

重庆两江新区悦来新城海绵城市 生态保水降温路面技术实践

**Technology Application on Ecological Water-
retention and Cooling Pavement of Sponge City in
Yuelai New City of Chongqing Liangjiang New Area**

重庆交通大学
凌天清 教授

**Chongqing Jiaotong University
Tianqing Ling, Ph.D., Professor**

10/25/2018

1.项目背景 Background

➤ 重庆悦来新城有幸获批成为国家首批海绵城市建设试点。

Chongqing Yuelai New City was honored to be approved as one of the first pilot projects for the construction of sponge cities in China.

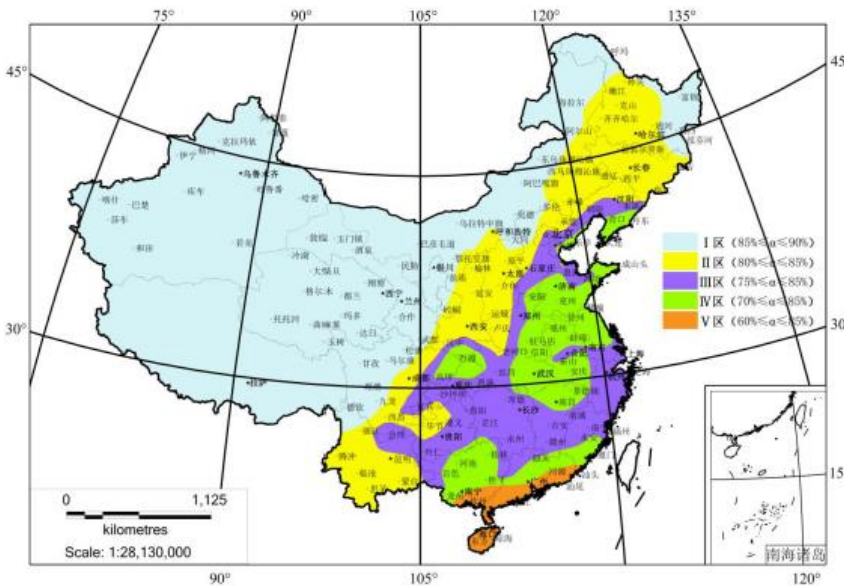
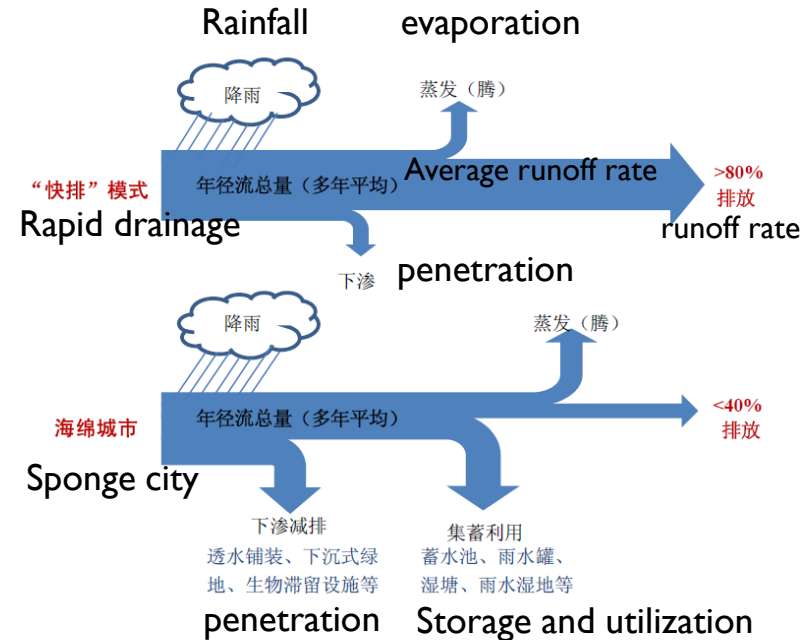


图 3-3 我国大陆地区年径流总量控制率分区图

Fig 3-3 Distribution map of annual runoff total rate in mainland China

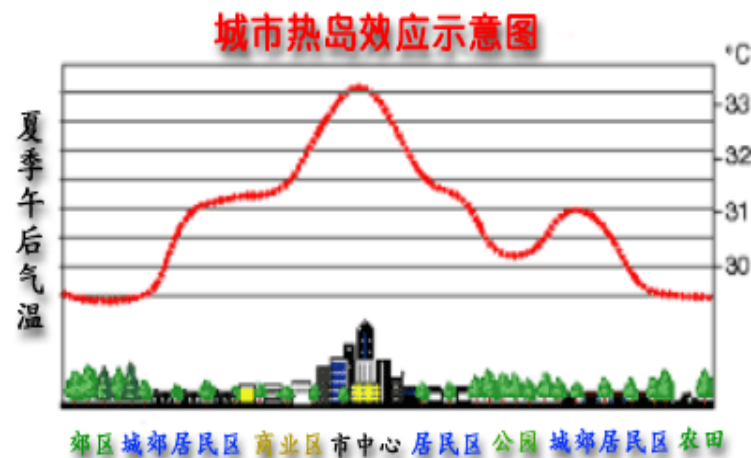
➤ 重庆作为山地城市要达到75%~85%的年径流总量控制率有相当大的难度，道路结构的地表径流控制是实现这一目标的途径之一。

As a mountainous city, it's difficult in controlling the total annual runoff rate to 75%-85%. Surface runoff control by pavement structure is one of the ways to achieve this goal.



1.研究背景 Background

Urban heat island (UHI) effect

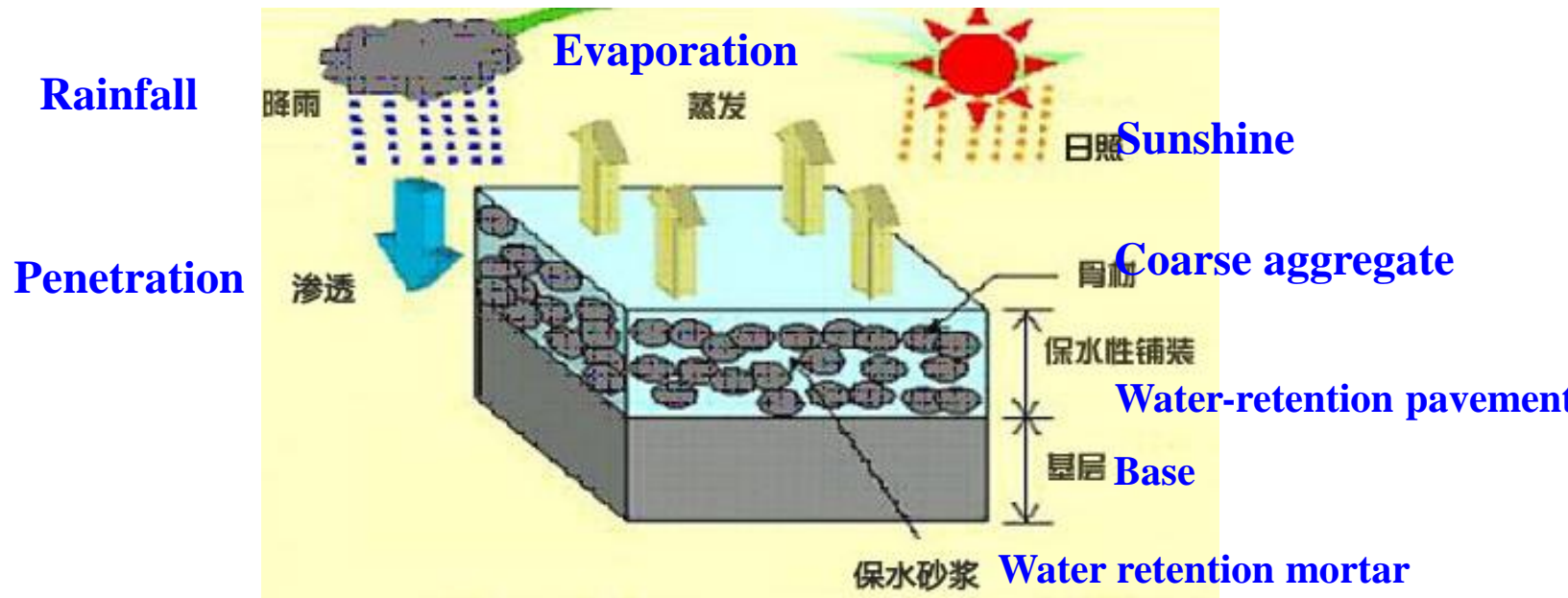


重庆是中国有名的火炉，城市热岛效应明显
Chongqing is a famous “stove” in China, and the urban heat island effect is obvious.

1. 研究背景 Background

- 保水半柔性路面对降低城市热岛效应起到一定作用

Water-retention semi-flexible pavement plays a role in reducing urban heat island effect.



- 满足交通荷载要求条件下，保水半柔性路面的保水率受路面材料渗透性（保水率）、降雨持续时间、路表径流速度等因素影响。
- Meeting the requirement of traffic load effect, the water-retention rate has been affect by the permeability of pavement material, rainfall time, surface runoff speed, etc.
- 本项目重点研究路面材料和结构的作用
- Our project mainly focuses on the function of pavement material and structure.

