Zydex
Innovating for Sustainability

Zydex Nanotechnology for Perpetual Pavements:

Sustainability: To build a Network of perpetual pavements with a life cycle of more than 50 years using minimal aggregates and thinner bituminous wearing course will be the key goal of the 21st century.

Zydex nanotechnology additives combined with Granular Soil Mix (GSM) enables a load bearing durable structural layer with key features of **base stabilization (very high strength), moisture resistance, reduced expansivity** and **nano flexible bonding (via nano polymers).**

All Zydex additives are added in water using conventional processes that are used for cement/lime/fly ash stabilization. Zydex pavements are expected to have a durability of 50 years.

Background Technology

The IRC SP 89: 2010 [1] (Guidelines for Soil and Granular Material Stabilization using Cement, Lime & Fly Ash) has already provided the proportion and gradation details for both soil and aggregates for a soil aggregate mix (see Table 1 below).

At Zydex, we have also experimented extensively with this granular mix in our lab. It has consistently resulted in a granular soil mix that has voids in the range of 5 to 7%. This is most desirable for a high performance structural layer/pavement.

Table 1	Suggested gradation of Aggregates/Soil Mix (IRC SP 89: 2010)					
Numerical difference between material A and Average Percent Passing	Material A (Soil) percent passing	Sieve Size	Recommended limits percent passing	Average percent passing	Material B (GSB) percent passing	Numerical difference between Material B and Average Percent Passing
Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7

0	100	40 mm	100	100	100	0
8	98	20 mm	80 - 100	90	73	17
26	94	10 mm	55 - 80	68	54	14
29	79	4.75 mm	40 - 60	50	40	10
20	60	2.36 mm	30 - 50	40	33	7
30	52	0.60 mm	15 - 30	22	20	2
7	17	0.075 mm	5 - 15	10	9	1
120	**TOTAL**					**51**

The table above confirms that the combination of GSB grade II material (65 – 70%) and local soil (30 – 35%) of CBR > 5 when combined to achieve the specified gradation will deliver a high performing granular soil mix (GSM). This combination (GSM) will consistently deliver voids between 5 to 7% after stabilizing(with 3% cement by weight of Soil Mix, 1.6 kg/ M3 Terrasil and 1 kg /M3 Zycobond), and compacting the moulds via Marshall hammer. These results were reproduced consistently across various types of soils of CBR ranging from 5 - 15.

Soil: GSB Material = 3:7 (i.e. 30 - 35% Soil and 65 - 70% Aggregate, specified in IRC SP 89 and which is also used in the Zydex design)

The significance of 5% - 7% air voids [2] in the stabilized base is its equivalence to the voids achieved in bituminous layers below wearing courses viz DBM. The moulded specimen of Zydex stabilized GSM show marshall compressive stability greater than 25-35 KN even after wet conditioning of 24 hours at

60°C. The tensile strength ratio (TSR) as per AASHTO T-283 shows > 90% retained strength.

The Zydex stabilized moulded samples did not show any absorbtion of water even after 7/15 days of wet conditioning at 60 °C and had TSR consistently above 80% (even up to 15 days saturation) – Table 2 & 3 below.

Table 2: Marshal Stability & TSR for Zydex GSM Mix
(For soils with CBR 4 – 6%)

Strength & TSR (30 Mins)		*Strength & TSR (3 days)*		*Strength & TSR (7 days)*		*Strength & TSR (15 days)*	
34.3 KN	*NA*	30.7 N	89.50%	28.3 KN	82.50%	28.0 KN	81.60%

Table 3: Marshal Stability & TSR for Zydex GSM mix

(For soils with CBR 8 – 10%)

Strength & TSR (30 Mins)		*Strength & TSR (3 days)*		*Strength & TSR (7 days)*		*Strength & TSR (15 days)*	
36.5 KN	*NA*	33.2 K N	91.00%	31.93 KN	87.50%	30.73KN	84.20%

DURABILITY AND LIFE CYCLE

The Zydex stabilized base core samples prepared were tested for durability vide ASTM-D 559 and BIS Standard IS 4332 (Part IV) – 1968 for ascertaining effect of wet and dry cycles.

The cores passed the specified 12 wet and dry cycles performance, thereby confirming service life of 20 years, extended testing up to five times i.e. measuring weight loss after 24, 36, 48 & 60 cycles was also found to be

below the failure point as shown in Table 4. This indicates that the water resistance and uniform flexible bonding is capable of increasing durability up to 5 times to exceed a life cycle of 50 years and more.

The conventional cement stabilized moulds fail in 12 cycles testing itself.

The higher dosage of cement (leading to brittleness and cracking) and water absorbtion (leading to expansivity/shrinkage cycles) are the key reasons for low durability.

The wet strength at 60 deg. C after 15 days conditioning of Zydex stabilized GSM moulds is twice the dry strength of DBM mixes, thereby confirming that cement stabilized GSM mixes with Zydex additives performs better than conventional DBM mixes.

Table 4 (Durability testing of cement stabilized GSM mixes)

	12 Cycles	*24 Cycles*	*36 Cycles*	*48 Cycles*	*60 Cycles*
Control 6% Cement	FAIL	FAIL	FAIL	FAIL	FAIL
GSM Mix	PASS	PASS	PASS	PASS	PASS

GSM composition when tested for CBR consistently gives reading above 200 (Table 5 below)

Table 5 (Improved CBR of GSM Mixes)

GSM	*CBR Soil*	*CBR Stabilized*
70 / 30	5	200
70 / 30	10	250
70 / 30	15	300

In the proposed Zydex design of stabilized road bases, the brittleness and cracking tendency is negligible because the cement quantity is restricted to 3% (many papers [3 & 4] across the world support the finding that 3 to 4% cement as the optimum dose in soil to avoid brittleness – **Ref Geotechnical Engg, Indianapolis)**. Though the stiffness is high (25 – 35 KN), the flow value of Zydex stabilized GSM moulds is between 2 to 5 indicating acceptable flexibility for bonded base layers. Next generation stabilized bases will have voids of 5 - 7% (in field), extraordinary resistance to moisture, higher stiffness and resilience to deformation coupled with flexibility as the critical parameters to deliver fatigue resistance and durability. (Flow table to be added subsequently)

The Zydex base will therefore now perform as a semi-rigid pavement base due to high strength and stiffness and the substantially reduced strain values under standard axle load. This will ensure meeting both the horizontal and vertical strain criterion for perpetual pavements to be less than 200 microns.

