Subbase/Basecourse with Lahar Materials Treated with Cement Based Solidifying Materials Utilization of lahar erupted from Mt. Pinatubo in Subic-Clark-Tarlac Expressway

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ABSTRACT: The Subic-Clark-Tarlac Expressway (SCTEx) is implemented providing a direct, efficient road connection between the vital developments areas in Central Luzon, specifically the three prime economic zones, the Subic Bay Special Economic and Freeport Zone in Zambales, the Clark Special Economic Zone in Pampanga, and the Central Techno Park in Tarlac. This was fully operationalized last July 25, 2008. The completion of SCTEx enhanced Central Luzon's sustainability development as a world class industrial center, an efficient agro-industrial logistic complex. This act as a catalyst to the development along the expressway's entity, complementing the North and South Luzon Expressway. Subic-Clark-Tarlac proximity to Metro Manila (MM) catches the spillover of its growth and population scattering the economic development, a solution to MM's traffic congestion, saturating population carrying capacity and sanitary environment, in accordance with the President's 10-point agenda for sustainable development and urban decongestion. To optimize utilization of 10 cubic km of abundant lahar deposits erupted from Mt. Pinatubo in 1991 that piled up along the alignment of the project, the utilization of Lahar as embankment material and mixing with cement based solidifying material for subbase/bacourse became the main objective in promoting this project. The nature and physical characteristic of lahar is similar to sand, that could withstand even in rainy season. Mixing with cement, lahar strength could be utilized as a core material for Subbase/Base Course. Since Lahar is abundant and can be easily handled from in the construction site, the cost impact of using it for embankment and Subbase / Base Course is lower compared with utilizing the gravel based Subbase/Base Course considering the transportation distance. The employment of Lahar in construction works contributes to the reduction of construction time and cost. With this objective, this Highway Project is cost effective and environmental friendly, since extracting lahar from the rivers improved the surface water flow.

KEY WORDS: SCTEx, lahar, Mt. Pinatubo, Subic-Clark-Tarlac Expressway, subbase/basecourse.

1 INTRODUCTION

The eruption of Mt. Pinatubo, in Central Luzon on 12 to 15 June 1991 is recorded as the second largest volcanic eruption of 20^{th} Century since that of Novarupta (Alaska) in 1912. The number of displaced people because of the eruption reached up to 1.2 million with a death toll to around 900 and hundreds injuries, mostly by roof collapsing under the weight of accumulated wet volcanic ash.

Figure 1: Eruption of Mt. Pinatubo

The former summit of Mt. Pinatubo was blown-off by the eruption and replaced by a caldera (crater) of 2.5 km wide. The highest point on the caldera rim (summit edge) now stood to 1,485 m above the sea level. i.e. 260 m lower than the pre-eruption summit (1,745 m). From the bottom of crater, which is located 800m below the summit, the high temperature pyroclastic flow descended along the mountain side.

The descending pyroclastic flow piled up on the surrounding of Mt. Pinatubo while volcanic ashes were also piled up. The piled up materials of pyroclastic flow was assumed to reach 6.7 billion m^3 and at the upper stream of pyroclastic flow piled up to a maximum of 200m. Materials piled up with pyroplastic flow are called Lahar in this region. Since the eruption, each rainy season has brought Lahars further to down stream, which have caused more displacement of thousands of people. Agriculture in the region also suffered badly from the effects of the eruption, with hundreds of square kilometers of formally arable (fertile) land being rendered infertile, destroying the livelihoods of thousand of farmers. Extensive damages to building and infrastructure cost billions of pesos to repair, and further costs were incurred in constructing dikes and dams to control the post-eruption Lahars.

Subic-Clark-Tarlac Expressway (herein after referred to as SCTEX) was conceptualized and planned in 2001 to contribute for the development of the Central Luzon. One of the main considerations in the design of SCTEP was to make use of vast Lahar materials from the vicinity of the project.   The Alignment of the SCTEX starts from Subic Bay Freeport Zone via Clark Free Economic Zone and ends at Tarlac City, where Luisita Industrial Park is located.

