Study for Management and Supervision of Road Pavement Works in Developing Countries

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Chapter 1. Construction Management／Supervision

1.1 Implementation structure for JICA assisted projects

1.1.1 Construction management／implementation structure of supervision

1.1.1.1 Construction management／study on the structure of management

In this study, consultation was conducted regarding construction management, collection of management plans and consultant companies responsible for management of the projects shown in table 1.1.1.

Table1.1.1 Project list for hearing survey

Project name	Country	Consultant*	Construction company
Project for Improvement of the National Road No.1	Cambodia	KEI	Hazama Ando Corp.
Project for Construction of Neak Loeung Bridge	Cambodia	Chodai	Sumitomo Mitsui Construction
Project for Reconstruction of the Bridges on the National Road No.9	Lao P.D.R	OCG	Obayashi Corp. Obayashi Road Corp.
Rehabilitation project of the outer Bangkok ring road	Thai	CTI	Hazama Ando Corp. Toa Road Corp. World Kaihatsu Kogyo Co., Ltd.
Project for the Improvement of Dusty-Nizhniy Pyandzh Road	Tajikistan	KEI	NIPPO
Project for Rehabilitation of Trunk Road, Phase IV	Ethiopia	OCG	Kajima Corp.
Project for Widening of Kilwa Road	Tanzania	ISEC	Kajima Corp.
Project for Widening of New Bagamoyo Road	Tanzania	ISEC	Konoike Construction Co., Ltd.
Project for Improvement of Livingstone City Road	Zambia	ISEC	Tokura Corp.
Project for the Improvement of the Living Environment in the Southern Area of Lusaka	Zambia	KEI	Shimizu Corp.
Project for Rehabilitation of National Trunk Road N8	Ghana	ISEC	Tokura Corp.
Project for Reconstruction of Somalia Drive in Monrovia	Liberia	KEI	Dai Nippon Construction

*Consultant
KEI: KATAHIRA & Engineers International
OCG: Oriental Consultants Global
CTII: CTI Engineering International
ISEC: INGEROSEC

1.1.1.2 System for construction supervision shown in the construction supervision plan

According to the collected management plans from consultant companies, the structure of administration by Japanese and local staff was as shown below.

Table1.1. 2 Structure of construction supervision (supervision plan)

Project name	Consultant	Technical staff for construction management
Project for Improvement of the National Road No.1	KEI	In Japan：1 person On site : Resident 1 person (Japanese), Short-term 1 person (Japanese) Local staff：No written
Project for Construction of Neak Loeung Bridge	Chodai	In Japan：1 person On site：No information Short-term 1 person (Japanese: Pavement expert) Local staff：Employed pavement engineer
Project for Reconstruction of the Bridges on the National Road No.9	OCG	In Japan：1 person On site：Resident1 person (Japanese), Short-term 1 person (Japanese: Pavement expert) Local staff：10 persons
Rehabilitation project of the outer bangkok ring road	CTI	In Japan：3 persons On site：Resident 3 person (Japanese) Local staff：7persons
Project for the Improvement of Dusty-Nizhniy Pyandzh Road	KEI	In Japan：1 person On site : Resident 1 person (Japanese), Short-term 2 persons (Japanese) Local staff：No info
Project for Rehabilitation of Trunk Road, Phase IV (1/2)	OCG	In Japan：3 persons On site : Resident 1 person (Japanese), Short-term 3 persons (Japanese) Local staff：2 persons
Project for Rehabilitation of Trunk Road, Phase IV (2/2)	OCG	In Japan：3 persons On site : Resident 1 person (Japanese), Short-term 3 persons (Japanese) Local staff：3persons
Project for Widening of Kilwa Road	ISEC	In Japan：1 person On site：Resident 1 person (Japanese) Local staff：2 persons
Project for Widening of New Bagamoyo Road	ISEC	In Japan：1 person On site : Resident 1 person (Japanese), Short-term 4 persons (Japanese) Local staff : Resident; 1 person, Short-term; 2 persons
Project for Improvement of Livingstone City Road	ISEC	In Japan：No written On site : Resident 1 person (Japanese), Short-term (Japanese) Local staff：1 person (no info whether resident)
Project for the Improvement of the Living Environment in the Southern Area of Lusaka	KEI	In Japan：1 person On site：Resident 1 person (Japanese) Local staff：No witten
Project for Rehabilitation of National Trunk Road N8	ISEC	In Japan：2 persons On site : Resident 2 person (Japanese), Short-term 2 persons (Japanese) Local staff：3 persons
Project for Reconstruction of Somalia Drive in Monrovia	KEI	In Japan：1 person On site：Resident 1 person (Japanese) Local staff：No written

A comparison of the results of this study and “Basic research for improvement of road development projects by Japan's ODA in African countries: Ethiopia, Ghana, Tanzania" (JICA, 2010), is shown below: However, "Project for Construction of Neak Loeung Bridge" is excluded due to lack of information on the total number of staff.

Table1.1.3 Number of resident Japanese engineers

Japanese residential supervisor	no one	1 person	2 persons	3 persons	4 persons	Remarks
This study	0	10	1	1	0	Total 12
The study in 2010	0	8	2	0	2	Total 12

Table1.1.4 Number of short-term Japanese engineers

Japanese short-term engineer	no one	1 person	2 persons	3 persons	4 persons	Remarks
This study	4	2	2	2	1	One has no info
The study in 2010	-	-	-	-	-	No item

Table1.1.5 Number of residential local engineers

Residential local engineer	no one	1 person	2 persons	3 persons	4 persons	Remarks
This study	0	2	2	2	2	Four has no info
The study in 2010	0	1	4	3	2	Total 12

Comparing the findings of this study to findings obtained in 2010, the number of Japanese engineers assigned to a project is mostly one or two; showing no change from 2010. On the other hand, the average number of local engineers have decreased from 3.3 to 2.3.

1.1.1.3 System for construction management shown in the construction management plan

According to the collected management plans, the administration structure by Japanese and local staff is as shown in table 1.1.6.

Table1.1.6 Structure of construction management (Construction management plan)

Project name	Construction company	Technical staff for construction management
Project for Improvement of the National Road No.1	Hazama Ando Corp.	PM：1 person (Japanese) Local staff：16 persons
Project for Construction of Neak Loeung Bridge	Sumitomo Mitsui Construction	No submission
Project for Reconstruction of the Bridges on the National Road No.9	Obayashi Corp. Obayashi Road Corp.	No submission
Project for Reconstruction of the Bridges on the National Road No.9	Hazama Ando Corp. Toa Road Corp. World Kaihatsu Kogyo Co., Ltd.	PM：1 person (Japanese) Others：6 persons (Japanese) Local staff：10 persons
Project for the Improvement of Dusty-Nizhniy Pyandzh Road	NIPPO	PM：1 person (Japanese) Others：6 persons (Japanese) Local staff：14 persons
Project for Rehabilitation of Trunk Road, Phase IV (1/2)	Kajima Corp.	No submission
Project for Rehabilitation of Trunk Road, Phase IV (2/2)		No submission
Project for Widening of Kilwa Road	Kajima Corp.	PM：1 person (Japanese) Others：5 persons (Japanese) Local staff：43 persons
Project for Widening of New Bagamoyo Road	Konoike Construction Co., Ltd.	PM：1 person (Japanese) Others：8 persons (Japanese) Local staff：17 persons
Project for Improvement of Livingstone City Road	Tokura Corp.	PM：2persons (Japanese) Others：5 persons (Japanese) Local staff：9
Project for the Improvement of the Living Environment in the Southern Area of Lusaka	Shimizu Corp.	PM：1 person(Japanese) Others：6(Japanese) Local staff：2 +o persons
Project for Rehabilitation of National Trunk Road N8	Tokura Corp.	PM：1 person(Japanese) Others：6(Japanese) Local staff：No written
Project for Reconstruction of Somalia Drive in Monrovia	Dai Nippon Construction	No submission

Table1.1.7 Number of resident Japanese engineers

Japanese residential manager	0 – 4 persons	5 - 9 persons	10 - 14 persons	15 persons or more	Remarks
This study	1	7	0	0	Number couldn't be verified for 4 projects
The study in 2010	8	2	0	2	Total 12

Comparing the findings of this study to the 2010 study, there are more cases of Japanese personnel in charge of key fields leading to an increase in the number of resident engineers. However, as records regarding the number of local engineers do not follow a distinct pattern (some indicate only the key personnel and others the total number of staff) comparison between the two time frames is impractical.

1.1.2 Summary for the result of hearing study

In this study, information on following eight projects was collected.

Project name	Consultant name
Project for Improvement of the National Road No.1	KEI
Project for Construction of Neak Loeung Bridge	Chodai
Project for Reconstruction of the Bridges on the National Road No.9	OCG
Rehabilitation project of the outer Bangkok ring road	CTI
Project for the Improvement of Dusty-Nizhniy Pyandzh Road	KEI
Project for Rehabilitation of Trunk Road, Phase IV	OCG
Project for Widening of Kilwa Road	ISEC
Project for Widening of New Bagamoyo Road	ISEC
Project for Improvement of Livingstone City Road	ISEC

The result of this hearing study is summarized as shown below:

1. Procurement and adoption for materials

Regarding procurement method of asphalt aggregate

Purchase from supplier	Asphalt plant set on site	Others
5	5	-

Regarding procurement method of asphalt mixture

Purchase from supplier	Asphalt plant set on site	Others
1	8	-

Regarding material testing and approval for each material.

	Material test	Material test and confirmation by consultant	Manufacturer's test report
Asphalt product (Binder)	1	1	8
Asphalt product (Tack coat)	2	1	6
Asphalt product (Prime coat))	2	1	6
Aggregate	1	8	-
Base course material	1	7	-
Subbase course material	1	7	-

Presence or absence of change for material procurement

Presence	Absence	Reason
1	-	Cost/Route
-	4	

Presence or absence of change for material sampling point

Presence	Absence	Reason
2	-	Quality of aggregate, transport distance
		Borrow pit (B/P) quantity
-	3	

2. Mixing test of asphalt mixture

Investigator and manager for mixing test of asphalt mixture.

Investigator	Manager
Japanese pavement engineer, local engineer	Consultant (Japanese pavement engineer)
Japanese plant engineer	Consultant , local engineer
Prime contractor	Prime contractor
Japanese expert of paving company (JV)	Inspector of contracting agency (change of quality management in road department)
Lab staff of contracting agency	-

Selection method for the operator and supervisor of mixing test.

Selected among engineers having experience on pavement.
Assigned in the contract (contract document, specification)
Approved experienced and skilled engineers proposed by contractors.
Lab staff of contracting agency

Flow property resistance for asphalt mixture.

Considered	Not considered	Reason
4	-	Troubled at previous project stage.
		Since outer two lanes of four lanes are available for heavy vehicles, modified asphalt was applied for surface only by considering the flow resistance.
		Flow resistance: Ratio Marshall Stability (KN) / Marshall Flow (0.25mm) should be 0.55 and more, according to specification. The high value is high strength for flow rutting. Peel resistance: The required residual stability value of over 75% was satisfied at the paving section affected easily by water.
-	5	The optimum asphalt content by Marshall test was determined referring existing pavement condition.
		Standard of the country considering risk by using modifying material.

Inspection by consultant for asphalt mixture testing

Witness inspection (on site)	Paper inspection
9	-

3. Management of asphalt plant

Management staff (Number of staff and position).

12 persons (1 Japanese manager, 1 plant manager, 2 operators, 2 asphalt suppliers, 2 for Cold Bin, 1 for Wheel Loader, 3 dump cleaners)
13 persons (1 Japanese manager, 1 plant manager, 1 operator, 3 asphalt suppliers, 2 for Cold Bin, 1 for Wheel Loader, 3 dump cleaners)
Construction plan by contractor
1 quality manager, 1 for asphalt mixing
1 QC engineer, 3 assistant workers, 1 plant operator

Selection method for plant manager (Experience etc.)

Experience of previous project
5 years experience
Construction plan by contractor
Experience for quality management and asphalt work, and the language skill
Contractor is not involved on the selection since the manager belongs to pavement company as a subcontractor. Construction experience of subcontractor is considered to the selection.

Plant capacity (Product's name, country, year and production capacity).

Maker name	Country	Year	Capacity
	Singapore	new	100t/h
	China	new	100t/h
SPECO L.T.D.,	Korea	2012	104t/h
	Italy	new	200t/h
	Japan	new	90t/h
	Japan	used	100t/h
	Japan	used	100t/h
Amman	Germany	-	90t/h
PT RUTRAINDO PERKASA Batch Type 800kg Model	Indonesia	-	4 to 60ton/hr, Batch type, 800kg/batch, semiautomatic / full automatic

Choose plant facility if you had any trouble during operation.

