SHANGHAI’S EXPERIENCE ON UTILIZING THE RUBBLIZATION FOR JOINTED CONCRETE PAVEMENT REHABILITATION

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ABSTRACT

As agencies continue looking for cost-effective methods to rehabilitate deteriorated JCP, rubblization using resonant breaker has been experimented by the Shanghai Municipal Roadway Authority (SMRA). It was demonstrated that rubblization using resonant breaker offers a viable option for the SMRA because the rubblized pavement sections have been performing very well with no visible distress. Based on field observation for a typical HMAC overlay on a non-rubblized JCP, it was found the treatment normally would have reflective cracking for the same overlay thickness in first three years. Beside the cost advantage over the reconstruction, resonant breaker also had yielded the minimum disturbance during the rubblization. It was observed that it was very effective to use water during compaction on rubblized JCP surface to improve compaction efficiency and to control dust. Furthermore, there is no need to apply prime coat before the HMAC overlay as there was no detrimental effect could be identified. The averaged rubblized JCP moduli were found to be 1323 to 1375MPa which are within the range reported in the literatures. It was believed that there were high possibilities to increase rubblized JCP moduli without sacrificing the performance by increasing the particles size, because a reduction of 200 mm of HMAC was observed when rubblized JCP increased from 345 to 3445 MPa at subgrade modulus of 138MPa and traffic of 30 million ESAL. However, further researches are needed to optimize the rubblized JCP moduli in an attempt to reduce overlay thickness without creating reflective cracking.

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INTRODUCTION

Since 1990, the Portland Cement Concrete (PCC) pavement in China has experienced tremendous growth. The PCC pavements grow from 11,373km in 1990 to 199,000km in 2003 [Qin 2004]. In terms of percentage in overall paved roadway mileage, the PCC pavements grow from 24.4% in 1990 to 58% in 2003, as shown in Fig. 1. Unlike asphalt cement that mainly relies on import, cement is a local available material. Thus, it is very economical to use cement for roadway construction. Qin (2004) reported that 700 million tons of cement were manufactured and consumed in China in 2002. This is about half of the cement output in the world. The concrete pavements have been and will continue to play a critical role on the development of local economy. However, higher truck volumes and overweighed trucks have caused significant damages to the concrete pavements. In addition, there are lacking of proper methodologies and specifications on rehabilitating the deteriorated concrete pavements in China. Under such conditions many pavements have severe faulting and shattered slabs which causes very poor ride quality, as shown in Fig. 2A, 2B and 2C. Faulting is the difference in elevation across a joint between two slabs. Some of the common causes of faulting are settlement due to a soft foundation, pumping or eroding of material under the slab, and poor load transfer between two slabs (Shahin, 1994). Full Depth Repairing (FDR) and undersealing the voids with grout are the common treatments for deteriorated slabs. However, field observations indicated that many repaired areas or adjacent slabs often failed again in less than 3 years. For example, Fig. 2D shows a slab received FDR and it failed again that needs additional asphalt patch. It has been reported by Chen and Moon [2007] that due to lack of proper acceptance criteria for base preparation for the FDR, the repaired areas often failed again in few years. Pavement rehabilitation/maintenance programs for those severely deteriorated concrete pavements have been found to be quite costly because many treatments have not been proved to be effective to prolong or extend their life as more repairs become needed every year. Even with a costly rehabilitation/maintenance program, it is not able to maintain a satisfactory pavement condition and repairs are not able to stop the continuous pavement deterioration. China is facing with the challenges of identifying a cost effective rehabilitation strategy for an aging Jointed Concrete Pavement (JCP) highway system

Rehabilitation of aging JCP with a Hot Mix Asphalt Concrete (HMAC) overlay is problematic and prone to reflective cracking. Reflective cracking is recognized as one of the main distresses in HMAC overlays of concrete pavements. Although reflective cracking has been studied for a long time, it is still occurring and is responsible for millions of dollars per year in damage. Reflective cracking is defined as the propagation of an existing crack or joint upward to the new pavement surface. It is one of the most common causes of deterioration in overlay systems [Al-Qadi and Baek, 2006].

Rubblization has become very popular over the last 20 years in the United Stated. Many highway agencies in United States have reported their successful experiences on utilizing rubblization [LaForce, 2006, Wolters et al, 2007]. Rubblization is an unique means of rehabilitating concrete pavements by in-place conversion of the old concrete pavement into a useable base that eliminate all reflective cracking concerns. Rubblizing the concrete pavement obvious reduce the structure support for the overlay. However, it causes the old JCP to perform as flexible but interlock system. The rubblized base has proven to be 1.5 to 3 times stronger than a high quality, dense-graded crushed stone base [Thompson, 1997; Timm and Warren 2004]. According to research conducted by Thompson (1997), the rubblized base was most effectively obtained with a resonant breaker. Resonant rubblization has been used successfully in 37 U.S. states and two Canadian provinces [Fitts 2006]. Arkansas has rubblized over 300 miles of her interstate highway using resonant breaker with excellent results [Decker and Hansen 2006]. Although rubblization using resonant breaker has been very common in US, it is a new technology to China. In 2005, Shanghai Municipal Roadway Authority (SMRA) has selected resonant breaker to rubblize Huchinping highway and KimShan Broadway with satisfying results. Because of these two successful projects, SMRA has utilized the same technology again in 2007 for the National Highway 320 (~3.2km long). So far, there are over 15km of JCP in Shanghai were rubblized with resonant breaker.

To determine if the rubblization process was a viable rehabilitation technique through evaluating the performance of the rubblized pavements would eventually improve pavement technology by providing cost effective rehabilitation alternative. The focus of this paper was to present the performance of the JCP pavements that have been rehabilitated with the rubblization in Shangha. The lessons learned from these projects are expected to provide valuable information on effective rehabilitation methods of JCP sections that experience severe distresses and would not be able to be mitigated with conventional concrete restoration methods. In addition, the measured layer moduli from this study can be used as the input references for future rubblization projects. Furthermore, SMRA would like to determine the impact of the rubblization on the stiffness of base and subgrade.

PROJECT DESCRIPTION- HUCHINPING HIGHWAY

Huchinping highway was widen and reconstructed between 1990 and 1993 from original 7m two lanes roadway to 28.4m four traveling lanes plus two slow moving lanes, as shown in Fig. 3. The design speed for the four traveling lanes is 100km/h. The typical structure consists of 240mm concrete slab, 300mm fly ash treated based and 150mm river aggregate and sand mix subbase. Based on the 2002 traffic survey, the maximum daily traffic reached 23,613 vehicles per day. The estimated 15-year design traffic is 8.63 millions repetitions of 100-kN Axle load which is approximately 20.66 millions of 80-kN Equivalent Single Axle Load (ESAL).