This sustainable design will enable building of future perpetual pavements for rural as well as highway road networks. Table below confirm that all the performance requirements expected from a perpetual pavement are consistently met and exceeded.

Role of additives in Zydex GSM

Parameter	Terrasil	Zycobond	Cement
Waterproofing of soil bases	✓		
Increased strength(CBR)	✓	✓	✓
Fatigue and stress reduction	✓	✓	
Dimensional stability (reduced expansivity)	✓		✓
Prevent capillary rise	✓		
Aging/Heat protection (reduced strength loss over time)		✓	
Early strength gain			✓
Improves compaction density	✓		✓
Non-leaching	✓	✓	✓
Environment friendly	✓	✓	✓
Ease of application	✓	✓	
Dust control (improved		✓	

abrasion/erosion resistance)			
Compatibility with wide variety of soils	✓	✓	✓

Zydex technology can now make the stabilized GSM layers entirely waterproof. This negates the effect of wet-dry cycles and provides dimensional stability, protects cement stabilization and enhances flexibility & extends pavement life.

CTSB – Stabilized soil sub base with cement and Zydex additives.

Long-term performance of pavement structures is significantly impacted by enhancement in the stability of the underlying structural layers. Soil subgrades are expected to maintain minimum load bearing strength under wet conditions, resist the weathering effect over its design life, and have reduced permeability.

The sub base is one of the load bearing layer of the pavement. In a pavement structure load is distributed from top layers to the underneath sub base and sub-grade layers. There is no consistency in regards to the terms of sub base and subgrade, but normally the subgrade is the native soil while the sub base is the layer of soil or aggregate on top of the subgrade. For the construction of perpetual pavement with Zydex design and additives, no soil with expansivity (free swell index) > 5% will be considered. (If such soils are not available then Terrasil treatment from 0.25 kg to 1 kg /M3 can be used to get FSI below 5%). The major issues that can be

detrimental to performance of the sub base include lack of density, permeability to water, lack of bonding, and segregation.

Results from the leading Indian lab [5 & 6] have showed that soils alone or mixed with granular materials when treated with Zydex additives and cement have significant improvement in their engineering properties - increased strength and stiffness (15 – 25 times improved CBR), higher UCS and durability and up to 500 times reduction in permeability.
ASTM paper on use of Zydex additives have confirmed similar findings[7]

ORGANO SILANE TREATED SOIL DISPLAYED THE FOLLOWING,
- ✓ Soil Swelling Reduced by 85 %
- ✓ Compaction Density Increased by 4%

Sr	Parameters	Measure	Soil w/o additive	Soil + Cement 3%	Soil + Silane 0.75 kg/m^3 + nano polymer 0.75 kg / m^3 + Cement 3%
1	CBR	%	7	67	125
		% Improvement	-	857%	1685%
2	UCS	MPa	0.27	1.02	2.43
		% Improvement		278%	800%
3	Durability (Wet – Dry Cycles)	No. of cycles	0	4	12
		IS : 4332 (Part 4)	Fails	Fails	Passes (Simulates 20 years life)

With Zydex additives the original FSI value of soil reduces to ~ 85 %, in comparison to natural soil. This is because of Terrasil modifying clay to significantly reduced swelling resulting in decreased swelling capacity.

Other than increase of CBR, UCS and durability, results of the resilient modulus tests have shown that Zydex additives work well in combination with cement and make the soil stiff and water resistant. For low traffic

areas, stabilized gravel roads with cement and Zydex additives can be a very good substitute.

With the above improvement in strength, reduction in expansivity and improved durability it becomes viable to substitute WMM and GSB layers with a stabilized sub base with reduced bitumen thickness.

With the combination of a stabilized sub base built on a base with granular soil mix (explained earlier), it is possible to optimize the pavement design and also increasing the traffic capacity of a pavement. From an economic point of view, utilization of Zydex additives with cement is attractive and supports sustainable development in road construction.

Research suggests that the perpetual pavement with the strong and flexible base layer will have superior fatigue performance.

Increased Strength + Reduced Deformation = Perpetual Base

With Foundation secure…..what's next..?

Zydex additives for prime coat

Typically, the prime coat has VOC issues. We have now seen the world move from cutback bitumen to water based emulsions preferably cationic. However, the issues with prime coat are spotty spraying (less than 100% coverage), thick layer deposition and poor tracking.

TerraPrime from Zydex ensures the emulsion has uniform coverage, improved penetration and track resistance at lower residual bitumen content (20% instead of normal 60%). The setting time is reduced to 60 -120 minutes instead of 7 to 8 hours enabling quicker resumption of work. The permanent anchoring of the bitumen delivers higher bond strength and ensures complete and homogenous load transfer between the various layers of the pavement (higher fatigue life), while significantly reducing the potential of the bitumen to track and be prone to moisture damage.

Zydex additives for tack coat

Poor tack coat application also leads to thick deposition, slippage cracking and water absorption. This is true both for milled surfaces as well as new surfaces. This typical 60% bitumen content leads to deposition of 250 – 350 micron thick coating which is spotty. (calculation is based on coverage area

and residual deposition for a cationic emulsion). A mere 10% loss in bond strength of tack coat can result in up to 50% reduction in fatigue life [1] (**Ref: Tech brief {FWA-HIF- 16 – 017}: Tack coat best practices FHWA, US DOT).**

Several studies conducted the world over have shown that de-bonding and slippage cracks have led to structural distresses like fatigue cracking and potholes that ultimately reduce pavement life.