Weighing equipment, Mixing facility, Mixture storage facility

Facility name	Number of answer	Facility name	Number of answer
Aggregate supply facilities	5	Stone powder storage and supply facilities	-
Aggregate drying heating equipment	1	Weighing equipment	2
Screening facilities and Hottobin	4	Mixing facility	2
Dust collection equipment and recovery equipment	3	Mixture storage facility	-
Asphalt storage and supply facilities	-		

Witness inspection of the plant by consultant

	Paper inspection	Inspection on site
Plant overview, Meter inspection result (aggregate, asphalt, stone powder, etc.)	9	-
Meter inspection for each parts, thermometer inspection for each parts, discharge rate test of asphalt)	-	9

4. Inspection and management for road construction

Confirmation of subgrade strength before construction

Questions	Yes	No
Confirmation of subgrade strength before the construction was defined in the specification	6	2
Construction company confirmed themselves though no regulations.	-	2
Consultant inspected on site.	5	2

Proof loading test

Questions	Yes	No
Proof loading test to subgrade and base course was implemented.	7	1
Implementation of proof loading test was defined in the specification.	6	1
Report of proof loading test result was produced.	6	1
Consultant inspected proof loading test on site.	6	1

Test construction

Questions	Yes	No
Test construction of pavement was implemented.	9	-
Consultant inspected test construction on site.	9	-

5. Defect of pavement

Defect detail	Assumed cause
Breathing of the pavement surface for a few days after construction.	Inappropriate management on temperature and mixture ratio of tack coat produced by contractor, in repeating daytime construction and night time preparation.
Vertical direction crack	Insufficient sub grade replacement (Appropriate construction and inspection could not be conducted since replacement method of the black cotton soil was complex.)
Breathing of the pavement surface for a few days after construction.	Inappropriate management on mixture ratio at asphalt plant. (Supplying excess asphalt)
Vertical direction crack	Cracking in the widened part from the existing road width. (Due to differences in compaction of the new road of the existing road section.)
Subsidence nearby the crossing drainage structure.	Lack of surface compaction during back-filling work, and Inappropriate back-filing materials.
Cracking at the surface.	Rainwater was accidentally mixed with the

	mixture before compaction, due to a sudden squall. Leaking oil from disabled vehicles.
	Lack of knowledge, experience, effort and self-inspection.
Occurring alligator crack and rut, during or immediately after construction at narrow portion.	Reputing compactions after the water bearing used water during construction.
Pavement damages by overloaded vehicles broke down. Details: 16-wheel truck being failure of cargo packed, stopped by the woods. Due to the heavy weight and the shock, the woods damaged the surface of pavement. Repair: The truck owner covered the cost to repair surface. The repairing order was to cut damaged area by concrete cutter, remove it, spread tack coat, and pave asphalt.	Excessive vehicle weight due to overload. Inappropriate vehicle lock instrument for stopping in trouble. The shock and stress concentration caused by aspects above.

6. <u>Fill in any opinion regarding reduction of early pavement damage during construction and quality assurance of the road improvement project.</u>

<u>Enough construction period</u> Pavement construction of longer distance at one time as possible may keep stable quality. However, different sections have to be infrequently constructed day to day in short construction period, therefore, machinery and equipment must be moved every time. Then, the defect risk is increased since quality control becomes difficult for that.
Enough construction periods should be needed in order to avoid future defect due to natural compaction by traffic if traffic opens to private vehicles temporarily after construction of each layer as a sub grade, base course and binder course.
<u>Cement improvement of back-filling material</u> Compaction of back-filling should be managed carefully in order to prevent subsidence nearby crossing drainage structure. For the area where appropriate materials are not obtained easily, adoption of cement improvement should be obligated in the specification.
<u>Reduce asphalt amount as possible.</u> Refusal test part as following sentence should be included in the specification in order to confirm appropriate asphalt amount. “Extended time 500 blows and the resulting air voids in the mix shall not be less than 3.0% for Binder Course and 2.5% for Surface Course”
Pavement maintenance by client after handing over should be made compulsory.
Control over- loading strictly by client.
Client should strictly control and prevent the oil leaking from vehicles of defective maintenance to new paving roads.
Cleaning drainage systems by client.
Improvement of extreme specialization structure of Japanese contractors, implementation of technical training before construction, adoption of manuals for Japanese company, and collection of defect examples, should be needed.
Presence or absence of groundwater level fluctuations and the impact on the sub grade should be confirmed.
Suitable waste water treatment should be considered.

Asphalt concrete mixture especially asphalt amount should be carefully considered.
Concern for underground drainage treatment during construction and open to traffic, should be considered.
Use and evaluate existing pavement from the result of FWD test. Consider overlay remaining existing structure, recycled asphalt stabilization, and the method to use existing pavement, should be considered.
Damages caused by sub grade In case of Neak Loeung Bridge, since all of embankment was newly constructed, the bearing capacity of sub grade was enough. However, in case of improvement work for the existing pavement, partially the sub grade does not have enough design bearing capacity, therefore, the replacement must be appropriately done in many cases. Defects caused by asphalt mixture design Marshall standard value for asphalt mixture should be adopted considering climate and transport condition on the site. If Japanese standard was just adopted for it, rutting might be occurred in early stage after paving. Also a cracking and peeling might be occurred in some cases.

1.2 Comparison of quality management standards on pavement construction

1.2.1 Japan

1.2.1.1 Quality management system for road

In Japan, civil work clients such as the ministry, local government and privatized road authority (e.g. NEXCO), have individually prepared their own standards regarding construction management of infrastructure. These standards indicate details of standard values on earthwork, pavement work and several other works. The contractors must comply with these standards according to the contract. Generally, in Japan, "quality management" is based on providing reliability of construction by applying standardized methods even though there may be variations. For any project of civil works undertaken, "Construction management" generally means "schedule management", "quality management", "cost management" and "safety management". This concept of construction management differs from that of an industrial product.

Since pavement is easily affected by weather and external load compared to general civil works, construction should be conducted carefully as well as steadily to achieve good quality control. Quality control is conducted by the contractor, who, in order to achieve the product of the qualities stipulated in the specification, devises the most economical method, and the most efficient schedule. The contractor conducts the necessary supervision so that the final product, to be inspected by the client, satisfies the standards indicated in the design document.

Management is implemented by the client who, in consideration of the inspection standard, scale of work, workability, etc, sets the reasonable terms of management, frequency and limits, and accordingly prepares a construction management plan and decides the responsible personnel before the construction process.

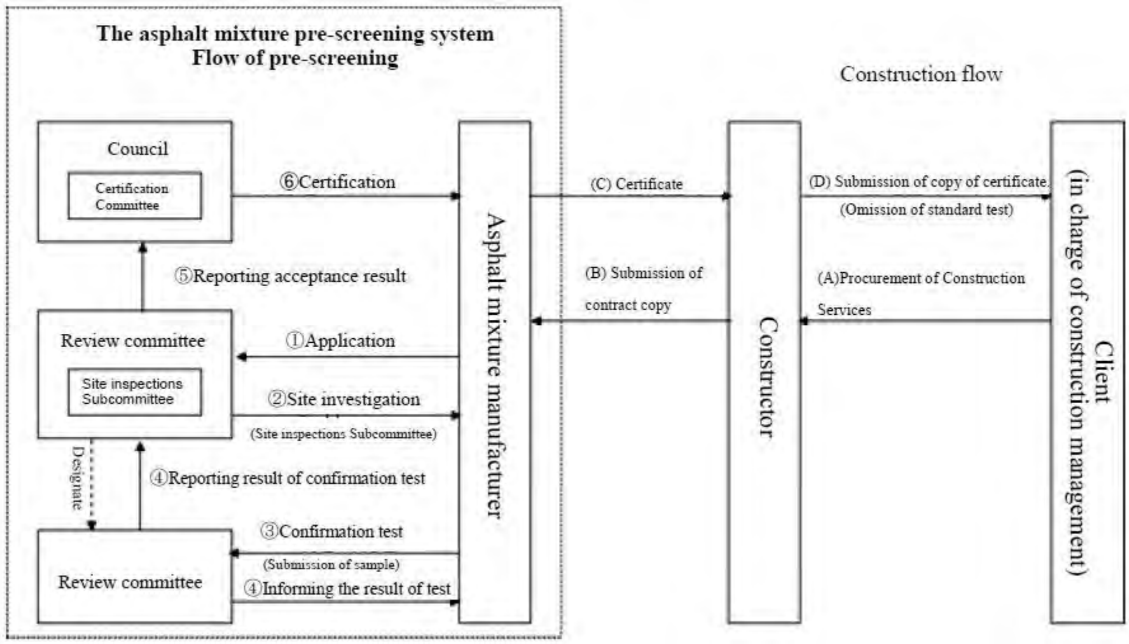
1.2.1.2 Management standard of pavement construction

The first Japanese pavement technical standard was the "Asphalt pavement standard", first published in 1950, and "Cement concrete pavement standard", in 1955. These standards have since both been revised, in accordance with social needs and advances in technology. In 2001, the "Standard for pavement design and construction" and "Pavement construction handbook", were both published by the Japan Road Association, taking over from previous standards. These standards indicate the technical standards for the management of pavement construction. Recent versions of the pavement construction standards stipulate that the contractor has a responsibility of management and the client has a responsibility of inspection to ensure that the design document standard is satisfied. Management consists of a standard test, product control and quality control whereas inspection consists of product and quality inspection.

1.2.1.3 Standard test

Standard tests are performed to verify whether the materials used and the method of construction are appropriate. It is generally conducted before construction begins, even though in some cases tests may be conducted during construction for large scale construction projects. There are several types of tests, including tests for the quality of the material, for obtaining a reference value such as standard density, and for obtaining a working standard. In principle, a standard test is conducted by the contractor, and the results verified and approved by the client.

However, some tests for material and mix design may be omitted, if a pre-screening certificate issued by the manufacturer* (plant) of the material can be submitted. The application of the asphalt mixture pre-screening system has become mainstream with the aim of rationalizing the quality management of asphalt mixing plants for public works and stabilizing quality. The availability of this system makes it possible to omit some standard tests, including mix design and test mixing for each construction, by certifying in advance the standard of asphalt mixture shipped from asphalt mixer by a third party such as a mixture review committee consisting of government, university and private personnel. Also, this has been introduced in Okinawa general bureau of cabinet office and seven regional bureaus, Tohoku, Kanto, Chubu, Kinki, Chugoku and Kyushu, since Kanto regional bureau introduced in 1994. Many local governments have adopted this method as well. However, Nippon Expressway Company Limited (NEXCO), utilize a large amount of asphalt, and have their own asphalt plants at each project site, and therefore do not need this system.



Source: Chubu technical office, Chubu regional bureau, MLIT

Figure 1.2.1 The process of pre-screening asphalt mixtures

The main test items are as follows. (Asphalt pavement quality control standards)

Specific gravity and water absorption test / abrasion weight loss / unit volume weight of measurement / measurement of aggregate gradation/ clay lump length / filler that is included in the aggregate in quality paving test method handbook / aggregate of stability testing / aggregate freestone amount of test / penetration test / flash point test / softening point test / elongation test / evaporation rate of mass change test / toluene soluble test / density test / emulsion of quality tests, etc.

1.2.1.4 Quality management standard

Examples of quality control standards for middle scale construction by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is shown in table 1.2.1.

Table1.2.1 Examples of quality management standard (MLIT)