The condition survey indicated that there were many severe longitudinal cracks, settlements, and shattered slabs on Huchinping highway. The shattered slabs have been determined to be more than 10%. With increasing annual maintenance spending but no improvement on pavement condition, SMRA was studying different alternatives. In addition to rubblization, two other alternatives in consideration to rehab severely deteriorated JCP were (1) to remove the JCP and to reconstruct the pavement section (2) to conduct full depth repair, to underseal voids with pressure grout, and then to overlay with hotmix asphalt concrete (HMAC). However, the initial construction costs and user delays make the alternative 1 impossible and there are significant risks for reflective cracking for alternative 2. Furthermore, there are many local businesses and residents along the Huchinping highway with underground utilities. The closest building to the Huchinping highway is only 15m. To minimize the disturbances (noise and vibration) to the local residents, resonant breaker was selected by the SMRA to rubblize the Huchinping highway. It was thought that the resonant breaker would yield minimum disturbance during the rubblization due to its low impact/amplitude and high frequency operation.

The length of the section was 471m, as it was the first rubblization project using resonant breaker in China. The short section was to gain experience and confidence on using this technique for rehabilitating severe deteriorated JCP. Nondestructive testing (Falling Weight Deflectometer), lab tests, and the condition survey were performed to evaluate the rubblization performance.

RUBBLIZATION ON HUCHINPING HIGHWAY

The resonant breaker uses a 200 to 275 mm shoe located on the end of a pedestal that is connected to a beam with 5,450 to 9,100 kg (12,000 to 20,000 lbs) counter weight. It is operated under a low amplitude (<12.5 mm) high frequency (44 Hz) shoe to deliver energy to the slab that is near the harmonic frequency of PCC pavement. The low amplitude is to avoid disruption of base and prevent damage to underground structures (e.g. utilities), as shown in Fig. 4.

Fig. 5 shows the rubblization using resonant breaker on Huchinping highway and the rubblized concrete surface condition. A 1m square test trench was dug after the rubblization to exam the particle sizes. That was conducted to calibrate the rubblization equipment to the existing site conditions. The test trench was also used to assure that the JCP had been fractured throughout its entire thickness. As shown in Fig. 5, the rubblization was very effective and it did rubblize the JCP throughout its entire thickness (240mm). Specimens were collected and the sieve analyses were performed. Only the samples at the top 50mm were collected due to the accessibility. The samples below 50mm were not collected because there was wire mesh in the concrete layer that prevents sample collection. It was found that the majority (~ 73%) of the particle sizes ranged from 2.5mm to 31.6mm. The most particle sizes were 5mm and 10mm that consists of 14.4% and 14.6%, respectively. All particles were less than 50mm. The gradation met the flexible base requirements, as shown in Table 2. As reported by Fitts [2006], the required particle sizes for most highway specifications are usually 150 mm nominal maximum size and 200 mm maximum particle size. If the rubblization process did not achieve these maximum particle size requirements, the contractor was required to repeat the process with other equipment to meet the requirements or remove and replace the materials. However, experience had shown that particles of 300mm to 450mm in the lower half of the slab did not adversely impact the effectiveness in reducing reflection cracking [Decker and Hansen 2006].

Also, the observation from test trench indicated there were fractured slabs at the bottom of the rubblized JCP with 45 degree angle that provided better aggregate interlocked and load transfer. The observations from this study regarding the particle size and fractured slabs with 45 degree angles were consistent with those reported in the literatures [Fitts 2006]. For Huchinping Highway, vibratory rollers were utilized to compact the rubblized JCP with the main purpose to seat the particles. No traffic was allowed to prevent unseating the rubblized particles. Experience has shown that traffic should not be allowed on the rubblized surface until the minimum HMA thickness for the type of facility had been placed [Decker and Hansen 2006]. Although it was originally thought that the rolling should occur while the material was in a dry state, this had changed over time with experience. As with rolling any unbound material, moisture lubricates particle surfaces and facilitates particle reorientation [Fitts 2006]. Water was used during the compaction for Huchinping Highway to enhance the effectiveness of the compaction and dust control. Two passes of vibratory rollers were employed before the HMAC overlay. It was recommended by AI [2006] that the HMA overlay over a properly compacted rubblized PCC pavement should occur within a 48 hour period from the compaction process to prevent the rainfall water from entering the pavement system. The HMAC overlay was placed on Huchinping Highway on the same day after the compaction.

HMAC OVERLAY THICKNESS DESIGN FOR HUCHINPING HIGHWAY

In China, there is no specific guideline to address HMAC overlay thickness design with rubblization. Thus, the lesson learned from this study will be valuable for future design and construction using this technique. The current design equation in China is to limit the maximum allowable surface deflection using the equation given in Eq. 1. It was based on the concept that for a given traffic level, the HMAC overlay and the underlying structure needs to provide sufficient bearing capacity to meet the maximum allowable surface deflection requirement. One of the most important parameters in computing the surface deflection is the determination of appropriate layer moduli. The Falling Weight Deflectometer test results from before rubblization, immediately after rubblization and immediately after HMAC overlay provided critical information for verification and validation of layer moduli used in the analyses and pavement designs.

$$L_d = 600 N_e^{-0.2} A_c A_s A_b \qquad (1)$$

Where

L_d = Allowable deflection (0.01mm). Note that the deflection acceptance is done by Benkelman beam.

N_c = Number of 100kN axle repetition for one lane

A_c = Highway classification, A_c =1.0 for highway or 1st class national roadway. 1.1 for 2nd class and under.

A_s = Type of pavement. 1.0 for flexible pavement

A_b = Type of base. 1.0 for treated base; 1.6 for flexible base.

The estimated design traffic is 8,626,837 repetitions of 100kN Axle load (or 20.66 millions of 80-kN ESAL) which are considered to be medium to high volume roadway. Because of the highway classification and level of the traffic, A_c is consider to be 1.0. Since the asphalt overlay will be placed on top of the rubblized concrete pavement, it was considered as the flexible pavement with A_s =1.0. In addition, the rubblized concrete was considered as a flexible base with A_b =1.6.

Thus, the maximum allowable surface deflection could be computed as

$$L_d = 600 * (8626837)^{-0.2} 1.0 * 1.0 * 1.6 = 40 * (0.01mm) = 0.40mm$$

0.40 mm is the maximum allowable surface deflection measured by the Benkelman beam.

To determine the AC overlay thickness, 104 FWD tests were conducted to determine the in-situ base and subbase and subgrade moduli through backcalculation process. The 104

FWD tests were conducted along the test pavement at mid-slab, corner-slab and edge-slab. 62 of the 104 FWD tests were conducted at the mid-slab. EVERCAL backcalculation software [EVERCAL 2005] was utilized to compute the layer moduli as shown in Table 1. The determined average, maximum, and minimum layer moduli and the coefficient of variation (CV) are presented in Table 1 as well. For convenience, the 300mm fly ash treated base and 150mm river aggregate and sand mix subbase were combined as one layer (called base+subbase hereafter) in the analyses. On average, the backcalculate moduli for concrete, base+subbase, and subgrade were found to be 30 153, 1 454, and 143 MPa, respectively.