NanoTac emulsion additive from Zydex ensures a finer bitumen droplet size that delivers better absorbtion and helps to create a permanent chemical bond between the emulsion and the underlying surface[2 & 3]. Due to the formation of a permanent chemical bond, the tack coat is resistant to tracking, has high bond strengths and can be used at lower residual bitumen content [4&5]. This permanent anchoring ensures complete and homogenous load transfer between the various layers of the pavement. Several international approvals have been received for the commercial use[6]. In fact Texas DOT has not only approved Zydex technologies in their approved vendor list but also accepted Zydex's recommendation for dilution to be followed as it shows good results on pavements[5].

100% coverage, Reduced Tracking and Better absorbtion – Higher Bond Strength

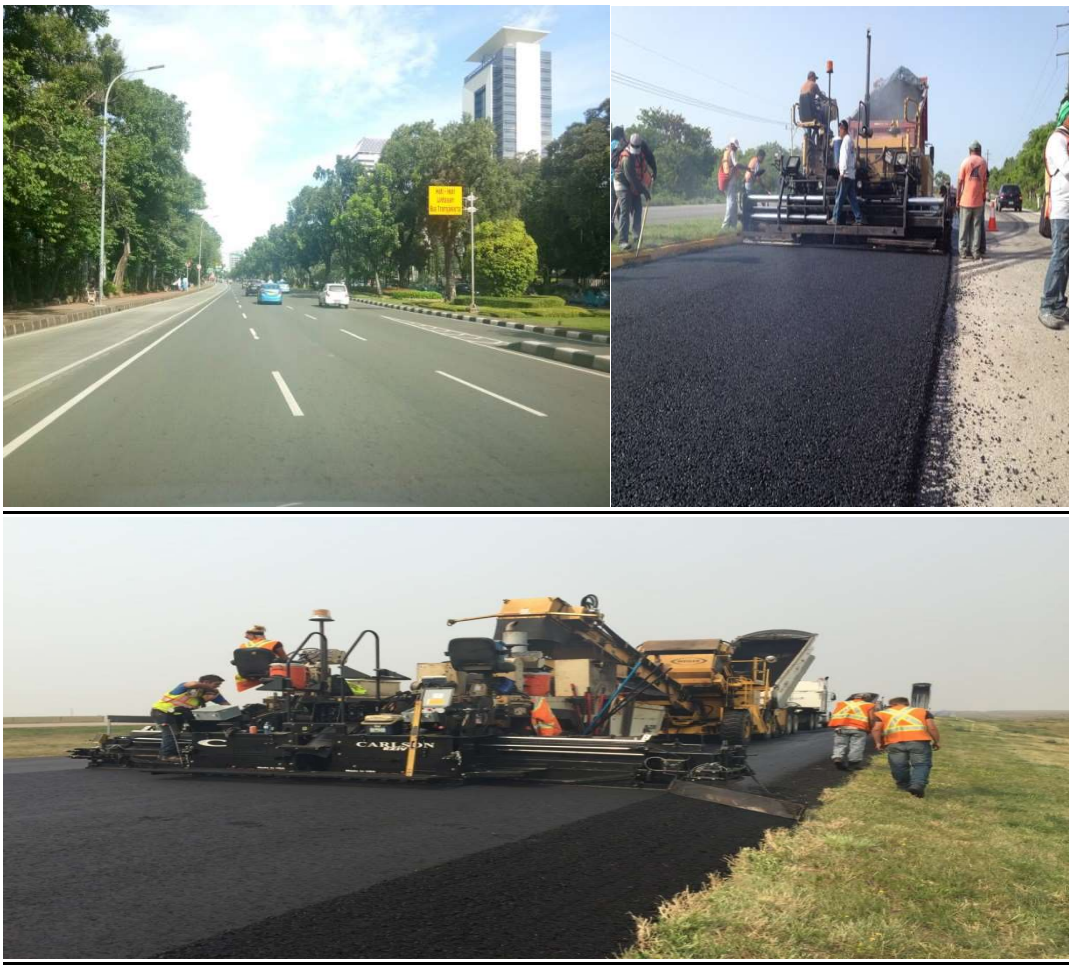
Email: info@zydexindustries.com

Website: www.zydexindustries.com

Zydex additive for Wearing Course/Surface course

The wearing course should be dense, water resistant, high modulus, high strength and flexible. Uniform high density and water resistance are the two key factors that lead to extended life of the pavement. Density of a balanced mix design will ensure good rutting and fatigue performance as well as high crack resistance. Chemically bonded aggregates thru silane technology ensure enhanced water resistance. The new generation of silane additives from Zydex improves workability, maintain elastic recovery, and provide 100% coating[2] and higher density even at low compaction temperatures[3&4].

The bitumen layers of future perpetual pavements must ensure aggregate surface modification for water resistance, 100% coating of fines with bitumen binder (dense asphalt mix) and enhanced workability for consistently improved density[8 - 10]. This will ensure that wearing course resurfacings are limited to 2 or 3 over the life span of the pavement[14].



Perpetual Pavements – A Way Forward

New technologies and advancements in material and application can now address soil expansivity, provide water resistance, nano flexible bonding, reactive bonded layers, aggregate modification for chemical bonding and enhanced workability of bitumen mixtures. All put together these advancements will allow new generation of perpetual pavements with reduced material demand (bitumen & aggregate), lower life cycle costs and sustainable roads of tomorrow.

Email: info@zydexindustries.com

Website: www.zydexindustries.com

We will now compare the design and cost of a conventional pavement with 20 year design life with that of a 50 year perpetual pavement built with Zydex design. The traffic consideration will be for 2 lane 50 MSA traffic that has a design life of 20 years. With traffic growth assumed @ 5% the perpetual pavement is expected to handle 320 MSA over 50 year design life[3].

Perpetual pavement – Zydex design

With materials and technology advancements, the following design parameters will be improved.

