International Journal of Civil and Structural Engineering – IJCSE 2018
Copyright © Institute of Research Engineers and Doctors , SEEK Digital Library
Volume 5 : Issue 1- [ISSN : 2372-3971] - Publication Date: 25 June, 2018

Environment Friendly Asphalt in Industrial Roads (Green Roads)

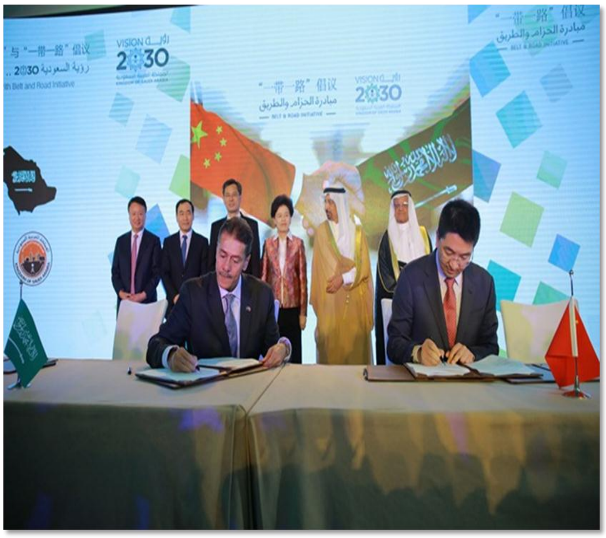
[Engineer. Muhammed Hussain Sheariya]

Yanbu Industrial City is located 350 Kilometers north west of Jeddah. It possesses tourism features due to its location on a coastal line the red sea and hijaz hills. The red sea with its crystal water and attractive coral reefs welcomes the people who visit and frequent it for marine picnics, diving and several types of water sports. In this young city – just over 40 years became a center for modern industries. It plays a major role in Kingdom's gross national income.

Yanbu port includes the facilities that enable it export more than three (3) million barrels / day while its location near the Suez channel makes it an excellent access to European markets and the developing markets in Affric and Middle East. Yanbu, moreover is located in the middle of the distance between America and the countries of the pacific ocean.

The main objective of Yanbu Industrial City Economic review is to gain better and current understanding of the city wide economic performances. The specific objectives are:

- To monitor / keep track of City's economic trends on a quarterly basis.
- To understand the changes in the economic structure of the city over the period of time.
- To generate economic awareness.



The Royal Commission vision is "The best choice for investors in petrochemical and energy-intensive industries and the leading contributor to the Kingdom's growth.

The Royal Commission Mission is "Plan, promote, develop & manage petrochemical and energy intensive industries through successful focus and partnerships with investors, employees, communities and other stakeholder

The Royal Commission's strategic objectives are:

- Growth: Expand industrial base through growth in number of cities and industrial output.
- Tenant Portfolio: Optimize tenant portfolio by attracting investments of added value.
- Cities of Excellence: Gain recognition as one of the top industrial cities globally.
- Distinctive Staff : The best in attracting distinctive human resources in the Kingdom
- Financial: Gradually develop financial sustainability and increased efficiency.

> ➢ EXISTING COMMUNITY AREA = 7,000 HA
> ➢ EXISTING INDUSTRIAL AREA = 11,500 HA
> **EXPANSION AREA = 42,100 HA**
> **TOTAL AREA OF RC YANBU = 60,600 HA (606 SQ. KM)**

Royal Commission at Yanbu Industrial City, Saudi Arabia was keen to raise the efficiency of its main & secondary roads network in Industrial Yanbu due to its strategic location in the kingdom's map and its association with neighboring countries. Our goal is to provide a safe roads network with high quality specifications without defects, that includes the study for an advanced asphalt mix design system where Industrial Yanbu will expand significantly in industrial, urban and investment field.

Type of road	Kilo meter	meter	Square meter
Highway (TAMA & Bypass Road)	124	124,300	3,395,600
Primary Streets (Main Roads)	102	101,400	2,183,000
Secondary Streets	101	100,950	1,736,350
Tertiary Streets	195	195,350	1,707,950
Parking Area	-	-	296,000
Total	**522**	**522,000**	**9,318,900**

The roads in Yanbu Industrial City were frequently damaged due to the extensive use of overloaded trucks without using control or balance weight, mainly on highway and roads in heavy & light industrial park areas, resulting in asphalt rutting, cracks, bleeding, etc. (See Figure # 1).