A typical asphalt modulus of 3 445MPa (500ksi) was utilized in a multilayer computer analysis program (BISAR) to compute the overlay thickness. Note that there is no design parameter (e.g. the rubblized JCP modulus) in China prior to Huchinping highway. The following layer moduli were used in the analyses which were directly from the FWD backcalculation : (1) 240mm of rubblized JCP=1375MPa, (2) 450mm of base+subbase =1 454 MPa, (3) subgrade= 143 MPa. The analyses indicated that 130mm asphalt overlay produced a 0.18mm deflection under 50kN load. Note that the minimum overlay thickness recommended by National Asphalt Pavement Association [NAPA 1994, NAPA 2006] is 125mm (5 inch).

Since the current acceptance is based on the Benkelman beam deflection, Eq. 2 developed by Shanghai Municipal Roadway Authority (2002) was employed to convert FWD deflection to Benkelman beam deflection.

$$L_{BB} = 0.1786 L_{FWD} - 6.9876 \quad (2)$$

L_{BB} = Equivalent Benkelman beam deflection, in 0.01mm

L_{FWD} = FWD No.1 sensor deflection normalized to 50kN, in 0.001mm

Thus, the Equivalent Benkelman deflection can be computed as

$L_{BB} = 0.1786 * 180 - 6.9876 = 25 * (0.01mm) = 0.25$mm.

The AC thickness of 130mm would generate surface deflection of 0.25mm that was less than the maximum allowable deflection of 0.40mm (from Eq. 1). However, to investigate the effects of the pavement structures on the pavement performance, 3 sections with different thickness for 100m long each were constructed. It included (1) 130mm HMAC (40mm of SMA with SBS as the modifier + 90mm of AC-25) (2) 160mm HMAC (40mm of SMA with SBS as the modifier + 50mm of AC-20+ 70mm of AC-25) (3) 200mm HMAC (40mm of SMA with SBS as the modifier + 70mm of AC-20+ 90mm of AC-25). There were 50m of transition areas between the 100m sections to accommodate the variation of the HMAC thickness. Based on the discussion with engineers from the Louisiana Department of Transportation and Development on their experiences with rubblization projects, it was found that there was no need to apply prime coat before the HMAC overlay as the prime coat had been found to stick to the construction vehicles. No detrimental effects had been found based on their 8 years of experience without prime coat. Thus, no prime coat was used for the Huchinping Highway project.

The condition survey after more than 2 years of trafficking indicated that there was no visible distress and no variation among those 3 sections. Figs. 6A and 6B show the pavement conditions after 1 month and 2 years of trafficking, respectively. Based on field observation for typical a HMAC overlay on non-rubblized JCP, it was found that the treatment would normally have reflective cracking in first 3 years for the same overlay thickness.

FWD TESTING AND MODULUS FROM HUCHINPING HIGHWAY

20 and 32 FWD tests were conducted immediately after rubblization and immediately after HMAC overlay. The main reason for the less test points than the before rubblization (104 tests were conducted) was the time constraint (e.g. construction schedule and traffic disruption). The comparisons of the backcalculate modulus values before rubblization, immediately after rubblization and immediately after HMAC overlay are presented in Table 2. The average rubblized PCC moduli for immediately after rubblization and immediately after HMAC overlay were 379 MPa and 1375 MPa, respectively, meaning over 300% increase on rubblized PCC modulus after HMAC overlay was expected because of the overburden pressure from HMAC overlay. Galal and Chehab [2005] reported that the typically rubblized PCC modulus values used in the HMAC overlay design ranged from 448 to 3238MPa (65 to 470 ksi). It demonstrated

that the rubblization process and backcalculated moduli were within the range reported in the literatures. It is author' view that in the pavement design the rubblized PCC moduli should use the measured value after HMAC overlay not the value immediately after rubblization before HMAC overlay.

Efforts were made to determine the impact of the rubblization on the stiffness of base and subgrade. As presented in Table 2, the modulus for base and subbase before the rubblization was 1 454 MPa and immediately after HMAC overlay was 1 080 MPa (a 35% reduction). Similarly, the modulus for subgrade before the rubblization was 143 MPa and immediately after HMAC overlay was 114 MPa (a 25% reduction). Based on past experience on non-rubblization projects, it has been observed that the moduli for base and subbase, and subgrade would increase with time till they reach an equilibrium values. It was authors' view that the impact of the rubblization on the stiffness of base and subbase, and subgrade was not significant as the modulus would increase with time after rubblization.

The computed average equivalent Benkelman beam deflection from 32 measured FWD deflections (using Eq. 2) was found to be 0.28mm which is lower than required 0.40mm.

The 471m experiment section using rubbilization on Huchinping highway had met all expectations and requirements. It addition, there were no complaints from business owners and residents during the rubblization operation. Because the successful experience on Huchinping highway and from past experience reflective cracking is a major concern for HMAC over JCP, SMRA had selected rubblization to rehab this deteriorated JCP sections for 6.8 km KimShan Broadway.

KIMSHAN BROADWAY

The typical structure for KimShan Broadway consists of 240mm concrete slab, 300mm fly ash treated based and 150mm river aggregate and sand mix subbase. KimShan Broadway has been widen and reconstructed in 1990-1991 with four traveling lanes for a total width of 16m. The pavement distresses before rehabilitation included faulting and shattered slabs that caused poor ride. The 20 year design traffic for KimShan Broadway is 2,589,344 repetitions of 100kN Axle load which is approximately equal to 6.2 millions of 80kN ESAL. KimShan Broadway has been rubblized with resonant breaker in

September 2006. Since KimShan Broadway is the longest section to be rehabilitated in Shanghai and China, a more conservative approach with thicker AC was utilized. Thus, the overlay thickness for KimShan Broadway is 200mm (40mm SMA-13, 70mm AC-20, 90mm AC-25) for 6626m long and 250mm (40mm SMA-13, 60mm AC-20, 150 mm AC-25) for 200m long.

FWD tests were performed before rubblization, immediately after rubblization and after HMAC overlay. For convenience, base and subbase was combined and considered as one 450mm layer. The comparisons of the backcalculated moduli among before rubblization, immediately after rubblization and after HMAC overlay are presented in Fig. 7. The backcalculated moduli after HMAC overlay are 1 361, 328, and 172 MPa for rubblized JCP, 450mm of base+subbase, and subgrade, respectively. The rubblized JCP modulus of 1 361 MPa is very close to the Huchinping Highway (1 375MPa) and both are within the range reported in the literature.

There are several factors that may affect the rubblized JCP moduli (1) the age of the rubblized JCP, as rubblized JCP moduli normally increases with time due to cement stiffing effect, (2) the underlying support as rubblized JCP moduli increases with increasing underlying support, and (3) the rubblization efforts as rubblized JCP moduli normally increases with particle size and dimension of fractured slab. LaForce [2006] found increases in rubblized JCP modulus (stiffening of the pavement section) because of cementing of the rubblized concrete. Decker and Hansen [2006] reported that the particles of 300mm to 450mm in the lower half of the slab did not adversely impact the effectiveness in reducing reflection cracking. Thus, the current prevailing specifications to have all particles size to less than 200mm should be re-examined.