I. Zydex additives like Terrasil and Zycobond can eliminate capillary rise at bottom of the base soil itself. Along with that the base and sub base will have a much better response to stress/loading (resilient modulus) due to intra particle bonding and flexibility. The silane additives will reduce the swelling potential below 5% (FSI) and improve water resistance. **This will increase the strength and dimensional stability and not allow de-compaction due to wet and dry cycles during the lifecycle.** Cement stabilization with Zydex additives will deliver extended life cycle due to this swelling and expansivity control.

II. The **strong inter layer chemical bonding** with 100% coverage resulting from Zydex additives in emulsions, will ensure the **pavement** responds **as** one **monolithic (fully bonded) structure**. Stronger bonding and 100% uniform load transfer between layers will ensure reduction in bottom up reflective cracking, lower deformation and improved fatigue response.

III. Zydex organosilane bitumen additives, ensures consistent compaction performance and reduced moisture succesptibility. Surface

deterioration is greatly minimized leading to lower roughness and reduced renewal need (perpetual pavement requirement).

Taken together, these advantages will push back and delay the repair and serviceability needs (rehabilitation, renewal, full depth reclamation) of the pavement significantly, resulting in a perpetual pavement that reaches its terminal serviceability after a much longer time (design life > 50 years) than conventional pavement.

As per the conventional design philosophy, one should always provide for an unbound layer between the asphaltic layers and the CTB, because cracks in the CTB layers have a tendency of propagating to asphaltic layers, which is detrimental to pavement. However, with the new technology, the cement will be restricted to 3%. And, as these CTB layers are bound and flexible it eliminates cracking. It is now therefore possible to have thinner layers of WMM (75 mm)

This substantiates the theory of Inverted Pavement – Rigid Base with a thinner granular layer on top followed by a thin asphalt layer overlay

Zydex Perpetual Pavement: Design Example

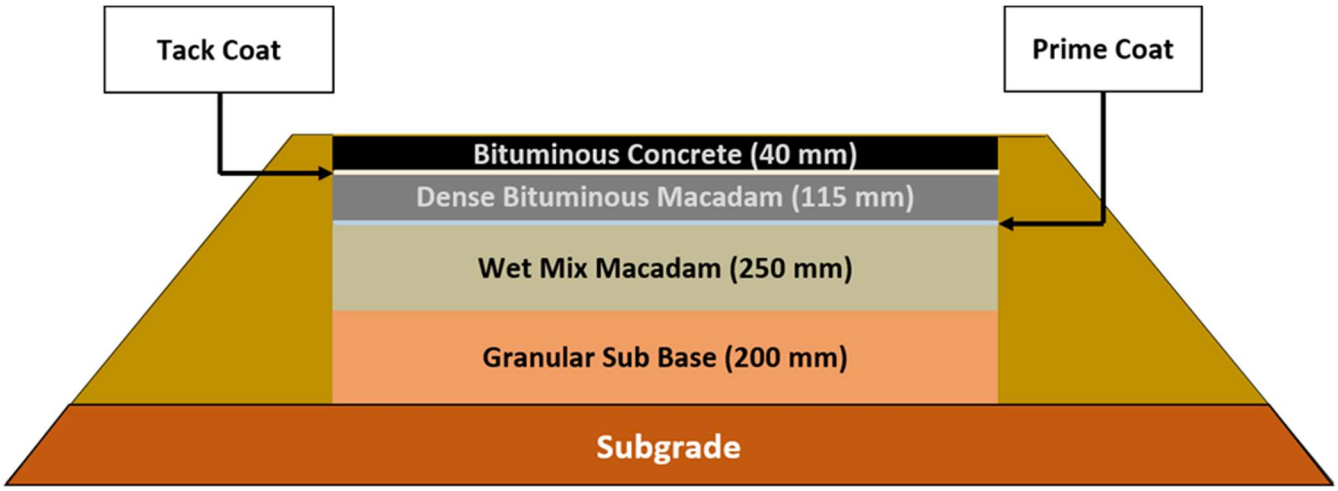
We will compare the conventional 50 MSA design for 20 years design life with the Zydex perpetual pavement design (design life > 50 years)

- For comparison, national highway design for 50 MSA traffic has been selected (Subgrade soil CBR – 8%, plate 6 as per IRC: 2012)[2].

- The structural adequacy and costing for a 2 lane highway will be compared between the 2 designs (as per AASHTO design)
- Zydex pavement will be designed for 320 MSA traffic (projected traffic growth of 50 MSA to 50 years @ 5% annual growth rate)[3]
- For comparing the cost of construction (Initial cost), approved rates (schedule of rates) of material, labour and equipment of an Indian state has been considered.
- The life cycle cost comparison has been done for material savings. Savings derived from lesser use of fuel, lesser wear and tear, lesser emissions, higher productivity, lesser accidents, lower user delay costs and higher comfort & safety have not been considered as it varies from project to project and place to place.

(A) Picture and table below showing conventional design (50 MSA)

Conventional Design & Estimate (IRC 37: 2018, Plate 4, CBR 8%, 50 MSA)												
S.No	Description	Specifications	Quantity	Thickness	Width	Rate		Cost Per Km	Project Cost	Layer Coefficient	Drainage Coefficient	Structural Number
				mm	m	Unit	Rs	Rs	Rs Lacs			
1	Bituminous Concrete		280	40	7.00	CuM	7341.95	20.56	20.56	0.40	-	0.63
2	Tack Coat		7000		7.00	SqM	11.11	0.78	0.78			
3	DBM		805	115	7.00	CuM	6446.01	51.89	51.89	0.40	-	1.81
4	Prime Coat		7000		7.00	SqM	30.22	2.12	2.12			
5	WMM		1750	250	7.00	CuM	888.27	15.54	15.54	0.13	1.00	1.28
6	GSB		1400	200	7.00	CuM	678.29	9.50	9.50	0.12	1.00	0.94
7	**Total (A)**			**605**				**100.4**	**100.4**			**4.67**



Conventional Design (IRC 37: 2018, Plate 4, CBR 8%, 50 MSA)