2.高黏高弹沥青研究

Research on high viscous and elastic asphalt binder

自主探索了采用橡胶粉制备高粘改性沥青的可行性并分析了影响因素。结果表明：采用25%的50%左右活化程度橡胶粉、6% SBS、2% Sasobit、2%树脂的添加比例下制备的高粘改性沥青的性能得到大幅提升，同时可较大程度降低材料成本。

We studied the feasibility of using rubber powder to prepare high-viscosity modified asphalt and the related influencing factors. The result shows that high-viscosity modified asphalt can be prepared to satisfy the requirement of JT/T860.2-2013 by using high-mesh rubber powder with proper amount of SBS, polymer and resin, the addition rates of each additive are 12%, 6% , 2% , 2%. In order to further reduce cost, we also studied the feasibility of using activated rubber powder to prepared the high-viscosity modified asphalt. The result shows the performance of high-viscosity modified asphalt can be prepared and substantially reduces costs by adding 12% asphalt rubber with 50% activated degree, 6% SBS, 2% Sasobit, 2% terpene resin.

2.高黏高弹沥青研究

Research on high viscous and high elastic asphalt binder

自主研发的高黏高弹改性沥青性能对照表

Table of self-made high viscous and high elastic modified asphalt binder performance

序号 Number	检测项目 Items	技术指标 Technical Index	检测结果 Result	结果判定 determination
1	针入度 Penetration (25°C100g, 5s)(0.1mm)	≥ 40	45	qualified
2	延度 Ductility (5cm/min, 15°C) (cm)	≥ 80	94.8	qualified
3	软化点 Soften point (°C)	≥ 80	90.5	qualified
4	运动粘度 Dynamic viscosity 60°C (Pa·s)	≥ 50000	50453	qualified
5	闪点 Flash point (°C)	≥ 260	320	qualified
6	运动粘度 Dynamic viscosity 135°C (Pa·s)	≤ 3	2.5	qualified
7	旋转薄膜加热 试验 Rotating film heating test	质量损失 Quality loss (%)	0.16	qualified
		残留针入度比 Residual penetration ratio 25°C (%)	88.6	qualified

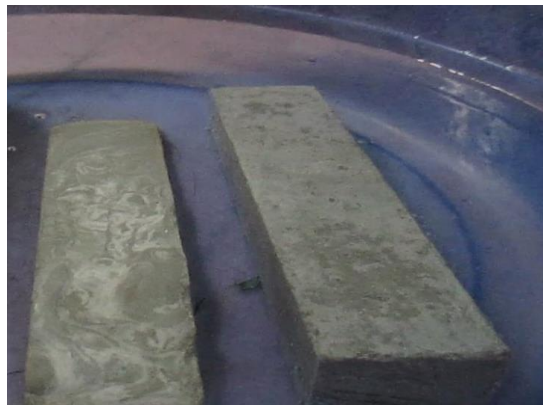
3. 保水砂浆的材料开发

Material development of water-retentive cement mortar

保水砂浆性能目标值

Performance target of water-retentive mortar

检测项目 Items	范围 Technical index	备注 Remarks
流动度 Liquidity (s)	10~14	P load法 (1725mL)
抗折强度 Flexural strength (MPa)	≥ 0.5	7d养生 7 days curing
抗压强度 Compressive strength (MPa)	≥ 2	
保水率 Water retention rate (%)	≥ 30	24h



砂浆的保水试验

Fig mortar water-retention test



流动度测定仪

Fluidity meter

3.保水砂浆的材料开发

Material development of water-retention mortar

- 经过各种保水材料 and 外加剂的试配 and 优化试验, 最终确定满足目标设计要求的保水砂浆配合比为水泥: 粉煤灰: 水: 高炉矿渣粉: 助滤剂: 缓凝高效减水剂: 微硅粉=1626.8:697.2:1790:414:112.8:27.9:185.9为推荐方案, 其流动度为13.62s, 7d抗折强度为3.05MPa, 7d抗压强度为10.3MPa, 2h保水率为31.66%, 24h的保水率为43.51%, 48h的保水率为44.27%, 满足性能指标要求。
- **Through the trial and optimization tests of various water-retaining materials and admixtures, the mix ratio of water-retention mortar to meet the target design requirements is finally determined. The recommended mix ratio is following, Cement: fly ash: water: blast furnace slag powder: filter: water reducer: micro-silica powder = 1626.8: 697.2: 1790: 414: 112.8: 27.9: 185.9. The Liquidity is 13.62s, 7 days flexural strength is 3.05MPa, 2 hours water retention rate is 31.66%, 24 hours water retention rate is 43.51%, 48 hours water retention rate is 44.27%, all of them meet the performance requirements.**

4.保水降温半柔性路面路用性能

Pavement performance of water-retention and cooling asphalt pavement

基体沥青混合料级配组成表

Aggregate gradation and quality control of matrix asphalt mixture

筛孔尺寸 (mm) Sieve size	通过质量百分率 Passing percentage of mass		
	SFAC-13	SFAC-16	SFAC-20
26.5	—	—	100
19.0	—	100	90~100
16.0	100	90~100	60~90
13.2	90~100	80~90	30~60
4.75	10~30	9~30	7~24
2.36	5~22		
0.6	4~15		
0.3	3~12		
0.15	3~8		
0.075	1~6		
Asphalt ratio (%)	2.8~4.5		
水泥基砂浆的最大渗透深度 (路面结构层厚度) (cm) The maximum penetration depth of cement mortar (the thickness of pavement structure layer).	5		10



4. 保水降温半柔性路面路用性能

Pavement performance of water-retention and cooling asphalt pavement

基质沥青混合料SFAC-13的试验数据(双面各击50次)
SFAC-13 Asphalt mixture test data (50 strikes on each side)

级配	最佳油石比/%	毛体积相对密度 γ_f	理论最大相对密度 γ_t	空隙率VV (Volume of air Voids) /%	沥青体积百分率 V_A /%	矿料间隙率VMA/%	沥青饱和度VFA/%	马歇尔稳定度 (Marshall stability) /kN	流值 (Flow) /0.1m m
上限	3.4	2.180	2.598	16.10	6.63	22.67	29.24	6.22	36.5
中值	3.3	2.090	2.611	19.90	6.58	26.45	24.86	5.58	34.5
下限	3.1	2.010	2.627	23.40	5.88	29.29	20.09	5.14	33.4
requirement				18~25				>5.0	20~40

由肯塔堡飞散试验和谢伦堡析漏试验确定了级配上限的最佳油石比为3.4%、级配中值的最佳油石比为3.3%、级配下限的最佳油石比为3.1%。

The optimal asphalt-aggregate ratio of the grading upper limit is 3.4%, the optimal asphalt-aggregate ratio of the grading medium is 3.3%, and the optimal asphalt-aggregate ratio of the grading lower limit is 3.1%, all these data were tested by the Kentberg scattering test and the Schellenberg leak test.

基质沥青混合料的各项性能指标均达到技术要求，只有上限的空隙率为16%低于技术标准要求。

The performance indexes of the matrix asphalt mixture meet the technical requirements, and only the upper limit void ratio is 16%, which is lower than the technical standard.