The deflection after 200mm HMAC overlay was designed to be less than 0.5 mm ($L_d = 600 * (2589344)^{-0.2} 1.0 * 1.0 * 1.6 = 50 * (0.01mm) = 0.50mm$). The average equivalent Benkelman beam deflection from FWD measurements after 200mm HMAC overlay was 0.25mm (refers to Fig. 8). It means the measured deflections were much less than the required. As aforementioned, conservative design was employed in this case to have thicker section.

As indicated on Fig. 8, the normalized 50kN FWD deflection has been reduced from 0.748mm to 0.178mm (a 4.2 times reduction). Similarly, the equivalent Benkelman beam deflection reduced from 1.27mm to 0.25mm (a 5 times reduction) after 200mm of HMAC overlay.

Fig. 9 shows the pavement condition after 1 years of trafficking. No visible distress could be observed and the performance has been satisfactory.

Based on the recommendation from the Asphalt Institute [2000], one of the critical steps before rubblization is to install edge drain system. If the edge drain system was not installed, the loss of subgrade support would substantially reduce the amount of pavement fracture and increase the overall size of the rubblized particles [AI 2000]. Prior to the rubblization process, the underdrains dry out and stabilized the subgrade and during the service life of the new pavement they prevent water from becoming trapped inside the different layers of the pavement structure. During construction, the edge drain system also serves to remove rainwater from the rubblized concrete layer, base layer and subgrade. It was reported by LaForce [2006] that a steady flow of water in the edge drain system is often observed. Longitudinal edge drain system was installed on KimShan Broadway prior to the rubblization with 80mm diameter of proliferated rigid corrugated polyvinyl chloride (PVC) pipe. The outlet interval was set from 30m to 40m, depending on the location. It was witnessed that water was coming out of the outlet pipe during the rubblization and after HMAC overlay. It means the edge drain system on KimShan Broadway has been function properly.

Efforts were made to determine the impact of the rubblization on the stiffness of base, subbase, and subgrade. As presented in Table 2 for Huchinping Highway, the modulus for base and subbase before the rubblization was 1 454 MPa and immediately after HMAC overlay was 1 080 MPa (a 35% reduction). Similarly, the modulus for subgrade before the rubblization was 143 MPa and immediately after HMAC overlay was 114 MPa (a 25% reduction). As shown in Fig. 7 for KimShan Broadway, the modulus for base and subbase before the rubblization was 668 MPa and immediately after HMAC overlay was 425 MPa (a 57% reduction). Similarly, the modulus for subgrade before the rubblization was 174 MPa and immediately after HMAC overlay was 167 MPa (a 4%

reduction). It was authors' view that the impact of the rubblization using resonant breaker on the stiffness of base and subbase, and subgrade was not so detrimental. In particular, with time the stiffness of base and subbase, and subgrade would increase with time after rubbilization.

OVERLAY THICKNESS

Graphic design charts were developed using FPS19 [Scullion and Michalak 1997] design software. Note that FPS19 has been used by TxDOT in routine pavement design for decades. Since almost all JCP built in early 1990 in China was 240mm thick, it was the thickness used in this analyses. In addition, twenty year design life with 90% reliability was utilized to develop the design charts. Figs. 10 and 11 show the required HMAC thickness for three layers system (HMAC+Rubblized JCP+Subgrade) with a typical HMAC modulus of 3 445 MPa (500ks). Those charts were aimed for four traffic levels (5, 10, 20, and 30 million 80-kN ESAL) with rubblized JCP moduli from 345 to 4 134 (MPa) and subgrade moduli from 138 to 413 MPa. For simplicity, no subbase was considered as it can be combined into subgrade. It was the reason that subgrade was starting from a higher modulus of 138 MPa (20ksi). Backcalculation analysis was performed for the KimShan Broadway and it was found the combined base and subgrade moduli immediately after the AC was approximately 207MPa.

The minimum HMAC was set at 50mm. These values were established to ensure adequate prevention of reflection cracking for a specific structural requirement. It can be observed that the overlay thickness increased from 165 to 305 mm when traffic increased from 5 to 30 million ESAL for rubblized JCP at 345 MPa and subgrade at 138MPa. Reductions of 200 mm of HMAC was observed when rubblized JCP increased from 345 to 3 445 MPa at subgrade modulus of 138MPa and traffic of 30 million ESAL. Thus, it indicated that higher rubblized JCP modulus would significantly reduce the required HMAC thickness. It is possible to achieve high rubblized JCP moduli. For example, Scullion [2006] conducted FWD tests on two Interstate 10 (I-10) sections in Louisiana and found the backcalculated rubblized JCP moduli exceed 850 ksi. The two sections tested were 2 and 3 years old, both consisted of old JCP which had been rubblized and surfaced with between 200 to 250mm of Superpave binder and wearing courses. The rubblized concrete base modulus of 850 ksi is well above that traditionally found with Class 1 flexible bases of 70 to 80 ksi. These very high moduli values would support that the rubblization only rubblized the upper layers and introduces diagonal cracks in the lower part of the slab. This indicated that the rubblized JCP was not being reduced to a flexible base; it was still retaining many features of a fractured slab.

Graphic design charts for four layers system (HMAC+ Cement Treated Base+ Rubblized JCP + Subgrade) are presented in Figs. 12 and 13. The benefits of including the Cement Treated Base (CTB) are (1) it is more cost effective than the HMAC; (2) CTB can be used as level up layer for areas with significant settlement and uneven surface. In addition, using CTB layer is a common practice in roadway design in China as it can be constructed with abundant experiences and locally available materials. In the analyses, 150mm and 1 723 MPa were used for the CTB thickness and modulus, respectively. Note that the CTB modulus of 1 723 MPa was a typical design value. Other variables remained the same as the three layers system, including the minimum HMAC of 50mm. Since the required HMAC overlays for traffic level of 5 million ESAL always yield the minimum HMAC of 50mm, they are not included in Figs. 12 and 13. Reduction of 100 mm of HMAC was observed as compared to the 3 layers system (without 150mm of CTB) at base + subgrade modulus of 207MPa and traffic of 20 million ESAL. Because many roadways are severely deteriorated with uneven surfaces, it is advisable to use CTB layer.

In view of Figs. 12 and 13, with higher rubblized JCP, the required overlay HMAC thickness is reduced as expected. When the three layers (Figs. 10 and 11) and four layers (Figs. 12 and 13) systems were compared, it was found that for most cases, 100mm of HMAC can be reduced with inclusion of the 150mm of CTB. Combining with better quality control during rubblization to increase rubblized JCP moduli and utilizing CTB layer, the required overlay HMAC can be further reduced to 50mm even with traffic level of 30 million ESAL. Cares are needed to ensure proper cement content is used in the CTB to prevent reflective cracking from the CTB layer.

