THEORETICAL DEVELOPMENT AND ENGINEERING PRACTICE OF PAVEMENTS IN CHINA

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Abstract: *This paper presents a comprehensive review of historical theory development and current construction practice of pavement engineering in China. Mechanical models, design guides, construction techniques, evaluation methods and maintenance standards are elaborated for PCC pavements and AC pavements. Differences in design methodology among pavements of rural highways, urban roads and airport fields are discussed based on service requirements. Lessons and experiences based on past 20 years' construction practice and pavement performance are summarized. Current research areas in pavement engineering associated with unconventional geological and/or landscaping in China's highway construction and national strategic plan for pavement engineering are also covered in this paper.*

Key words: *Pavement Engineering, Asphalt Concrete Pavement, Portland Cement Concrete.*

During last two decades, China has witnessed rapid developments in pavement engineering with upgrading of transportation market and expansion of transportation infrastructures including highways, city roads and airports. Total length of highways in China reached 1,930,500 km with 132,674 km of National Trunk Road connecting major cities at the end of 2005[1]. Construction of the first freeway, Hu-Jia Freeway in Mainland China started in 1984 was completed in 1988 linking Shanghai municipal center to Jiading, a suburban district 20 km away. The "7918 Program" [2], China's National Freeway System as shown in Figure 1, was approved by the State Council on Dec. 17, 2004 and has a total mileage of 85,000 km. The "7918 Program" was made to meet the national modernization goal in the middle of 21st century, and China will have a freeway of 0.83 km/100 km2 by then, a standard roughly equal to the current freeway system in US[] given in Figure 2. According to China's 2005 highway statistics[1] issued by Ministry of Communications in May, 2006, total mileage of China's freeway has reached 41,005 km, which is ranked the second longest freeway system in the world just after US with a freeway system of 91,285 km (56,699 miles) in 2005's Highway Statistics[3] issued by US federal Department of Transportation. Besides the huge task of completing domestic highway network, the Asia Highway Route[4] as illustrated in Fig. 3 was approved in November, 2003 connecting 32 countries in Asia with a mileage of over 140,000 km, among which China has 26,000 km in Fig. 4, almost one-fifth of the whole program.

Figure 1. China's National Freeway System

Figure 2. Eisenhower Interstate System

Figure 3. Asian Highway (AH) Route Map

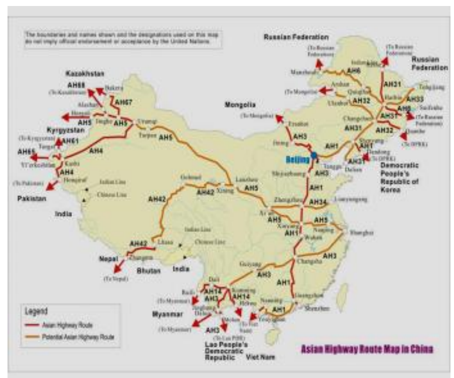

Figure 4. China's AH routes

At the same time, pavements for urban roads expanded to 247,000 km in China's 661 cities by the end of 2005 with an average road density of 10.93 m2 per capita[5]. Current city residents accumulated to 358,940,000 while city land covers 412,700 km2 in 2005[5]. Routine maintenance, rehabilitation, resurfacing, reconstruction, and new construction of road pavements will continue to grow with the fast development of urbanization and industrialization in next decades. Urbanization ratio will be increased from current 41.7% to 60% during the national program of "Socialist New Village Program"[5], which obviously requires more urban roads to be built.

In airfield sector, there are 142 certified airports with operating air routes connecting major cities in the world and/or major domestic cities in mainland China by the end of 2005[6]. Among 133 airports, nearly 60 are close to design capacity or oversaturated with rapid expansion of air traffic. Air passengers reached 241,935,000 and cargo transportation exceeded 5,526,00 tonnage with a platoon of 863 commercial jetliners. Annul increase in air transportation is expected to be 14% in the next 5 years in China, which leads to an increase of commercial jetliners to 1580 and dozens of runways to be expanded, rehabilitated, and/or newly built[6]. A Boeing projection in 2002[7] expected that 2320 commercial jetliners will be required in 2022 to support the second largest air transportation market in the world, right after US. Several metropolitan airports such as Shanghai Pudong International Airport, Beijing Capital International Airport, Guangzhou Baiyun International Airport, and Chengdu Shuangliu International Airports are potential candidates to develop hub-and-spoke system (HSS) in order to become a key node in world air route network.

