was mixed by Wirtgen KMA200 Mixer, laid and compacted with a thickness 13cm, and intact core and be drawn out after 3 days curing period, which means the cold recycling with foamed asphalt succeeded.

6 CONCLUSIONS

On the basis of comprehensive pavement evaluation and traffic analysis, the rehabilitation scheme using a combination of the two "recycling" technologies-rubbilization and cold recycling-is successfully applied together the first time in China for PCC with asphalt concrete overlays. The construction process of rubbilization and cold recycling are also given in this paper and may be reference for similar projects.

It shows FWD test can also be used an effective tool to investigate and evaluate the pavement condition, and it seems the criteria to evaluate bond condition of PCC pavement are valid for composite pavement (PCC with thin AC overlay) as well.

Rubbilization is used to eliminate the reflective cracking and got good effect, and the the PCC slabs after rubbilization with similar characteristics to graded crushed rock, worked as the sub-base layer and provided good drainage pass. The cold recycling layer worked as a flexible base course which can also mitigate the reflective cracking.

Three design schemes are presented in this paper according to different section conditions and environments, the three schemes are used in different sections to achieve long-term performance and for comparison with long time observation.

For "Seconded rehabilitation" of PCC pavements with asphalt overlays, it's critical to treat the PCC slabs well, and maybe rubbilization and thick overlays are good options.

7 ACKNOWLEDEGEMENT

The authors would like to thank Mr. Ji Zenghui of Yangzhou Communication Bureau who assisted in reviewing this project and supplying some of the test data. Thanks also due to Mr. Jia Yu of Jiangsu Transportation Research Institute for reviewing this paper and advices.

REFERENCE

Ministry of *Communications*, 2002. *Specification of cement concrete pavement design for highway*" *(JTG D40-2002)* (in Chinese). Beijing, China

Ministry of Communications, 2006. *Specifications for design of Highway asphalt pavement" (JTG D50-2006)* (in Chinese). Beijing, China

Ministry of Communications, 2008. *Technical specifications for highway asphalt pavement recycling (JTG F41-2008)* (in Chinese). Beijing, China

Transportation Research Board, 2006. *Rubblization of Portland Cement Concrete Pavements.* Transportation Research Circular E-C087,Washington, USA

National Asphalt Pavement Association (NAPA), 1997. *Rubblization*. National asphalt pavement association information series publication IS-132. USA

Asphalt Recycling and Reclaiming Association (ARRA), 2001. *Basic Asphalt Recycling Manual.*USA.

Wirtgen Group, 2004. *Wirtgen Cold Recycling Manual*. Germany.