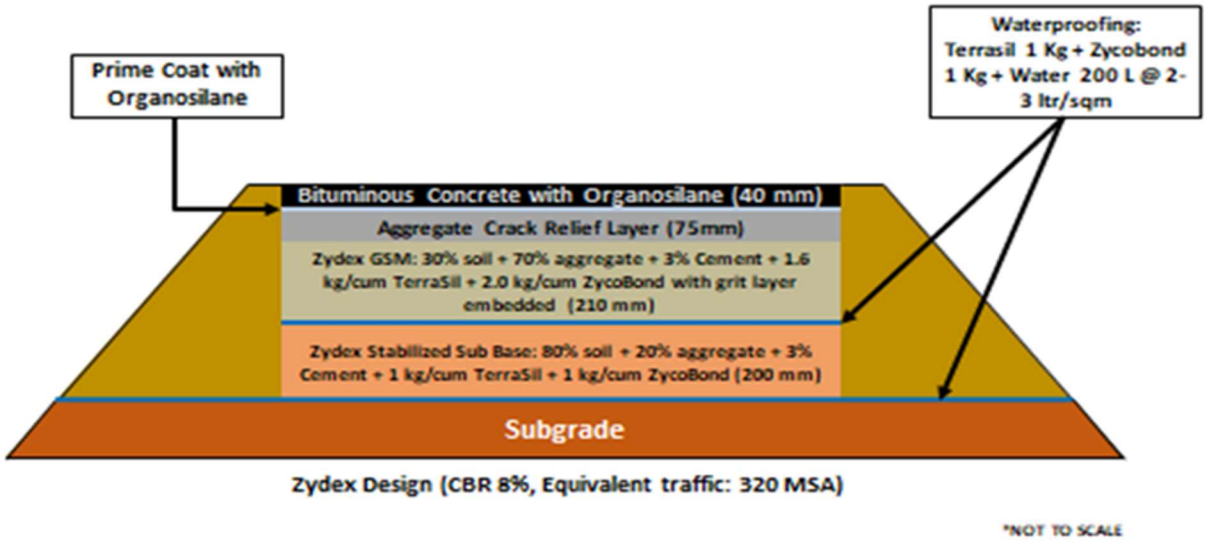
*NOT TO SCALE

(B) Picture and table below showing Zydex perpetual pavement design (320MSA)

Zydex Design & Estimate (CBR 8%, Equivalent traffic: 320 MSA)													
S.No	Description	Specifications	Quantity	Thickness	Width	Dosage	Rate		Cost Per Km.	Project Cost	Layer Coefficient	Drainage Coefficient	Structural Number
				mm	m	kg/ sqm	Unit	Rs	Rs	Rs Lacs			
1	Bituminous Concrete	With 0.1% ZycoTherm organosilane	280	40	7.00		CuM	7825.84	21.91	21.91	0.41	-	0.65
2	Tack Coat	**Eliminated**	0				SqM						
3	DBM	**Eliminated**	0				SqM						
4	Prime Coat	With Nanotechnology	7000		7.00		SqM	22.51	1.58	1.58	-	-	-
5	WMM	**Eliminated**	0				CuM						
6	GSB	**Eliminated**	0				CuM						
7	Aggregate Crack Relief Layer		525	75	7.00		CuM	888.27	4.66	4.66	0.13	1.00	0.38
8	Zydex GSM	30% soil + 70% aggregate + 3% Cement + 1.6 kg/cum TerraSil + 2.0 kg/cum ZycoBond	1470	210	7.00		CuM	2760.04	40.57	40.57	0.30	1.40	3.47
9	Stabilized Sub Base	80% soil + 20% aggregate + 3% Cement + 1 kg/cum TerraSil + 1 kg/cum ZycoBond with top surface waterproofing	2100	300	7.00		CuM	2113.39	44.38	44.38	0.17	1.40	2.81
10	Waterproofing (Subgrade + Shoulders)	1 kg Terrasil + 1 kg Zycobond + 200 liter water	10000		10.00	3	SqM	15.17	1.52	1.5			
A	**Total (A)**			**625**					**114.6**	**114.62**			**7.31**

Email: info@zydexindustries.com

Website: www.zydexindustries.com



Zydex Design (CBR 8%, Equivalent traffic: 320 MSA)

*NOT TO SCALE

- From the design details above, it is clear that Zydex design uses significantly less aggregates and bitumen but has a 60% higher structural no of 7.31 instead of 4.67 of conventional design. This increased structural strength of the pavement will lead to almost 6- 7 times increase in load carrying capacity and which is achieved at an incremental construction cost of only 12%. In the event that someone would like to try Zydex design keeping the same price constant, they will still get much better performance and life cycle costs than conventional design. The wearing course (50 mm) and crack relief layer (75 mm) remain unchanged and optimization would be in the GSM layer and the stabilized base.

Life cycle cost Savings: Conventional (50 MSA) Vs Zydex Design(320 MSA)

The life cycle cost will be so significantly reduced that the initial incremental cost is negligible & sustainability aspect of the pavement is also addressed.

For the LCCA, three main categories are taken into account:

Construction costs, M&R costs and User costs.