I. DEVELOPMENT OF DESIGN THEORY

Portland cement concrete (PCC) pavements and asphalt concrete (AC) pavements are the two major pavement categories in China's pavement engineering. With the decrease of pavement's share in total highway costs and understanding of life-cycle cost analysis, AC pavements have gained more and more applications in city roads and airports as well as rural highways. Data from highway statistics in China show that there are 532,697 km of high-type pavements with AC pavement of 226,075km and PCC pavements of 306,622 km, which account for 42.44% and 57.56%, respectively. All mid-type pavements are asphalt roads with a total length of 461,901 km. PCC pavements used to be the only type of paving of airfield including runways, taxiways, and aprons in China's airports including civil transport airports and military airports. However, the successful application of AC pavements in runway in Beijing Capital International Airport in 2001 proved an effective alternative in design of pavement types in runway construction. AC overlay became a competitive alternative in airport upgrading since then due to its better serviceability. With the development of structural analysis of pavements, design philosophy evolved from empirical methods in early days into mechanistic-based methodologies. Table 1 lists pavement design guides of various sectors current used in China, structural analysis theory of pavements varying from CBR (California Bearing Ratio) method to FEM (Finite Element Method) method. It should be noted that highways in China refers to roads in rural areas while urban roads is used to address in cities. Ministry of Communications of China's State Council and corresponding DOT (department of transportation) authorities in provincial and county governments are responsible for "rural" highways including issuing design specifications for highway pavements. At the same time, Ministry of Construction and corresponding municipal authorities are responsible for "city" roads including publishing design guides for urban roads. In the early days, design guide of highway pavements was also used for urban roads, forest road, airport and other sectors of industry. Between middle of 1980s and early of 1990s, separate design guides for urban road, forest road, industrial road and airport were developed and most of them borrowed ideas of highway guide, AASHTO guide[8], FAA guide and guides of other countries. Basically, AC pavements were analyzed based on Burmister's layer theory[9-12] while PCC pavements were designed based on Westergaard's solution or elastic solid foundation[13-21].

Table 1. List of pavement design guides of various sectors in China

Sector Category	Pavement Category	Current Design Guides	Code	Updated Year
Highway (rural)	AC	Specifications for design of highway asphalt pavement	JTG D50-2006	2006
	PCC	Specifications of cement concrete pavement design for highway	JTG D40-2002	2002
Commercial airport	AC	Specifications of asphalt concrete pavement design of civil airports	MH 5011-1999	1999
	PCC	Specifications for cement concrete pavement design for civil transport airports	MHJ 5004-95	1995
Military airport	PCC	Specifications of design of cement concrete pavement for military airport	GJB 1278-91	1991
Urban road	AC, PCC	Specifications of design of industrial roads	CJJ 37-90	1990
Forest road	AC, PCC	Design specifications of road surface for forest road	LYJ 131-92	1992
Industrial road	AC, PCC	Specifications of design of industrial roads	GBJ 22-87	1987

Note: *(1) New design guide for AC highway pavement JTG D50-2006 implemented starting Jan. 01, 2007.*

(2) Industrial roads refer to roads in factories and mines

II. PCC PAVEMENTS

Five types of PCC pavements, namely JPCP (jointed plain concrete pavement), JRCP(jointed reinforced concrete pavement), CRCP(continuous reinforced concrete pavement), RCCP(rolling compacted concrete pavement), and PRCP (prestressed reinforced concrete pavement) have been constructed in China. JPCP is the most widely-used PCC pavement for highways, urban roads, and runways. Design theory was based on elastic theory of Kirchhoff thick plate with a modulus of rigidity D, which is governed by Equation (1)[12,14,21]. Base layer and underlying subgrades can be assumed as elastic half space (Hogg's solution), Winkler foundation (dense liquid foundation, Westergaard's solution), Pasternak foundation, or multi-layer elastic foundation, leading to different equations of foundation reaction, p(r) under axisymmetric loading of q(r) in Equation (1).

$$D\nabla^4 w(r) = q(r) - p(r) \qquad (1)$$

Where $\nabla^4 = \nabla^2(\nabla^2) = \left(\frac{d^2}{dr} + \frac{1}{r}\frac{d}{dr}\right)\left(\frac{d^2}{dr} + \frac{1}{r}\frac{d}{dr}\right)$

Design guide for highway pavements was first published in 1958 with 1954 version of then Soviet Union's pavement design guide as blueprint[14]. The guide was revised in 1966 (JT1004-66) and served as the only existing guide for pavements including AC and PCC pavements for highways, urban roads and airports. A separate PCC pavement design guide, Specifications of cement concrete pavement design for highway JTJ012-84, was issued in 1984. Structural analysis was based on theory of elastic think plate over elastic solid foundations. Critical loading position was situated at the middle of transverse joints. Thickness calculation is solely based on loading stress without considering curling stress. In 1994, the guide was revised as Specifications of cement concrete pavement design for highway JTJ012-94 and curling stress was included into thickness design consideration. Critical loading position was selected in the middle of longitudinal joints. In 2002, design guide was revised again using reliability concept instead of factor of safety. Thickness is determined by limiting the combination of loading fatigue stress σpr and curling fatigue stress σtr to concrete strength fr with a reliability coefficient of γ_r in Equation (2).