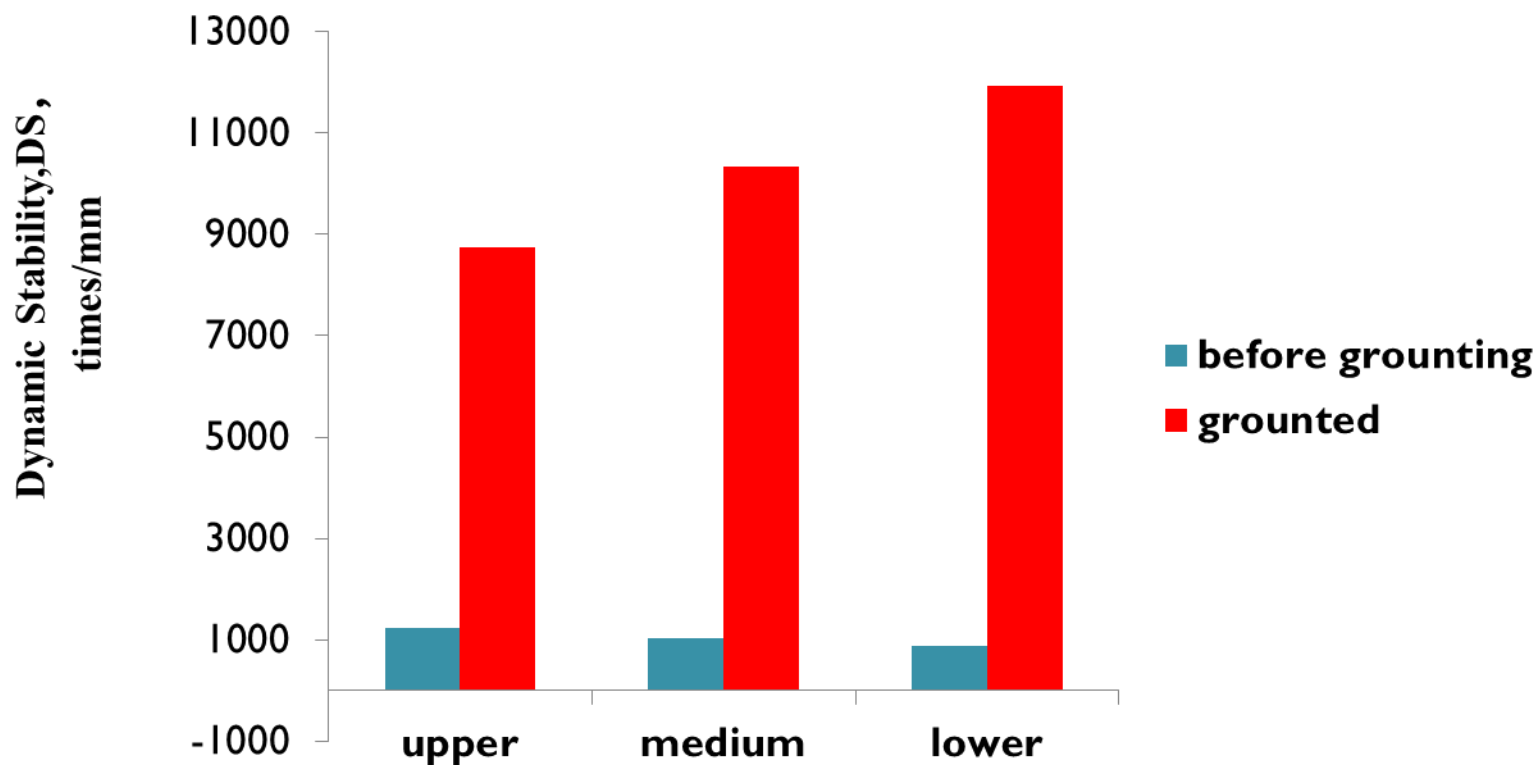
4.保水降温半柔性路面路用性能

Pavement performance of water-retention and cooling asphalt pavement

- 高温稳定性能
High temperature stability

SFAC-13抗车辙能力 (动稳定度) 试验结果

Test results of anti-rutting ability (Dynamic Stability, DS)



4.保水降温半柔性路面路用性能

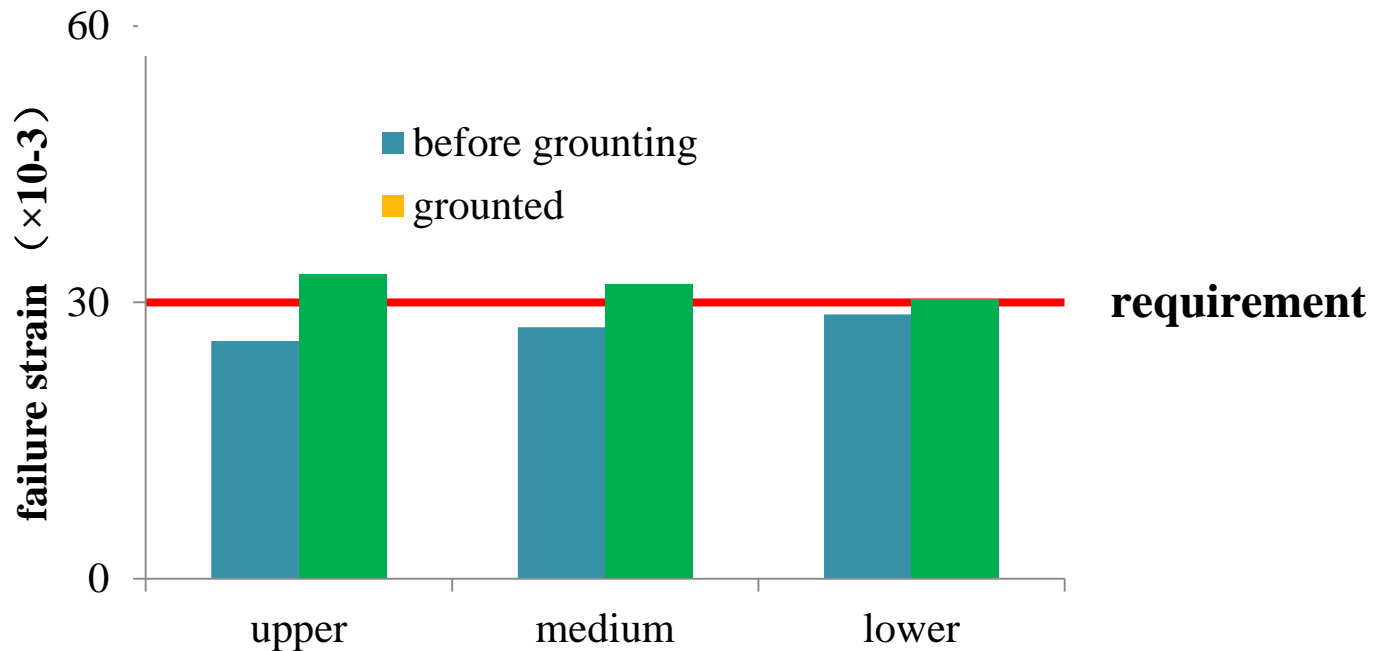
Pavement performance of water-retention and cooling asphalt pavement