User costs are the sum of vehicle operation cost, time related cost, work zone costs and accident costs. Life cycle cost (LCC) is a general term referring to sum of all the above mentioned one-time and recurring costs over the full life span of a highway. Considering the huge expenditure in the life cycle of a highway, even a little percentage of saving could be very substantial

Table 4. Rehabilitation and Maintenance Regime for 50 years

Pavement Type	Initial Lane Configuration	Widening	Full or Partial Reconstruction	Strengthening	Functional Overlay (times)	Diamond Grinding	Sealant Renewal
Conventional - Type 1	2L	-	Once	Once	Six	-	-
	4L	6L & 8L	Once	Twice	Five	-	-
	6L	8L	Once	Twice	Four	-	-
Semi-rigid – Type 2	2L	-	-	Twice	Four	-	-
	4L	6L & 8L	Once	Twice	Four	-	-
	6L	8L	Once	Twice	Four	-	-
RAP – Type 3	2L	-	Once	Once	Four	-	-
	4L	6L & 8L	Once	Twice	Five	-	-
	6L	8L	Once	Twice	Five		
PP Conventional Type 4, PP Semi-rigid Type 5 and PP RAP Type 6	2L	-	-	-	Four	-	-
	4L	6L & 8L	-	-	Three	-	-
	6L	8L	-	-	Three	-	-
Rigid Type (7)	2L	-	-	Once (concrete)	-	Once in 10 years	Once in 10 years
	4L	6L & 8L	-	Once (concrete)	-		
	6L	8L	-	Once (concrete)	-		

The table above (from article in Science Direct[3]: Perpetual pavement: A Boon) illustrates that in comparison to Zydex design (semi rigid perpetual pavement design), the conventional pavement will additionally require:

- 2 overlays (6 overlays against 4 – overlay will be provided every 7th or 8th year for pavement built with conventional design and every 12th to 14th year for pavement built with Zydex design)
- 1 reconstruction treatment &
- 1 strengthening treatment

Approximate costing for the above maintenance regime will be significant.

The cost of 2 additional overlays, 1 full reconstruction and 1 strengthening treatment itself will cost INR 50 to 80 Million per 2 lane KM additional **(Ref: Life cycle cost analysis, ISSN [ONLINE]: 2395-1052 IJSART - Volume 3 Issue 7 –JULY 2017[5]**

Table: Maintenance Costing for conventional design (50 MSA) for 50 years

MAINTENANCE COST 50 YEARS: Conventional Design & Estimate (IRC 37: 2018, Plate 4, CBR 8%, 50 MSA)										
S.No	Year	Type of Maintenance	Overlay Layer	Rate (Rs./Unit)	Length (m)	Width (m)	Thickness (m)	Cost per km	Inflation p.a.	Inflated Cost per km (Rs.)
1	7	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	23,88,926.78
2	14	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	27,44,125.95
3	20	Strengthening	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	1,14,82,237.18
			DBM	6,656.14	1,000.00	7.00	0.115	53,58,195.28		
			Tack Coat	11.11	1,000.00	7.00	-	77,777.30		
			Prime Coat	30.22	1,000.00	7.00	-	2,11,539.36		
4	25	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	34,11,975.71
5	32	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	39,19,287.59
6	38	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	44,13,754.40
7	45	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	50,70,016.41
Total										**3,34,30,324.01**

Table : Maintenance Costing for Zydex design (320 MSA) for 50 years

MAINTENANCE COST 50 YEARS: Zydex Design & Estimate (CBR 8%, Equivalent traffic: 320 MSA)										
S.No	Year	Type of Maintenance	Overlay Layer	Rate (Rs./Unit)	Length (m)	Width (m)	Thickness (m)	Cost per km	Inflation p.a.	Inflated Cost per km (Rs.)
1	12	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	26,37,568.20
2	24	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	33,45,074.22
3	36	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	42,42,362.93
4	48	Functional Overlay	BC	7,427.52	1,000.00	7.00	0.04	20,79,704.52	2.00%	53,80,341.98
Total										**1,56,05,347.33**

The maintenance cost comparison from the calculation (Ref tables above) confirm saving of INR 2 Crores (INR 20 Million) per 2 lane KM. The same can be calculated using net present value method of life cycle cost analysis.
The perpetual pavement on a low-volume roads in Washington itself saved over $160,000 per 2-lane miles over a 50 year period **(Ref: Perpetual asphalt pavements: A synthesis; Asphalt Pavement Alliance and Ref: Tech report 0-6856-1, cooperative research program, FHWA, DOT Texas)[1].**

They concluded that the cost of overlays and reconstruction on conventional pavement are the main reasons for higher LCC of conventional pavements. It has been pointed out that for longer design periods, perpetual pavement would become more and more economical, because of lower M&R costs.

Several of the life cycle cost comparison projects (Perpetual Vs Conventional) studied worldwide have also confirmed, LCC reduction in the range of 4– 20% (Ref [4]: International Journal of Pavement Engineering) Table below taken from a paper published in science direct, confirms semi rigid type pavement (similar to Zydex design) is the best pavement type for (50, 100 & 200 MSA traffics) based on initial and LC costs.

Table 5. Observation on best suited pavement type based on initial cost, LCC and material savings

Lane configuration or traffic category	Criteria	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Remarks / Observation	
									Adequate fund	Fund constraint
50 MSA (2-lane)	Initial cost	√	√		X	X		X	Semi-rigid CTB type best	
	LCC	X	√		X	X		X		
	Aggregate savings	X	√		√	√		√		
150 MSA (4-lane)	Initial cost	√	√	Not applicable	X	X	Not applicable	√	Rigid (Concrete) best	Semi-rigid CTB type best
	LCC	X	√		X	-		√		
	Aggregate savings	X	√		√	√		√		
200 MSA (6-lane)	Initial cost	√	√		X	X		√	Any Perpetual pavement best	Perpetual pavement with semi-rigid CTB type best
	LCC	X	√		X	√		√		
	Aggregate savings	X	√		√	√		√		

Note: 'X' denotes benefits are negative; '√' denotes positive benefits; '-' denotes borderline case

Table showing Bitumen consumption difference for 50 year life cycle

BITUMEN CONSUMPTION 50 YEARS: Conventional Design & Estimate (IRC 37: 2018, Plate 4, CBR 8%, 50 MSA)												
S.No	Year	Type of Maintenance	Overlay Layer	Qty/CuM (Tonnes)	Length (m)	Width (m)	Thickness (m)	Qty per km (Tonnes)	Rate (Rs./Tonnes)	Cost per km (Rs.)	Inflation p.a.	Inflated Cost per km (Rs.)
1	0	Original Construction	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	10,80,576.00
			DBM	0.10	1,000.00	7.00	0.115	83.32	32,160.00	26,79,557.18	2.00%	26,79,557.18
2	7	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	12,41,242.16
3	14	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	14,25,797.08
4	20	Strengthening	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	16,05,679.09
			DBM	0.10	1,000.00	7.00	0.115	83.32	32,160.00	26,79,557.18	2.00%	39,81,681.02
5	25	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	17,72,799.46
6	32	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	20,36,389.33
7	38	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	22,93,305.14
8	45	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	26,34,286.75
Total								435.44				2,07,51,313.22