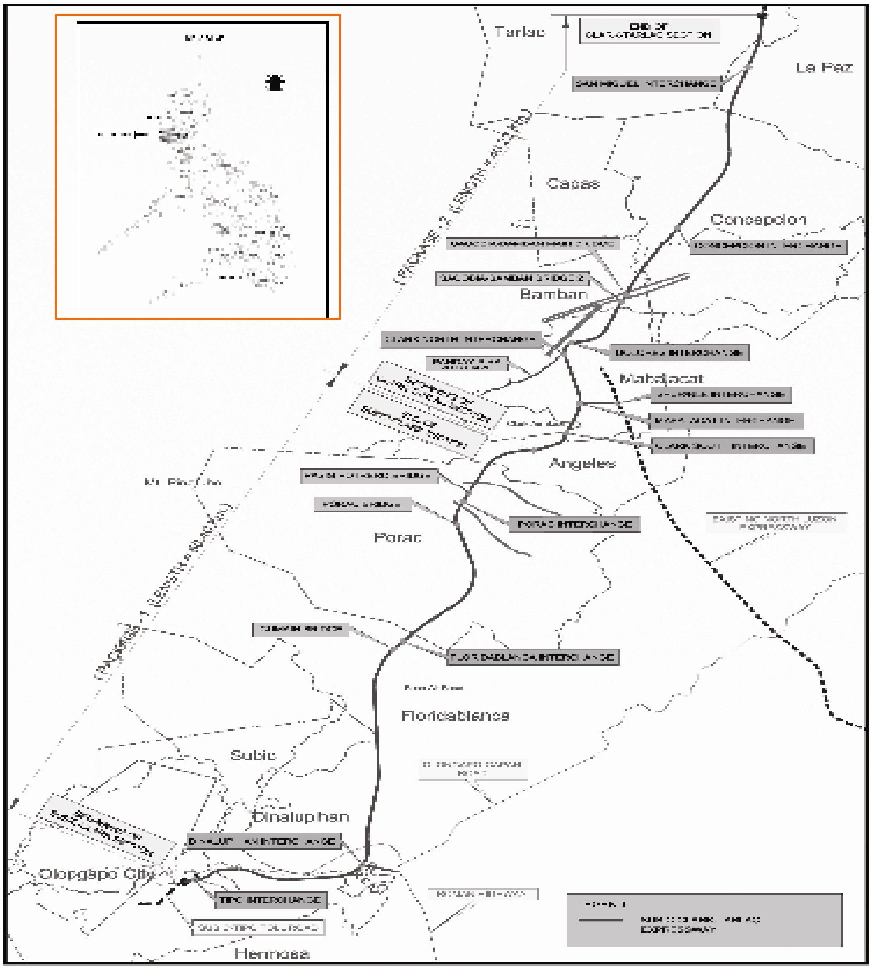

Figure 2: Location Map and Project Alignment

The SCTEX is connected with North Luzon Expressway at Mabalacat Interchange in Clark Free Economic Zone directly linking it to Metro Manila. It is now further planned to extend to Northern Part of Luzon i.e. Baguio City (Benguet Province) and Poro Point (La Union Province) and to the Eastern part of Aurora City (Aurora Province). The extension of SCTEX will finally be linked to Cagayan Valley which is the granary of Luzon Island.

SCTEX is a world-class four lane divided highway. The completed alignment starts at Subic Bay Freeport Zone and runs along the foot of Mt. Pinatubo and reaches Clark Free Economic Zone wherein it is linked to North Luzon Expressway.

The total length of SCTEX is 92.0 km consisting of Package-1 which is between Subic and Clark with a total length of 52.0 km and Package – 2 between Clark and Tarlac of 40/0 km. The total construction cost is 60 billion Japanese Yen. The source of funds used in the procurement of the Consulting Services for the design and construction supervision, and the procurement of eligible goods and services from suppliers and contractors necessary for the implementation of the civil works comes from the proceeds of the Special Yen Loan No. PH-226 extended by the Japan Bank for International Cooperation (JBIC) under Official Development Assistance (ODA) of Japanese Government to the Government of the Republic of the Philippines through the Bases Conversion and Development Authority. Last 1 Oct 2008, JBIC has been merged into New JICA. A total of seven (7) years was required from planning to completion of the project, three (3) years for planning inclusive of survey of geography, soil conditions and the detailed design while four (4) years was required for the construction.