弯曲抗裂性能

Anti-cracking performance

SFAC-13抗裂性能 (弯曲) 试验结果
Result of anti-cracking (bending) test

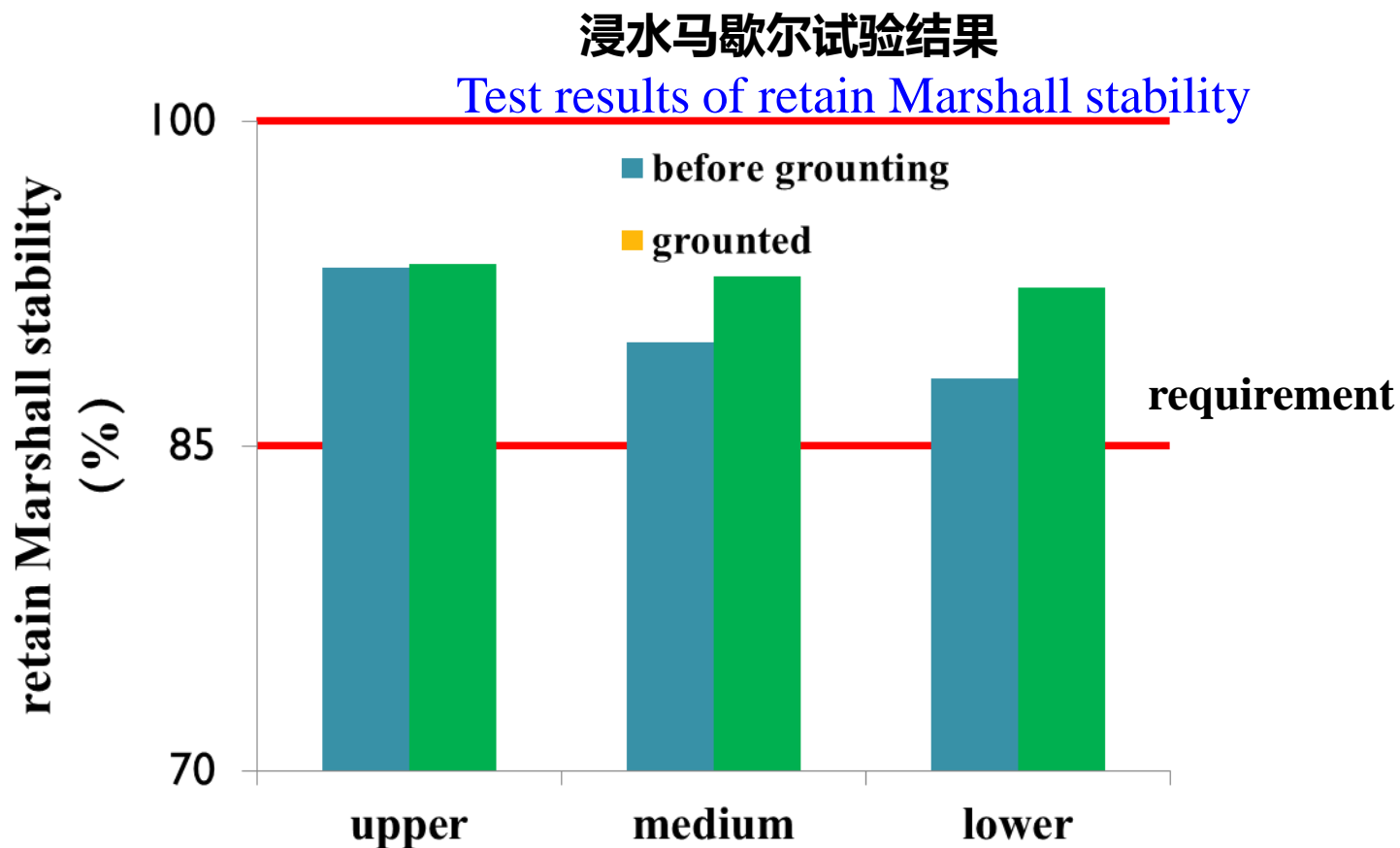


4. 保水降温半柔性路面路用性能

Road performance of water-retention and cooling asphalt pavement

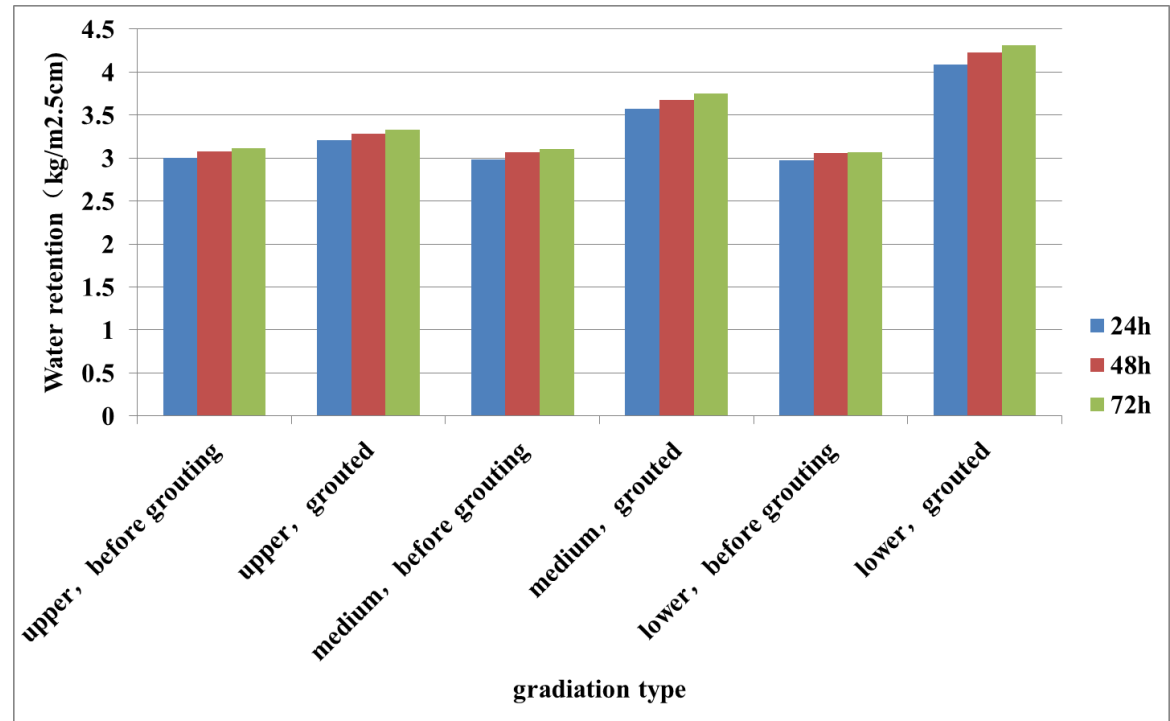
- 水稳定性

moisture resistance



5.保水降温半柔性路面保水性能

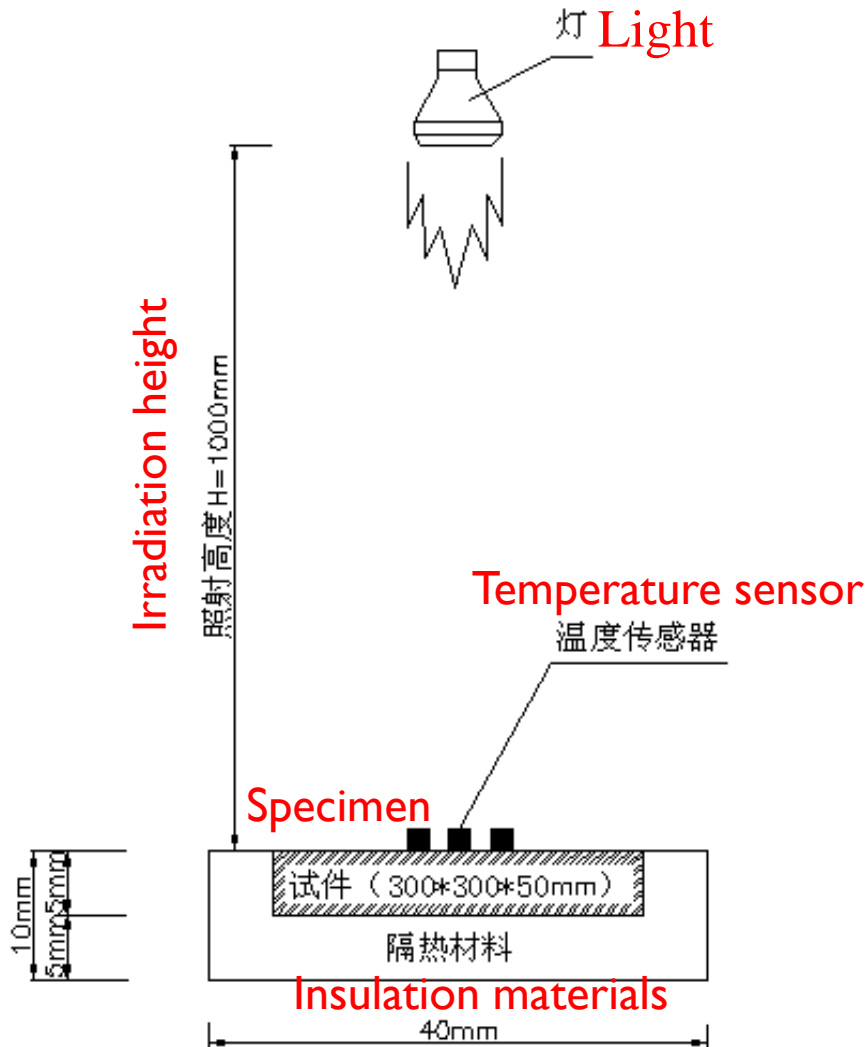
Water-retention performance of water-retention and cooling asphalt pavement



SFAC-13上中下三种不同级配的混合料的保水量在灌入保水砂浆后, 对比灌浆前的隐性保水率, 仍有显著提高, 增幅为7% ~ 38%之间, 保水效果相当明显, 说明保水砂浆对混合料路面起到了良好的保水功能, 为路面降温创造了基本条件 **The water retention capacity of the mixture of three different gradations of SFAC-13 is significantly improved after filling the water retention mortar, compared with the hidden water retention rate before grouting, with an increase of 7% to 38%. It is quite obvious that the water-retention mortar has a good water-retention function on the pavement surface and creates basic conditions for the road surface to cool down.**