Work type	Category	Test class	Test item	Test method	Standard value	Condition	Remarks
Subbase course work	Construction	Obligate	Compaction test	Pavement investigation & Test Method Handbook	≥93% ρ_{dmax} of individual values	>3000m2: 3 points	-
Subbase course work	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	Ave. x10: 95%≤	3001-10000m^2: 10 points	-
Subbase course work	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	x6: 96%≤	≥10001m^2: add 10 every 10000m^2	-
Subbase course work	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	x3: 97%≤		-
Subbase course work	Construction	Obligate	proof rolling test	Pavement investigation & Test Method Handbook	-	Conduct all section	-
Subbase course work	Construction	Others	Screening test	JIS A 1102	-	Larger work than middle scale work Conduct For abnormal situation	"Larger work than middle scale work", means a manageable work by control chart, and work area is ≥10000m^2 or total mixture amount for surface and binder course is ≥3000.
Subbase course work	Construction	Others	PI:Plasticity index test	JIS A 1205	PI: ≤6	Larger work than middle scale work Conduct For abnormal situation	"Larger work than middle scale work", means a manageable work by control chart, and work area is ≥10000m^2 or total mixture amount for surface and binder course is ≥3000.
Subbase course work	Construction	Others	Moisture content test	JIS A 1203	acc. Design document	Larger work than middle scale work Conduct For abnormal situation	"Larger work than middle scale work", means a manageable work by control chart, and work area is ≥10000m^2 or total mixture amount for surface and binder course is ≥3000.
Base course work	Construction	Obligate	Compaction test	Pavement investigation & Test Method Handbook	93%≤ ρ_{dmax} of individual values	>3000m2: 3 points	-
Base course work	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	Ave. x10 95%≤	3001-10000m2: 10 points	-
Base course work	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	x6 96%≤	≥10001m^2: add 10 every 10000m^2	-
Base course work	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	x3 97%≤		-
Base course work	Construction	Obligate	Particle size 2.36mm	JIS A 1102	within ± 15%	Larger work than middle scale work Conduct when periodic or as needed. (1-2times/day)	
Base course work	Construction	Obligate	Particle size 75μm	JIS A 1102	within ± 6%	Larger work than middle scale work Conduct when periodic or as needed. (1-2times/day)	
Base course work	Construction	Others	Screening test	JIS A 1102	-	Larger work than middle scale work Conduct For abnormal situation	
Base course work	Construction	Others	PI	JIS A 1205	PI: ≤4	Larger work than middle scale work Conduct For abnormal situation	
Base course work	Construction	Others	Moisture content test	JIS A 1203	acc. Design document	Larger work than middle scale work Conduct For abnormal situation	
Cement stabilization	Construction	Obligate	Particle size 2.36mm	JIS A 1102	within ± 15%	Larger work than middle scale work Conduct when periodic or as needed. (1-2times/day)	
Cement stabilization	Construction	Obligate	Particle size 75μm	JIS A 1102	within ± 6%	Larger work than middle scale work Conduct For abnormal situation	
Cement stabilization	Construction	Obligate	Compaction test	Pavement investigation & Test Method Handbook	≥93% ρ_{dmax} of individual values	>3000m2: 3 points	-
Cement stabilization	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	Ave. x10: 95%≤	3001-10000m^2: 10 points	-
Cement stabilization	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	x6: 95.5%≤	≥10001m^2: add 10 every 10000m^2	-
Cement stabilization	Construction	Obligate	Compaction test	Sand replacement method JIS A 1214	x3: 96.5%≤		-
Cement stabilization	Construction	Others	Moisture content test	JIS A 1203	acc. Design document	For abnormal situation	
Cement stabilization	Construction	Others	Cement content test	Pavement investigation & Test Method Handbook	within ± 1.2%	Larger work than middle scale work Conduct when periodic or as needed. (1-2times/day)	
Bituminous stabilization	Plant	Obligate	Particle size 2.36mm	Pavement investigation & Test Method Handbook	within ± 12%	Larger work than middle scale work: Conduct when periodic or as needed. (1-2times/day) In the case of printing record, Screening test for all or sampled.(1-2times/day)	
Bituminous stabilization	Plant	Obligate	Particle size 75μm	Pavement investigation & Test Method Handbook	within ± 5%	Larger work than middle scale work: Conduct when periodic or as needed. (1-2times/day) In the case of printing record, Screening test for all or sampled.(1-2times/day)	
Bituminous stabilization	Plant	Obligate	Asphalt amount	Pavement investigation & Test Method Handbook	within ± 0.9%	Larger work than middle scale work: Conduct when periodic or as needed. (1-2times/day) In the case of printing record, Screening test for all or sampled.(1-2times/day)	
Bituminous stabilization	Plant	Obligate	Temperature measurement	Thermometer	Mixing temperature determined by mixture design	Any time	
Bituminous stabilization	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	≥94% ρ_{dmax} of individual values	>3000m2: 3 points	-
Bituminous stabilization	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	Ave. x10: 96%≤	3001-10000m^2: 10 points	-
Bituminous stabilization	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	x6: 96%≤	≥10001m^2: add 10 every 10000m^2	-
Bituminous stabilization	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	x3: 96.5%≤		-
Bituminous stabilization	Pavement site	Obligate	Temperature measurement (at first compaction)	Thermometer	≥110°C	Any time	Recording of measured values 4 times/day (Am & Pm 2 times each)
Bituminous stabilization	Pavement site	Obligate	Visual test (mixture)	Visual	-	Any time	
Asphalt pavement	Plant	Obligate	Particle size 2.36mm	Pavement investigation & Test Method Handbook	within ± 12%	Larger work than middle scale work: Conduct when periodic or as needed. (1-2times/day) In the case of printing record, Screening test for all or sampled.(1-2times/day)	
Asphalt pavement	Plant	Obligate	Particle size 75μm	Pavement investigation & Test Method Handbook	within ± 5%	Larger work than middle scale work: Conduct when periodic or as needed. (1-2times/day) In the case of printing record, Screening test for all or sampled.(1-2times/day)	
Asphalt pavement	Plant	Obligate	Asphalt amount	Pavement investigation & Test Method Handbook	within ± 0.9%	Larger work than middle scale work: Conduct when periodic or as needed. (1-2times/day) In the case of printing record, Screening test for all or sampled.(1-2times/day)	
Asphalt pavement	Plant	Obligate	Temperature measurement	Thermometer	Mixing temperature determined by mixture design	Any time	
Asphalt pavement	Plant	Others	Water immersion wheel tracking test	Pavement investigation & Test Method Handbook	acc. Design document	acc. Design document	Confirmation of peel resistance of asphalt mixture
Asphalt pavement	Plant	Others	Wheel tracking test	Pavement investigation & Test Method Handbook	acc. Design document	acc. Design document	Confirmation of the flow resistance of asphalt mixture
Asphalt pavement	Plant	Others	Raveling test	Pavement investigation & Test Method Handbook	acc. Design document	acc. Design document	Checking the wear resistance of asphalt mixture
Asphalt pavement	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	≥94% ρ_{dmax} of individual values	>3000m2: 3 points	-
Asphalt pavement	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	Ave. x10: 96%≤	3001-10000m^2: 10 points	-
Asphalt pavement	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	x6: 96%≤	≥10001m^2: add 10 every 10000m^2	-
Asphalt pavement	Pavement site	Obligate	Compaction test	Pavement investigation & Test Method Handbook	x3: 96.5%≤		-
Asphalt pavement	Pavement site	Obligate	Temperature measurement (at first compaction)	Thermometer	≥110°C	Any time	Recording of measured values 4 times/day (Am & Pm 2 times each)
Asphalt pavement	Pavement site	Obligate	Visual test (mixture)	Visual	-	Any time	
Asphalt pavement	Pavement site	Others	Slip resistance test	Pavement investigation & Test Method Handbook	acc. Design document	Every 200m of pavement road	

Generally, in Japan however, in addition to the stipulated specification, quality control is also conducted at the asphalt plant, in accordance with their own severe standard.

Table1.2. 2 Example of quality management standard

Management items			Data in 2011				Target management values in 2012				
			Max	Min	$\bar{x}$	σ	Set Value	Range	Max	Min	
Aggregate	Aggregate No.5	19 ㎜ passed	95.5	86.6	90.8	2.7	90.8	±5.4	96.2	85.4	
		13.2 ㎜ passed	13.3	6.8	10.3	2.0	10.3	±4.0	14.3	6.3	
	Aggregate No.6	13.2 ㎜ passed	96.1	89.5	93.4	2.1	93.4	±4.2	97.6	89.2	
		4.75 ㎜ passed	9.2	2.4	6.4	2.0	6.4	±4.0	10.4	2.4	
	Aggregate No.7	4.75 ㎜ passed	98.2	92.1	95.2	1.9	95.2	±3.8	99.0	91.4	
		2.36 ㎜ passed	15.3	6.9	10.7	2.7	10.7	±5.4	16.1	5.3	
	Screenings	2.36 ㎜ passed	97.3	89.4	93.1	2.3	93.1	±4.6	97.7	88.5	
		75 μm passed	14.1	8.4	11.4	1.7	11.4	±3.4	14.8	8.0	
	Fine Aggregate	0.6 ㎜ passed	81.1	73.8	77.9	2.0	77.9	±4.0	81.9	73.9	
		0.3 ㎜ passed	49.1	40.9	45.1	2.6	45.1	±5.2	50.3	39.9	
		75 μm passed	2.6	0.5	1.5	0.6	1.5	±1.2	2.7	0.3	
	Filler	75 μm passed	88.4	84.4	86.5	1.2	86.5	±2.4	88.9	84.1	
		Specific gravity	2732	2732	2732	1	2732	±2.0	2734	2730	
		Moisture amount	0.06	0.04	0.04	0.01	0.04	±0.02	0.06	0.02	
Asphalt	60/80	Penetration	75	64	68	4	68	60～80	80	60	
		Density ($\times 10^{-3}$)	1040	1032	1035	2	1035	±4.0	1039	1031	
	Modified Type 2	Penetration	53	50	51	1	51	40<	—	40	
		Density ($\times 10^{-3}$)	1030	1029	1030	1	1030	±2.0	1032	1028	
Extracted mixture (Gap from standard)		2. 36㎜ passed	3.9	-1.5	0.4	1.6		±3.2	3.2	-3.2	±12
		75 μm passed	1.2	-2.0	-0.3	0.8		±1.6	1.6	-1.6	±5
		Asphalt amount	0.36	-0.23	-0.01	0.17		±0.34	0.34	-0.34	±0.9
Hot bin particle size (Gap from standard)		2. 36㎜ passed	1.6	-1.3	0.1	0.8		±1.6	1.6	-1.6	±12
		75 μm passed	0.6	-1.0	0.0	0.5		±1.0	1.0	-1.0	±5
1bin particle size (Gap from standard)		0.6 ㎜ passed	3.3	-5.3	-0.4	2.5		±5.0	5.0	-5.0	
		0.3 ㎜ passed	2.4	-5.6	-0.8	2.4		±4.8	4.8	-4.8	
Marshall density (Gap from standard) $\times 10^{-3}$		V-06	10	-8	0	5		±10	10	-10	
		R-06	12	-12	1	8		±16	16	-16	
Printing management		1Bin(2.36㎜)						± 3%			±12
		(75 μm)						± 0. 35%			±5
		Asphalt amount						± 0. 25%			±0.9
		Target temperature of mixer						± 5℃			

1.2.2 Australia

1.2.2.1 Road quality management system

The quality management of pavement works in Australia is outlined in the "Guide to Pavement Technology, Part8 Pavement Construction, Quality Assurance". The details of the quality standard are as shown below

- Part 4B; Asphalt (for materials, mix design, Asphalt manufacturing etc.)
- Part 8; Asphalt Pavements and Surfacing (for construction of asphalt)

- Austroads (for cement stabilization, unusual soil, CBR etc.)
- Technical standards for each region (quality management, materials, mix design, asphalt plants and paving)

1.2.2.2 Management

In Australia, the contractor prepares the quality plan and inspection plan. The contractor prepares the quality management plan based on their own quality assurance manuals. In most cases, submission of the quality management plan is required before the contract is agreed. The quality management plan includes the following:

- Quality management system
- Work schedule and work method
- Hold points defined by the contract
- Check list
- Investigation plan
- Witness examination record

The responsibility of the contractor and the principal (client) in Australia is as shown in figure 1.2.2.

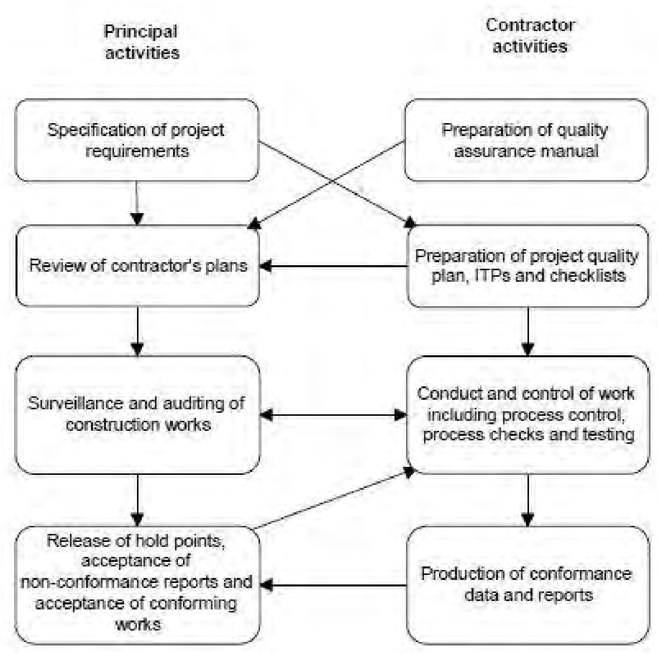


Figure 1.2.2 Principal and contractor responsibility

The principal specifies the standard requirement, reviews the contractor's plan, supervises and audits construction works, releases of hold points, and attends to irregularities. The consultant conducts verification (quality assurance) on behalf of the principal.

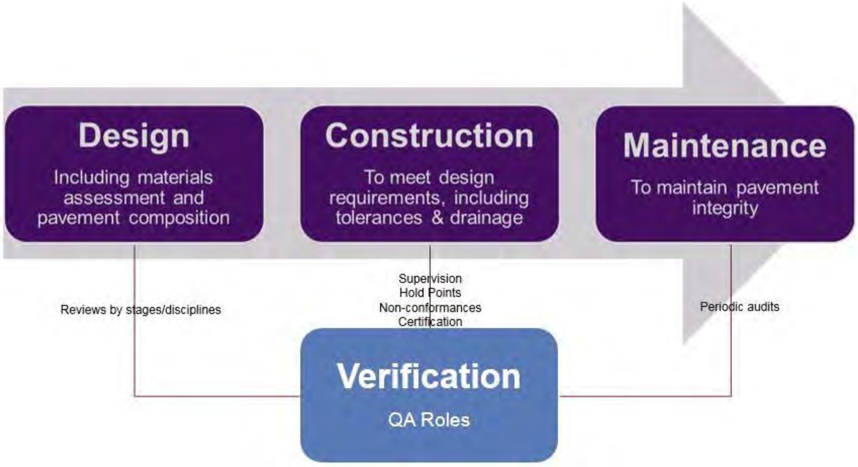


Figure 1.2.3 Consultant service at the stage of construction

Verification is conducted at each stage of design, construction and maintenance as shown in figure 1.2.3. At the stage of construction, the consultant supervises the standard for allowable values in order to meet the design requirement. The breakdown of verification for the construction stage is as shown below:

- Supervision and inspection of construction
- Inspection and approval of hold points
- Attendance to irregularities (by the contractor or design)
- Issue of certification

1.2.2.3 Management standard for pavement construction

An example of mix design standards used in Australia is shown in table 1.2.3, 1.2.4 and 1.2.5.