$$\gamma r\ (\sigma pr + \sigma tr) \leq fr \qquad (2)$$

Pavement maintenance has to meet standards in "Technical specifications of cement concrete pavement maintenance for highway JTJ 073.1-2001". RQI (ride quality index) in terms of IRI (international roughness index), TD (textural depth), PCI (pavement condition index) and DBL (ratio of breaking plates), and representative deflection are used to evaluate roughness, skid resistance, distress and strength of pavement structures, respectively. For freeway system, a separate specification, "Expressway maintenance quality evaluation standards", should be used for quality requirements in maintenance work.

Distress is evaluated based on type, amount and severity and different weigh factors are allocated to specific type of distress with certain amount and severity in calculating PCI. Major distresses found in PCC pavement include fatigue cracking, pumping, faulting, corner breaking, joint spalling, scaling, load-transfer deterioration, depression, durability cracking, pop-outs and reactive aggregate distress.

III. AC PAVEMENTS

Asphalt pavements used in China include asphalt concrete (AC), asphalt macadam (AM), asphalt penetration, and asphalt surface treatment. Other types such as SMA (stone mastic asphalt), OGFC (open graded friction course), cold mix, color mix, slurry seal, micro-surfacing, and recycled asphalt pavement. Burmister's layer foundation theory[15-17] was used these days for asphalt pavement design for highways and urban roads. Airport engineers usually use CBR method to design AC runway pavements in accordance with MH 5011-1999.

Design guide for asphalt pavements were included 1958 version of "Specification of pavement design " and revised version "Specification of highway pavement design(JT1004-66)". In those two versions of design guides, an elastic half space was assumed and M.H.Yakunin's solution in 1941 based on Boussinesq's theory was adopted to solve structural responses in Equation (3). Vertical stress at a depth of z from half space surface σz under load intensity of p applied over a single circular area of diameter z was approximated using a =1.5 in Equation (3). Practical application of design guide in 1950's and 1960's found that Yakunin's solution was not sufficient to conduct structural analysis of flexible pavements.

$$\sigma_z = \frac{p}{1+\alpha\left(\frac{z}{D}\right)^2} \qquad (3)$$

Field investigation, road tests, theoretical analysis and laboratory research had been conducted since 1968 and a new design guide was issued for practical use, "Design specification of flexible pavements for highways (interim guide)", in 1978. The structural theory of 1978's guide was based on Burmister's two-layer system. Surface deflection in the middle of tandem tires was used to check thickness. A nomograph was provided in the guide. With the development of computers and construction practice of pavement in highways and urban roads, a 1986 version, "Design specifications of flexible pavements for highways (014-86)", was issued. Burmister's three-layer system was used to solve structural responses. Allowable surface deflection, together with bending stress at the bottom of asphalt layer was used to calculate pavement thickness. Different interlayer status could be assumed based on construction process and specified methods in analyzing pavements. In order to accommodate tire application characteristics in urban roads, a shear index at the pavement surface was introduced with Mohr-Coulomb strength criterion for AC surface layer. In 1997, another version of pavement design guide, "Specifications for design of highway asphalt pavement", was published using design software APDS (asphalt pavement design software) based on Burmister's multi-layer system. Design deflection instead of allowable deflection was used to evaluate pavement structural integrity. In this guide which played a key role in the rapid expansion of China's freeway system, asphalt pavement with semi-rigid base was emphasized to reduce AC surface layer by increasing base strength. In 2004, new AC design guide based on engineering feedback, research inputs, lessons and experience of pavement industry abroad was drafted to seek reviews from industry and institutes. This draft, "Specifications for Design of Highway Asphalt Pavement (JTG D50-2004)", attracted controversial discussions from various sides based on different research backgrounds and versifying engineering practices. Many new ideas based on field investigations, research findings and pavement performance in last 10 years were incorporated. Four base types, semi-rigid base, flexible base, rigid base and composite base are recommended. In accordance with new construction guide, "technical specifications for construction of highway asphalt pavements (JTG F40-2004)", gradation was adjusted compared to JTJ014-97. Finally, JTG D50-2006, was approved at the end of 2006 by Ministry of Transportation after long discussions and/or debates.