Figure # 1; Deformation of asphalt pavements

In 2014, the Royal Commission for Yanbu bought an Equipment for the Evaluation of the roads to establish maintenance priorities. Condition data such as roughness, rutting, cracks and surface distress, and deflection are used to establish the projects most in need of maintenance and rehabilitation. Once identified, the projects in the poorest condition are more closely evaluated to determine repair strategies (See Figure # 2).

Figure # 2; Road survey / evaluation equipment

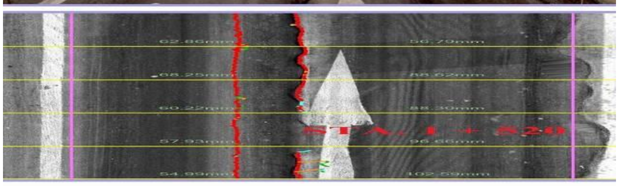
The Royal Commission conducts studies to overcome the asphalt pavement deformation problems for intersections and industrial roads and end up with three (3) major solutions:

1) Use of marshal Mix Design
2) Use of Reinforced Concrete pavement instead of asphalt
3) Use of Super pave Mix Design

Since 2004, the Royal Commission used the Marshall mix design of asphalt for rehabilitation industrial roads and intersections of highway road. The Marshall Mix Design method were originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the US Army. This method is very popular because of its relative simplicity, economical equipment and proven record. The Marshall method seeks to select the asphalt content at a desired density that satisfies minimum stability and range of flow values. The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C.

Construction of asphalt pavement using Marshall mix design method is relatively economical but it has some major drawbacks (See Figure # 3 & 4).

1) Less pavement strength.
2) Low resistance of rutting and cracking.
3) Short service life.
4) Requires regular maintenance, so uneconomical.



International Journal of Civil and Structural Engineering – IJCSE 2018
Copyright © Institute of Research Engineers and Doctors , SEEK Digital Library
Volume 5 : Issue 1- [ISSN : 2372-3971] - Publication Date: 25 June, 2018

Figure # 3; Road survey by evaluation equipment

Stret Name: TAMA MARSHALL
Description: Lane 1 (Corridor T8 to Wadi Bridge No. 2)

Station (m)	Rut Right (mm)	Severity Level	Rut Left (mm)	Severity Level
0 + 050	48	High	30	High
0 + 100	44	High	38	High
0 + 200	34	High	28	High
0 + 350	27	High	26	High
0 + 400	28	High	28.99	High
0 + 600	8.93	Medium	6.2	Medium
0 + 650	24.6	Medium	11.73	Medium
0 + 700	6.35	Medium	6.49	Medium
0 + 750	11.12	Medium	7.49	Medium
1 + 150	10.68	Medium	7.77	Medium
1 + 200	12.57	Medium	8.58	Medium
1 + 250	8.04	Medium	6.83	Medium
1 + 350	10.02	Medium	6.02	Medium
1 + 450	7.75	Medium	6.75	Medium
1 + 500	48.87	High	82	High
1 + 550	103	High	68	High
1 + 600	40	High	36	High
1 + 650	38	High	28	High
1 + 700	27	High	27.52	High
1 + 750	26	High	28.35	High
1 + 800	34	High	9	Medium
1 + 850	8.89	Medium	6.67	Medium
1 + 900	8.16	Medium	6.2	Medium
1 + 950	10.13	Medium	7.02	Medium
2 + 000	11.62	Medium	6.88	Medium
2 + 850	10.58	Medium	6.41	Medium
3 + 100	25.06	High	27.33	High
3 + 150	43.22	High	23.21	Medium
3 + 200	60.98	High	40.12	High
3 + 250	8.23	Medium	6.77	Medium

Figure # 4; Road survey results from evaluation equipment

Due to the increment in traffic volume, especially heavy trucks and trailers, The Royal commission decided to go through the second method that was Rehabilitation of Roads using Reinforced Concrete pavement instead of asphalt. The application was limited to intersections with rutting problem (See Figure # 5).