BITUMEN CONSUMPTION 50 YEARS: Zydex Design & Estimate (CBR 8%, Equivalent traffic: 320 MSA)												
S.No	Year	Type of Maintenance	Overlay Layer	Qty/CuM (Tonnes)	Length (m)	Width (m)	Thickness (m)	Qty per km (Tonnes)	Rate (Rs./Tonnes)	Cost per km (Rs.)	Inflation p.a.	Inflated Cost per km (Rs.)
1	0	Original Construction	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	10,80,576.00
2	12	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	13,70,431.65
3	24	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	17,38,038.69
4	36	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	22,04,253.31
5	48	Functional Overlay	BC	0.12	1,000.00	7.00	0.04	33.60	32,160.00	10,80,576.00	2.00%	27,95,526.17
Total								**168.00**				**91,88,825.81**

As we can see from the table above, a perpetual pavement built with Zydex design and additives will use nearly 280 tons (62%) less bitumen over the life cycle of the pavement.

Table showing Aggregate consumption over 50 year life cycle

AGGREGATE CONSUMPTION 50 YEARS: Conventional Design & Estimate (IRC 37: 2018, Plate 4, CBR 8%, 50 MSA)												
S.No	Year	Type of Maintenance	Overlay Layer	Qty/CuM (CuM)	Length (m)	Width (m)	Thickness (m)	Qty per km (CuM)	Rate (Rs./CuM)	Cost per km (Rs.)	Inflation p.a.*	Inflated Cost per km (Rs.)
1	0	Original Construction	BC	1.46	1,000.00	7.00	0.04	409.45	473.06	1,93,692.31	5.00%	1,93,692.31
			DBM	1.44	1,000.00	7.00	0.115	1,162.05	468.22	5,44,089.56	5.00%	5,44,089.56
			WMM	1.32	1,000.00	7.00	0.250	2,310.00	415.20	9,59,104.52	5.00%	9,59,104.52
			GSB	1.28	1,000.00	7.00	0.200	1,792.00	416.98	7,47,220.99	5.00%	7,47,220.99
2	7	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	323.50	1,32,456.97	5.00%	1,86,380.26
3	14	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	323.50	1,32,456.97	5.00%	2,62,255.74
4	20	Strengthening	BC	1.46	1,000.00	7.00	0.04	409.45	323.50	1,32,456.97	5.00%	3,51,447.77
			DBM	1.44	1,000.00	7.00	0.115	1,162.05	324.35	3,76,913.79	5.00%	10,00,064.50
5	25	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	323.50	1,32,456.97	5.00%	4,48,546.31
6	32	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	323.50	1,32,456.97	5.00%	6,31,149.71
7	38	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	323.50	1,32,456.97	5.00%	8,45,800.97
8	45	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	323.50	1,32,456.97	5.00%	11,90,126.91
Total								**9,701.66**				**73,59,879.56**

AGGREGATE CONSUMPTION 50 YEARS: Zydex Design & Estimate (CBR 8%, Equivalent traffic: 320 MSA)												
S.No	Year	Type of Maintenance	Overlay Layer	Qty/CuM (CuM)	Length (m)	Width (m)	Thickness (m)	Qty per km (CuM)	Rate (Rs./CuM)	Cost per km (Rs.)	Inflation p.a.*	Inflated Cost per km (Rs.)
1	0	Original Construction	BC	1.46	1,000.00	7.00	0.04	409.45	339.55	1,39,028.94	5.00%	1,39,028.94
			Aggregate Crack Relief Layer	1.32	1,000.00	7.00	0.05	462.00	314.54	1,45,318.87	5.00%	1,45,318.87
			Zydex GSM	0.70	1,000.00	7.00	0.21	1029.00	325.76	3,35,209.61	5.00%	3,35,209.61
			Zydex Stabilized Sub Base	0.20	1,000.00	7.00	0.30	420.00	325.76	1,36,820.25	5.00%	1,36,820.25
2	12	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	339.55	1,39,028.94	5.00%	2,49,676.00
3	24	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	339.55	1,39,028.94	5.00%	4,48,382.22
4	36	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	339.55	1,39,028.94	5.00%	8,05,230.05
5	48	Functional Overlay	BC	1.46	1,000.00	7.00	0.04	409.45	339.55	1,39,028.94	5.00%	14,46,077.48
Total								3,958.23				37,05,743.42

As we can see from the table above, a perpetual pavement built with Zydex design and additives will use nearly 8600 tones (68%) less Aggregates over the life cycle of the pavement.

<u>Conclusion</u>: Against this HUGE saving of 280 tons of bitumen and nearly 8600 tons of aggregate, the additional material that is required will be only 212 tons of cement & 10 tons of Zydex additives over the 50 year life cycle. Therefore, with only 12 % additional construction cost, the total savings realized over a 50 year life cycle are nearly 53%. With this magnitude of savings resulting only from material consumption, Zydex design is the futuristic and sustainable pavement design of 21st century. Even at same cost as conventional, pavement with Zydex design will provide for a higher structural number (more ESAL) and significant performance improvement.

<u>The distinctive features of Zydex Perpetual pavement Design:</u>

- Only bituminous layer of 50 mm is used as surface wearing course
- Soil layers below CTSB with expansivity (FSI) > 5% not to be used in design/construction. If availability is an issue then use Terrasil in the range of 0.3 to 1 kg per cu mtr to bring the FSI below 5 and then

compact at OMC. Below this layer, capillary rise prevention can be done by spraying Terrasil + Zycobond @ 3 ltr per sq. mtr at the dilution rate of 1: 1: 200.

