ORAPA Diamond Mine

Haul Road Stabilization

ORAPA DIAMOND MINE

The **Orapa diamond mine** is the world's largest diamond mine. The mine is located in Orapa, a town in the Boteti Sub-District of Botswana about 240 kilometers (150 mi) west of the city of Francistown. Orapa ("resting place for lions") is owned by Debswana, a partnership between the De Beers company and the government of Botswana. It is the oldest of four mines operated by the company, having begun operations in July 1971.

Orapa is of open pit construction and is the largest diamond mine in the world by area. The mine is located on two kimberlite pipes that converge near the surface, covering 1.18 square kilometres at ground level. Orapa operates seven days per week, and produces 20 million tons per year of ore and an additional 40 million tons per year of waste rock. Currently, the Orapa mine annually produces approximately 11 million carats (2200 kg) of diamonds. The mine was expanded in 1999, doubling its previous capacity. The mine maintains an ISO 14001 certificate for environmental compliance, and places some importance on water conservation and waste management.

In October 2012 Orapa diamond mine placed their first order to stabilize their haul roads with TeraForm,, the local distributor of Polymer Pavements.

STABILIZATION – SOILTECH MK. III POLYMER

The existing haul road was ripped to a depth of 150mm. SoilTech Mk. III polymer stabilizer, supplied by Polymer Pavements was applied at a ratio 1.5 liters per m^2.

SoilTech Mk. III was diluted with water and sprayed over the ripped area. Further water was added to the soil and once the material was brought to optimium moisture content, the road was profiled

Once OMC was reached the stabilized base-layer was compacted with a 12 tonne vibrating roller to 98% MOD.

The road was opened to traffic 24 hours later

After 3 days of curing, a diluted concentration of ClearTech polymer was sprayed over the top, using a water bowser. ClearTech assists in keeping the surface of the base-layer in a stable condition

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STRUCTURAL STRENGTHS OF HAUL ROADS

Three months after stabilization the haul roads were tested for structural strength using a dynamic cone penetrometer (DCP).

Base Line Testing – Several DCP tests were conducted to ascertain the strengths of the base and sub-base layers.

On 27 June 2013 several dynamic cone penetrometer tests were completed on unstabilized areas of the Tholo Ramp. See attached detailed report in the Appendix I It must be noted that the mine has constructed a solid haul road with very good substrate rock and fill material. Base layer material is also very good as can be seen from an impressive CBR base and sub-base results

Table 1 – Strengths of Untreated Roads

DEPTH	CBR Strength %	Ave. E-Moduli (MPa)
160mm (Base layer)	55%	208
161-320 mm (Sub-Base layer)	75%	269

DCP Report - Average analysis

Region: Orapa Mine - Tholo Ramp Road - Non Constructe**Road number:** Tholo Ramp - Non Constructed
Project date: 27 June, 2013 **Print date:** 28 June, 2013

Measurements included in analysis

Measurement Names	Measurement Date	Position	Distance (km)	Condition	Rutting	Pumping	Long. Crack	Croc. Crack	Deform	Other
Tholo Ramp - Control 1	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No
Tholo Ramp - Control 2	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No

Ave. Design Structure Number in blows (DSN_{800}): 1042

Selected DCP Design Curve: Heavy traffic

Road catagory B
Base type: Granular
Moisture condition of base: Optimum

Rut Limit: 20mm
Structural capacity (MISA): 1097.5
(MISA = MIllion Standard Axles, 80 kN)

Average equivalent strength (Existing Pavement Structure)

Depth (mm)	W. Ave. Pen. * (mm / blow)	Blows	SD (mm / blow)	90P (mm / blow)	CBR ** (%)	UCS *** (kPa)	Ave. E-Moduli (MPa)	E-Moduli Range 10P - 90P (MPa)
0 - 160	4.86	34	0.6	5.6	55	510	208	78 - 570
161 - 320	3.82	46	0.8	4.9	75	669	269	91 - 866
321 - 480	2.85	61	0.5	3.5	108	926	367	128 - 1111
481 - 640	0.73	422	0.3	1.2	359	2657	1566	419 - 9252
641 - 800	0.60	480	0.0	0.6	389	2855	1919	842 - 4376

** Weighted average penetration rate*
*** California Bearing Ratio - calculated from weigthed average penetration rate*
**** Unconfined Compressive Strength - calculated from weigthed average penetration rate*
P = Percentile value in %

SOILTECH STABILIZED - Structural Strength – Tholo Ramp & TeraForm Ring Road

Management Summary

On 27 June 2013, three dynamic cone penetrometer tests were completed on three SoilTech stabilized sections of the **Tholo Ramp** . See attached detailed report in the Appendix III section of this document.