One of the remarkable features of this project is utilizing lahar, an abundant supply pyroclastic material from Mt. Pinatubo that piled up around the vicinity particularly along the project alignment. Lahar is deposited in abundant volume and the availability is almost infinite and how to utilize this Lahar efficiently, both cost-wise and time-wise is the key concept of SCTEX design. Thus, the utilization of Lahar to this expressway project is further elaborated.

2. PROFILE OF PROJECT

2.1 Package – 1

The Major Work Items for Package 1 includes:

- Main Carriageway: 4-lanes divided/limited access expressway with total length of 50.4km (Package – 1)
- Junction and 1 Interchange (original contact, additional 2 interchanges were added under variation order)
- 28 Bridges (8 steel bridges and 20 PCDG bridges)
- 7 Corrugated Metal Pipe Culvert
- 81 Cross drainages (RCBC and RCPC)
- Manual Toll Collection System
- Tollway Lighting and Electrical System

Table 1: Major Quantities for Package 1

NO	DESCRIPTION	QUANTITY	UNIT
1	Earthworks	7,740,000,000	cu.m
2	Cement Treated Lahar Subbase/Base Course	610,000	cu.m
3	Asphalt Pavement	215,000	Tons
4	Structural Concrete	170,000	cu.m
5	Reinforcement Bars	21,400	Tons
6	Board Piling	14,500	m
7	PCDG	659 nos.	(20m and 30m)
8	Structural Steel for Bridge	10,100	Tons

2.2. Package – 2

The Major Work Items for Package 2 includes:

- Main Carriageway Four (4) lanes expressway (divided)
- Spur Road (Connecting the North Luzon Expressway – NLEX)
- Nine (9) River Bridges
- Six (6) Interchange Structures
- Eight (8) Underpass Structures
- Toll Operation Center Building (TOCB)
- Additional Works Under Variation Order:
    a. Panday Pira Access Road
    b. Clark South Interchange

Table 2: Major Quantities for Package 2

NO	DESCRIPTION	QUANTITY	UNIT
1	Earthworks (Embankment)	3,200,000	cu.m
2	Asphalt Pavement	238,000	Tons
3	Structural Concrete	66,000	cu.m
4	Reinforcing Bars (Grade 60)	11,900	tons
5	Bored Piling	13,000	M
6	Structural Steel for Bridges	7,600	tons

3. TYPICAL CROSS SECTION FOR EMBANKMENT

The typical cross section utilizing Lahar as an Embankment Material is as follows:

Package 1 and Package 2 has different profile characteristic. Package – 1 is constructed in the mountainous area, the design concept is mostly on cut and fill, Lahar collected from adjacent riverbed was utilized as embankment material. On the other hand, most of Package – 2 alignment fall on plain land no cutting, as such, all the alignment is designed in the embankment of Lahar. The nature and physical characteristic of lahar is similar to sand, that could withstand even in rainy season. One strong characteristic of Lahar is that it could easily dry-up. Considering this advantageous point, Lahar is applied as a Sand Material for the embankment in soft ground of the paddy field and swamp. It posses the high workability for embankment.

The appropriate material of coarse and fine aggregate use for pavement work is difficult in the area adjacent to Project area, thus, Lahar was also considered as a Subbase/Base Course material.