New South Wales (NSW): volumetric design method by a gyratory compactor

Victoria: combining volumetric design method by a gyratory compactor and the Marshal method

Table1.2.3 Compaction standard of Gyratory compactor

NSW government

Traffic level	Design cycle time	Voids in Asphalt (at design stage)	Last cycle time	Voids in Asphalt (at design stage)
Light	50	3-6%	not adopted	not adopted
Medium	80	3-6%	250/350	2.0 % and over
Heavy	120	3-6%	250/350	2.0 % and over

Attention; “Light traffic”: targeting light traffic, 7-10mm for maximum particle size of aggregate, small voids in asphalt, large amount of asphalt

“ Medium traffic”: targeting medium traffic, 7-14mm for maximum particle size of aggregate

“Heavy traffic”: targeting heavy traffic, 7-14mm of the maximum particle size of aggregate

Source: Standard in NSW government

Table1.2.4 Compaction standard of Gyratory compactor

Victorian government

Traffic level	Design cycle time	Voids in Asphalt (at design stage)	Voids in Asphalt at 10 cycle times	Voids in Asphalt (at design stage)
Light	50	4%	not adopted	not adopted
Medium	80	4%	9.0%	2.0 % and over
Heavy	120	4%	9.0%	2.5 % and over

Source: Standard in Victorian government

Table1.2.5 Standard of Marshall's method

Maximum particle size (mm)	Stability (kN)	Flow value (mm)	Voids in Asphalt (%)	Voids in aggregate (%)
14	6.5	1.5~3.5	4.9~5.3	16
20	6.5	1.5~3.5	4.9~5.3	15

Source: Standard in Victorian government

Table1.2.6 Standard of stabilization

Category of stabilisation	Indicative laboratory strength after stabilisation	Common binders adopted	Anticipated performance attributes
Subgrade	CBR[1] > 5% (subgrades and formations)	▪ Addition of lime ▪ Addition of chemical binder	▪ Improved subgrade stiffness ▪ Improved shear strength ▪ Reduced heave and shrinkage
Granular	40% < CBR[1] < +100% (subbase and basecourse)	▪ Blending other granular materials which are classified as binders in the context of this Guide	▪ Improved pavement stiffness ▪ Improved shear strength ▪ Improved resistance to aggregate breakdown
Modified	0.7 MPa < UCS[2] < 1.5 MPa (basecourse)	▪ Addition of small quantities of cementitious binder ▪ Addition of lime ▪ Addition of chemical binder	▪ Improved pavement stiffness ▪ Improved shear strength ▪ Reduced moisture sensitivity, i.e. loss of strength due to increasing moisture content ▪ At low binder contents can be subject to erosion where cracking is present
Bound	UCS[2] > 1.5 MPa (basecourse)	▪ Addition of greater quantities of cementitious binder ▪ Addition of a combination of cementitious and bituminous binders	▪ Increased pavement stiffness to provide tensile resistance ▪ Some binders introduce transverse shrinkage cracking ▪ At low binder contents can be subject to erosion where cracking is present

Notes:
1. Four day soaked CBR.
2. Values determined from test specimens stabilised with GP cement and prepared using Standard compactive effort, normal curing for a minimum 28 days and 4 hour soak conditioning.

Source : Austroads, Guide to Pavement technology, 4D stabilized materials

Table1.2.7 Routine inspections for batch mix plants

Process	Checklist
Cold feed	▪ Stockpile construction, separation, labelling and handling ▪ Source of aggregate ▪ Stockpile contamination ▪ Aggregate gradation and moisture content ▪ Aggregate levels in bins ▪ Calibration and setting of cold feeders ▪ Rate of feed in relation to the rest of the plant
Dryer and dust collector	▪ Accuracy of temperature measuring device ▪ Efficiency of the dust collection system and either the disposing of collected fines or feeding uniformly into the mix at the predetermined rate ▪ Temperature of aggregate
Screens and hot bins	▪ Screen capacities in relation to the rest of the plant ▪ Pegged or clogged screens ▪ Damage (including holes) and degree of wear of the screens ▪ Excessive or irregular carryover ▪ Operation of overflow vent ▪ Bin levels ▪ Sampling point ▪ Temperature of aggregate ▪ Moisture content of aggregate
Binder heating, circulation and storage	▪ Quality of binder ▪ Quantity of binder in storage ▪ Temperature of binder ▪ Sampling point ▪ Leakage in lines and at pump flanges ▪ Circulation system (including continuous stirring within the tank only for modified binder)
Proportioning and mixing	▪ Maintenance, calibration, accuracy and sensitivity of scales ▪ Tare mass of binder bucket ▪ Temperature of aggregates and binder ▪ Proportioning of materials ▪ Binder cut-off valve ▪ Leakage from binder bucket or aggregate weigh hopper ▪ Batching sequence and size ▪ Introduction of filler ▪ Aggregate distribution in the mixer ▪ Uniformity of distribution of binder into the mixer ▪ Dry mixing time ▪ Wet mixing time ▪ Pugmill condition and operation, including paddle tips and dead spots ▪ Appearance of the mix ▪ Confirmation of grading and other target properties of the asphalt

Source ：Austroads, Guide to Pavement technology,4B Asphalt）

1.2.3 South Africa

(1) Road quality management system

Quality management of pavement construction in South Africa is summarized in “Chapter 13 Quality Management” of the “South Africa Pavement Engineering Manual” (SAPEM). This manual serves as a handbook that engineers use for reference. Stipulation for quality standard is provided in COLTO ("Committee of Land Transport Officials"), Standard Specifications (1998) No. 8200 "Quality control (Scheme I)" and No. 8300 "Quality control (Scheme 2)".

(2) Outline of the management

For quality management during construction, the management system conducted by the contractor and an authorized engineer as consultant is adopted. In SAPEM, the role of the contractor is defined as "Quality Management", and the role of the engineer as "Quality Control".

Table1.2.8 Quality Management versus Quality Control

Quality Management (Contractor)	Quality Control (Engineer)
Prevents problems	Reacts to problems
Does the right thing	Does the right thing
Controls activity	Provides end inspection
Involves all people in the organization	Places reliance on quality control specialist
Places responsibility for quality with the people who do the work	Client supervision

Source : South Africa Pavement Engineering Manual

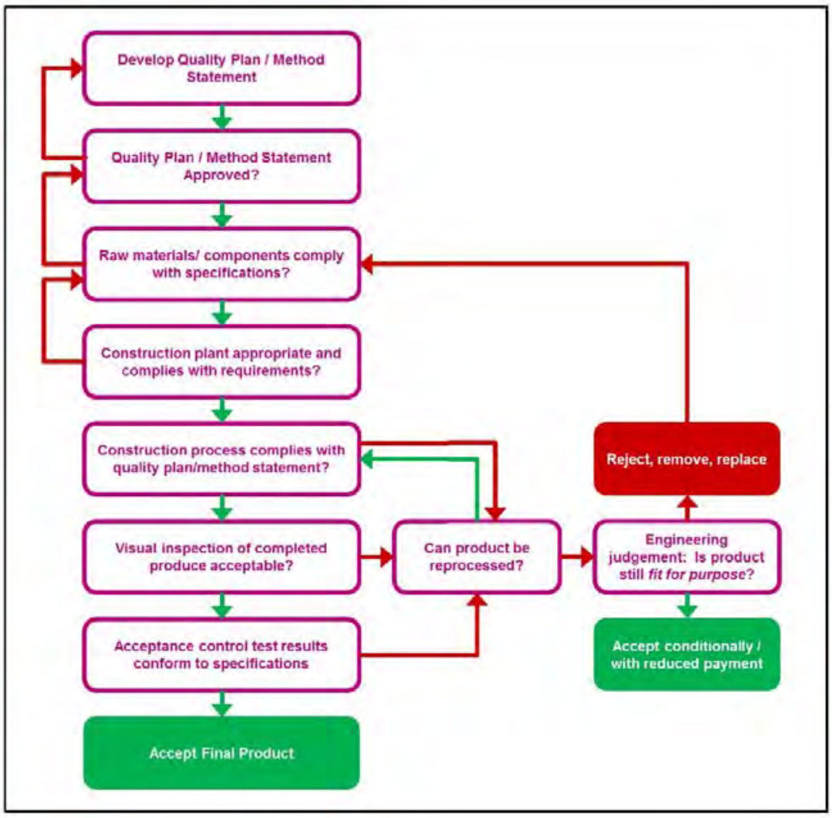


Figure 1.2.4 Basic flow of the quality management in South Africa

(3) Management standard for pavement construction

SAPEM identifies the quality management items for each step of construction shown below:

- **Selection of materials to use**
  - Confirmation of standards
- **Material design (test center)**
  - Material quality
  - Design parameter
- **Guarantee of design (test construction)**
  - Construction procedure
  - Material quality
  - Design parameter
- **Management of each pavement layer**
  - Construction procedure
  - Material quality
  - Design parameter

Detail of quality management standard for pavement construction is shown as below:

Table1.2.9 Laboratory Tests for the Constructed Selected Layer

Component	Aspect to be Controlled	Type of Control	Sample Size	Sampling Frequency	Test Method
Compaction	Maximum dry density	Mod. AASHTO	30 kg	2 samples per 500 m^3	SANS 3001–GR30
	Density	Sand replacement	N/A	1 sample per 1000 m^3 per 150 mm layer, minimum of 5 samples per layer per lot	SANS 3001–GR35
		Nuclear	N/A		SANS 3001–NG5
Moisture Content		Gravimetric analysis	1 x 1 to 1.5 kg	1 sample per test	SANS 3001–GR20
Layer Placement	Layer thickness	Measurement			
Material Properties	Grading	Sieve analysis Grading modulus Soil mortar analysis	15 kg	1 sample per 1000 m^3 per constructed layer thickness, minimum of 5 samples per layer per lot	SANS 3001–GR1
	Atterberg limits	Plasticity Index Liquid limit Linear shrinkage			SANS 3000–GR10, 11 & 12
	Bearing strength and swell	CBR	2 x 30 kg	1 sample per 2500 m^3, minimum of 3 per source	SANS 3001–GR30 & 40

Table1.2.10 Laboratory Tests for the Constructed Non-Cemented Subbase Layer

Component	Aspect to be Controlled	Type of Control	Sample Size	Sampling Frequency	Test Method
Compaction	Maximum dry density	Mod. AASHTO	30 kg	2 samples per 500 m^3	SANS 3001–GR30
	Density	Sand replacement	N/A	Minimum of 6 samples per lot	SANS 3001–GR35
		Nuclear			SANS 3001–NG5
Moisture Content		Gravimetric analysis	1 x 1 to 1.5 kg	1 sample per test	SANS 3001–GR20
Layer Placement	Layer thickness	Measurement			
Material Properties	Grading	Sieve analysis Soil mortar analysis Grading modulus	15 kg	Minimum of 6 stratified random samples per lot	SANS 3001–GR1
	Atterberg limits	Plasticity index Liquid limit Linear shrinkage			SANS 3001–GR10, 11 & 12
	Aggregate shape	Number of fractured faces			SANS 3001–AG4
	Bearing strength	CBR	2 x 30 kg	CBR assessed prior to compaction: 1 per km CBR not assessed prior to compaction: 3 per km	SANS 3001–GR30 & 40

Table1.2.11 Laboratory Tests for the Base Layer Constructed with G1, G2 or G3 Material[1]

Component	Aspect to be Controlled	Type of Control	Sample Size	Sampling Frequency	Test Method
Material Properties	Grading	Sieve Analysis	15 kg	Minimum 6 stratified random samples per lot – refer to COLTO Standard Specifications	SANS 3001–GR30
	Atterberg limits	Plasticity Index Liquid limit Linear Shrinkage			SANS 3001–GR10, 11 & 12
	Shape	Number of fractured faces		2 sample per lot	SANS 3001–AG4
Compaction	Maximum dry density	Mod. AASHTO	30 kg	2 samples per construction lot	SANS 3001–GR30
	Density	Sand replacement		Minimum of 6 stratified random samples	SANS 3001–GR35
		Nuclear			SANS 3001–NG5
Layer Placement	Layer thickness	Levels in test holes Measurement	N/A	Same as for density	Measurement
Layer Moisture Condition	Moisture content (full depth)	Gravimetric or by any other approved method	Minimum of 1 kg	Minimum of 1 test position per 100 m, selected randomly Sections: > 1 km: min of 10 tests < 1 km: min of 4 tests	SANS 3001–GR20
Surface Texture	Mosaic	Visual	Total Area	N/A	

[1] G1, G2 and G3 are pavement material code of South Africa. From G1 to G3 is categorized in Graded Crushed Stone and classified by rock condition, PI, density, etc. G1 shows the highest grad.

Table1.2.12 Laboratory Tests for the Base Layer Constructed with G4 Material[2]

Component	Aspect to be Controlled	Type of Control	Sample Size	Sampling Frequency	Test Method
Material Properties	Grading	Sieve Analysis	15 kg	Minimum 6 stratified random samples per lot	SANS 3001–GR30
	Atterberg limits	Plasticity Index Liquid limit Linear Shrinkage			SANS 3001–GR10, 11 & 12
	Shape	Number of fractured faces		2 sample per lot	SANS 3001–AG4
	Bearing	CBR	2 x 30 kg	1 sample per lot	SANS 3001–GR40
Compaction	Maximum dry density	Mod. AASHTO	30 kg	2 samples per construction lot	SANS 3001–GR30
	Density	Sand replacement			SANS 3001–GR35
		Nuclear		Minimum of 6 stratified random samples	SANS 3001–NG5
Layer Placement	Layer thickness	Levels in test holes Measurement	N/A	Same as for density	Measurement
Layer Moisture Condition	Moisture content (full depth)	Gravimetric or by any other approved method	Minimum of 1 kg	Minimum of 1 test position per 100 m, selected randomly Sections: > 1 km: min of 10 tests < 1 km: min of 4 tests	SANS 3001–GR20
Surface Texture	Mosaic	Visual	Total Area	N/A	SANS 3001–NG5

Table1.2.13 Laboratory and Field Tests for Stabilized layers

Component	Aspect to be Controlled	Type of Control	Sample Size	Sampling Frequency	Test Method
Compaction	Maximum dry density	Mod. AASHTO	30 kg	1 test of material from each density site	SANS 3001–GR51
	Density	Sand replacement	N/A	1 sample per 1000 m^3 per 150 mm layer, minimum of 5 samples per layer per lot	SANS 3001–GR35
		Nuclear	N/A		SANS 3001–NG5
Moisture Content		Gravimetric analysis	1 x 1 to 1.5 kg	1 sample per test	SANS 3001–GR20
Layer Placement	Layer Thickness	Measurement			
Material Properties	Grading	Sieve analysis Grading modulus Soil mortar analysis	15 kg	1 sample per 1000 m^3 per constructed layer thickness, minimum of 5 samples per layer per lot	SANS 3001–GR1
	Atterberg Limits	Plasticity Index Liquid limit Linear shrinkage			SANS 3001–GR10, 11 & 12
	Strength	UCS, ITS	150 kg for each	1 sample per 800 m^2, minimum of 4 per job lot	SANS 3001–GR51, 52, 53 & 54
Stabiliser Content	Distribution and quantity of added stabiliser	Laboratory determination of calcium content	6 kg	10 samples per lot including 2 samples from top and bottom of layer at 3 positions	SANS 3001–GR58

In South Africa, unlike Japan, there is no pre-screening plan. Quality management of the materials in asphalt mixtures is therefore required during construction as indicated below:

[2] G4 is also pavement material code of South Africa. G4 is categorized in Crushed or Natural Gravel.