Maintenance work is governed by "technical specifications for maintenance of highway asphalt pavement JTJ 073.2-2001" and PQI (pavement quality index) is used to designate maintenance levels. PCI, RQI, SSI(structural strength index), and SFC (side friction coefficient) are calculated to evaluate pavement condition, ride quality, structural integrity, and traffic safety, respectively. Automatic distress survey equipments, such FWD (falling weight deflectometer) for deflection and RTRRMS (response type road roughness measuring system) roughometer or profilometer for roughness, are recommended for fast investigation of pavement condition. Fatigue cracking, rutting, reflection cracking and water damage are the primary four distress types. Other distresses include low temperature cracking, structural cracking, bleeding, slippage cracking, and pumping.

IV. PAVEMENT RESEARCH IN CHINA

Major research topics in early days concentrated in analytical solution of pavement structures, based on theory of elasticity of Boussinesq half space, Winkler system, Burmister multilayer system, elastic solid system. Influence charts, nomograph and design tables were published for design reference[6]. With the fast development of freeway system in China, asphalt pavements gained more and more attention in research fields as well as in industry. Mix design with a SHRP (Strategic Highway Research Program, of US) Superpave® understanding, pavement evaluation with PCI and PSI (present serviceability index), transportation management system based on Web-GIS (geographic information system), automatic pavement data acquisition, preventive maintenance, and pavement recycling, all these topics became interests of research which resulted in updating of specifications of pavements with respect to policy, design, construction, supervision, acceptance, and maintenance fields.

One special research interest in China is non-conventional subgrade deformation and pavement responses in the context that China has many mountainous areas, soft ground zones, and existing highways with low standards. Literature reported research effort in embankments in sloped ground, cut-fill subgrades, road widening over soft ground, crack propagation, and structured subgrades, see Figures 5-22 (note: All these illustrations were cited from thesis-dissertation works of Master and PhD students of the author's). Figure 5 and Figure 6 show the difference in deformation characteristics of embankments over flat and sloped ground, which is a common alignment result of roads in mountainous areas. It can be seen that deformation concentration at the downside toe of embankment constitutes a great concern in slope stability.

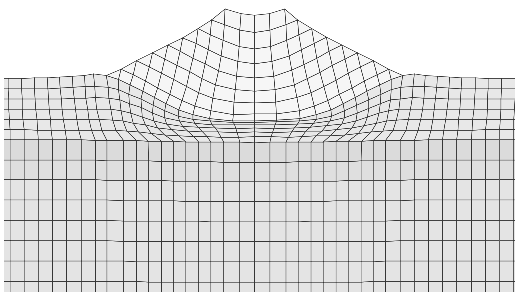

Figure 5. *Deformation characteristics of flat ground*

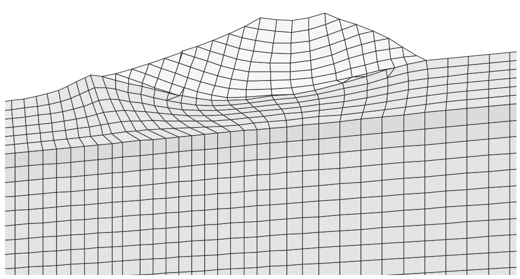

Figure 6. *Deformation characteristics of sloped ground*

Soft and weak ground is one of the traditional geotechnical challenges. Residual settlement after construction completion poses significant influence on structural performance of pavements over embankment in soft ground. Step by step consolidation prediction can be predicted as shown in Figure 7 and Figure 8 and can be a practical reference in embankment construction monitoring. Figure 7 and 8 are simulation results of embankment with a top width of 34.5m in Chengdu 4th Ring Road Freeway (Chengdu Bypass Freeway).

Cut-fill transitional subgrade sections are common practice in highway design in mountainous areas due to geometric limitations and geological conditions. Traffic loading in pavements over cut-fill subgrades in Figure 9 will produce additional structural responses as shown in Figure 10 which in turn will result in shortened pavement service life.

Major problems in road widening projects as illustrated in Figure 11 are differential deformation between existing roads and newly-added section, especially in soft and weak ground. Additional structural responses produced in pavements as a result of differential deformation behavior of subgrades will influence pavement performance. In figure 12, it can be seen that different widening scenarios will cause different deformation curve across transverse section.