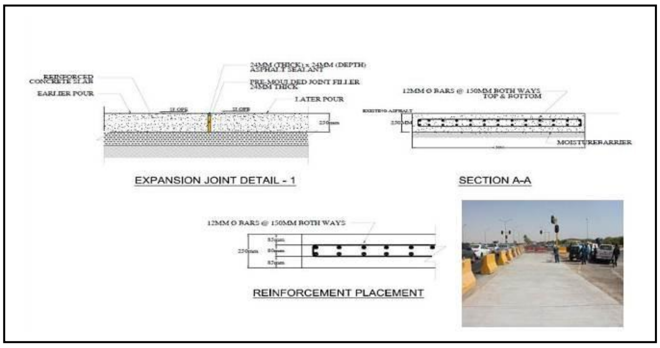


Figure # 5; Section details of reinforced concrete pavement

The advantages of this method are:

1) Improved skid resistance compared with traditional type of asphalt pavement.
2) Better visibility at night time and less glare.
3) Long Service life.

The disadvantages are:

1) High construction cost.
2) Less resistance of transverse cracking compare with Marshall mix design.
3) Increase pavement noise due to expansion joints and type of surfacing pattern (transverse thinking).

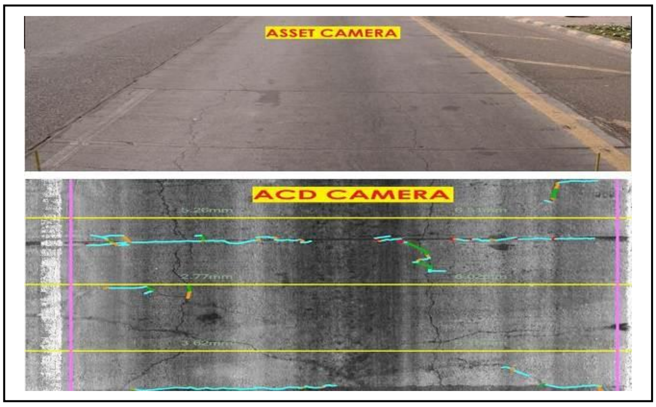


Figure # 6; Road survey by evaluation equipment

Chainage (m)	Cracks Percentage (%)	Extent Level	Ave. Crack Width (mm)	Severity Level	Crack Length (m)
800	6.67	Occasional	16.59	Moderate	4.40
850	11.33	Occasional	12.40	Moderate	8.38
900	8.67	Occasional	13.10	Moderate	6.82
950	6.00	Occasional	11.07	Moderate	3.20
1000	3.33	Occasional	7.95	Moderate	2.29
1050	0.67	Occasional	3.72	Moderate	0.53
1100	7.33	Occasional	8.91	Moderate	7.84
1150	4.00	Occasional	8.51	Moderate	2.28
1200	1.33	Occasional	25.13	High	0.94
1250	9.33	Occasional	8.72	Moderate	11.64
1300	6.00	Occasional	13.27	Moderate	5.85
1350	0.67	Occasional	4.21	Moderate	0.22
1400	3.33	Occasional	5.72	Moderate	3.06
1450	0.67	Occasional	6.70	Moderate	0.34
1500	1.33	Occasional	9.38	Moderate	0.57
1550	3.33	Occasional	18.17	Moderate	2.37
1600	3.33	Occasional	5.62	Moderate	4.93
1650	3.33	Occasional	26.76	High	4.31
1700	0.67	Occasional	6.08	Moderate	0.26
1750	2.00	Occasional	12.49	Moderate	1.75
1800	2.00	Occasional	11.94	Moderate	0.95
1850	9.33	Occasional	15.16	Moderate	9.87
1900	44.67	Frequent	15.53	Moderate	113.84
1950	8.00	Occasional	11.51	Moderate	7.42
2000	9.33	Occasional	14.38	Moderate	10.62
2050	1.33	Occasional	7.56	Moderate	0.64
2100	4.67	Occasional	8.32	Moderate	2.33
2150	14.67	Occasional	9.74	Moderate	25.24