Table1.2.14 Tests and Testing Frequencies for Aggregates Used in Asphalt

Property	Test	Quantity Per Test (Maximum)	Lot Size (Maximum)	Samples Per Lot (Minimum)	Test Number
Grading	Sieve analysis	1 000 m^3	Stockpile	4	SANS 3001–AG1
Shape	Flakiness index	1 000 m^3	Stockpile	4	SANS 3001–AG4
Resistance to crushing	Aggregate crushing value (ACV) 10% FACT (wet & dry)	5 000 m^3 5 000 m^3	Stockpile Stockpile	4 4	SANS 3001–AG10
Sand equivalent	Sand equivalent on fine aggregate	2 000 m^3	Stockpile	4	SANS 3001–AG10
Polishing	Polished stone value (PSV)	per source		1	SANS 3001–AG11
Adhesion	Adhesion test	5 000 m^3	Stockpile	4	TMH1 B11
Absorption	Absorption test	5 000 m^3	Stockpile	4	TMH1 B14 & B15
Plasticity of added fines	Plasticity index	2 000 m^3	Stockpile	4	SANS 3001–GR10
Durability	Methylene Blue test	per source		1	SANS 3001–AG44

Table1.2.15 Acceptance Control Tests on Fillers used in Asphalt Mixes

Property	Test	Quantity per Test (Maximum)	Lot Size (Maximum)	Samples per Lot (Minimum)	Test Number
Fineness	Percent mass passing 0.075 mm sieve	100 tons	per delivery	4	SANS 3001–AG1
Bulk density	Bulk density in toluene	100 tons	per delivery	1	BS 812
Void content	Void content in dry compacted filler	100 tons	per delivery	1	BS 812

Table1.2.16 Test Requirements and Testing Frequencies on Asphalt Mix and on the Constructed Asphalt Layer

Property	Quantity Per Test (Maximum)	Lot Size (Maximum)	Samples Per Lot (Minimum)	Test Number
Grading and binder content	200 tons	days work	6	SANS 3001–AG1
Sand equivalent	5 000 tons	week	1	SANS 3001–AG5
Marshall stability, flow and void content	500 tons	days work	2	SANS 3001–AS1, AS2, AS10
Relative compaction	2 000 m^2	days work	6	SANS 3001–AS11
Spread of rolled-in chips	2 000 m^2	days work	6	
Immersion index	Every change in aggregate or design			TMH1–C5

1.2.4 Specification for the compaction of a mechanically stabilized base course

According to the "Guide on Pavement Design" of Japan, a minimum value of 95% is required for the compaction rate of the base course. Meanwhile the minimum required value of compaction in South Africa or Australia is often 100% and higher. The reasons for this difference can be explained as follows:

Table1.2.17 Specification for the rate of compaction for mechanically stabilized crushed stone base course

Items	Pavement Engineering Manual (SA)	Pavement design handbook	Austroads
Compaction for setting of CBR Value*	98% of maximum dry density	95% of maximum dry density	Base course: not required Subbase course: 98% of maximum dry density
Compaction method 1.Moisture content 2. Rammer mass, dropping height, layer number, tampered times, Mold volume 3. Compaction energy	Optimum moisture content 4.5kg, 45cm, 5 layers, 56 times/layer, 2209 cc 27.4(cm・kgf/cm^3)	Optimum moisture content 4.5kg, 45cm, 3 layers, 92 times/layer, 2209cc 25.3(cm・kgf/cm^3)	Standard compaction: Optimum moisture content 2.49kg, 305mm, 3 layers, 25 times/layer, 1000cc 5.7(cm・kgf/cm^3) Modified Compaction: Optimum moisture content 4.45kg, 457mm, 5 layers, 25 times/layer, 1000cc 25.4(cm・kgf/cm^3)
Required CBR value	80%≤ of Minimum requirement of compaction	80%≤ of Minimum requirement of compaction	Base course: not required Subbase course: 30%≤
Requirement of compaction at site*	100%≤ of maximum dry density (TRH14) 98 or 100%≤ of maximum dry density (COLTO)	95%≤ of maximum dry density	Queensland Govt.: 102 or 100% NSW Govt.: 102% Victoria Govt.: 100 or 98%

*Evaluation of CBR value of mechanically stabilized crushed stone is based on the minimum requirement of compaction on site. It is indicated by percentage against the maximum dry density. The standard required for South Africa is higher than in Australia.

Table1.2.18 Example of acceptance criterion for compaction in Australia

	Characteristic value of relative compaction	
	Subbase	Base
QDMR, Queensland (Type 1)	≥ 102.0% (standard)	≥ 102.0% (standard)
QDMR, Queensland (Type 2,3,4)	≥ 100.0% (standard)	≥ 100.0% (standard)
RTA, NSW	≥ 102.0% (standard)	≥ 102.0% (standard)
VicRoads, VIC (Scale A)	≥ 98.0% (modified)	≥ 100.0% (modified)
VicRoads, VIC (Scale B)	≥ 97.0% (modified)	≥ 98.0% (modified)

Source: QDMR (1999), RTA (2007a) and VicRoads (2008b)

In the Japanese Industrial Standards (JIS), embankment and materials for base course are calculated from the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) according to "JIS A 1210 soil compaction test by rammer (F007 and E011, guide on pavement investigation and test methods)". The compaction on site should be managed based on the required MDD.

There are five types (A to E) of the compaction test method by rammer, divided into the following two types, depending on the calculated impact load (Ec).

a. A, B named in JIS: "Standard Proctor" Ec≒550kJ/m^3

b. C, D, E named in JIS: "Modified Proctor" Ec≒2500kJ/m^3

$$Ec = \frac{W_R \cdot H \cdot N_B \cdot N_L}{V} \quad (\mathrm{kJ/m^3})$$

W^R: Rammer weight (kN)

H: Rammer drop height (m)

M^B: Compaction time for each layer

N^L: Layer number

V: Mold volume (compacted sample volume) (m^3)

Table1.2.19 Specification for the rate of compaction in Japan

Compaction method	Mold radius (mm)	Mold depth (Sample height) (mm)	Mold (Sample) volume (cm^3)	Rammer weight (kg)	Drop height (cm)	Ramming time (time)	Layer number (layer)	Permissible maximum particle diameter (mm)	Ec (kJ/m^3)
A	100	127.3	1,000	2.5	30	25	3	19.0	552
B	150	125.0	2,209	2.5	30	55	3	37.5	549
C	100	127.3	1,000	4.5	45	25	5	19.0	2,482
D	150	125.0	2,209	4.5	45	55	5	19.0	2,472
E	150	125.0	2,209	4.5	45	92	3	37.5	2,481

Table1.2.20 Selection of compaction test

Item	Standard Proctor (Method ①)	Modified Proctor (Method ②)
Adopted standard	Required by unconfined compression strength	Required by modified CBR
Rammer weight	2.5 kg	4.5 kg
Rammer drop height	30 cm	45 cm
Ramming time and layer	25 times and 3 layers	92 times and 3 layers
Required compaction on site	100% and over	95% and over

When the same material is tested by two methods a) and b) each, MDD for a) is likely to be comparatively smaller than the one for b), and OMC for a) is larger than the one for b)as shown in Figure 4.18. (Austroads Guide to pavement part8 2009 P.48)

The standard density differs according to either method adopted to the rammer test. a) is described in “Standard compaction-AS 1289 5.1.1”and b) in “Modified compaction-AS 1289 5.2.1” on Page 47 of “Austroads Guide to pavement part8 2009”.

- Standard compaction – AS 1289 5.1.1: Determination of the dry density or moisture content relation of a soil using standard compactive effort.
- Modified compaction – AS 1289 5.2.1: Determination of the dry density or moisture content relation of a soil using modified compactive effort.

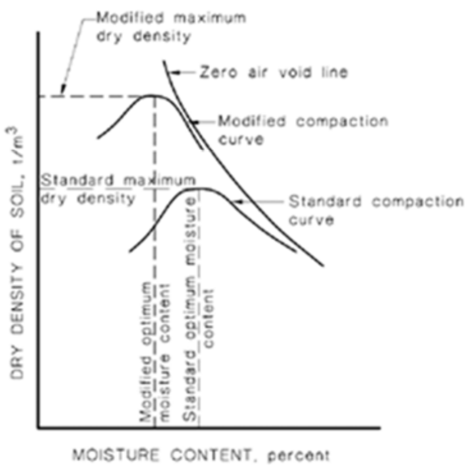


Figure 1.2.5 Standard and modified compaction curves ***(Austroads 2009 P.47)***

In Japan, the ramming method is designated depending on whether the base course material is required according either to modified CBR or unconfined compression strength. The sample for unconfined compression test is made by the method A (a)), and the sample for modified CBR is made by the method E (b)).

In case of construction of the base course, method b) is adopted for the standard density on site since basically the modified CBR is required in Japan. As indicated in the red box in table 1.2.11, (NEXCO) adopts method a) for standard density since the unconfined compression strength is required for the base course material out of cement stabilization base course. On the other hand, method b) is adopted for subbase course required by modified CBR. Required compaction for the base course is at least 100%, and for the at least 95% for the subbase course. The management standard on site for MLIT and NEXCO is shown in table 1.2.11.

Table1.2.21 Specified compaction methods in Japan

Client	Work type	Category	Test item	Test method	Standard value
MLIT	Subbase course work	Material	Modified CBR test	Pavement investigation & Test Method Handbook E 001 (JIS A 1210)	Mechanical stabilization: Modified CBR (95) 20%?
		Construction	Densitytest on site	Pavement investigation & Test Method Handbook G021	93%c pdmax Ave. ×10: 95%?
	Base course work	Material	Modified CBR test	Pavement investigation & Test Method Handbook E 001 (JIS A 1210)	Mechanical stabilization: Modified CBR (95) 80%?
		Construction	Densitytest on site	Pavement investigation & Test Method Handbook G021	93%c pdmax Ave. ×10: 95%?
	Cement stabilization	Material	Unconfined compression test	Pavement investigation & Test Method Handbook E 013	Unconfined compression strength (σ7)0.98Mpa
		Material	Modified CBR test	Pavement investigation & Test Method Handbook E 001	Base course: Modified CBR (95) 20%? Subbase course: Modified CBR (95) 10%?
		Construction	Densitytest on site	Pavement investigation & Test Method Handbook G021	93%c pdmax Ave. ×10: 95%?
NEXCO	Mechanical stabilization	Material	CBR test	JIS A 1211 (Related standard: Pavement investigation & Test Method Handbook E 001)	Base course: Modified CBR (95) 80%? Subbase course: Modified CBR (95) 30%?
		Construction	Densitytest on site	Pavement investigation & Test Method Handbook G021	Base course: 97%c pdmax Subbase course: 95%c pdmax
	Cement stabilization	Material	Unconfined compression test	Pavement investigation & Test Method Handbook E 013	Unconfined compression strength (σ7)3N/mm²?
		Material	CBR test	Pavement investigation & Test Method Handbook E 012	Subbase course: Modified CBR (95) 60%?
		Construction	Densitytest on site	Pavement investigation & Test Method Handbook G021	Base course: 100%c pdmax Subbase course: 95%c pdmax

1.3 Examples of pavement damage caused mainly by construction defects

1.3.1 Early damage on asphalt pavement in warm and tropical climate area

On Japanese ODA road projects in African and Asian countries of high temperatures and rainfall, pavement damage of the kind no longer seen in Japan can be seen.

Particularly rutting, occurring mainly in the road surface is prevalent. There are two types of rutting damage occurring in the road surface, that is, plastic deformation of asphalt due to continuous pressing of the asphalt mixture by the tires of passing vehicles, and wearing away of the surface by friction due to the action of spike-like tires. Of these, the former type is more common due to repeated exertion of load on the surface by vehicles in high temperatures causing the asphalt mixture to be permanently deformed.

Tanzanian case: Rutting occurred at the flat section of the urban trunk road. Surface layer “flows” to the center.

Ethiopian case: Rutting occurred at a steep curve section of a rural road in precipitous mountains. Surface layer flows to the inside of the curve.

1.3.2 Damage of asphalt pavements and the main causes

Deformation of asphalt mixture is often due to the formation of the asphalt mixture (aggregate gradation, type and amount of binder, etc), and external factors such as traffic load and temperature. Therefore, more damages occur in regions of heavy traffic in temperate regions due to plastic deformation caused by the heavy traffic load and high temperatures.