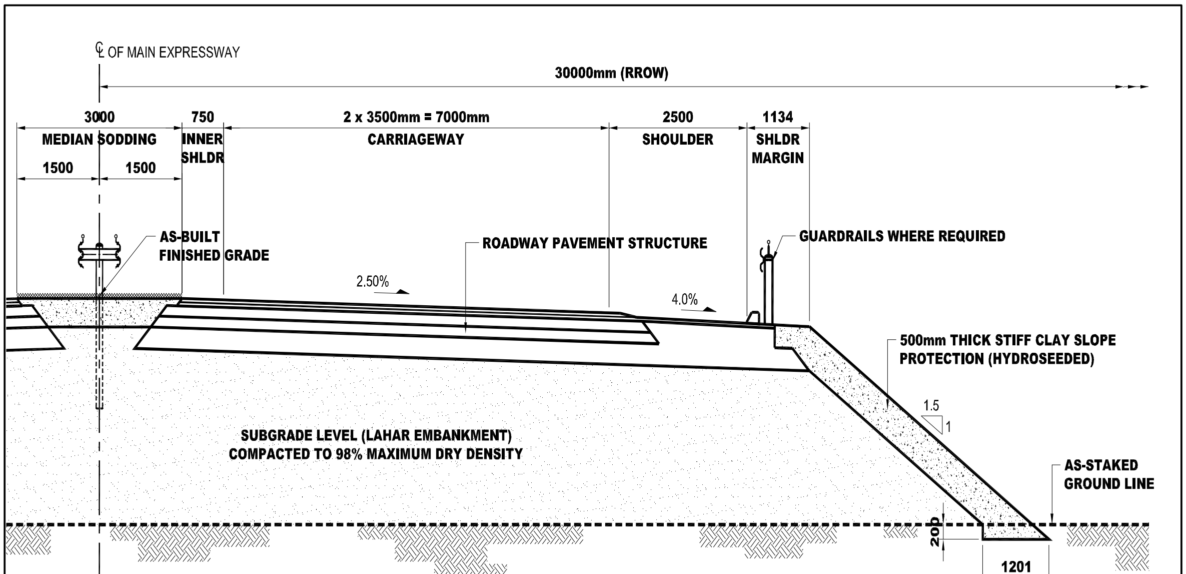

Figure: 3 Typical Cross-sections for Embankment

4. MATERIALS

4.1 General

In normal asphalt pavement road, the aggregate is employed for Subbase and Base Course material. Aggregate for Subbase and Base Course consists of hard, durable particles or fragment of crushed stone, crushed slag or natural gravel and natural sand. However, there is no appropriate aggregate in the surrounding area of SCTEX, the utilization of Lahar as Subbase/Base Course Material was planned, but using Lahar alone could not reach the prescribe design strength of Subbase/Base Course hence it was proposed to mixed it with cement, mixing with cement enhanced the strength but created hair cracks due to shrinkage which were reflected on the asphalt surface. As such, to minimize the occurrence of surface cracks due to shrinkage, it was planned to add admixture to solidify the Lahar treated with cement.

4.2 Soil Property of Lahar

The designed strength of stabilized Lahar is almost the same as the Japanese guideline value (the paving design and execution guideline, Japan Road association), thus, it is considered that the designed strength is adequate. The experimental relationship between the plastic index and the shrinkage is shown in Figure 4, which is quoted from “The study of stabilized highway embankment, Mishima, 1995”). This figure means the shrinkage becomes lower as the plastic index becomes lower. Lahar is a non-plastic material; therefore, the shrinkage is lower than other soil with high-plasticity.