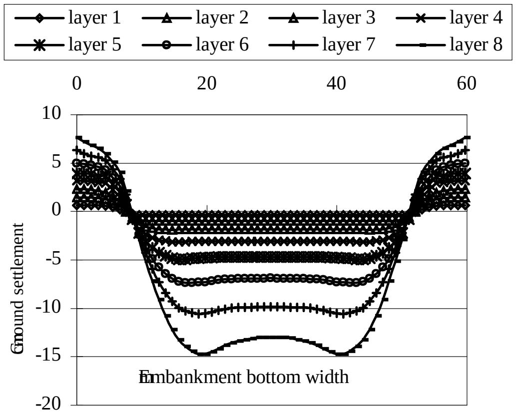

Figure 7. *Consolidation process during embankment fill*

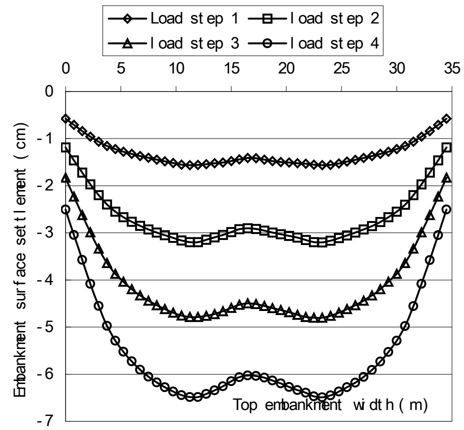

Figure 8. *Settlement development under traffic*

Cut – fill boundary

1#

2#

3#

4#

5#

6#

Figure 9. *Traffic loading on cut-fill section*

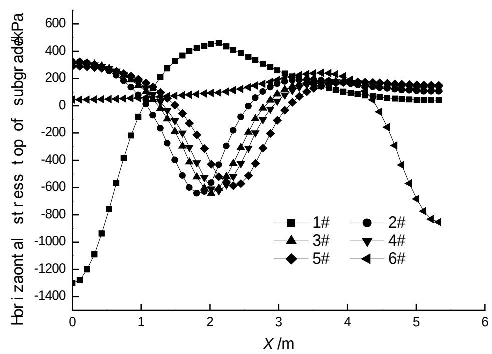

Figure 10. *Structural responses of cut-fill section*

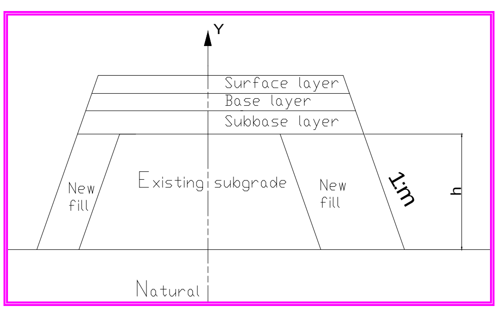

Figure 11. *Pavement over road-widening section*

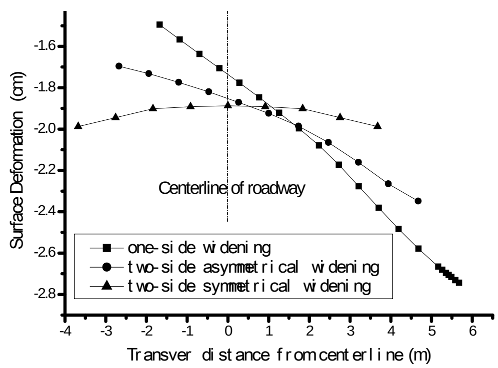

Figure 12. *Structural responses of widened roads*

Semi-rigid base structure has been mainstream type of asphalt pavements since 1980s. Main idea of semi-rigid base is to provide a strong base to bear traffic loading while surface AC layer is in a compressive stress state, which is very different from traditional flexible AC pavement structures where tensile stress produced at the bottom of surface AC layer controls fatigue cracking[5]. Major problems with semi-rigid base AC pavement structures are reflection cracking. Figure 13 shows that AC layer in flexible structure will produce tensile stress at low depth while only compressive stress existed in surface AC layer in semi-rigid base. Figure 14 suggests that tensile stress existed in flexible AC bottom will move down to semi-rigid base and surface AC thickness can thus be reduced to produce economical benefits.

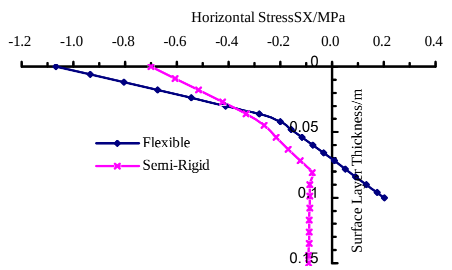

Figure 13. *Maximum horizontal stress of AC layer*

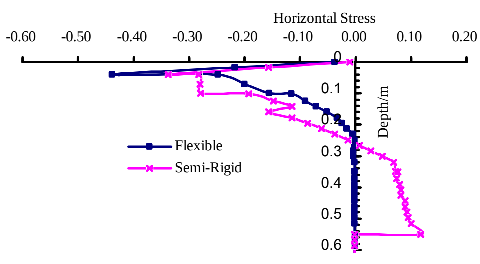

Figure 14. *Horizontal stress at deflection point*

Figure 15 and Figure 16 shows difference in structural responses of AC pavements between contact layer interface and continuous layer interface using Burmister's layer model. China's AC pavement design guide use only continuous model since 1986. Surface deflection between these two models exhibit significant state as shown in Figure 15 while vertical stress are relatively similar.