These kinds of damages on asphalt pavements arise from erroneous setting of conditions at the design level, mix design that does not appropriately account for the true conditions of service, defective construction, illegal overloading of vehicles, low-speed movement of heavy vehicles, etc. The damages on asphalt pavement due to construction and the respective causes are shown below:

Table1.3.1 Asphalt pavement's main causes in warm and tropical climate area

Defect type		Problems and Cause									
		Earthwork		Stabilization		Asphalt				Other work	Design and others
		Material selection	Construction management	Material selection	Construction management	Material selection	Storage and manufacturing	Mix design	Construction management	Construction management	
Slope gully / collapse		Material selection for surface		Material selection for surface							Inappropriate drainage design
Rutting	Flow rut					Unsuitable of asphalt quality, adopt natural stone	Lack aggregate washing	Inappropriate mix design	Inappropriate plant management		Heavy vehicle traffic, Traveling speed, temperature
Rutting	Subsidence / Structure rut		Lacking in compaction and uniformity		Lacking in compaction and uniformity				Lack of compaction		Inappropriate base course drainage
Crack	Hair crack						Inappropriate moisture management	Lack of asphalt amount, plethora of fine fraction	Construction temperature, Roller weight, Rainfall measures		Overloaded
Crack	Vertical crack / Turtle crack		Lacking in compaction and uniformity	Lack of aggregate strength	Lacking in compaction and uniformity			Lack of stability	Construction seam failure, Tuck prime coat defective		Bearing resistance shortage, Overloaded, Poor drainage
Aggregate scattering etc						Aggregate abrasion test			Tack coat construction deficiencies		Base course problem of cement stabilization
Others		Unusual soil measures	Rationalization of earthwork management		Rationalization of earthwork management		Approach of plant management	Theory meshing aggregate			

Also, indicated below is an example of confirmation tests for the cut core of asphalt pavement conducted on African roads. The relationship between deviation from the specification and the extent of pavement damage (mainly due to rutting) is clear. The actual condition of this damage is shown in Figure1.3.2.

Table 1.3.2 Sampling Results

Surface condition	No.	Sample Position	Rate of aggregate deviation*1
a) Sections of severe damage	1	4.0km left side	10.9%
	2	12.5km left side	29.5%
	3	5.0km right side	17.9%
	4	4.0km right side	18.2%
	a) Average = 19.1% (13 times c)		
b) Sections of partial damage	1	7.5km left side	9.9%
	2	10.5km left side	7.6%
	3	1.5km left side	14.3%
	4	2.0km left side	3.9%
	b) Average = 8.9% (6 times c)		
c) Undamaged sections	1	5.4km left side	2.0%
	2	-0.2km left side	1.0%
	c) Average = 1.5%		

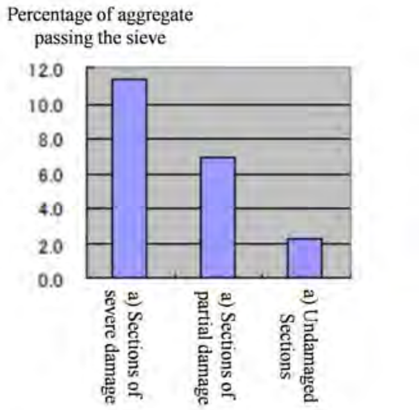


Figure 1.3.1 Quality management for aggregate distribution of asphalt aggregate (amount remaining in the sieve)

Note: Rate of aggregate deviations in table 1.3.2 and figure 1.3.2 are not corresponded because the survey time and the sampling locations are different.

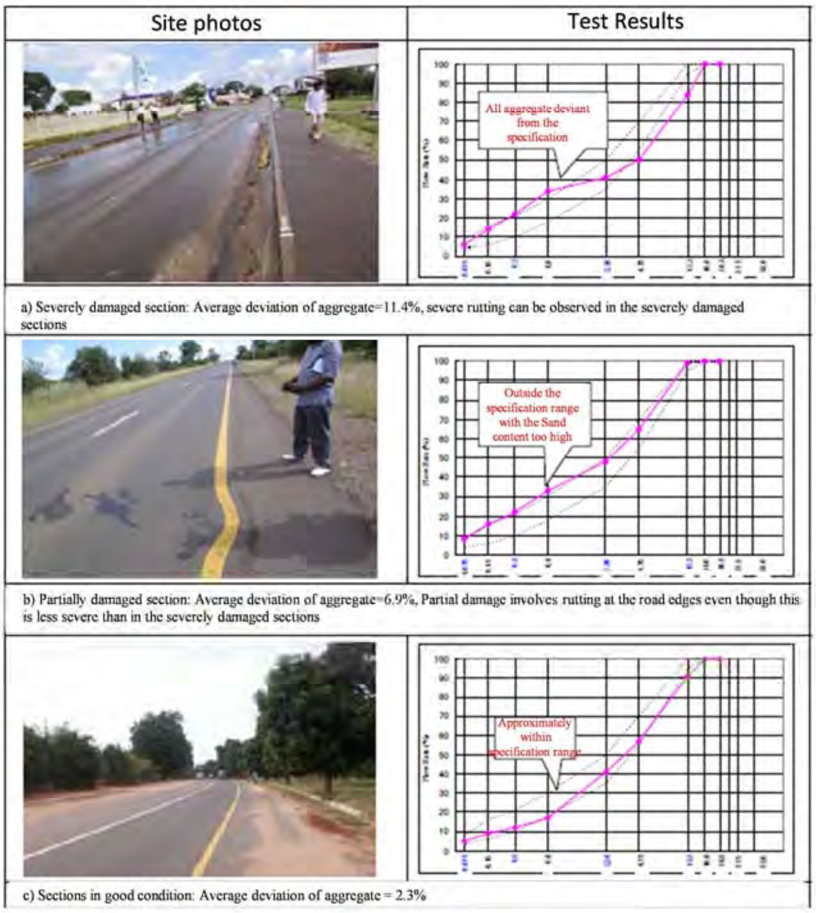


Figure 1.3.2 Aggregate distribution for asphalt and examples of damaged pavements

Here, it is important to note that the relationship between deviation from the standard of aggregate distribution and the extent of damage is clear. Estimation for the aggregate void of this pavement was not been conducted. However, from Figure1.3.2 a), it is possible that aggregate integration was insufficient due to a high content of fine aggregate; which led to failure. From this, the importance of aggregate distribution as well as integration in avoiding rutting is shown.

1.3.3 Improper plant management

The kind of deviation of aggregate distribution from specification shown above is often caused by improper plant management. The typical structure of an asphalt plant is as shown below:

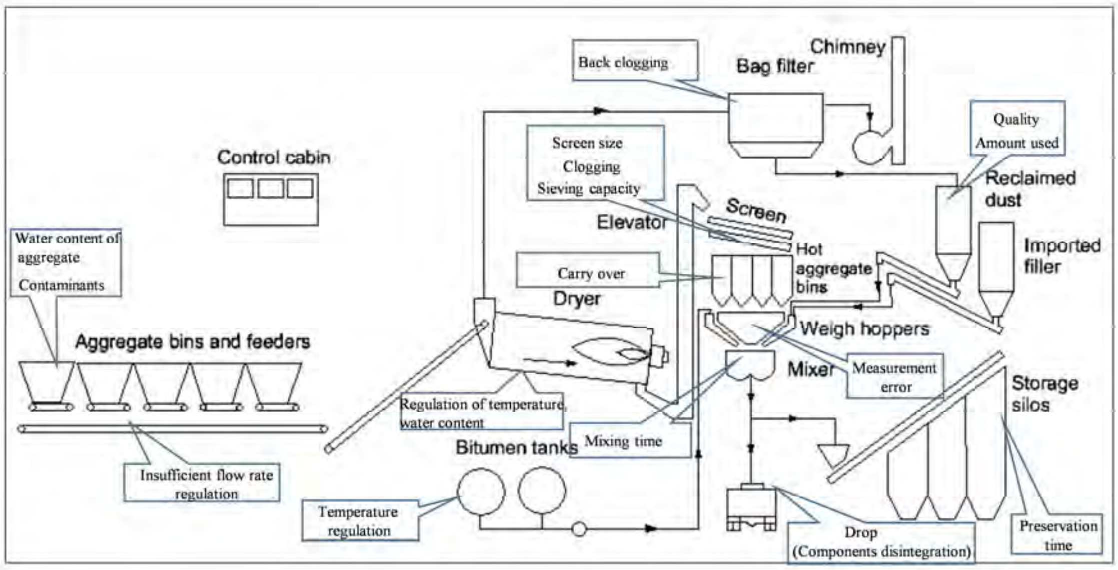


Figure 1.3.3 Composition of an asphalt plant

Shown below are cases of asphalt pavement plants where proper management was lacking.

Table1.3.3 Examples from mismanaged asphalt plant

Area of management	Mismanagement case	Phenomenon expected	Defects caused by the left hand side phenomena.
Stockyard	1) Absence of a roof or a suitable cover during rains (especially with fine sand). 2) Poor drainage from the plant.	1) Aggregate water content overshoots.	1) Peeling of the pavement caused by residual water remaining after drying of the aggregate. 2) The flow of the cold bin is worsened.
Cold bin feeder	1)Insufficient checks for the set amounts (lack of calibration)	1) Contents vary (especially for fine sand). 2) Overflow of the hot bin and shortage with sieves.	1) Mixture grading is altered. 2) Loss of materials
Drier	1)Insufficient thermometer checks 2) Clumsiness with burner controls.	1) Decrease of mixture temperature 2) Temperature of the mixture is too high.	1) Unevenness of asphalt coating 2) Unevenness of pavement rolling 3) Asphalt deterioration

Screen	1) Clogging and tear 2) Use of sieves of irregular sizes (sieving for aggregate 2.5mm and below is impossible)	1) Irregularity with the hot bin gradation. 2) Important values such as the amount passing through the 2.5mm sieve cannot be determined.	1) Irregularity with the mixture gradation 2) Properties of the mixture are not stable.
Hot bin	1) Improper management of the hot bin gradation 2) Insufficient thermometer checks	1) Failure to detect the screen irregularity 2) Adjustment of the gradation is impossible 3) Proper temperature management is impossible	1) Irregularity with the mixture gradation. Also, correction is rendered impossible 2) Irregularity with the mixture temperature
Scale	1)The accuracy of the scale is poor (insufficient checks)	1)Irregularity with aggregate contents 2) Irregularity with the asphalt content 3)Irregularity with the filler content	1)Irregularity with the gradation 2)Overshoot or deficiency in the asphalt amount 3)Dryness and glare
Mixer	1)Unsuitable mixing time	1) Mixing time is too short 2) Mixing time is too long	1) Inadequacy in aggregate dispersion and asphalt coating. 2)Deterioration of asphalt
Dump pit	1)Improper temperature management during kneading and delivery	1)Irregularity with the mixture temperature.	
Bag filter	1) Clogging of the filter cloth 2) Open holes in the filter cloth	1) Reduced suction leading to entry of dust into the hot bin 2) Escape of dust to the atmosphere through the chimney.	1) Excess filler in the mixture 2) Soot

1.3.4 Measures against rutting by country

(1) Japan

In Japan, the resistance of a pavement to rutting is shown through dynamic stability (DS).

The Ministry of Land Infrastructure and Transport (MLIT) has set as the target for dynamic stability, the values indicated in Table1.3.4 in accordance with traffic volume.

Table1.3.4 Standard for plastic deformation wheel number in Japan (MLIT, No.103)

Classification	Pavement design traffic volume （Unit：vehicles／day per direction）	Plastic deformation wheel number: DS (Unit: Turns/mm)
Types 1 and 2, Type 3 Class 1 and Class2, Type 4 Class 1	3,000 and above	3,000
	Less than 3,000	1,500
Others		500

Example from the Kantou Regional Office

The Kantou Regional Headquarter design guide has prescribed the use of modified asphalt (rubber or other polymer is added to ordinary asphalt (or “straight asphalt”) as a means of preventing loss of viscosity) as a measure against rutting as well as setting target values of dynamic stability by conduction of wheel tracking tests.

Table1.3.5 Target values for Dynamic Stability (DS) (Turns/mm)

	Traffic Group C		Traffic Group D	
	Typical section	Intersection	Typical section	Intersection
Surface Course Dense graded asphalt concrete (20) Thickness 5cm	About 3000 Modified Asphalt	About 4000 Modified Asphalt	About 4000 Modified Asphalt	About 5000 Modified Asphalt or semi-flexible asphalt especially for areas of sever rutting
Binder course Course graded asphalt concrete (20) Thickness 5cm	Straight Asphalt	About 4000 Modified Asphalt	About 4000 Modified Asphalt	About 5000 Modified Asphalt

Source: Design Guide (Pavement) (MLIT Kanto Regional Office

Example from NEXCO

At NEXCO, with consideration of resistance to plastic deformation as well as noise reduction, high function (porous asphalt) is standard and other types of mixtures than high function asphalt can be seen in a section of the roads. The standard for measures against rutting due to plastic deformation in other types of surface mixtures than the high functioning type target the dynamic stability values shown in the table below. However, there are no target values specified for high functioning pavement.

Table1.3.6 Dynamic Stability target values for other pavement types than the high functioning type (turns/mm)

Classification by traffic		Target value of dynamic stability (turns/mm)	Type of asphalt used
Light and medium traffic	Less than 5,000 vehicles /day/direction	800	Straight asphalt
Heavy traffic	5,000/day/direction and above	3,000 and above	Modified asphalt

Source: Design Guide First Collection- Pavement(NEXCO)

Meanwhile, high functioning pavement (porous pavement) is a porous asphalt mixture applied in the surface course that is formed from Type II modified asphalt (a “high viscosity asphalt” type (over 20000 pores) with a higher content of polymer than conventional modified asphalt).