Figure #7 ; Road survey results from evaluation equipment

Figure #8 ; Maintenance of cracks by crack sealing

In 2016, many studies and site visits were conducted including the road survey analysis by Royal Commission's Road Evaluation Equipment which can provide the detailed reports like type of deformation of asphalt layers, degree of damage in asphalt layer, cracks, rutting, etc. Moreover, the Royal Commission Roads Department was coordinated and discussed with several consultants around the globe to find out the right solution to avoid deformation in asphalt pavement at the industrial roads. Furthermore, Roads Department conducted site visits in all batch plants in Yanbu in order to check the quality of the materials used for mix design. Based on the thorough evaluation results, The Royal Commission decided to execute the third method as trial, since the previous methods are not suitable for the industrial city being un-efficient and un-economical. We applied the wearing course by super pave mix design on the existing asphalt base course having Marshall Mix design. This procedure established the precedent in the world. This method is called environment friendly asphalt layer in Industrial Roads (Green Roads).

The Royal Commission decided to execute the third method (superpave mix design) at the critical locations, including:

- Applying super pave mix design in light industrial area
- Applying super pave mix design at intersections along King Abdulaziz highway (TAMA)

The Royal Commission Roads Department was executed the following steps:

Step # 1 : Count the number of vehicles and Trucks using yanbu industrial city Roads (see Figure # 9).

RTMS - REMOTE TRAFFIC MICROWAVE SENSOR

RTMS	TOTAL RTMS GENERATED COUNTS WITH VEHICLE CLASSIFICATION				GRAND TOTAL	ESTIMATE YEARLY TOTAL
	SMALL<6.2M PASSENGER CARS	MEDIUM(6.2-10.1M) COASTER, VAN, TRUCK	LARGE(10.1-12M) BUS, TRUCK SINGLE UNIT	TRUCK>12M TRUCK, TRAILER TRUCK		
RTMS TOTAL FOR THE YEAR 2014	2,760,535	387,024	79,740	510,589	3,737,888	44,854,656
RTMS TOTAL FOR THE YEAR 2015	2,838,457	376,526	74,168	538,872	3,828,023	45,936,276
RTMS TOTAL FOR THE YEAR 2016	3,033,399	371,675	89,177	604,121	4,098,372	49,180,464
RTMS TOTAL FOR THE YEAR 2017	3,190,465	374,901	98,503	660,260	4,324,129	51,889,548

Figure # 9; RTMS Data

Step # 2 : Compare with standards (see Figure # 10).

Class Designation		ESALs Range	Applications
VL	Very Light	Less than 300,000	Agricultural roads with light traffic , local and city streets without trucks
L	Light	300,000 to 3 million	Agriculture, Feeder and collector roads
M	Medium	3 million to 10 million	Main roads and city streets
H	Heavy	10 million to 30 million	Highways and Expressway
VH	Very Heavy	More than 30 million	Heavily trafficked highways, industrial areas ...

Figure # 10; ESAL and traffic Designation

Step # 3 : Determine Super pave Mix Design requirements (see Figure # 11).

The Super pave mix design method was designed to replace the Hveem and Marshall methods. Final product of the 1987-1993 FHWA Strategic Highway Research Program to investigate better pavement materials & design methods. The Super pave (Superior Performing Asphalt Pavements) mix design method ties asphalt binder and aggregate selection into the mix design process, and consider traffic and climate as well. The compaction devices from the Hveem and Marshall procedures have been replaced by a gyratory compactor and the compaction effort in mix design is tied to expected traffic.

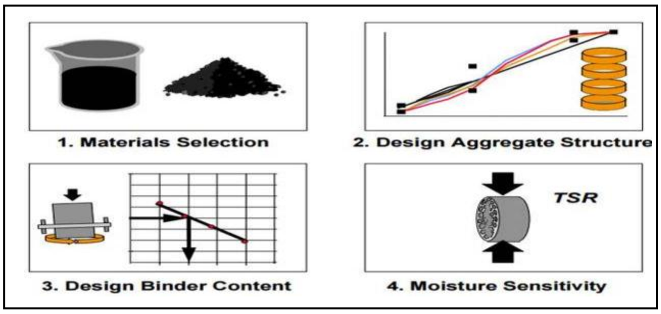


Figure # 11; Steps of Super pave mix design

The Super pave mix design Evaluation Criteria includes the following:

1) Specimen heights
2) Mixture volumetric
   a. Air voids
   b. Voids in mineral aggregate (VMA)
   c. Voids filled with asphalt (VFA)
   d. Mixture density characteristics
3) Dust proportion
4) Moisture sensitivity

The Crushed Fragments in Gravels used as aggregate shall have the following characteristics:

1) Quarried materials always 100% crushed minimum two sides of aggregate(See Figure # 12).
2) Minimum values depended upon traffic level and layer (lift).
3) Defined as percentage mass with one or more fractured faces.

Crushed face aggregates helps to reduce shear plane slides and mass deformation of the pavement structure.

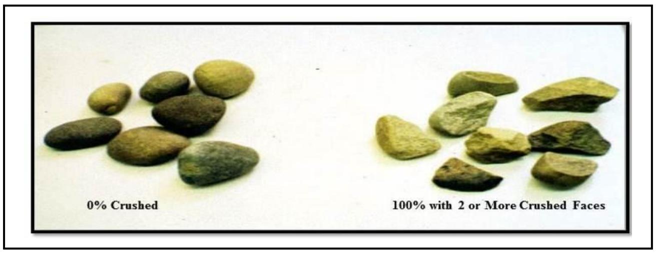


Figure # 12; Crushed fragments in gravel

Super pave Asphalt Binder Specification (Performance Grade Specification) depends on the following (see Figures # 13 &14):

1) Fundamental properties related to pavement performance.
2) Environmental factors.
3) In-service & construction temperatures.
4) Short and long term aging.

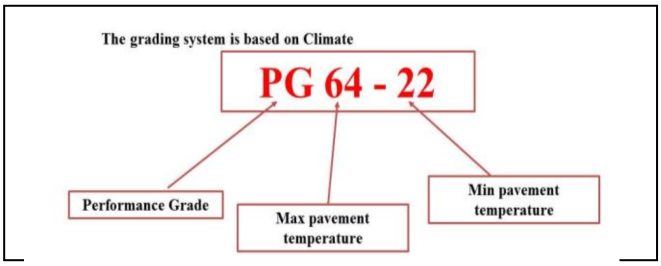


Figure # 13; Super pave asphalt binder grading system

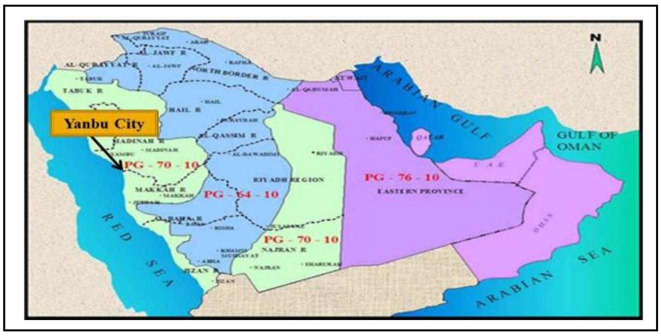


Figure # 14; The grading system is based on Climate in KSA

Asphalt cement is a viscoelastic material and its behavior depends on the following:

1) Temperature
2) Time of loading
3) Aging (properties change with time)

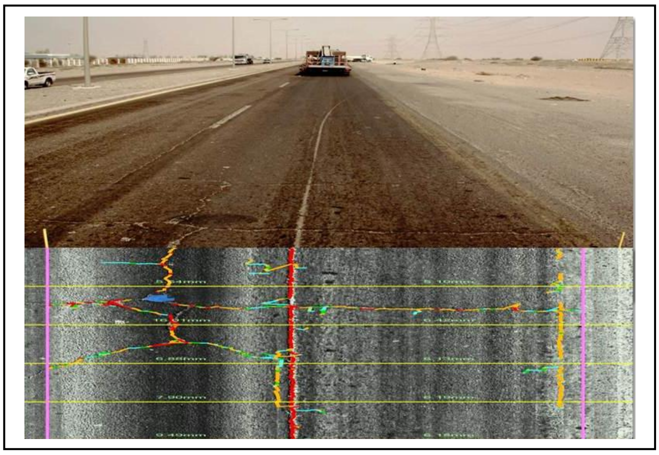
Step # 4 : Site visit to Asphalt patch plant:
Visiting of asphalt patch plant is important step to check How we can apply and requirement of super pave mix design (see figure # 15).