6. 保水降温半柔性路面的降温性能

Cooling performance of water-retention and cooling asphalt pavement

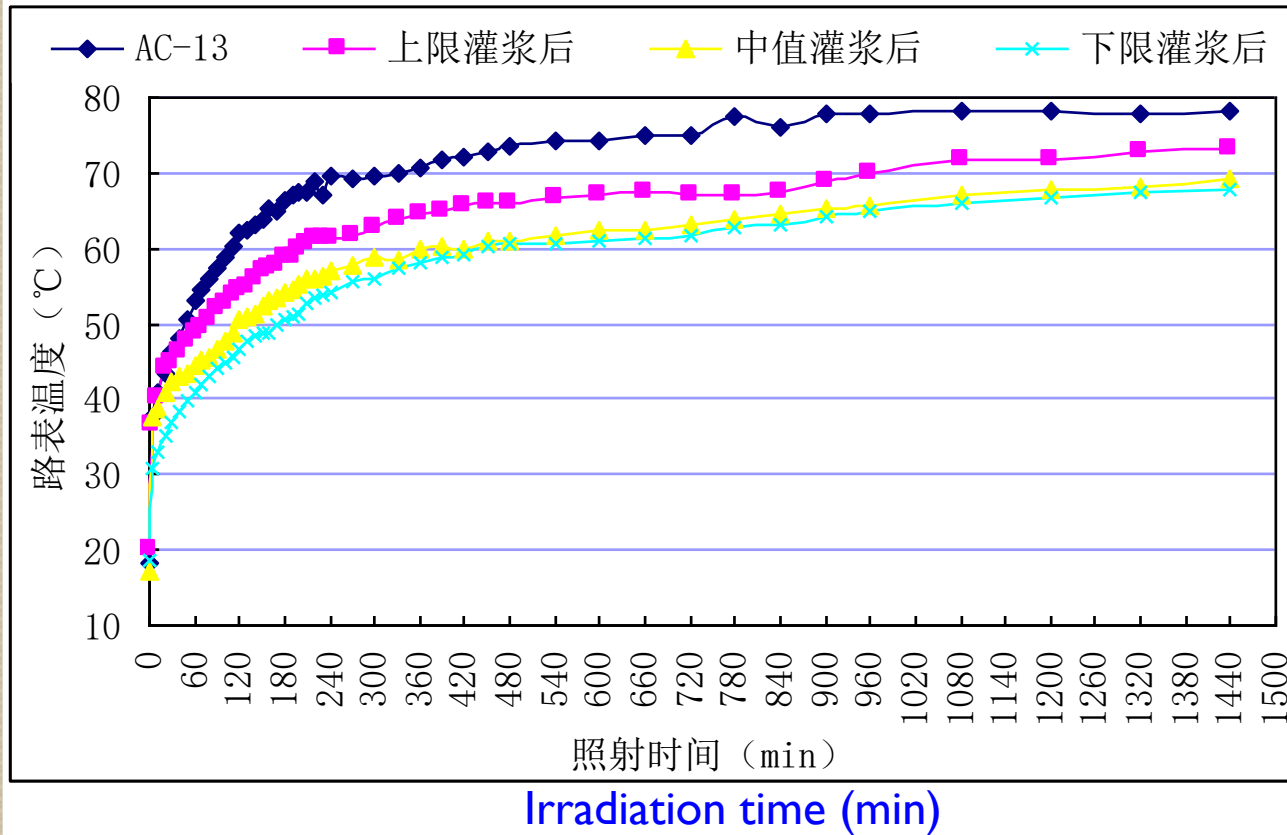


6. 保水降温半柔性路面的降温性能评价

Cooling performance of water-retention and cooling asphalt pavement

upper, grouted medium, grouted lower, grouted

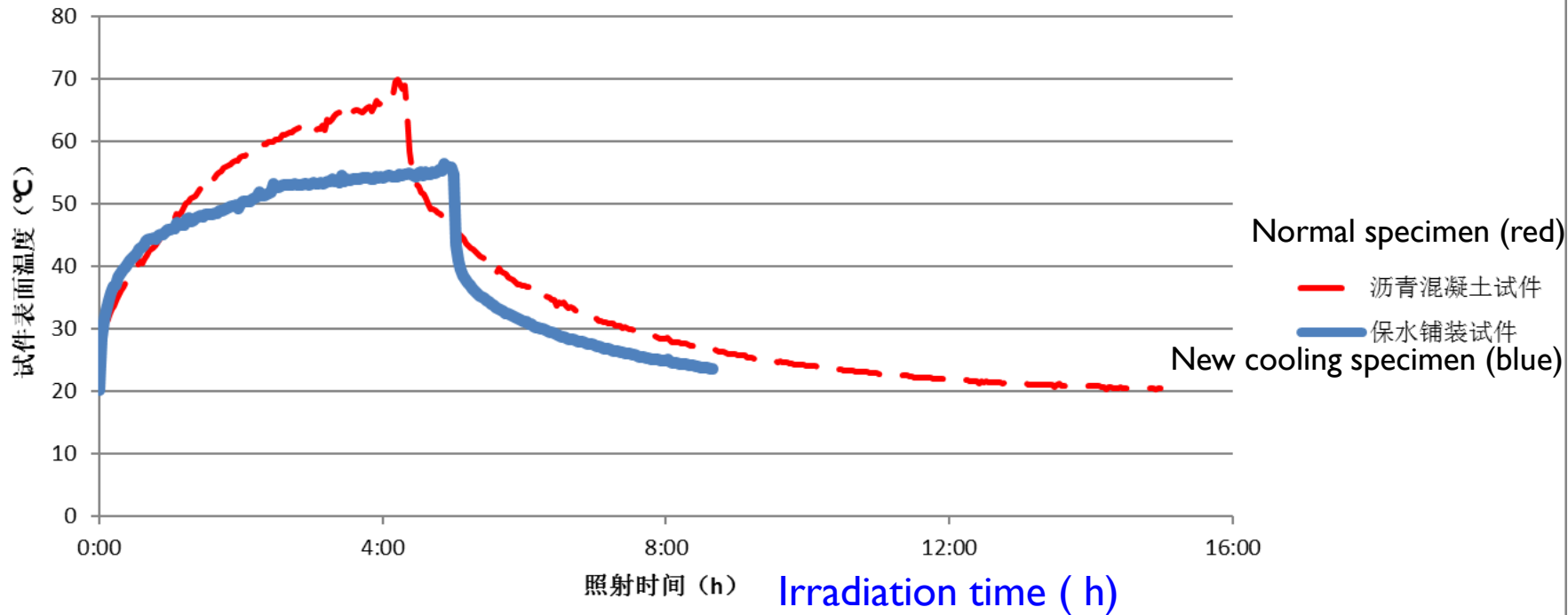
Surface temperature (° C)



6. 保水降温半柔性路面的降温性能评价

Cooling performance of water-retention and cooling asphalt pavement

试件表面温度随时间变化



相同照射时间下的温度差（降温效果）可达 16.4°C

The temperature difference (cooling effect) at the same irradiation time can reach 16.4°C .

7.悦来新城新型生态路面示范工程

Demonstration project of new ecological pavement in Yuelai new city



叶家沟支路
Yejiagou branch road
(2550m²)



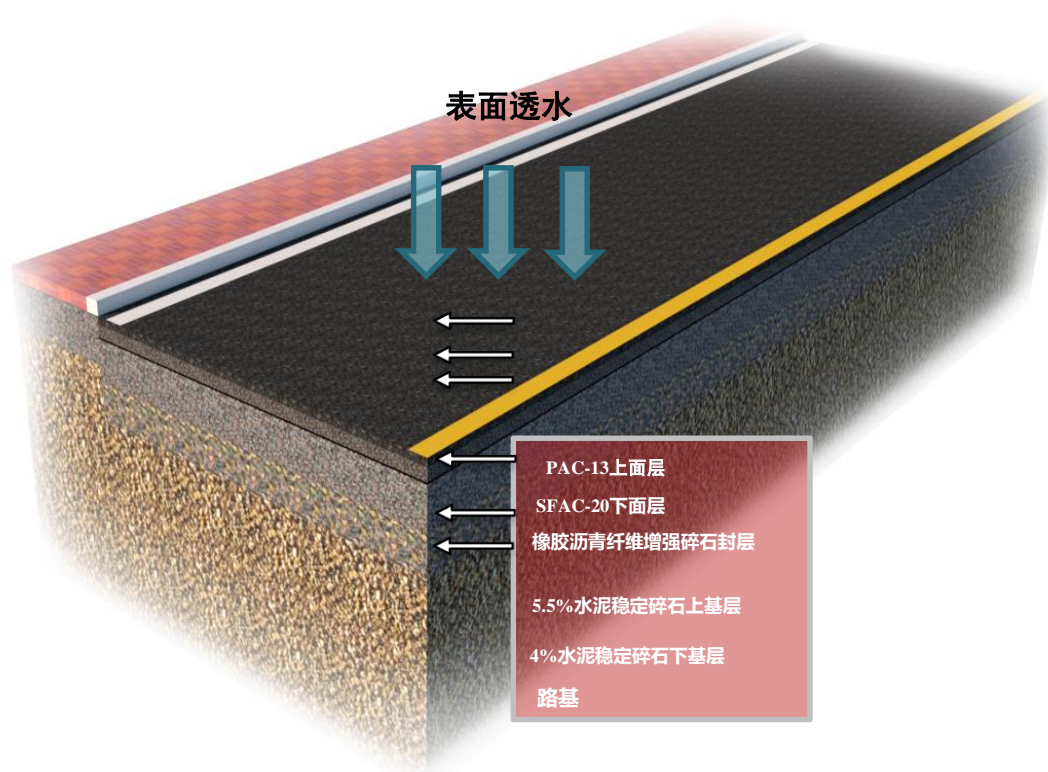
塘木湾支路
Tangmuwan branch road
(9784m²)

7.悦来新城新型生态路面示范工程

Demonstration project of new ecological pavement in Yuelai new city

➤ 叶家沟支路路面结构及剖面示意图 特点：公路纵坡达到7%

Pavement structure and section diagram of Yejiagou branch road
Feature: longitudinal slope reaches 7%



PAC-13上面层
SFAC-20下面层
橡胶沥青纤维增强碎石封层
5.5%水泥稳定碎石上基层
4%水泥稳定碎石下基层
路基

PAC-13 upper surface course 4cm
Water-retentive SFAC-20 lower surface course 6cm
fiber reinforced chip seal with asphalt rubber 1cm
Cement stabilized macadam(5.5%cement) 20cm
Cement stabilized macadam(4%cement) 20cm
subgrade



7.悦来新城新型生态路面示范工程

Demonstration project of new ecological pavement in Yuelai new city

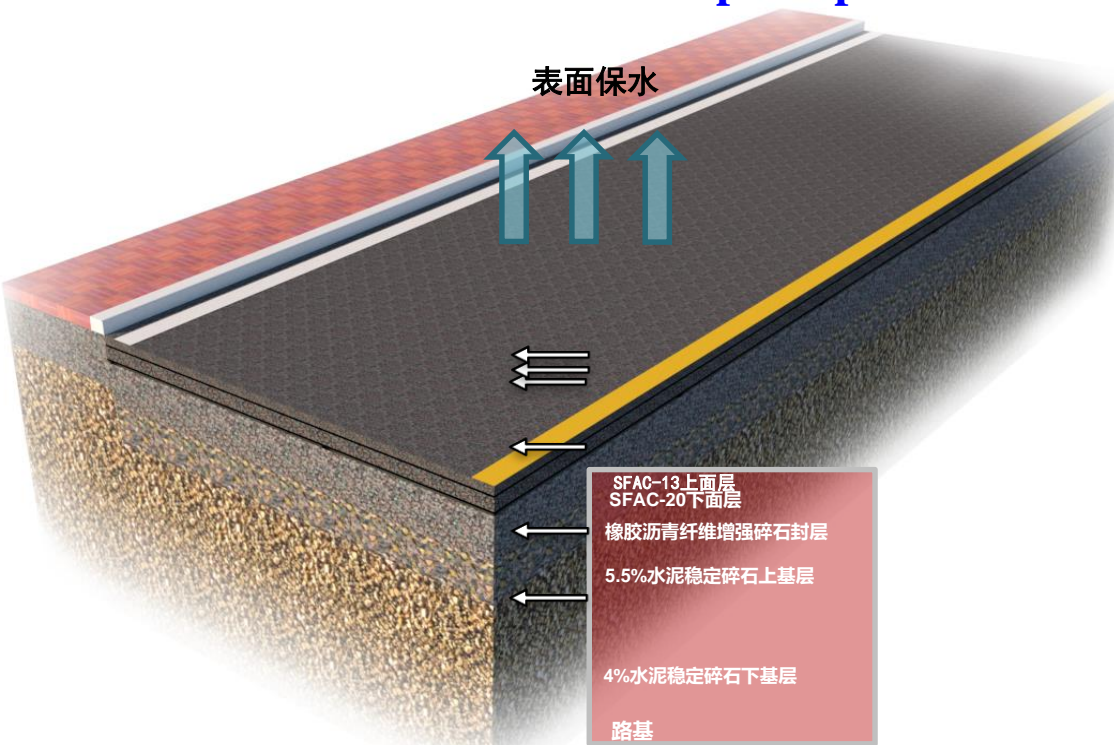
➤ 塘木湾支路 Tangmuwan branch road

特点: 纵坡小 ($\leq 1.7\%$), 五种路面结构 (表面透水和表面保水两大类)