CONCLUSIONS

The rubblized pavement sections have performed very well and have proven to be an efficient means of rehabilitating deteriorated JCP. Based on field observation for typical HMAC overlay on a non-rubblized JCP, it was found the treatment would normally have reflective cracking for the same overlay thickness in first 3 years. It was concluded that rubblization using resonant breaker provide a viable option for the rehabilitation of deteriorated JCP. Beside the cost advantage over the reconstruction, resonant breaker also had yielded the minimum disturbance during the rubblization due to its low impact and high frequency operation. In fact, there were no complaints during the rubblization from business owners and residents for the Huchinping Highway and KimShan Broadway. As agencies continue looking for cost-effective methods to rehabilitate JCP, it is clear that rubblization offers an excellent tool for the pavement engineers. The rubblization using resonant breaker has provided SMRA with a cost competitive tool for the rehabilitating severe deteriorated JCP.

Based on the field monitoring study during the rubblization, it was found that the edge drains were very effective on preventing moisture from building up under the rubblized concrete. The averaged rubblized JCP moduli were found to be 1323 and 1375MPa for KimShan Broadway and Huchinping Highway, respectively. It was believed that there were high possibilities to increase rubblized JCP moduli without sacrificing the performance by increasing the particles size, because a reduction of 200 mm of HMAC was observed when rubblized JCP increased from 345 to 3445 MPa at subgrade modulus of 138MPa and traffic of 30 million ESAL. However, further researches are needed to optimize the rubblized JCP moduli to reduce overlay thickness without creating reflective cracking.

It was also observed that it was very effective to use water during compaction on rubblized JCP surface to improve compaction efficiency and to control. Furthermore, there is no need to apply prime coat before the HMAC overlay as there was no detrimental effect could be identified. Efforts were made to determine the impact of the rubblization on the stiffness of base, subbase, and subgrade. It was concluded that rubblization using resonant breaker was not so detrimental to the stiffness of base, subbase, and subgrade. In addition, the modulus values would increase with time till they reach an equilibrium values.

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Table 1 Sieve Analyses for Specimens Retrieved from the Rubblized Concrete Layer for Huchinping Highway

Sieve (mm)	Passing (%)	Spec Requirement (%)
50	100	100
40	99.3	90--100
20	78.2	65--85
10	62.1	45--70
5	47.5	30--55
2.5	33.1	15--35
0.63	17.7	10--20
0.08	5.1	4 --10

Table 2 FWD Backcalculation Modulus Results (MPa) for Huchinping Highway

Layer	Time	Average	Maximum	Minimum	CV (%)
Concrete (MPa)	Before Rubblization	30,153	51,156	7194	38.9
	After Rubblization	379	549	234	28.5
	After HMAC overlay	1375	2352	322	40.6
Base and subbase (MPa)	Before Rubblization	1454	1910	891	24.4
	After Rubblization	981	1341	774	21.7
	After HMAC overlay	1080	1591	491	35.1
Subgrade (MPa)	Before Rubblization	143	181	113	13.43
	After Rubblization	87	132	65	27.2
	After HMAC overlay	114	135	101	9.2

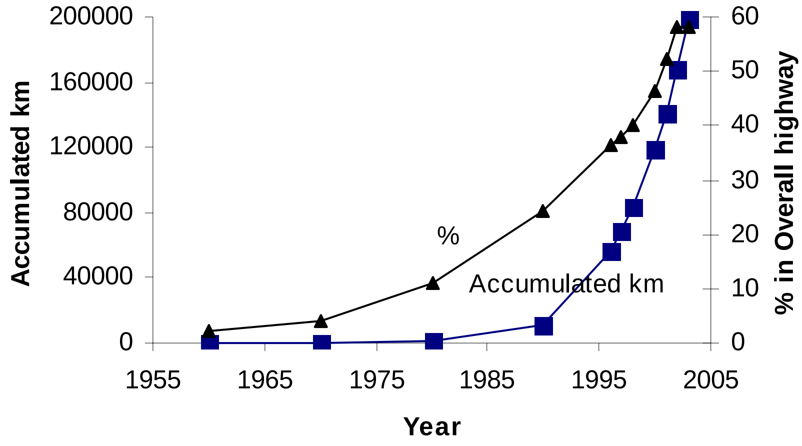


Fig. 1 Accumulated Joint Concrete Pavement In Terms of Lengths and Percentage (%) in Overall Highway System

Fig. 2 Severe Distresses Including (A &B) Shattered Slabs, (C) Faulting/ Settlement (D) Additional Distress Reappeared on Area where received Full Depth Repair (FDR)

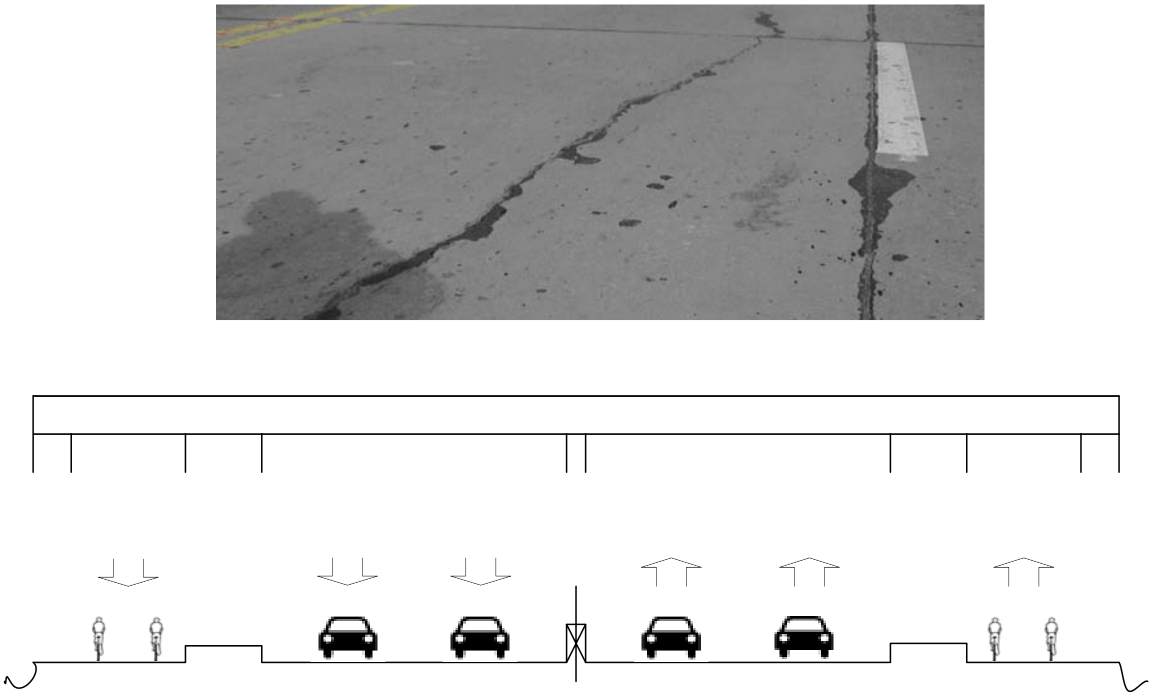


Fig. 3 Before Rubblization Pavement Condition and the Geometric for the Huchinping Highway

28

1.0 3.0 2.0 8.0 0.