Figure # 15; Visit to asphalt batch plant

Step # 5 : preparation of super pave mix design in patch plant (see figure # 16).

Figure # 16; preparation of super pave mix

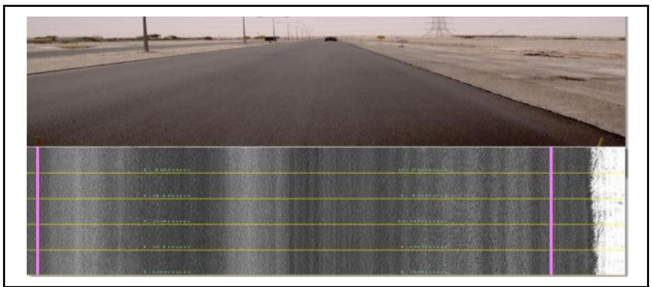
Step # 6 (a) : Applying super pave mix design in light industrial area (see figure # 18)



Chainage (m)	Cracks Percentage (%)	Extent Level	Max Crack Width (mm)	Severity Level	Crack Length (m)
50	30.07	Frequent	8.93	Moderate	43.05
100	[illegible]	Extensive	10.05	Moderate	96.10
150	22.67	Frequent	6.93	Moderate	30.60
200	10.67	Occasional	10.47	Moderate	11.07
250	4.67	Occasional	5.30	Moderate	6.67
300	13.33	Occasional	7.33	Moderate	10.37
350	12.67	Occasional	6.09	Moderate	15.02
400	15.33	Occasional	9.14	Moderate	17.86
450	47.33	Frequent	10.55	Moderate	75.19
500	38.00	Frequent	11.95	Moderate	57.59
550	33.33	Frequent	8.89	Moderate	53.42
600	16.00	Occasional	10.87	Moderate	24.24
650	11.33	Occasional	9.67	Moderate	15.07
700	0.00		0.00		
750	32.67	Frequent	12.41	Moderate	51.08
800	25.33	Frequent	11.42	Moderate	29.74
850	20.67	Frequent	13.54	Moderate	29.72
900	23.33	Frequent	8.85	Moderate	30.77
950	34.00	Frequent	23.98	Moderate	52.82
1000	[illegible]	Extensive	6.66	Moderate	75.70
1050	36.00	Frequent	8.07	Moderate	52.43
1100	35.33	Frequent	9.65	Moderate	46.20
1150	40.67	Frequent	10.40	Moderate	59.04
1200	[illegible]	Extensive	15.02	Moderate	130.20
1250	[illegible]	Extensive	8.77	Moderate	94.99
1300	32.67	Frequent	9.36	Moderate	44.57
1350	28.67	Frequent	8.95	Moderate	39.48
1400	44.67	Frequent	11.97	Moderate	73.41
1450	46.00	Frequent	10.97	Moderate	86.30
1500	14.00	Occasional	8.15	Moderate	21.44
1550	10.67	Occasional	5.40	Moderate	13.85
1600	4.00	Occasional	4.95	Moderate	4.49
1650	24.00	Frequent	5.98	Moderate	37.54
1700	44.00	Frequent	7.56	Moderate	69.41
1750	27.33	Frequent	4.59	Moderate	37.87
1800	33.33	Frequent	6.93	Moderate	52.18
1850	26.00	Frequent	7.88	Moderate	35.91
1900	16.67	Occasional	5.36	Moderate	23.14
1950	34.00	Frequent	6.00	Moderate	63.57
2000	28.67	Frequent	5.08	Moderate	38.14
2050	20.67	Frequent	5.97	Moderate	23.44
				TOTAL CRACK LENGTH:	1,774

Figure # 17: Condition of asphalt layers at light industrial park before the application of super pave