Column 1 Volumetric Mix Design

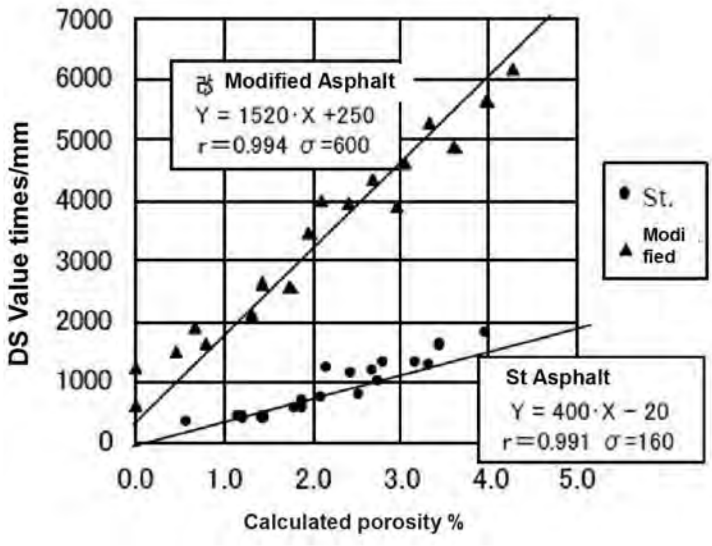
A mix design method based on aggregate void ratio is introduced in following literatures (from 1) to 3)). In this design mix method, aggregate void ratio is estimated beforehand from aggregate gradation and; after the minimum void ratio has been secured, the amount of asphalt necessary to fill the remainder of the voids provisionally determined. The contents are finally determined by conducting a confirmation test.

This design method is based on the SUPERPAVE volumetric mix design method. Also, other literature by the same authors indicate an equation for determining aggregate void ratio from the gradation as well as the relationship between the final void ratio and DS. This literature is indicated in the appendix.

1) Proposal of volumetric mix design method for hot mix asphalt based on aggregate void ratio (Japan Society of Civil Engineers (JSCE) Essay Collection on Pavement Engineering, No.5 Dec.2000 Yasuo Gunji, Takemi Inoue, Hirokazu Akagi)

2) Research on estimation methods for hot mix asphalt aggregate void ratio based on aggregate gradation (JSCE Essay Collection on Pavement Engineering, No.5 May.2000; Yasuo Gunji, Takemi Inoue, Hirokazu Akagi)

3) Observations on VMA and mechanical features of SMA mixture (JSCE 55th Academic Lecture, No.5 Sep.2000; Yasuo Gunji, Takemi Inoue, Hirokazu Akagi)



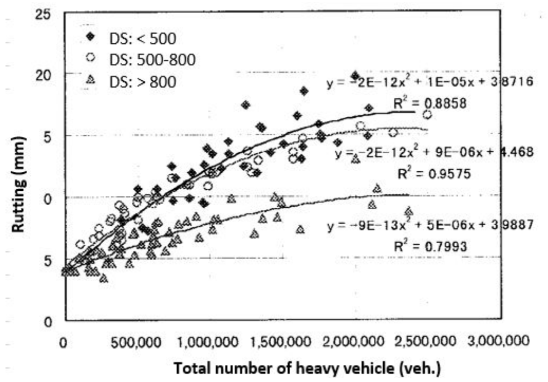
Source: Proposal of volumetric mix design method for hot mix asphalt based on aggregate void ratio
Fig. Relationship between calculated void ratio and DS

Figure 1.3.4 Calculated porosity DS value

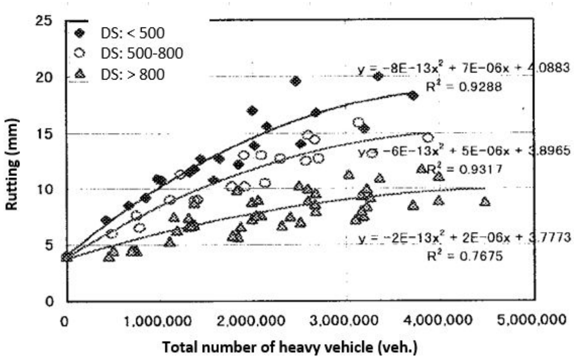
Column 2 Rutting rate for dense graded asphalt

The literature below indicates an example of a study conducted on DS and the rate of rutting for daily heavy traffic volume on expressways. According to the study, progression of rutting can be contained for areas of daily volume of heavy traffic less than 5,000 by application of at least DS 800 (straight asphalt) and for traffic volume 5,000 and above by application of DS 2,000 and above (modified asphalt). Also, resistance to plastic deformation can be improved setting the amount of aggregate passing through the 2.36mm at 42%, and reference values for the amount of modified asphalt effective against plastic deformation are indicated.

1) Field survey of rutting on dense graded asphalt pavement expressways and evaluation of resistance to plastic deformation (JSCE Essay Collection on Pavement Engineering, No.4 Dec.1999; Akio Iida, Shigeru Shimeno, Masahiro Kaneda, Masakazu Satou)



Less than 5,000veh/day/direction



5,000 veh/day/direction and above

Source：Proposal of volumetric mix design method for hot mix asphalt based on aggregate void ratio

Figure 1.3.5 Rutting rate per DS

(3) Australia

1) Outline

Mix design and testing in Australia is primarily conducted by application of volumetric methods using a gyratory compactor. In some state and regional roads, the Marshall method is used.

2) The method of volumetric design

a) Volume of voids in mineral aggregate (VMA)

Volume of voids in mineral aggregate is determined in accordance with the gradation distribution, shape, surface texture and compaction features of the aggregate.

13 to 20% voids in mineral aggregate are required in accordance with the maximum aggregate size to secure the necessary amount of asphalt (durability) as well as voids ratio upon compaction (stability).

When the voids ratio is too small, problems may occur with too much asphalt per unit void causing the mixture to be unstable, or too little asphalt resulting in insufficient adhesion, leading to insufficient durability.

The methods for increasing voids in mineral aggregate are as follows:

Shifting the gradation distribution from the maximum density curve to a more coarse direction.

Reducing the amount of the 0.075mm (filler) component.

Improving the compaction features of the aggregate by changing the aggregate shape and surface texture.

b) Volume of air voids (VIM)

Volume of air voids of a mixture is a function of the volume of voids in mineral aggregate (VMA), amount of asphalt and rate of compaction.

Too large VIM leads to the degeneration of asphalt, infiltration with water, making the mixture prone to peeling.

Too small VIM on a road in service (less than 2%) causes to plastic deformation leading to rutting.

The maximum density of a mixture upon opening to service (minimum VIM) can be determined from compaction at the maximum number of turns of the gyratory compactor. VIM at the number of turns for a mixture of heavy traffic (250 or 350 standard) can be applied in mix design of asphalt for heavy traffic.

c) Volume of bitumen (Vb)

Optimum volume of bitumen is a balanced value for the volume necessary for securing durability, at the same time avoiding excess that would cause the mixture to be un^0stable.

Optimum volume of bitumen is determined in accordance with aggregate type, gradation, level of compaction, and design volume of air voids.

The volume of bitumen effective for performance is determined by subtracting from the total volume of bitumen, the volume that is absorbed by the aggregate.

The volume of bitumen absorbed by aggregate can be determined from the measured and the theoretical maximum density of the mixture. The fraction absorbed in the aggregate varies in accordance with the aggregate's absorptive features as well as the type of bitumen. In general, this fraction is between 0.3 and 0.7.

d) Volume of voids filled with bitumen（VFB）

The volume of voids filled with bitumen (VFB) refers to the fraction of VMA that is occupied by effective bitumen. This figure is generally between 65 and 80%.

Mixtures with low VFB (about 60%) tend to show susceptibility to drying and deterioration of adhesion, durability and fatigue resistance. Too high VFB (about 85% and above) causes the mixture to be unstable and creates the danger of rutting.

Given the target value for VIM, aggregate with high VFB will yield high VMA whereas low VFB yields low VMA.

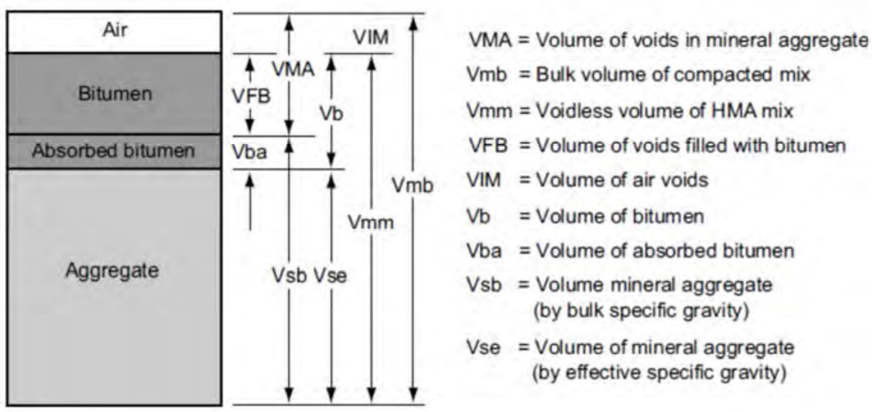


Figure 5.2 Representation of volumes in a compacted HMA specimen (Asphalt Institute, MS-2, 1994)

Figure 1.3.6 Volumetric composition of compacted pavement(example).

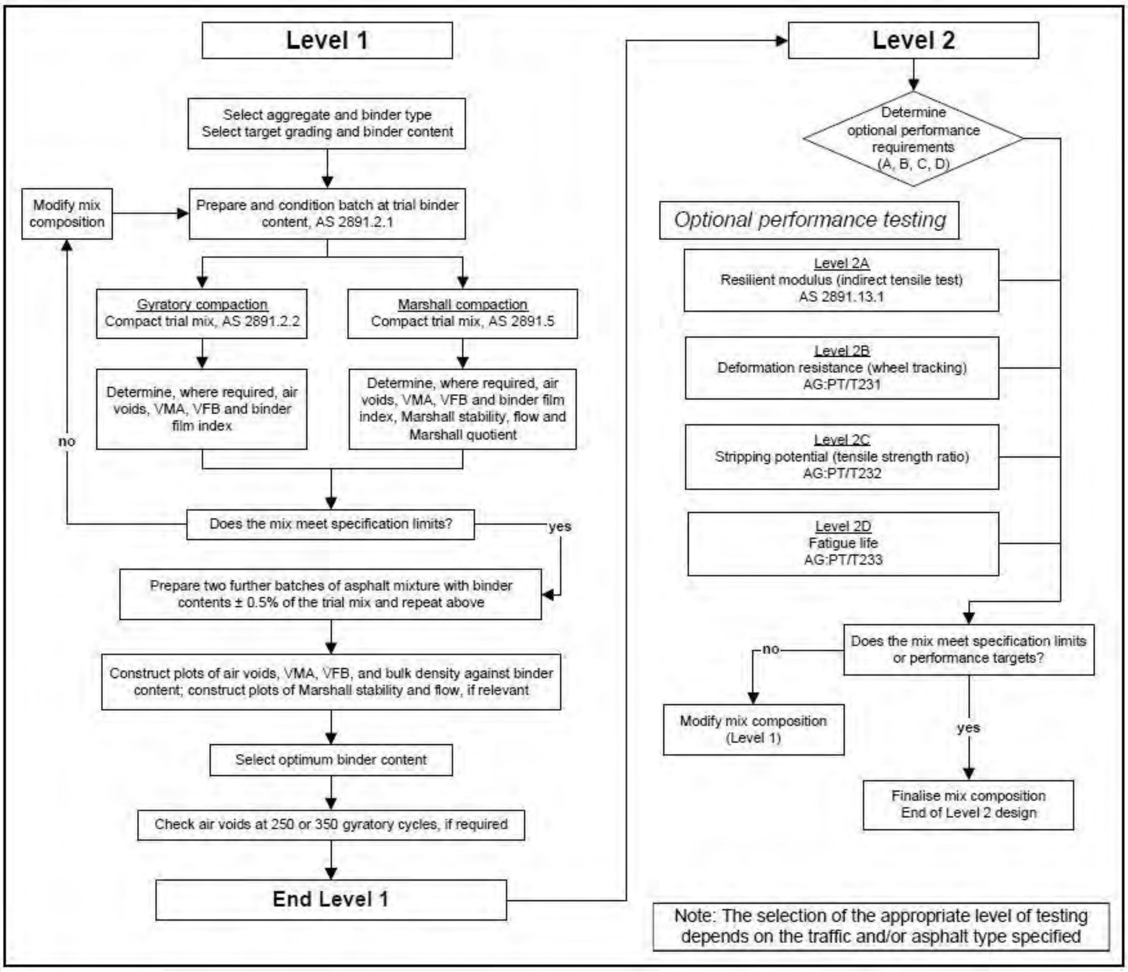


Figure 1.3.7 The procedure for mix design (for dense grades)

The volume of voids is an important parameter of mix design. The volume of voids for mixtures for heavy traffic in particular should not fall below a specific value after maximum gyratory cycling. Increasing the volume of air voids by decreasing the volume of bitumen affects durability and workability of the mixture. The minimum VMA therefore should be secured. Adjustment for the volume of binder necessary for satisfying the required VMA and target VIM involves the following:

a. Adjusting the texture of the mixture to a coarser or finer form and/or the grade increased. Generally, the specified gradation curve provides target grades closest to the maximum density curve. Changing a part of the gradation to a coarser or finer form therefore, generally leads to an increase in VMA. However, careful attention should be paid to stiffness of the mixture and effect on the surface texture.

b. Altering the percentage of the fine aggregate components (the components passing through the 2.36mm sieve). However, careful attention should be paid to stiffness of the mixture and effect on the surface texture same as above.

c. Adjusting the volume of the filler yields a direct effect. Increasing the filler volume lowers VMA and decreasing it leads to a higher VMA.

d. Altering the aggregate shapes, especially with fine aggregate. Smooth and soft aggregate increases workability (improved compaction of the mixture, etc) and decreases VMA. Here, attention should be kept to check for decrease in the mixture's s stiffness.

e. Addition of natural sand increases VMA by the spaces in the sand particles.