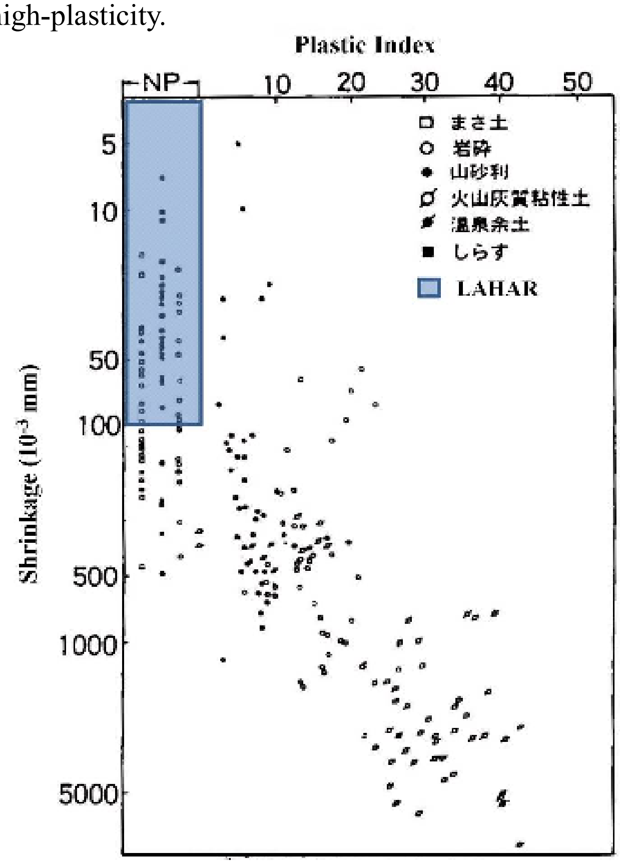

Figure 4: Relationship between plastic index and shrinkage (The length of specimen is 340m)

4.3 Shrinkage of Solidified Material

Prior to the Laboratory Test to decide the mix proportion of the Solidified Material to Lahar, the test to apprehend the characteristic of Solidified material was conducted. Appearance of shrinkage in the Solidified Material mixed with Lahar is not special. In case of clayey soil, the appearance of shrinkage is further big, however in case of Lahar, it is smaller due to the reason of Lahar being a sandy soil.

The figure below shows the development of shrinkage –cracks along the lapsed time. This graph demonstrates Shrinkage Ration (%) along the Elapsed Time (days) for two cases.

1) Portland Cement + Lahar
2) Cement based solidifying material (Cost + Anti-shrinkage Admixture) + Lahar

The result is self explanatory and Shrinkage Ratio (%) of Lahar + Cement base, solidifying material is smaller than Lahar + Cement only.

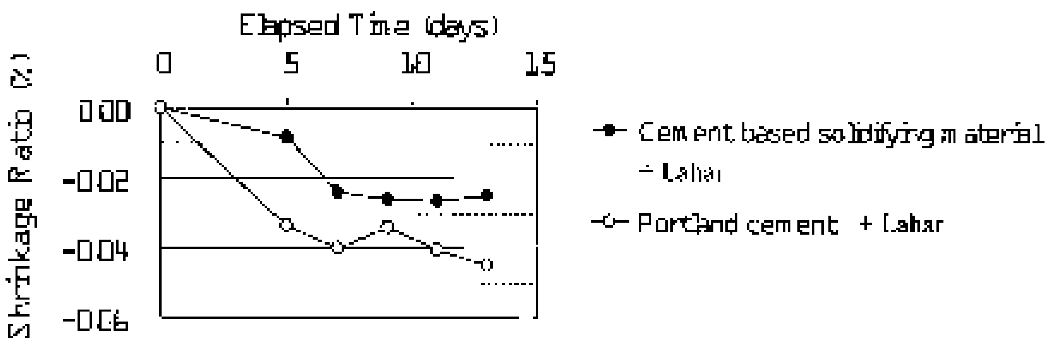

Figure 5: Development of Shrinkage – Cracks along the Lapsed Time

This figure shows shrinkage ratio is 0.02% for the cement based solidified material and 0.04% for Portland cement.

0.02% means 1 crack occurs at 2.5m spacing, because visible crack width is only 0.5mm, and 0.04% means 1crack/1.25m.

Shrinkage crack itself is unavoidable; it derives from the nature of cement.

4.4 Selection of Cement based Solidified Material

For Selection of chemical, the evaluation of optimum chemical for Lahar Material is conducted through Trial Mixing. Each Test of mix proportion is in accordance with the specifications and test method follows the ASTM and AASHTO designation.

4.4.1 Cement Based Solidifying Material

Among the list of suppliers that was officially submitted to the consultants, Three (3) Cement Corporation from Japan confirmed the intention to supply Cement Based Solidifying material to the Philippines.