Figure # 18; rehabilitation of roads in light industrial parks



Chainage (m)	Cracks Percentage (%)	Extent Level	Ave. Crack Width (mm)	Severity Level	Crack Length (m)
20	0.00		0.00		
40	1.67	Occasional	[illegible]	Moderate	0.20
60	0.00		0.00		
80	0.00		0.00		
100	0.00		0.00		
120	0.00		0.00		
140	0.00		0.00		
160	1.67	Occasional	2.82	Low	0.26
180	1.67	Occasional	2.82	Low	0.26
200	0.00		0.00		
220	0.00		0.00		
240	0.00		0.00		
260	0.00		0.00		
280	1.67	Occasional	3.50	Moderate	0.28
300	3.33	Occasional	[illegible]	Moderate	0.79
320	0.00		0.00		
340	0.00		0.00		
360	6.67	Occasional	[illegible]	Moderate	2.00
380	0.00		0.00		
400	0.00		0.00		
420	0.00		0.00		
440	0.00		0.00		
460	0.00		0.00		
480	0.00		0.00		
500	1.67	Occasional	[illegible]	Moderate	0.26
516	0.00		0.00		
536	0.00		0.00		
556	0.00		0.00		
576	0.00		0.00		
596	5.00	Occasional	[illegible]	Moderate	1.23
616	0.00		0.00		
636	0.00		0.00		
656	0.00		0.00		
676	3.33	Occasional	[illegible]	Moderate	0.43
696	0.00		0.00		
716	0.00		0.00		
736	0.00		0.00		
756	0.00		0.00		
776	0.00		0.00		
796	0.00		0.00		
816	0.00		0.00		
836	0.00		0.00		
856	0.00		0.00		
876	0.00		0.00		
896	0.00		0.00		
912	0.00		0.00		
				TOTAL CRACK LENGTH:	6

Figure # 19: Condition of asphalt layers at light industrial park after the application of superpave

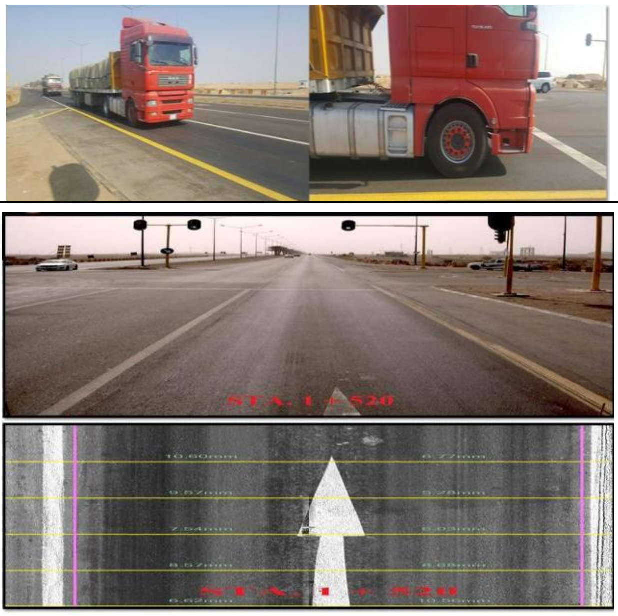
Step # 6 (b) : Applying super pave mix design at intersections along King Abdulaziz highway (TAMA)

International Journal of Civil and Structural Engineering – IJCSE 2018
Copyright © Institute of Research Engineers and Doctors , SEEK Digital Library
Volume 5 : Issue 1- [ISSN : 2372-3971] - Publication Date: 25 June, 2018

Stret Name: TAMA MARSHALL
Description: Lane 1 (Corridor T8 to Wadi Bridge No. 2)