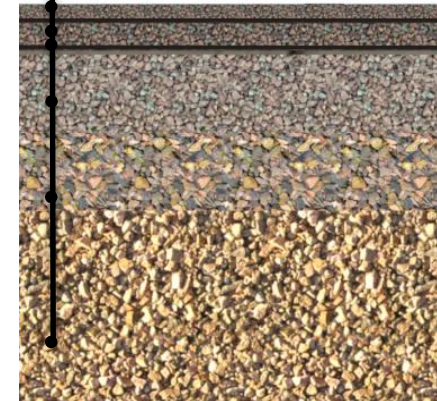
Feature: Small longitudinal slope ($\leq 1.7\%$), five pavement structures (surface permeable and surface water retention)

a) 双层保水沥青路面结构 (K0+000-K0+225段)

Water-retention asphalt pavement structure with double layers



Water-retentive SFAC-13 4cm
Water-retentive SFAC-20 6cm
fiber reinforced chip seal with asphalt rubber 1cm
Cement stabilized macadam(5.5% cement) 20cm
Cement stabilized macadam(4% cement) 20cm
subgrade



7.悦来新城新型生态路面示范工程

Demonstration project of new ecological pavement in Yuelai new city

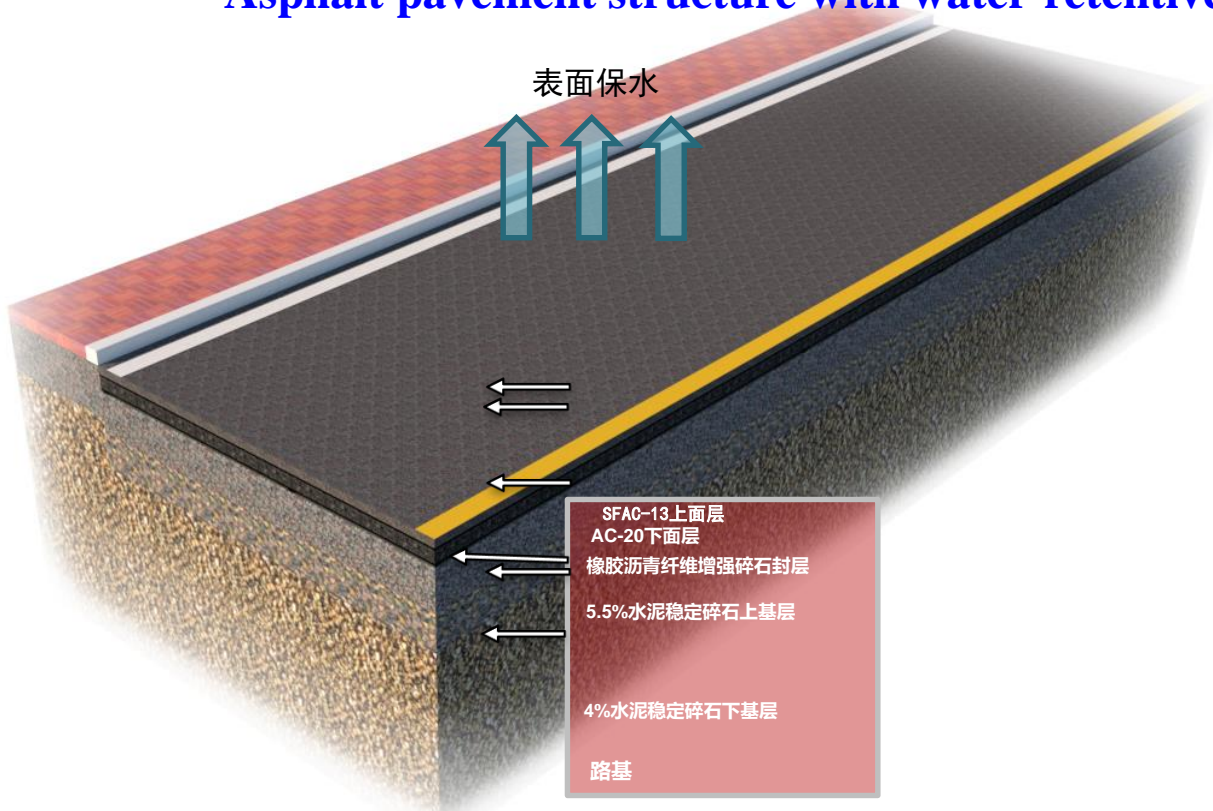
➤ 塘木湾支路 Tangmuwan branch road

特点: 纵坡小 ($\leq 1.7\%$), 五种路面结构 (表面透水和表面保水两大类)

Feature: Small longitudinal slope ($\leq 1.7\%$), five pavement structures (surface permeable and surface water retention)

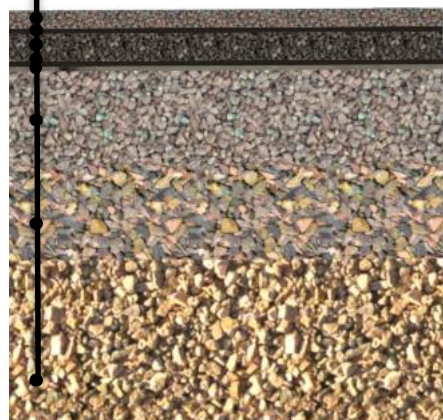
b) 保水+不透水沥青路面结构 (K0+225~K0+521段)

Asphalt pavement structure with water-retentive course and impervious course



SFAC-13上面层
AC-20下面层
橡胶沥青纤维增强碎石封层
5.5%水泥稳定碎石上基层
4%水泥稳定碎石下基层
路基

Water-retentive SFAC-13 4cm
AC-20 6cm
fiber reinforced chip seal with asphalt rubber
Cement stabilized macadam(5.5% cement) 20cm
Cement stabilized macadam(4% cement) 20cm
subgrade



7. 悦来新城新型生态路面示范工程

Demonstration project of new ecological pavement in Yuelai new city

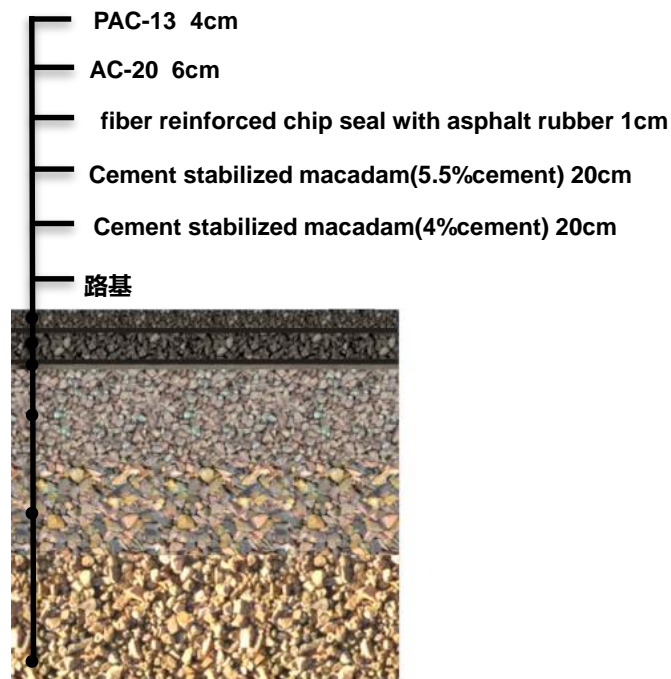
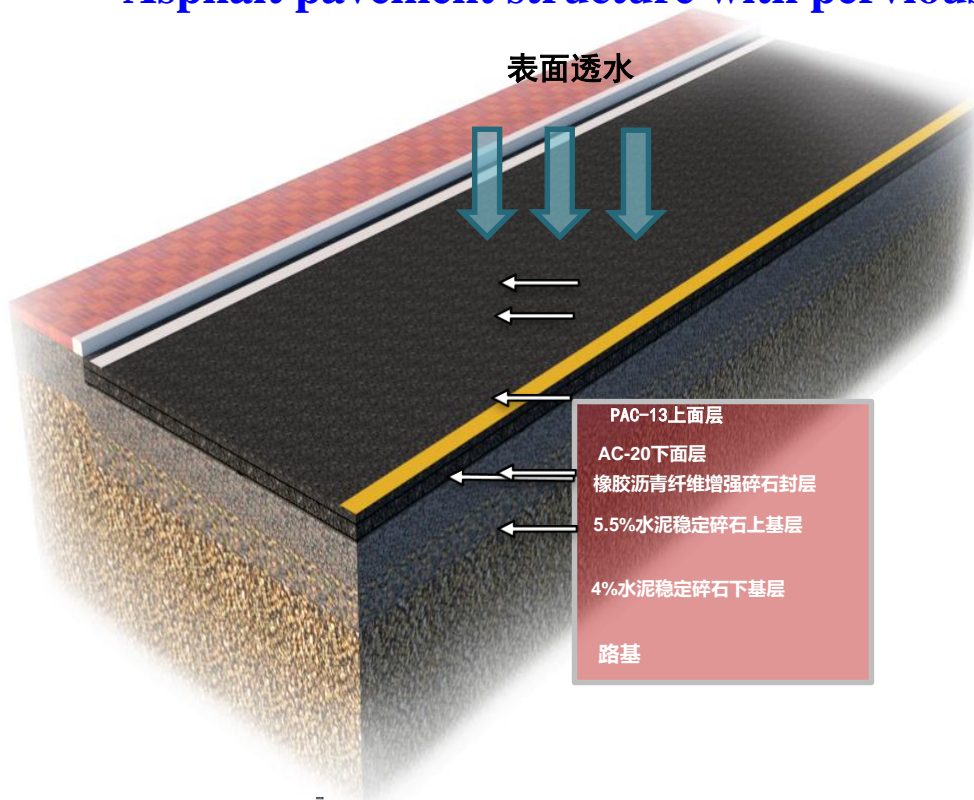
➤ 塘木湾支路 Tangmuwan branch road