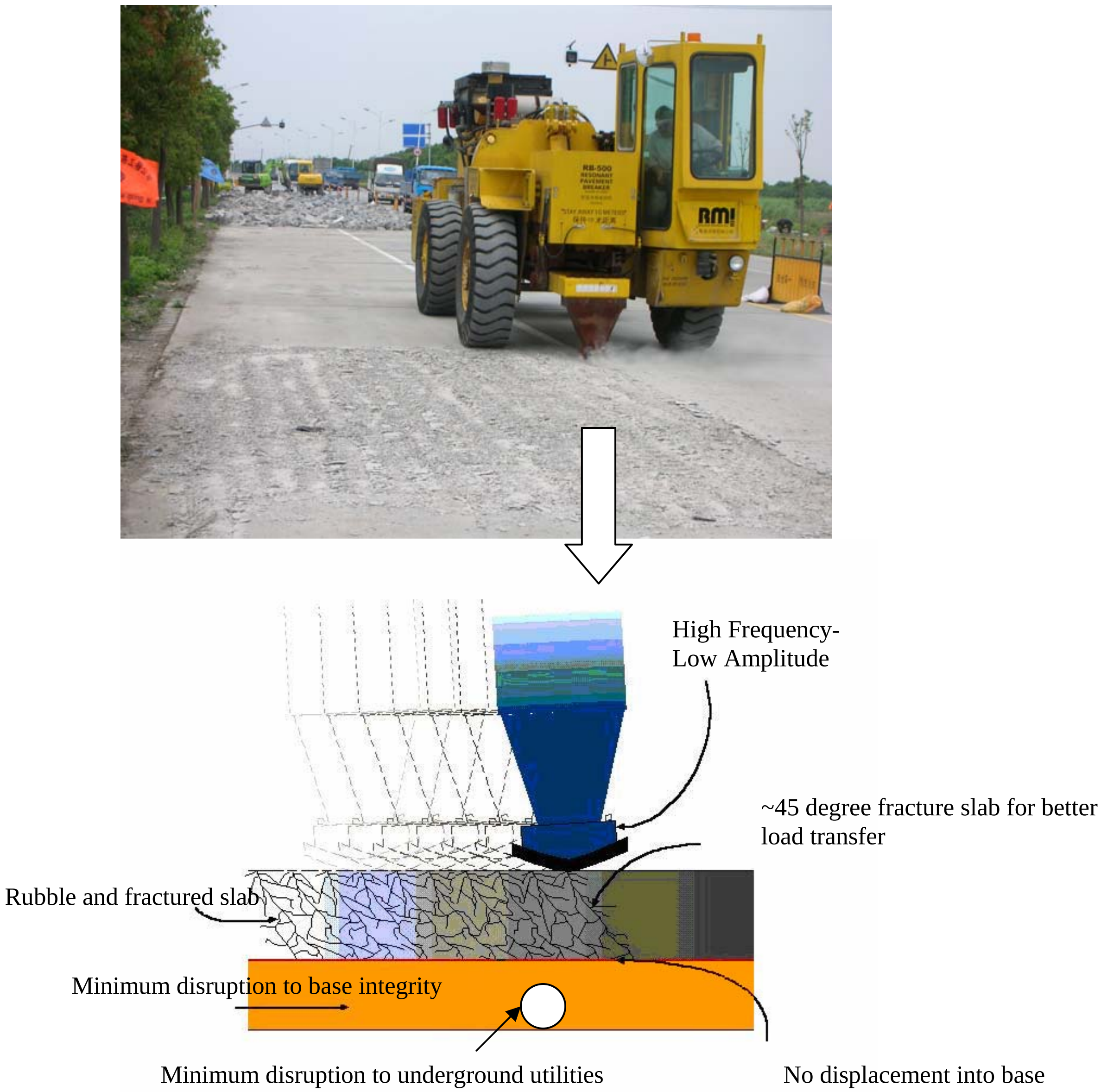


Fig. 4 Resonant Pavement Breaker and Illustration of PCC Fracturing Resulting from Resonant Rubblization

Fig. 5 Rubblization Using Resonant Breaker on Huchinping Highway (A) Two RMI RB500 Resonant Breaker in Action (B) Rubblized Surface Condition Before Rolling, and (C) Test Trench Show Fractured Particles Throughout Entire JCP Thickness.

Fig. 6 Pavement Conditions for Huchinping Highway After (A) 1 Month and (B) 2 Years of Trafficking