Table 3: Supplier of Cement Base Solidifying Material

No.	Name of Supplier
1	FUJIKAWA KENZAI KOGYO Corp.
	a. Subbase Course
	b. Base Course
2	TAIHEIYO CMENT Corp. (Geoset 100 Series)
3	NITTETSU CEMENT Corp. (Earth Tight # 104)

4.4.2 Result

1. All of the Cement Base Solidifying Material that had been used in the test passes the Compressive Strength requirement stipulated in the specification for SPL 208/209 but fails to meet the fineness and some of the Chemical Properly requirement such as Aluminum oxide, Sulfur trioxide and Tricalcium Aluminate.
2. All of the Cement Base Solidifying Materials that was used for the test performs well on California Bearing Ration Test but hard to satisfy the requirement for Unconfined Compression Test and Linear Shrinkage and Erosion Test.
3. For the first and second of Unconfined Compression Test each Cement Base Solidifying Material surpass the 1.0 Mpa for Subbase Course at 5% chemical content but fails to meet the 3.0 Mpa strength requirement for the Base Course.
4. None of the proposed mixture attains the requirement for the Linear Shrinkage of not greater than 1.0% and 100% erosion resistant for Erosion Test.
5. The CBSM that has the smallest value of volume change for 1% chemical content is Fujikawa Base Course at 3.8%, for 3% chemical content Geoset has the smallest of value at 3.48% and for 5% chemical content the least value is 2.69% for Geoset.
6. Fujikawa Base Course has the least value of Soil-Cement Loss for 3% with 20.85% loss and for 5% chemical content Fujikawa Subbase Course has the least value with 3.30%. All the specimen for 1% chemical content was broken before it reaches the 12^{th} cycle.

5. MIX PROPORTION OF SUBBASE AND BASE COURSE UTILIZING LAHAR TREATED WITH A CEMENT BASED SOLIDIFIED MATERIAL

Following the Selection of Cement based solidifying material, Mix proportion Test was conducted at Laboratory. Based on the result of Mix proportion in Laboratory (Laboratory Test), Trial Mix was conducted at Mixing Plant and Site Trial Test (Trial Pavement on the Subgrade at Site) was made.

However, it is inevitable to avoid the occurrence of shrinkage cracks on the surface employing Lahar treated with Cement Based Solidifying Material. (Lahar + Cement Based Solidified Material). To increase cement content to enhance the strength of subbase, Base course resulted in the increase of shrinkage-cracks.

To improve the shrinkage phenomenon and to increase the strength of Base Course, Aggregate by 20% was mixed. The result was favorable too. As the required strength of Base Course is more the 3MPA, it is very difficult to reduce the cement content and decided to mix the aggregate.

5.1 Design Requirement

The Design strength of subbase and base course is decided with assumption that CBR in embankment reached to more than 6 and Target Design Strength is shown in Table 4, Table 5 shows the Lahar Mix Proportions.

Table 4: Target Design Strength

Subbase Course	Unconfined Compression Strength (7Days)	> 1 MPA
Base Course	Unconfined Compression Strength (7Days)	>3 MPA

Lahar Natural Moisture Content   to be determine
Coarse Aggregate (Absorption)   3.09%

Table 5: Lahar Mix Proportions

MIXTURE	MDD (kg/m3)	OMC (%)
100% Lahar : 0% Coarse Aggregate	1760	14.1
80% Lahar : 20% Coarse Aggregate	1860	11.4

SUPPLIER	MIXTURE	STRENGTH (MPA)	Cement (Kg)	Solidify Material (Kg)	LAHAR (Kg)	COARSE AGGREGATE (Kg)	WATER (Kg)
FUJIKAWA KENZAI KOGYO Co. (Chemical II)	1	1.0	31.91	0.12	1727.97	-	248.16
		2.1	48.40	0.18	1711.42	-	
		3.0	61.90	0.23	1697.87	-	
		5.0	91.88	0.34	1667.78	-	
	2	1.0	24.65	0.09	1468.21	378.39	212.04
		2.1	38.18	0.14	1457.34	375.59	
		3.0	49.30	0.18	1448.42	373.29	
		5.0	73.94	0.27	1428.63	368.19	

Note: The above figure is the weight of material required for 1m3 Subbase/Base course with Lahar Materials Treated with Cement Based Solidifying Materials.