特点：纵坡小 ($\leq 1.7\%$)，五种路面结构（表面透水和表面保水两大类）

Feature: Small longitudinal slope ($\leq 1.7\%$), five pavement structures (surface permeable and surface water retention)

c) 透水+不透水沥青路面结构（K0+521~K0+706段）

Asphalt pavement structure with pervious course and impervious course



7. 悦来新城新型生态路面示范工程

Demonstration project of new ecological pavement in Yuelai new city

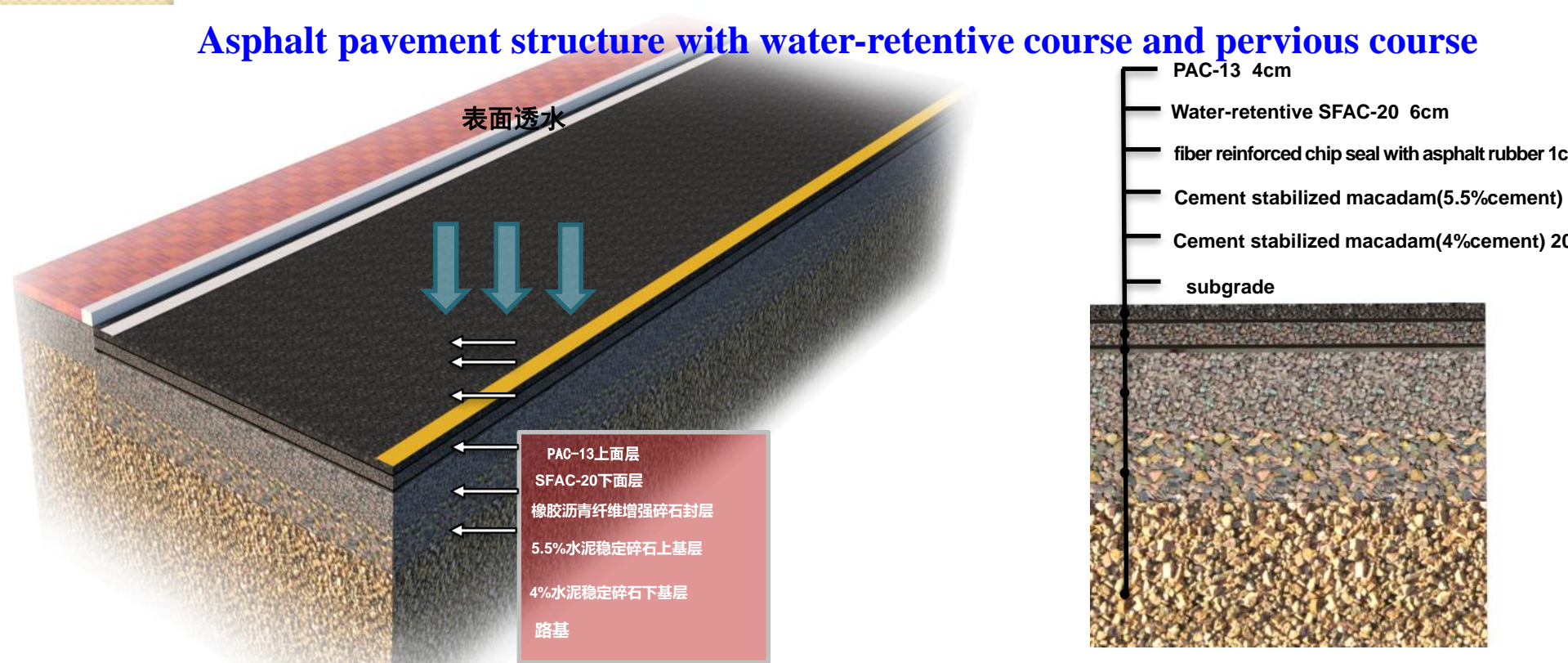
➤ 塘木湾支路 Tangmuwan branch road

特点: 纵坡小 ($\leq 1.7\%$), 五种路面结构 (表面透水和表面保水两大类)

Feature: Small longitudinal slope ($\leq 1.7\%$), five pavement structures (surface permeable and surface water retention)

d) 透水+保水沥青路面结构 (K0+706~K0+930段)

Asphalt pavement structure with water-retentive course and pervious course



7. 悦来新城新型生态路面示范工程

Demonstration project of new ecological pavement in Yuelai new city

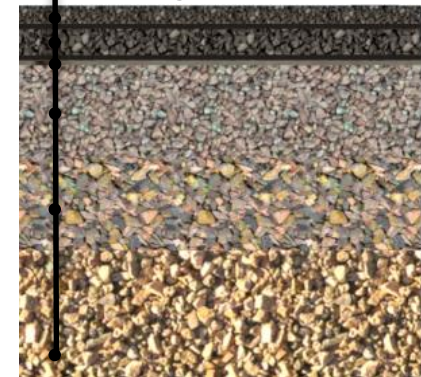
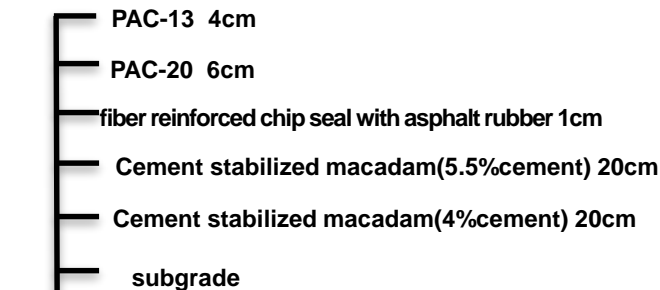
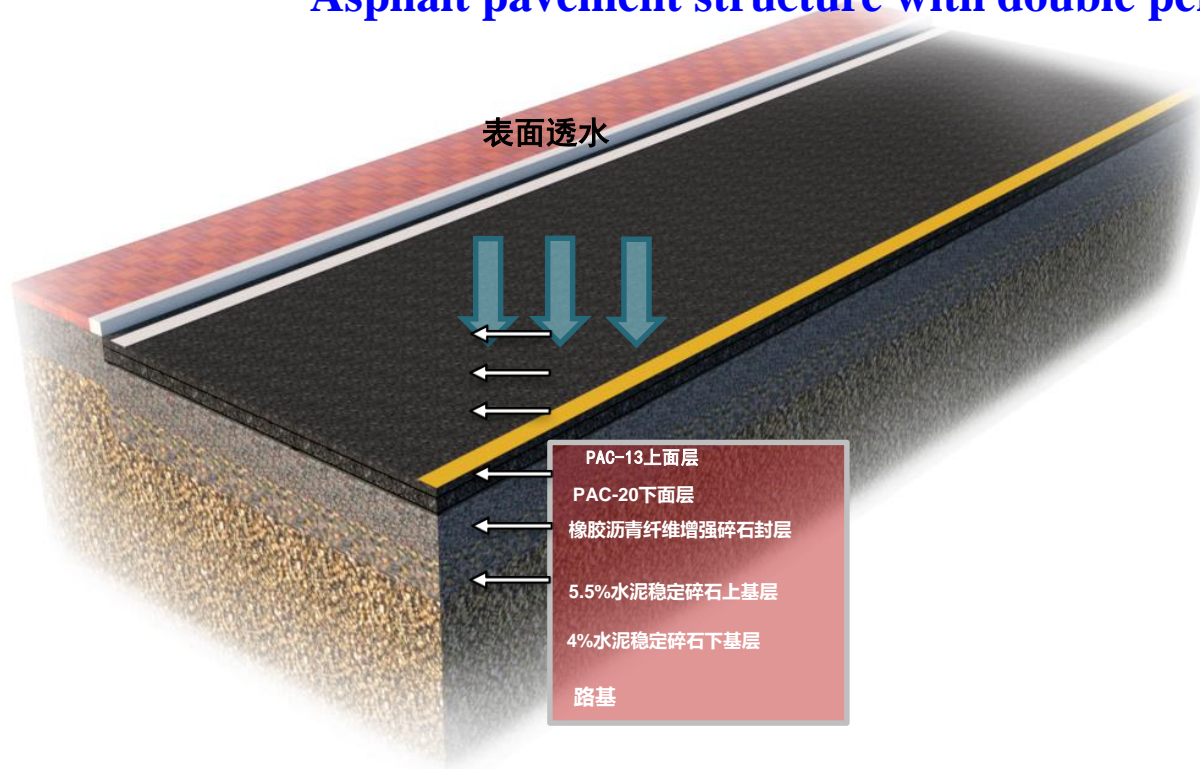
➤ 塘木湾支路 Tangmuwan branch road