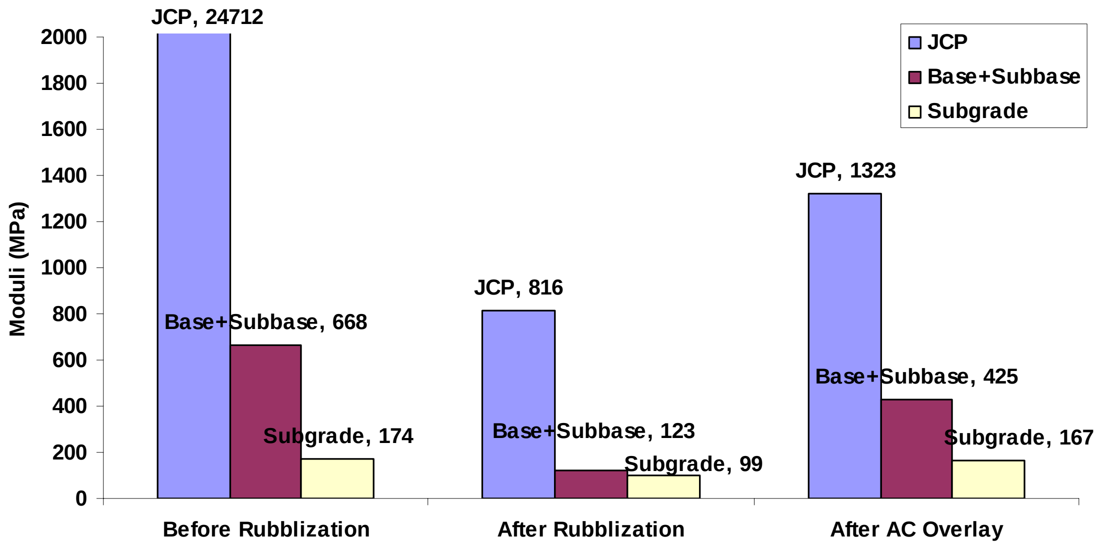


Fig. 7 FWD Backcalculation Modulus Results (MPa) for KimShan Broadway

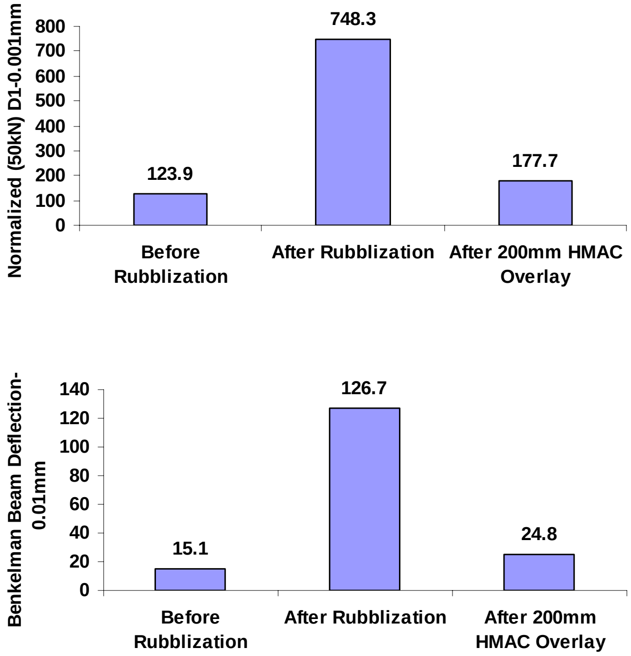


Fig. 8 Normalized 50 kN FWD D1 Deflection and Computed Benkelman Beam Deflection (0.01mm) from FWD D1 Deflection Using Eq. 1 (KimShan Broadway)

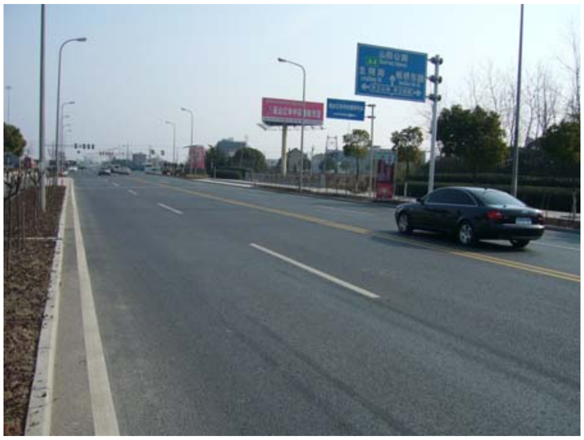
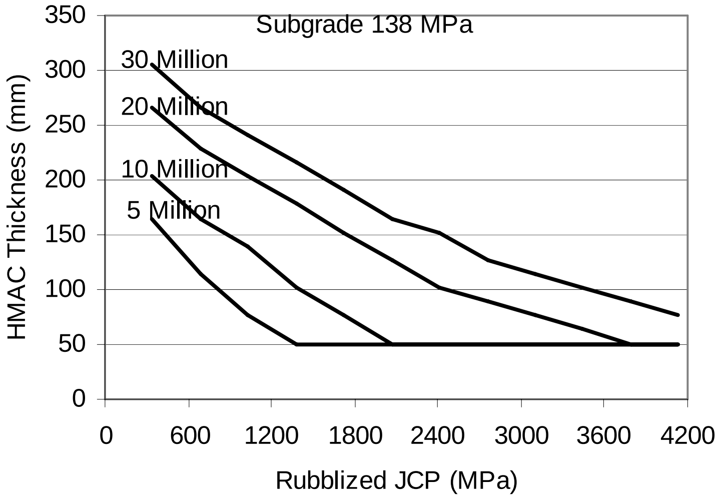
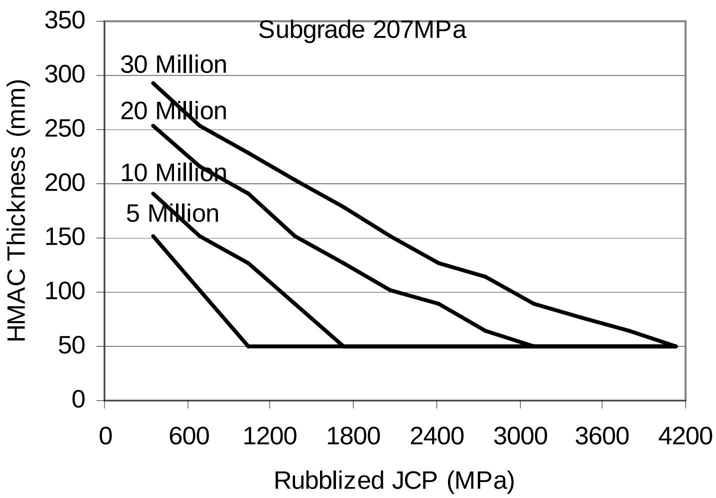


Fig. 9 Pavement Conditions for KimShan Broadway After 1 year of Trafficking

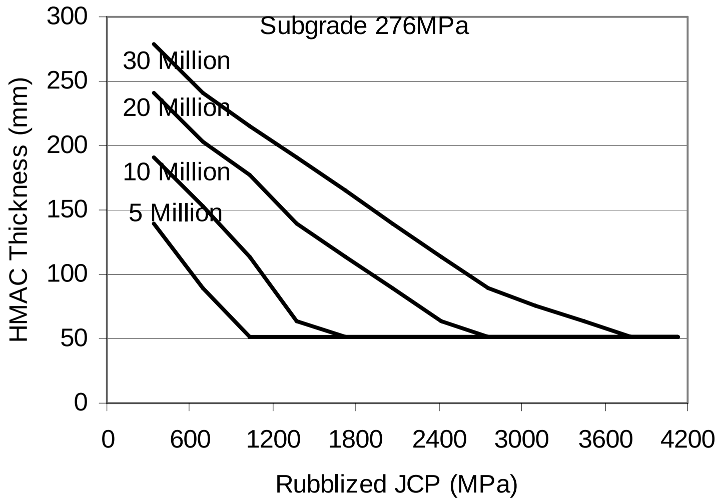


(A)

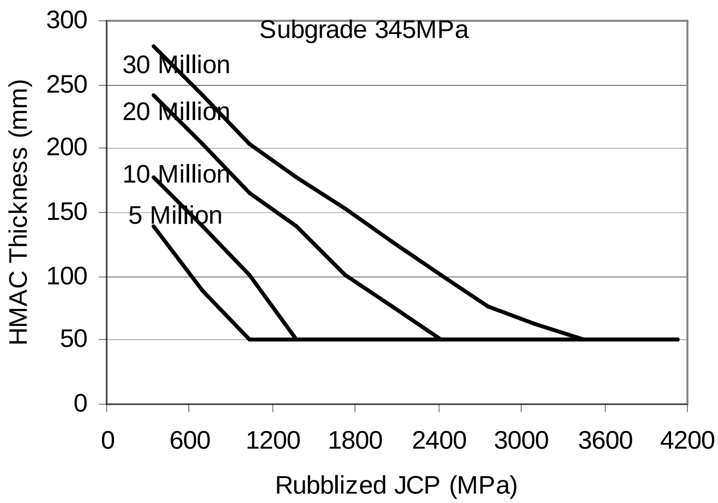


(B)