- Unbound GSB layer is replaced with bound cement stabilized soil layer
- Cement stabilized subgrade and sub base will compensate the strength of WMM and base and binder course (DBM).
- WMM layer of 75 mm to be used as crack relief interlayer
- Significant amount of aggregates and bitumen is saved with small increase in cement and speciality Zydex additives the Structural Number of Zydex design 7.31 is much higher than conventional design – Higher structural integrity leading to higher performance.
- Several other benefits like improved safety and work cycle efficiency, reduced vehicle maintenance, reduced capital fleet expense, reduced diesel/fuel consumption for production and hauling, reduced carbon emissions, better road surface protection, resistance to degradation, reduced future liabilities for closure, reduced environmental impact and public perception and several other intangible advantages which are substantial and over and above the savings discussed so far. These benefits will vary from place to place and project to project and can be quantified as per project need and requirement.

IRF

Global Award Winning Nanotechnology

References (Global reports and technical papers)

(A) Soil Stabilization treatment with Zydex additives

1) IRC SP 89: Guidelines for soil and granular material stabilization using cement lime and fly ash
2) International Journal of Civil Engineering and Technology (IJCIET)
IJCIET, Volume 8, Issue 6, June 2017

3) American Journal of Civil Engineering; 2018 ^(1), 39: 43 – Determination of optimum content of cement for stabilization of soil
4) J P Rojas Suárez et al 2019 J. Phys.: Conf. Ser. 1386 012079 - Comparative for obtaining the optimum dosage of soil-cement in clays of high and low plasticity
5) CRRI report from Geo Tech Engg. division: Effect of Zydex additives with cement I soil stabilization
6) CRRI FPD report Laboratory evaluation of Zydex additives on Subgrade soil, aggregates and sand
7) ASTM paper on Design Approach for Construction of Rural Roads Using Zydex additives in Stabilized Soil
8) Project execution report from TAMATAVE Madagascar
9) Soil stabilization report from Provincia Dal Azuray, Eucador
10) Soil stabilization report from San Martin, Peru
11) Soil stabilization report of Parking Fuerte de San Cristobal Badajoz, Spain
12) Soil stabilization report from the stabilization of Industrial bases, Kenya
13) Terrasil chemical stabilizer application report from Deuco, Angol, Aracanua region, Chile
14) Lab evaluation report from TARMAC soil and material testing laboratory, Dubai LLC
15) Report from Ministry of construction transport Eucador

(B) Tack/Prime coats/Bond coat application with Zydex additives

1) Tech brief {FWA-HIF- 16 – 017}: Tack coat best practices FHWA, US DOT).
2) NCAT report on Effects of Nanotac additive on bond strength and moisture resistance of tack coats
3) CRRI lab report on evaluation of cationic bitumen emulsion having Zydex Nanotac (Tack coat additive)
4) Report on use on Nanotac by TAMBA Mexico
5) Mention under approved material list of Texas Dept of Transportation website (Tracking resistance asphalt inter layer – TRAIL)
6) Test report on Nanotac for Forays International Trading LLC Dubai, conducted for Ministry of Public Works, Dubai

(C) Bituminous Mix production and paving with Zydex Additives

1) Paper no 564, Guidelines for long lasting bituminous pavements in India, Journal of IRC, October – December, 2010
2) CSIR CRRI field performance report, Ref: CRRI/FPD/NHAI/PIU/290/301
3) TTZ no. 100174 - Report TSW/034-14 about the mixing and compaction properties of asphalt when using Zycotherm from Braunschweig University Germany – iTUBS
4) Veidekke lab evaluation Poland
5) Report from PRD Lidzbark Warmiński, ZDW Olsztyn, ZYDEX Industries
6) Report from PRDiM Lidzbark on evaluation of Zycotherm mixes
7) Report from road & Bridge reseach institute, Poland
8) Report from Sweden Fridhemsgatan Sundsvall, Peab
9)Labrotary evaluation of bituminous mixes with Zycotherm from Mexico transport institute - Instituto Mexicano del Transporte
10) Report from Washington state DOT
11) Report on application of Zycotherm in Bituminous mixes on the Colorado Long Haul Project USA with Elam Construction
12) Report on application of Zycotherm in bituminous mixes on the Trans-Canada Highway project with Lehmann Construction

13) Report on evaluation of bituminous mixes by TARMAC Dubai
14) Report on Zycotherm evaluation in hot asphalt mixes by Central American consulting engineers ICC, SA, Managua, Nicaragua
15) Properties of Asphalt binders and mixtures incorporating ZYCOTHERM by school if civil engineering, USM Malaysia
16) Report on evaluation of Zycotherm mixes from the Wisconsin DOT
17) Report on evaluation of Zycotherm mixes from Virginia DOT
18) Warm mix asphalt report from Eagle Engineering Corp, Alberta, Canada
19) Evaluation of Zycotherm in bituminous mixes by National Japanese lab
20) Evaluation of bituminous mixes with Zycotherm by UTT, Vietnam
21) Evaluation by Asphalt technologies Inc.
22) Review report from New York DOT
23) Report on review of performance of mixes from Optima soil Spain
24) Report from P&D RR on evaluation of Zycotherm
24) Laboratory evaluation of bituminous mixes with Zycotherm by Royal Scientific Society (RSS) Jordan

(D) Pavement design Journals :

1) Asphalt Pavement Alliance (APA), Perpetual Pavements: A Synthesis, APA 101, Lanham, Maryland, 2002.
2) IRC: 37-2012, Tentative Guidelines for the Design of Flexible Pavement, (The Indian Roads Congress: New Delhi)
3) Perpetual Pavement A Boon for the Indian Roads Chandan Basu, Atasi Das, Pavanaram Thirumalasetty, Tanmay Das
4) Perpetual pavement, APAI
5) Life cycle cost analysis, ISSN [ONLINE]: 2395-1052 IJSART - Volume 3 Issue 7 –JULY 2017