5.2 Final Mix Proportion

The employed design and its mix proportion with lahar are as follows:

a) Sub-base Course

1.0 MPa @ 7 days

Lahar	Aggregate	Cement + Solidifying materials
100%	0%	32.03 kg/cu.m

b) Base Course (1st layer)

3.0 MPa @ 7 days

Lahar	Aggregate	Cement + Solidifying materials
100%	0%	62.13 kg/cu.m

c) Base Course (2nd layer)

3.0 MPa @ 7 days

Lahar	Aggregate	Cement + Solidifying materials
80%	20%	49.48 kg/cu.m

5.3 Figure 5 shows the typical Cross Section of Road Pavement used for the SCTEX Project.

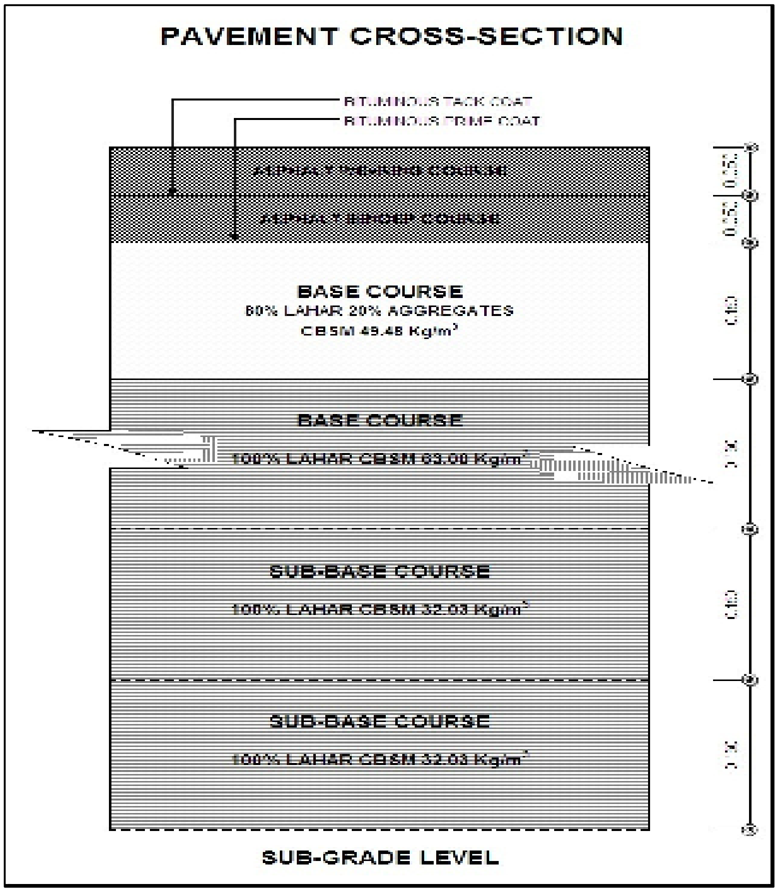

Figure 5: Typical Cross Section of Road Pavement

6. MATTERS TO BE IMPROVED AND POSSIBLE COUNTER MEASURE

In the government infrastructure projects, such as road project like SCTEX, it is important to optimize the balance between cost and quality which directly affects the maintenance cost and public safety. the Subbase/Base Course utilizing Lahar, the following was observed.

1. It was decided to utilize Lahar which is locally available, abundant and can be easily hauled from its physical location, the cost impact of using it for embankment and subbase/base course is lower considering the transportation distance. The employment of lahar in construction works contributes to the reduction of construction time and costs.
2. On the other hand, technical difficulty has been observed when utilizing and sustaining the design strength of Lahar treated by cement based solidifying material applied to Subbase/Base Course. Increasing the cement content to increase strength of subbase/base course caused cracking. The cracking was due to the difficulty in controlling water and cement contents during mixing at Soil Mixing Plant. To avoid such cracking, it is recommended to study the minimum Asphalt Pavement thickness considering the balance with the cost.

REFERENCES

Mishima, 1995. *The Study of Stabilized Highway Embankment.*