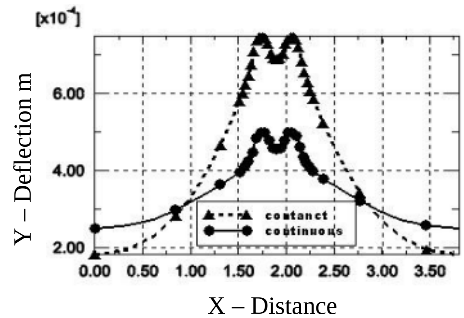

Figure 15. *AC pavement surface deflection*

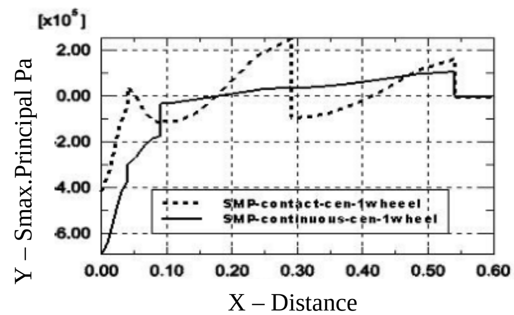

Figure 16. *AC pavement vertical stress*

Influence of contact area on pavement responses is given in Figure 17 and Figure 18. Circular loading has been used in China's AC pavement design guides since 1958, which is also a common assumption in other countries as a result of availability of analytical elastic solution in earlier days. Rectangular loading can be used with numerical methods to compare the difference of pavement responses among various assumption of contact area between tires and pavement surface.

Crack propagation simulation using computer simulation has been one of pavement research fronts in last decade with the development of damage mechanics and simulation program. Figure 19 and Figure 20 illustrate HMA crack propagation process using APCPPS2D program and computer technique used in the program.

Figure 21 and Figure 22 illustrate application of image recognition technique in pavement cracking research. Using image enhancing method, raw pavement cracking image can be processed to produce high quality data for computer recognition.