Table 2 – **Tholo Ramp**. SoilTech Polymer Stabilized Roads. Average readings of three tests

DEPTH	CBR Strength %	Ave. E-Moduli (MPa)
160mm (Base layer)	408%	2208
161-320 mm (Sub-Base layer)	442%	2852

DCP Report - Average analysis

Region:	Orapa Mine - Teraform Tholo Ramp Road	**Road number:**	Teraform Tholo Ramp Road
Project date:	27 June, 2013	**Print date:**	28 June, 2013

Measurements included in analysis

Measurement Names	Measurement Date	Position	Distance (km)	Condition	Rutting	Pumping	Long. Crack	Croc. Crack	Deform	Other
Teraform Tholo Ramp 1	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No
Teraform Tholo Ramp 2	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No
Teraform Tholo Ramp 3	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No

Ave. Design Structure Number in blows (DSN_{800}):	2423	**Selected DCP Design Curve:**	Heavy traffic
		Road catagory	B
Rut Limit:	20mm	**Base type:**	Granular
Structural capacity (MISA):	21016.8	**Moisture condition of base:**	Optimum
(MISA = MIllion Standard Axles, 80 kN)			

Average equivalent strength (Existing Pavement Structure)

Depth (mm)	W. Ave. Pen. * (mm / blow)	Blows	SD (mm / blow)	90P (mm / blow)	CBR ** (%)	UCS *** (kPa)	Ave. E-Moduli (MPa)	E-Moduli Range 10P - 90P (MPa)
0 - 160	0.53	468	0.1	0.7	408	2976	2208	700 - 8059
161 - 320	0.40	489	0.0	0.4	442	3192	2952	1294 - 6731

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SOILTECH STABILIZED

On 27 June 2013 three dynamic cone penetrometer tests were completed on three SoilTech stabilized sections of the **TeraForm Ring Road** . See attached detailed report in the Appendix III section of this document.

Table 3 – **Teraform Ring Road** - SoilTech Polymer Stabilized Roads. Average readings of three tests

DEPTH	CBR Strength %	Ave. E-Moduli (MPa)
160mm (Base layer)	451%	3237
161-320 mm (Sub-Base layer)	500%	6161

DCP Report - Average analysis

Region: Orapa Mine - Teraform Ring Road
Road number: Teraform Ring Road
Project date: 27 June, 2013
Print date: 28 June, 2013

Measurements included in analysis

Measurement Names	Measurement Date	Position	Distance (km)	Condition	Rutting	Pumping	Long. Crack	Croc. Crack	Deform	Other
Teraform Ring Road 1	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No
Teraform Ring Road 2	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No
Teraform Ring Road 3	26 June 2013	5 - MID	0	Sound	No	No	No	No	No	No

Ave. Design Structure Number in blows (DSN_{800}): 3842
Selected DCP Design Curve: Heavy traffic

Road catagory B
Rut Limit: 20mm
Base type: Granular
Structural capacity (MISA): 105424.2
Moisture condition of base: Optimum
(MISA = MIllion Standard Axles, 80 kN)

Average equivalent strength (Existing Pavement Structure)

Depth (mm)	W. Ave. Pen. * (mm / blow)	Blows	SD (mm / blow)	90P (mm / blow)	CBR ** (%)	UCS *** (kPa)	Ave. E-Moduli (MPa)	E-Moduli Range 10P - 90P (MPa)
0 - 160	0.37	642	0.2	0.6	451	3251	3237	798 - 28470
161 - 320	0.20	800	0.0	0.2	500	3558	6161	2702 - 14049

STABILIZATION SUMMARY

Determining the structural strength of the haul roads was done with field tests six months after stabilization, using a dynamic cone penetrometer machine and using WINDCP supplied by the Council for Scientific and Industrial Research (CSIR).