Station (m)	Rut Right (mm)	Severity Level	Rut Left (mm)	Severity Level
0 + 050	48	High	30	High
0 + 100	44	High	36	High
0 + 200	34	High	28	High
0 + 350	27	High	26	High
0 + 400	26	High	26.99	High
0 + 600	8.93	Medium	6.2	Medium
0 + 650	24.6	Medium	11.73	Medium
0 + 700	6.35	Medium	6.49	Medium
0 + 750	11.12	Medium	7.49	Medium
1 + 150	10.68	Medium	7.77	Medium
1 + 200	12.57	Medium	8.58	Medium
1 + 250	8.04	Medium	6.83	Medium
1 + 350	10.02	Medium	6.02	Medium
1 + 450	7.75	Medium	6.75	Medium
1 + 500	48.87	High	62	High
1 + 550	103	High	68	High
1 + 600	40	High	36	High
1 + 650	38	High	26	High
1 + 700	27	High	27.52	High
1 + 750	26	High	26.35	High
1 + 800	34	High	9	Medium
1 + 850	8.89	Medium	6.67	Medium
1 + 900	8.16	Medium	6.2	Medium
1 + 950	10.13	Medium	7.02	Medium
2 + 000	11.62	Medium	6.88	Medium
2 + 850	10.58	Medium	6.41	Medium
3 + 100	29.36	High	27.33	High
3 + 150	43.22	High	23.21	Medium
3 + 200	60.93	High	40.12	High
3 + 250	8.23	Medium	6.77	Medium

Figure # 20: Condition of asphalt layers at intersections along highway (TAMA) before the application of superpave



Street Name: TAMA SUPERPAVED
Description: Lane 1 (Corridor T8 to Wadi Bridge No. 2)

Station (m)	Rut Right (mm)	Severity Level	Rut Left (mm)	Severity Level
0 + 050	1.67	Low	4.62	Low
0 + 100	5.97	Low	1.44	Low
0 + 200	2.53	Low	2.56	Low
0 + 350	1.41	Low	2.77	Low
0 + 400	1.42	Low	1.95	Low
0 + 600	1.71	Low	2.58	Low
0 + 650	1.22	Low	3.2	Low
0 + 700	1.54	Low	4.17	Low
0 + 750	1.42	Low	3.28	Low
1 + 150	2.85	Low	2.32	Low
1 + 200	1.84	Low	2.94	Low
1 + 250	2.24	Low	2.55	Low
1 + 350	2.01	Low	2.74	Low
1 + 450	1.99	Low	3.49	Low
1 + 500	2.57	Low	2.59	Low
1 + 550	2.54	Low	5.24	Low
1 + 600	4.91	Low	5.41	Low
1 + 650	3.56	Low	4.28	Low
1 + 700	3.17	Low	3.63	Low
1 + 750	2.47	Low	2.97	Low
1 + 800	2.16	Low	2.23	Low
1 + 850	2.96	Low	1.81	Low
1 + 900	1.84	Low	2	Low
1 + 950	1.82	Low	2.25	Low
2 + 000	1.49	Low	2.18	Low
2 + 850	2.5	Low	1.59	Low
3 + 100	1.95	Low	2.22	Low
3 + 150	2.2	Low	3.1	Low
3 + 200	2.19	Low	2.56	Low
3 + 250	2.1	Low	2.12	Low

Figure # 21: Condition of asphalt layers at intersections along highway (TAMA) after the application of superpave

The advantages of super pave asphalt mix design are:

1) Reduced the amount and severity of pavement distresses.
2) Improved stability to prevent rutting.
3) Improved flexibility to prevent cracking
4) Improved durability to prevent potholes / weathering.
5) Long service life.
6) Low maintenance cost.
7) Less pavement noise.
8) Provide excellent riding quality.

The Royal Commission experiment for using the Super pave asphalt mix design in operation & maintenance and construction projects offers:

1) Sufficient asphalt to ensure a durable pavement.
2) Sufficient stability under traffic loads.
3) Sufficient air voids.
4) Upper limit to prevent excessive environmental damage.
5) Lower limit to allow room for initial densification due to traffic.
6) Sufficient workability and Sufficient skid resistance.

By this way the Royal Commission can provide to the motorist an Environment friendly asphalt industrial roads is calling (green roads).

Authors and Affiliations:

Engineer. Muhammad Hussain Sheariya
Civil Engineer, Associate Value Specialist (AVS)
Classify Professional Engineer from Saudi Council of Engineers
Manager, Roads Planning, Studies & Contracts Section
Roads Department, Royal Commission for Yanbu.

References:

- ***American Association of State Highway and Transportation Officials (AASHTO):***
- ***American Society for Testing and Materials (ASTM):***
- ***Saudi Arabian Standard - Ministry of Transport (MOT) Standard Specifications for Road and Bridge Construction:***