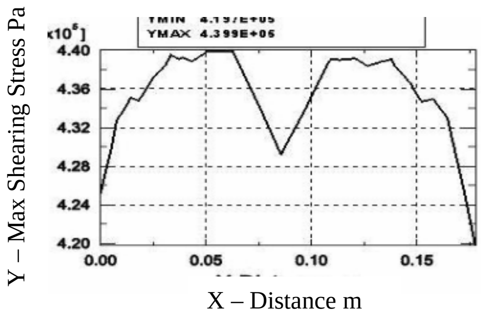

Figure 17. *Shearing stress of circular loading*

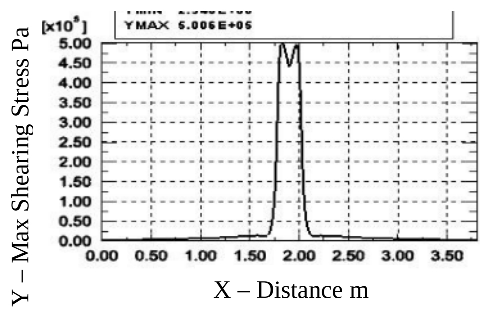

Figure 18. *Shearing stress of rectangular loading*

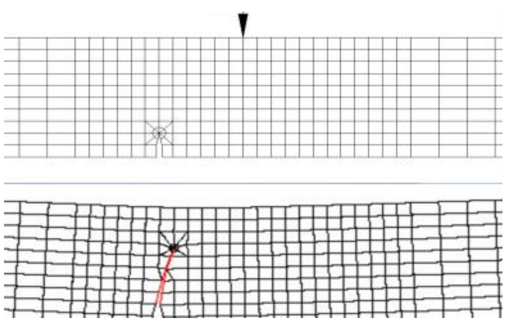

Figure 19. *Crack propagation of testing HMA beam*

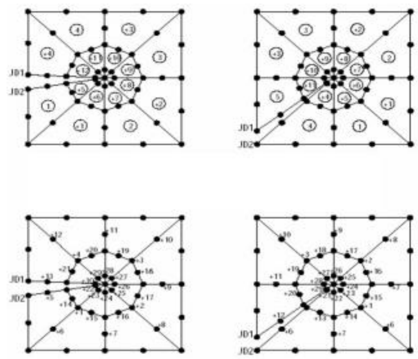

Figure 20. *Element technique of simulating crack tip*

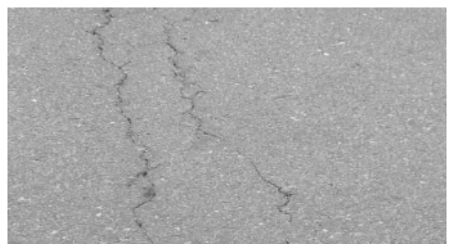

Figure 21. *Image Enhancing technique*

Figure 22. *Image threshold in MATLAB*

Figure 23 shows the scanning process of asphalt samples using computer tomography (CT) method. This new methodology proves to be an effective tool in analyzing the cracking propagation process of asphalt concrete under load application. Figure 24 is the scanned cross section of one Marshall specimen.

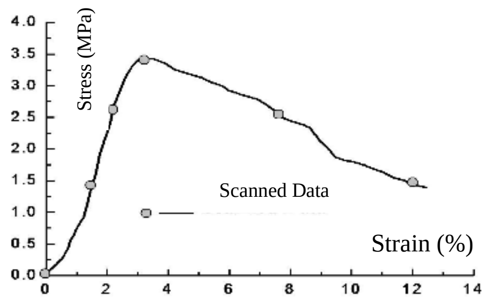

Figure 23. *CT process of pressured AC specimen*

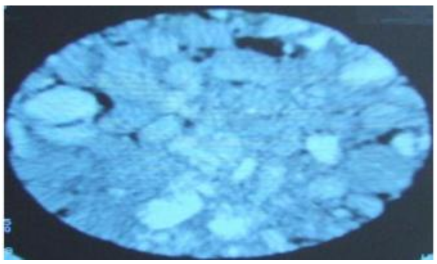

Figure 24 . *CT scanned AC specimen*

V. LESSONS AND EXPERIENCE

Major experience in pavement engineering learnt from last 20 years' rapid expansion of China's transportation infrastructures can be summarized as follows.

1. Overloaded truck axles have been top one factor to cause premature failure of pavements in highways. Orchestrated efforts from various government authorities and related industries must be taken to ensure the trucks rolling in pavements not to exceed specified axle load standards. WIM (Weigh-in-motion) and strict truck and transportation policy can help reduce heavy axles.

2. Drainage is the key factor to produce quality subgrade and sound pavement structures. Drainage facilities should be sufficiently designed since later adding after pavement completion and/or during operating proves to be an inefficient alternative.

3. Structural analysis and material design should be integrated to reach a balanced pavement quality. Thickness sufficiency can prevent pavement from premature failure in structural distresses such as fatigue cracking, while mix design plays a central role to avoid unexpected distresses such as AC shoveling, high-temperature rutting, water damage, potholes and other types of material-related distresses that cannot adequately addressed by structural design, especially for AC pavements.

4. Construction techniques in AC pavements such as application of tack coat and prime coat have to be fully implemented to form a layer structural which is close to the abstracted mechanistic model in design guide, usually based on Burmister's multi-layer elastic theory, otherwise, construction deficiency compared to structural model might lead to premature failure.

5. Thickness of PCC plates governs expected pavement life. A small increase in PCC thickness can lead to significant increase in pavement life. China's new design guide for PCC pavements, JTG D40-2003, reflects such understanding which is also based field investigation of PCC pavement performance.

6. Joint sealing in PCC is almost the latest field work in construction of PCC pavement which often leads to negligence in construction supervision. However, joint sealing is one of governing factor to prevent PCC from premature failure such as joint spalling, corner breaking, pumping and swelling. Care should be taken to ensure 100 percent joint sealing to produce sound pavement structure.

7. Deformation characteristics and engineering behavior of subgrades have to be adequately understood in design process, especially for multi-lane freeway roads in mountainous areas where cut-fill transition

and sloped ground are frequently found. Structural subgrade, such as pile-supported embankment, column-supported embankment, and other subgrade structures can limit soil deformation with the help of embedded structures.

8. Preventive maintenance, together with routine maintenance, proves an effective practice to keep pavement quality over time. Pavement distress of light severity may easily escalate to high severity during short period of time without timely engineering measures. Preventive maintenance such as crack sealing, slurry treatment, and seal coat are more cost effective than corrective maintenance.

9. Stage construction in highways used to be an engineering alternative in soft ground area to produce adequate consolidation rate and avoid excessive settlement after completion. However, experience in past two decades proved that stage construction is not a practical choice based on life-cycle cost effectiveness consideration.