Fig. 10 Required HMAC Thickness for 3-Layer System (A) Sugrade Modulus of 138 MPa (B) Sugrade Modulus of 207 MPa

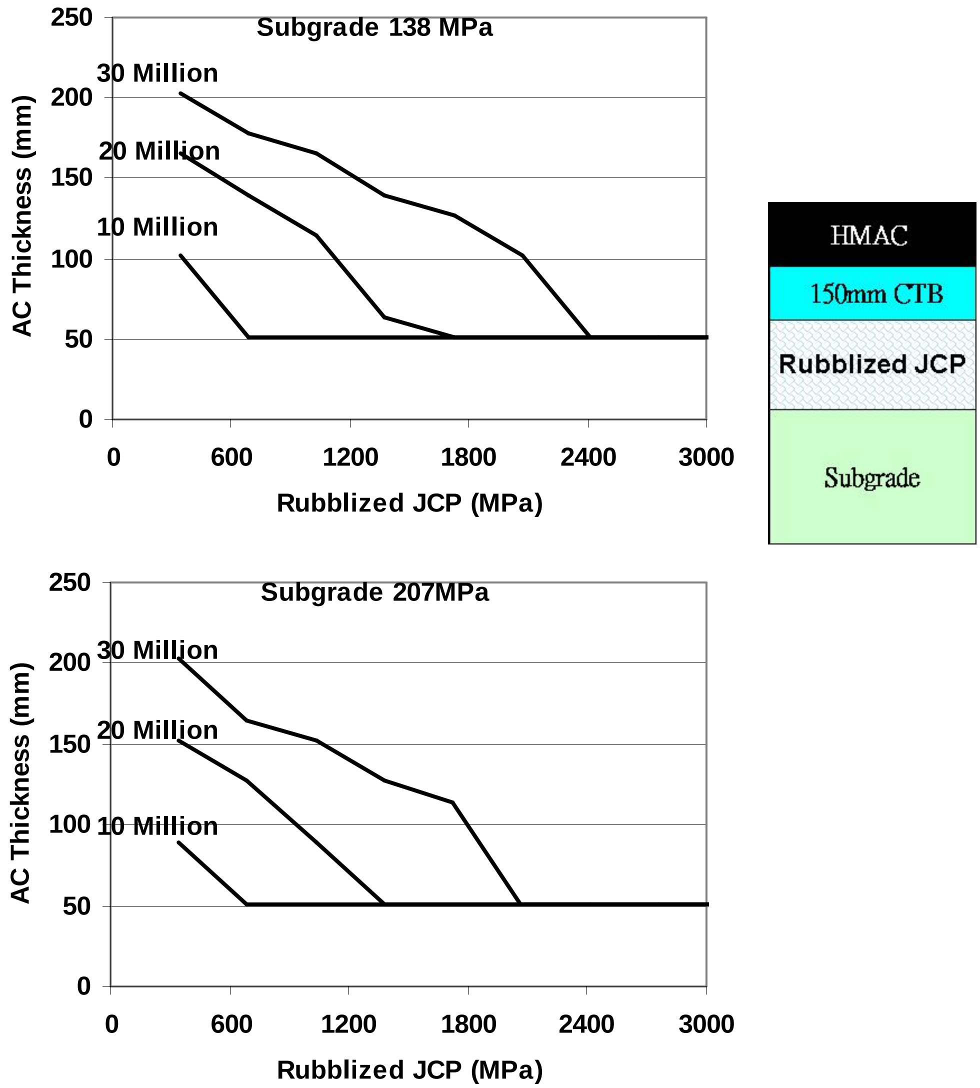


(A)



(B)

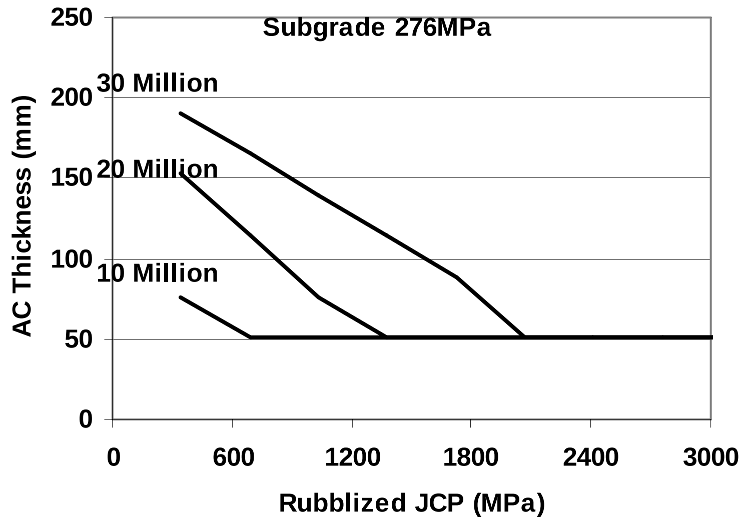
Fig. 11 Required HMAC Thickness for 3-Layer System (A) Sugrade Modulus of 276 MPa (B) Sugrade Modulus of 345 MPa

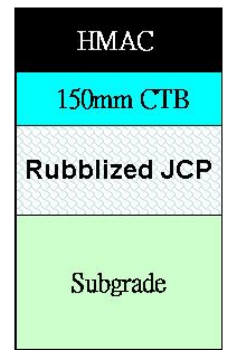


(A)

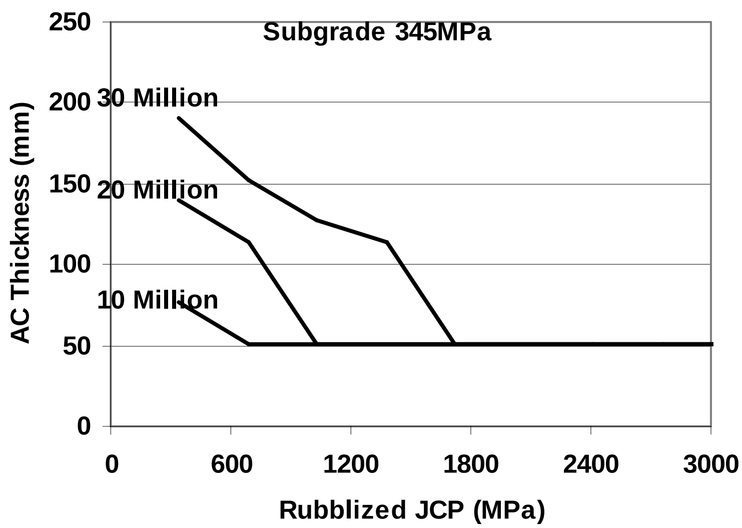
(B)

Fig. 12 Required HMAC Thickness for 4-Layer System (A) Sugrade Modulus of 138 MPa (B) Sugrade Modulus of 207 MPa





(A)



(B)

Fig. 13 Required HMAC Thickness for 4-Layer System (A) Sugrade Modulus of 276 MPa (B) Sugrade Modulus of 345 MPa