Parameters used for testing was:

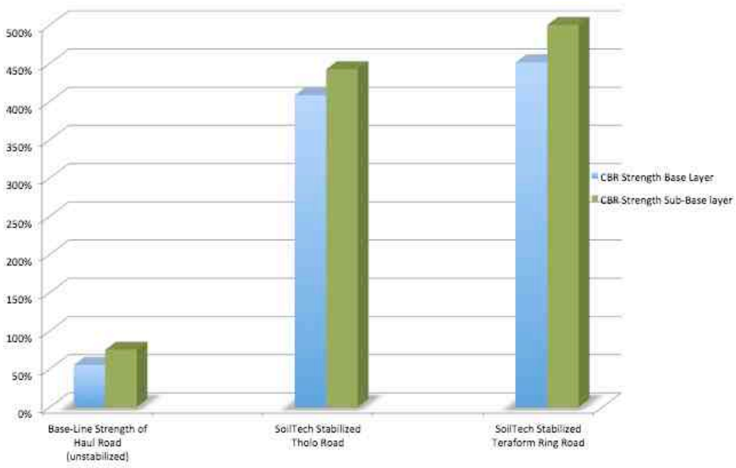
i. CBR (Californian Bearing Ratio)

ii. UCS (Unconfined Compressive Strength)

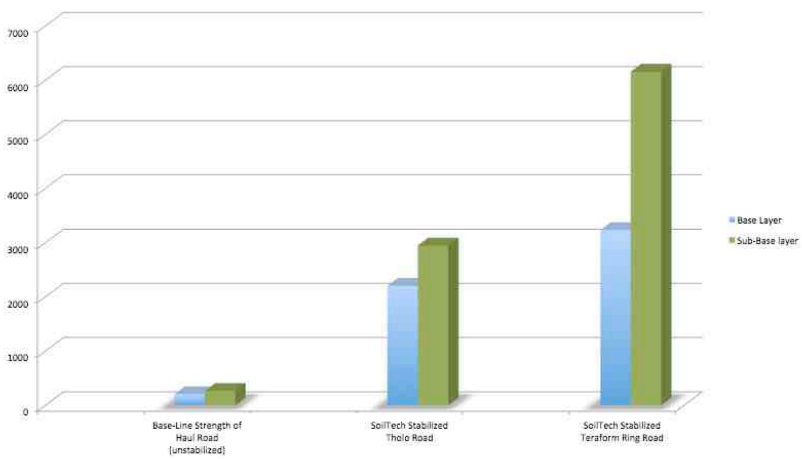
iii. E-Moduli (Elastic Modulus)

I.

	CBR Strength	
Haul Road	Base Layer	Sub-Base layer
Base-Line Strength of Haul Road (unstabilized)	55%	75%
SoilTech Stabilized Tholo Road	408%	442%
SoilTech Stabilized Teraform Ring Road	451%	500%



	E-Moduli	
	Base Layer	Sub-Base layer
Base-Line Strength of Haul Road (unstabilized)	208	269
SoilTech Stabilized Tholo Road	2208	2952
SoilTech Stabilized Teraform Ring Road	3237	6161



BASE & SUB-BASE STABILIZATION

Base Layer Stabilization
At Orapa diamond mine, only the base-layer was stabilized to a depth of 150mm, using SoilTech Mk. III polymer.

It must be noted that SoilTech has been purposely designed with multiple particle-sized nano-polymers, coated with micro surfactants, in order to lower surface tension and to utilize water as a medium to penetrate into the road's sub-base layer.

The result is a secondary stabilized layer, even though only one layer has been mechanically stabilized. Effectively, this results in a two-layer road design. Structural strength into the sub-base layer is dramatically increased.

In this document, each table displays a significant increase in the structural load-bearing strengths of the sub-base. A strong sub-base is essential in providing support to the base layer, especially for haul roads carrying unconventional loads, which places great stress on the road.