10. Road widening projects, especially in weak ground and/or sloped ground, need special considerations in differential deformation between existing subgrade and newly-added section. Additional structural responses resulted from differential deformation will lead to unexpected distress or even premature failure. Geosynthetics, if properly designed and laid between new and old subgrades, proved to be effective material to tackle subgrade problems.

11. Vegetation is the primary landscaping type which promotes highway quality, environmental friendliness, visual relaxation, sight guidance, and drive safety. One concern that should be addressed is that vegetation in medians and side slopes may cause drainage problems and weak subgrade. Therefore, effective drainage system for subgrades and other pavement layers must by fully designed, especially in vegetated medians.

12. Heavy trucks traveled at low speeds climbing long grades pose a great challenge to surface layer of pavements, especially for AC pavements in high temperature environment. In the summer of 2006 when temperature loomed historical high for several weeks, deep rutting, shoveling, and slippage cracking took place in several routes with AC pavements. Material design can address part of this problem. However, shear resistance of AC surface along long grade section is recommended for check in structural design, which is part of the code for pavement design for urban roads.

13. Structural evaluation of geometric design is one of the most important aspects in design stage and post-design stage. Analysis of highway location and geometric design based on statics, kinetics and dynamics will lead to a consistent design with respect to geometrical outputs, structural responses, and service life predictions.

14. It is not necessary to design pavement shoulders different from lane thickness. A reduced thickness of pavement structures in shoulder does not produce significant economical benefits compared to total costs of highway investment. Shoulders, usually used as emergency lanes and maintenance work space, can serve as traffic lanes when necessary. Furthermore, a single thickness along traffic lanes and shoulders will facilitate easy construction, especially for AC pavements.

15. Transitional sections of subgrades, such as bridge approaches, culvert approaches, tunnel approaches, short subgrade section between road structures, high-fill-deep-cut and cut-fill transitions, are common design scenarios in mountainous areas and deserve special consideration in construction

and supervision to form a pavement support of consistency along the route. Strict compaction standards, reliable subgrade drainage system and quality granular fills are effective measures to construct subgrades in transitional sections.

16. Temperature is the key factor in HMA mix production and paving. Climate prediction has to be tracked daily to assure adequate temperature at paving, compaction, as well as proof rolling. Sudden change in climate, such as temperature drop, should be avoided in the whole process. Mix has to be discarded if temperature cannot meet specified standards at every stage of construction from mixing to completion.

17. Adequate compaction is required for HMA surface layer for the mix to form a surface layer with sufficient strength to limit structural distresses such as fatigue cracking and rutting. However, over compaction is not rare due to inadequate understanding of AC pavement as well as HMA mix design. According to Superpave® mix design philosophy, over compaction is not allowed and a 2% of air voids at the end of pavement service life has to be expected. Over compacted AC pavements do not have sufficient voids to deform under the repetitive application of traffic loads and will exhibit rutting, shoveling and other types of premature distress.

18. Reflection cracking is the primary distress in AC pavements with semi-rigid base. It is crucial for all highway-related agencies responsible for design, construction, supervision, acceptance, maintenance, and/or management to understand that adequate base is sufficient to support pavement under traffic loading. "Over-strong" base, especially semi-rigid pavement will crack easily and lead to reflection cracking in surface layer. Flexible base, which constitute "flexible pavement" together with AC surface layer, is recommended instead of semi-rigid base. Literature reported that micro-cracks in the based layer produced by heavy roller compaction before surface AC layer placement prove to be an effective engineering practice to avoid reflection cracking caused by cracks in succeeding layers.

VI. CONCLUDING REMARKS

Pavement engineering in China is still a booming industry. Unpaved roads with a mileage of 935,945 comprised of 48.48% out of 1,930,500-km highway networks at the end of 2005. National Freeway System of China is still under halfway construction which is expected to be completed in 2040 and at the same time another 1,000,000 km new highway will be added to China's highway system. There are hundreds of runway pavements and other airport pavements will be newly built and rehabilitated during next 20 years to meet the rapid expanding of air transportation and hundreds of big cities will continue road upgrading work in the context of China's national policy of urbanization. Due to different environmental requirements, local industry and economy status, market fluctuation of raw materials including asphalt cement and Portland cement, emerging of new maintenance technologies, development of design guides and better understanding of road engineers, PCC pavements and AC pavement will continue to be the two major categories in the future. AC pavements will find more and more applications in urban roads and airport runways. Modified asphalt including color asphalt will be tailored to meet different transportation needs besides engineering requirements. International cooperation and exchange will play an even more important role in pavement industry which will promote the continuous development of theoretical understanding and engineering practice of pavement with better quality for roads and airports.

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