特点：纵坡小 ($\leq 1.7\%$)，五种路面结构（表面透水和表面保水两大类）

Feature: Small longitudinal slope ($\leq 1.7\%$), five pavement structures (surface permeable and surface water retention)

e) 双层透水沥青路面结构 (K0+930~K1+223.02)

Asphalt pavement structure with double pervious courses



8.结论

Conclusions

(1)经过试配和优化试验确定了具有良好性能的保水砂浆推荐配合比, 水泥: 粉煤灰: 水: 高炉矿渣粉: 助滤剂: 缓凝高效减水剂: 微硅粉=1626.8: 697.2:1790:414:112.8:27.9:185.9

(1) Through the trial and optimization, the recommended mix ratio of water-retaining mortar with good performance was determined.

Cement: fly ash: water: blast furnace slag powder: filter: water reducer: micro-silica powder = 1626.8: 697.2: 1790: 414: 112.8: 27.9: 185.9

8.结论

Conclusions

◦ (2)采用高降解程度的活化橡胶粉代替交联态橡胶粉，并自制了不同活化程度的橡胶粉用于制备高粘改性沥青。从制备高粘改性沥青的成本以及物理性能综合考虑，采用50%左右的活化橡胶粉，可实现大比例添加而不影响高粘改性沥青的综合物理性能。相比日本TPS改性沥青，沥青成本能降低700多元/吨。

(2)The activated rubber powder with high degradation level was used to replace the crosslinked rubber powder, and rubber powder with different activation levels was prepared for preparing high viscous modified asphalt. Considering the cost and physical properties of the high viscous modified asphalt, about 50% of the activated rubber powder can be used to achieve a large proportion without affecting the comprehensive physical properties of the high viscous modified asphalt. Compared with Japanese modified asphalt with TPS, the cost of asphalt can be reduced for more than 700 yuan per ton.

8.结论

Conclusions

(3) 5cm厚度保水半柔性路面的单位面积保水量可以达到 $4\text{kg}/\text{m}^2$ 。增加雨水保持，适当增加了城市大气湿度，减少了城市铺装对生态的影响。

(3) The water retention per unit area with a 5 cm thickness of water-retentive semi-flexible pavement can reach $4\text{kg}/\text{m}^2$. Increasing rainwater retention has appropriately increased urban atmospheric humidity and reduced the impact of urban pavement on ecology.

(4) $38\text{ }^\circ\text{C}$ 高温天气降低路面温度范围： $10\text{ }^\circ\text{C}\sim 15\text{ }^\circ\text{C}$ ，能消减洪峰、降低热岛效应。

(4) Ecological Water-retentive and cooling pavement can reduce the surfacing temperature $10\text{ }^\circ\text{C} - 15\text{ }^\circ\text{C}$ lower at high temperature weather ($38\text{ }^\circ\text{C}$), which can reduce the flood peak and mitigate the heat island also.

8.结论

Conclusions

○ (5) 灌注保水砂浆后，保水降温半柔性路面的高温稳定性、抗裂性和水稳定性均好于基体沥青混合料。

(5) After pouring water-retentive mortar and getting hardening, the high-temperature stability, anti-cracking performance and water sensitivity of the semi-flexible pavement with water retention are better than the those of matrix asphalt mixture.

级配	类型	动稳定度/次/mm	抗弯拉强度/MPa	弯曲破坏应变/ 10^{-3}	残留稳定度/%
上限	灌浆前	1224	3.31	25.8	93.2
	灌浆后	8750	2.41	33.1	93.4
中值	灌浆前	1020	3.22	27.3	89.8
	灌浆后	10336	2.59	32.0	92.8
下限	灌浆前	879	3.04	28.7	88.1
	灌浆后	11934	2.74	30.4	92.3

8.结论

Conclusions

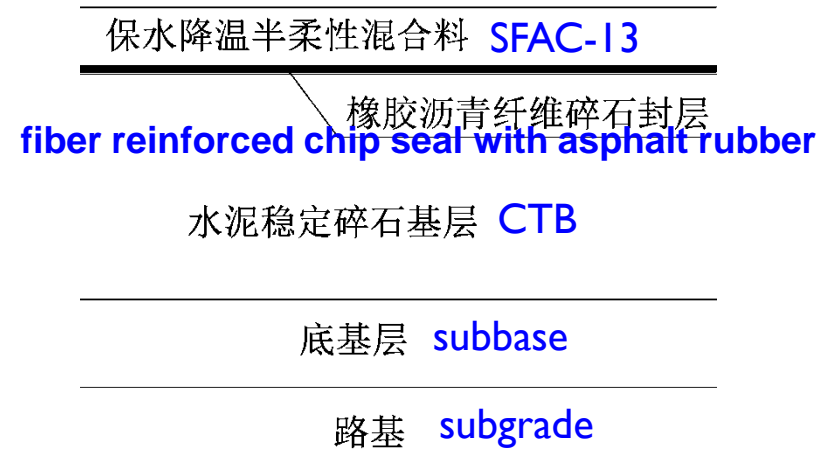
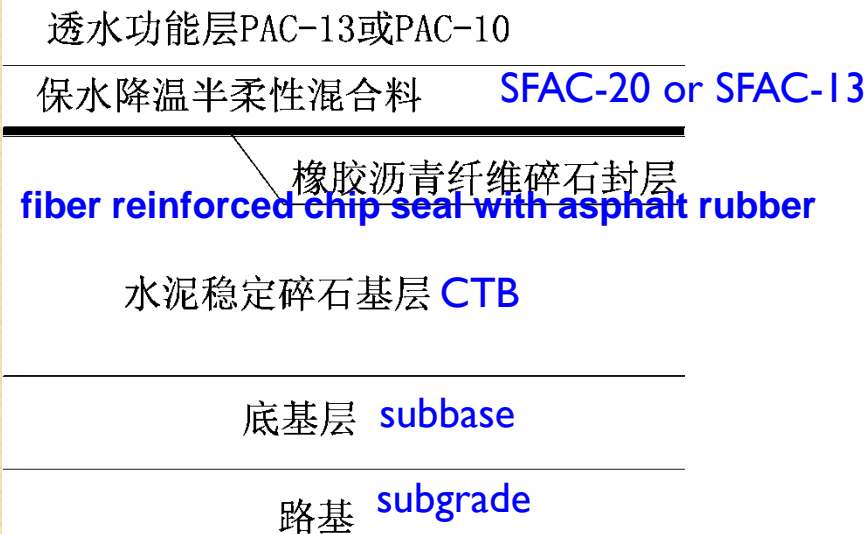
(6)悦来新城新型生态路面示范工程（叶家沟支路和塘木湾支路）的顺利实施，表明新型生态路面结构可行；相比进口国外沥青，成本降低，新型生态路面结构具有较高的推广价值。

(6) The successful implementation of the ecological pavement demonstration project of Yuelai New City (Yejiagou branch road and Tangmuwan branch road) shows that the new ecological pavement structure is feasible. Compared with imported asphalt, the cost is reduced, and the new ecological pavement structure has a very good promotion value.

8.结论

Conclusions

(7)结合重庆山地城市特点，机动车道在纵坡大于3%时基层以上建议采用2~4cm的PAC-13或PAC-10上面层+5~10cm的保水半柔性混合料SFAC-20（或SFAC-13）下面层+1cm的橡胶沥青纤维碎石封层的组合结构；机动车道在纵坡不大于3%时基层以上建议采用5~10cm的保水半柔性混合料SFAC-13面层+1cm的橡胶沥青纤维碎石封层的组合结构。



a) 纵坡大于3%时
longitudinal slope > 3%

b) 纵坡不大于3%时
longitudinal slope ≤ 3%

车行道路面结构 Driveway pavement structure

9.工程应用照片

Photos of Engineering Application



橡胶沥青纤维增强碎石封层施工

Construction of fiber reinforced
chip seal with asphalt rubber



基体沥青混合料施工

Construction of matrix
asphalt mixture

9.工程应用照片

Photos of Engineering Application



保水半柔性面层

Surface course with water-retention semi-flexible pavement

9.工程应用照片

Photos of Engineering Application




钻芯孔内情况 (降雨3d后)

Drilling hole condition (3 days after rainfall)



雨水井内软式盲管 (降雨3d后)

Soft blind pipe in rainwater well (3 days after rainfall) 33



谢谢！

Thank you for
your attention!