The stronger the road surface is, the less resistance there is to the rolling resistance of the haul trucks and effectively reduces operational wear and tear and maintenance costs, not to mention the reduction in fuel consumption.

It must be noted that phenomenon of sub-base stabilization is not restricted to haul roads only, but is empirically observed in all instances where SoilTech stabilization has been implemented.

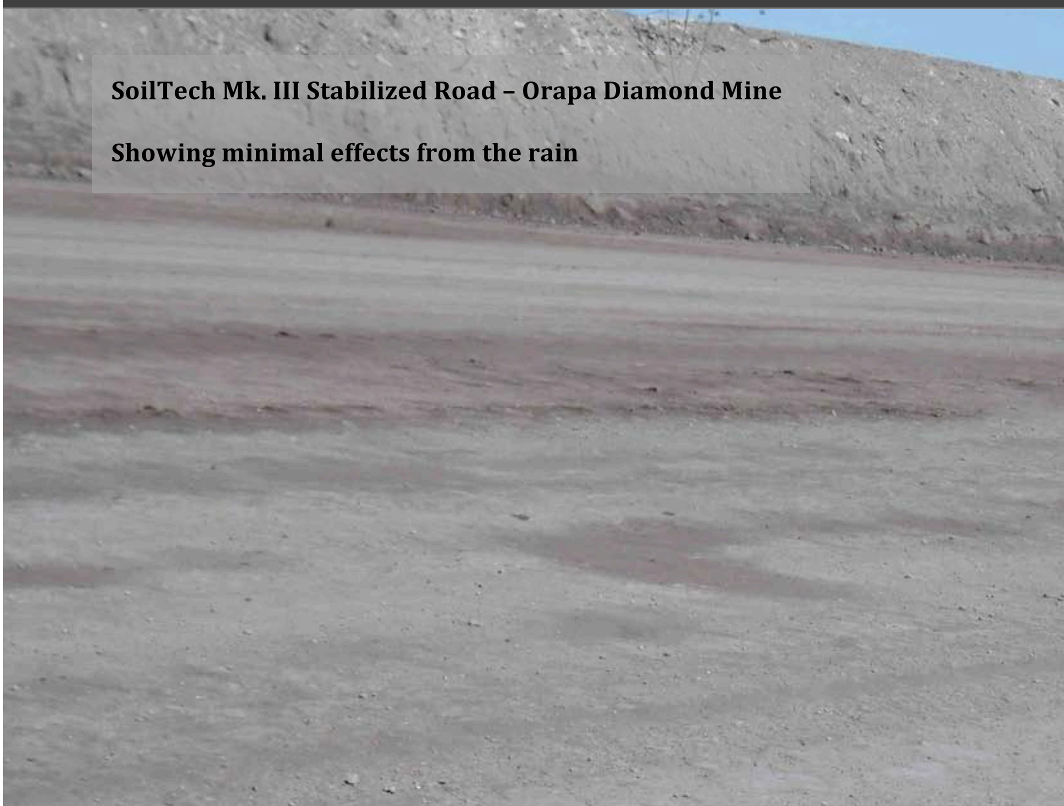
In January 2013 unseasonal tropical rain dumped more than 200mm of rain, in a week, over the North Eastern parts of Botswana.

Unstabilized roads at Orapa mine were virtually washed away (see inserts) by the rain and severly impacted on production.

The SoilTech polymer stabilized roads were virtually unscathed except for one or two "pothole" sized areas which were washed out. See main picture. These "potholes "were quickly repaired with a team, using spades and in-situ materials mixed in a wheelbarrow.

Subsequent to the tropical rainstorm, TeraForm, Botswana, was appointed to extend their operations and to stabilize the open pit ramp roads, in order to minimize production losses due to slippery roads.

Unstabilised roads after tropical stor



SoilTech Mk. III Stabilized Road – Orapa Diamond Mine

Showing minimal effects from the rain

"we were honestly amazed at the performance of SoilTech Mk. III polymers and the way it held the haul road together during the tropical downpour. The 300 ton haul trucks hardly impacted the road at all !

CEO, TeraForm - Steven McIntyre

Email: Steve@teraformbotswana.co.bw