3) Resistance to deformation

a. Insufficiency in deformation resistance has been known to cause rutting. Deformation resistance can be improved by the following:

b. Selecting mixtures of larger sizes.

c. Use of square or rough aggregate.

d. Use of hard binder

e. Application of coarse gradation

f. Reduction of voids (however, this is on the condition that the minimum volume of voids at the maximum number of turns is kept)

g. Increasing the filler volume

These factors affect other features. For example, the use of square or rough aggregate leads to reduced workability whereas increasing the filler volume may lead to mastic deficient in deflective properties, resulting in reduced fatigue resistance.

(4) South Africa

In South Africa, as in Japan, modified materials are used as a measure against rutting. The use of modified materials is typical. Also, in areas of very heavy traffic, mixtures of 10 to 20 penetration rate have been tried.

South Africa are in the midst of consideration of trial pavement with HiMA (High modulus asphalt) mixture (Erik Denneman; "Introducing High Modulus Asphalt(HiMA)").

1) HiMA refers to EME (Enrobé à Module Élevé), a mixture developed in France.

a. Although application is mainly with the base course, application with the binder and surface courses has been tried in Europe.

b. The features of EME are that, in comparison to conventional mixtures uses a hard binder (penetration rate of 10 to 20), high binder volume, low volume of air voids, high modulus, high rutting resistance and fatigue resistance. Indicated in the table below is the general guide for binder selection in South Africa.

Table1.3.7 Interim guidelines for the design of hot-mix asphalt in South Africa

Type of binder	Main application
Penetration grade 40/50	Applied with various traffic conditions. Generally used with thick layers and asphalt bases.
Penetration grade 60/70	Applied in the surface course for light to medium traffic. This is the commonest used binder type.
Penetration grade 80/100	Applied with low traffic. Generally not suitable for hot regions
Modified binder	Applied with heavy traffic. Generally used for resistance to rutting.

Source: INTERIM GUIDELINES FOR THE DESIGN OF HOT-MIX ASPHALT IN SOUTH AFRICA

2) The advantage of HiMA(EME) is that pavement thickness is reduced and longevity improved. Trial pavement with HiMA (EME) is therefore underway.

3) Application of HiMA in various kinds of projects is currently underway (currently, no test method for mix design or mix standard have been specified).

Also, mixt trials and the necessary tests are grouped in accordance with the levels of traffic. The standard for this is indicated in “INTERIM GUIDELINES FOR THE DESIGN OF HOT-MIX ASPHALT IN SOUTH AFRICA”

Table1.3.8 Mix design standard for South Africa

<table>
<tr><th rowspan="3">Traffic level</th><th colspan="2">Allowable range for air voids after initial Marshal compaction (75 blows)
(simulation of site compaction)</th><th colspan="3">Allowable range for air voids after extra compaction by passing vehicles</th></tr>
<tr><th rowspan="2">Minimum</th><th rowspan="2">Maximum</th><th rowspan="2">Total number of compaction blows</th><th colspan="2">Volume of air voids</th></tr>
<tr><th>Minimum</th><th>Maximum</th></tr>
<tr><td>Light</td><td>3.5%</td><td>5.5%</td><td>75＋15</td><td>3.0%</td><td>4.5%</td></tr>
<tr><td>Medium</td><td>4.5%</td><td>6.5%</td><td>75＋45</td><td>3.0%</td><td>5.0%</td></tr>
<tr><td rowspan="2">Heavy</td><td>5.5%</td><td>7.5%</td><td>75＋75</td><td>4.0%</td><td>5.0%</td></tr>
<tr><td colspan="5">Minimum volume of air voids set to 1.5% after 300 turns by a gyratory compactor in accordance with the SHRP test method.
The permeability of the mixture should satisfy the respective standard</td></tr>
<tr><td rowspan="2">Very heavy</td><td>6.0%</td><td>8.0%</td><td>75＋75</td><td>4.5%</td><td>5.5%</td></tr>
<tr><td colspan="5">Minimum volume of air voids set to 2.5% after 300 turns by a gyratory compactor in accordance with the SHRP test method.
The permeability of the mixture should satisfy the respective standard</td></tr>
</table>

Traffic level

Traffic level	Number of heavy vehicles /lane/day	Structural design of pavement 80 kN ESALs
Light	< 80	$<1\times10^6$
Medium	80－200	$1-3\times10^6$
Heavy	200－700	$3-10\times10^6$
Very heavy	>700	$>10\times10^6$

The features of the mix design method are as follows:

a. The method applies Marshal compaction, putting into consideration the compaction properties of the mixture as well as the traffic level. With the number of blows after construction at 75, compaction by passing vehicles upon opening to service is set in accordance with the traffic level.

b. Volume of air voids is the volumetric feature considered.

c. A graph is plotted of the air voids for Marshal compaction on the vertical axis against the number of blows on the horizontal, and a regression curve drawn. Gyratory testing is conducted for samples where the slope of the regression curve is greater than 5%. The mixture for which this slope is greater than 5% indicates that a refusal volume of air voids less than 2%. Refusal volume refers to the volume of air voids of the mixture after subjection to 300 turns of gyratory compaction. Gyratory compactor will be explained in "1.4.2 Points of consideration for mix design and testing".

Apart from these, there is a "Trouble Shooting Guide" on asphalt pavement produced by the Asphalt Society showing various measures to be taken when troubles are encountered with asphalt pavement. A detailed explanation is shown in "Chapter 3 Report on site study (The African Region)

The specification used in France (for base course) is indicated in table 1.3.9 for reference.

a. Binder: penetration 20-25%, softening point 62-72^{0}C.

b. Gradation range (as per; LCPCBituminous Mixtures Design Guide, 2007)

Table1.3.9 gradation range for base courses in France

Sieve (mm)	Maximum grade 20mm or 14mm			Maximum grade 10mm		
	Minimum	Target	Maximum		Target	Maximum
6.3	45(50)*	53	65 (70)		55	65
4	40	47	60	Minimum	52	
2	25	33	38	45	33	38
0.063	5.4	6.7	7.7	6.3	6.7	7.2

*the values indicated in parentheses correspond the 14mm maximum grade.

1.4 Points of Consideration for asphalt pavement works

1.4.1 Points of consideration for material selection and testing

(1) Pavement materials

Material testing and mix testing should be conducted on materials to be used in pavement to check that they meet the requirement of the specification. Also, trial construction may be carried out before actual construction is commenced to verify that the mixture obtained in the laboratory tests can be reproduced in the actual plant and that sufficient construction management can be conducted. Common asphalt components and their raw materials are shown below:

Table1.4.1 Common materials for asphalt mixtures

	Material
Asphalt	Petroleum asphalt: various grades for penetration, viscosity, PG Modified polymer asphalt: Modified polymer, PG
Emulsion	Cation based emulsified asphalt, cut back asphalt, etc
Coarse aggregate	Crushed stone, crushed gravel, gravel, slag, recycled aggregate, etc
Fine aggregate	Natural sand, artificial sand, slag, etc
Filler	Lime, recovery filler, cement, fly ash, etc.

1) Aggregate

Aggregate, referring to sand, gravel, filler, etc is the main component of an asphalt mixture. Also, from the particle size, aggregate is said to be fine aggregate or coarse aggregate.

Generally in Japan, aggregate in an asphalt mixture is grouped in accordance with the 2.36mm grade. Grades of 2.36mm and above are coarse aggregate and those smaller said to be fine aggregate. This classification however is not standard worldwide.

Filler refers to mineral powder where the fraction passing through the 0.075mm sieve is 70% and above. It is obtained from limestone and other rock based pulverized powder, slaked lime, cement and fly ash.

As aggregate comprises the structural backbone of the pavement, it is vital that in addition to gradation and shape, the very properties of the aggregate suit the desired application purpose of the pavement. The properties of aggregate generally desired for pavement are as follows:

A) That the aggregate satisfies the respective grade and shape.
  a) Maximum grade size affects finishing and workability whereas gradation affects stability as well as durability.
  b) Cubic and rough edged aggregate are desirable. Flat and elongated aggregate lead to deterioration of the mixture’s stability and poor workability.

B) It should not contain mud, organic matter or litter.
  a) Pollutants contained in an asphalt mixture lead to a deterioration of that mixture’s properties.

C) It should have good qualities for durability and resistance to abrasion
  a) It is required that the aggregate does not fracture during construction or wear away upon opening to traffic.

D) It should show strong adhesion to asphalt
  a) Generally, acidic rocks have poor adhesion to asphalt. Poor adhesion increases the danger of surface peeling.

The properties of aggregate have a strong influence on the asphalt mixture. Resistance to abrasion from passing vehicles and durability as well as good qualities of adhesion to asphalt can be said to be the conditions to be considered when selecting aggregate.

2) Bitumen (Asphalt)

Asphalt is susceptible to the effect of heat and greatly influences the durability of pavement. Therefore, it is vital that the type of bitumen selected is suitable for the respective application purpose, weather and traffic conditions. As modified asphalt is more expensive than straight asphalt, site conditions should be well considered before use.

A) The general application of various types of straight asphalt is as shown below

Straight asphalt 40/60	Typical region, relatively warm temperatures and high traffic volume
Straight asphalt 60/80	Typical region with high traffic volume
Straight asphalt80/100	Snowy cold region

※40/60、60/80、80/100 represent the grades of penetration.

Penetration grade	40～60	60～80	80～100
Penetration (at 25℃) /10mm	40～60	60～80	80～100
Softening point ℃	47.5～55.0	44.0～52.0	42.0～50.0
Ductility (at 15℃) cm	≧10	≧100	≧100
Toluene solubility %	≧99.0	≧99.0	≧99.0
Flash point ℃	≧260	≧260	≧260
Thin film rate of mass change by heating %	≦0.6	≦0.6	≦0.6
Residual penetration of thin film after heating %	≧58	≧55	≧50

Penetration rate after evaporation %	≦110	≦110	≦110
Density (15℃) g/cm^3	≧1.000	≧1.000	≧1.000

B) The general application of modified asphalt is as shown below

Polymer modified asphalt Type Ⅰ	Abrasion resistance
Polymer modified asphalt Type Ⅱ	Resistance to abrasion, plastic deformation
Semi-blown asphalt（AC-100）	Resistance to plastic deformation

※Semi-blown asphalt (AC-100) is formed by applying light blowing to straight asphalt to improve its sensibility to temperature and thus raise its viscosity.

Source：Guide on Pavement Construction（japan Road Association 2006）

3) Asphalt mixture

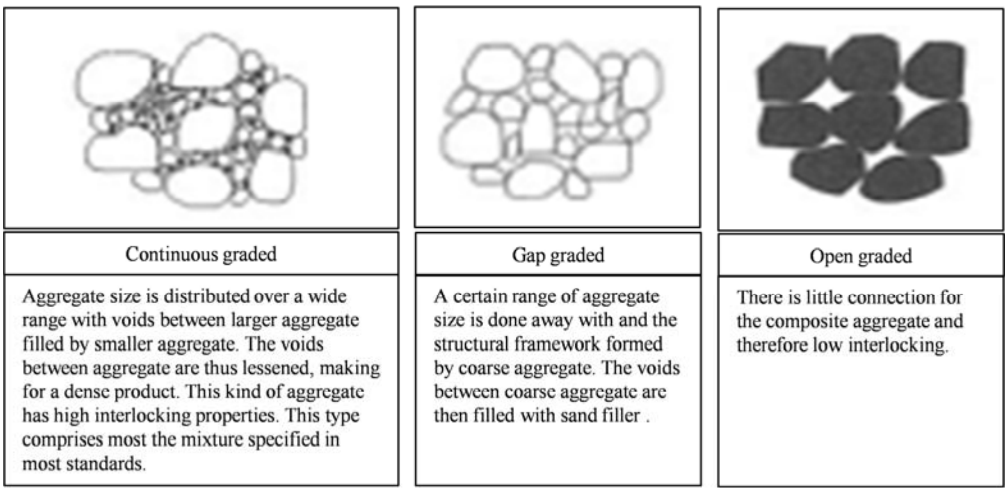
Asphalt mixture can be classified into a number of types depending on the composite materials (aggregate, asphalt binder, additives, etc) and the contents of their mixing. The general classification is as shown below:

Table1.4.2 The main types of asphalt mixtures

Type of mixture	Maximum grade size (mm)	Thickness upon finishing(cm)
Course graded	20	4-6
Dense graded	20	
	13	3-5
Fine graded	13	
Fined graded gap	13	
Open graded	13	3-4
Porous	20	4-5
	13	

Source: Guide on Pavement Construction (Japan Road Association, 2006)

A) Asphalt mixtures, in accordance with the grade of the composite aggregate, can largely be classified into continuous graded (dense graded), gap graded and open graded types. A conceptual diagram of these grades is shown below.



B) Comparing mixtures of maximum grade sizes 20mm and 13mm, in general, the former show better qualities of resistance to plastic deformation, abrasion and skidding whereas the former show superior water tightness and resistance to cracking.

C) In general, materials with superior qualities for resistance to plastic deformation are desirable for surfaces under heavy traffic conditions whereas superior qualities of deflection, water tightness and resistance to cracking are better for other types of traffic.

Table1.4.3 Main types of asphalt mixtures

Design standard	Guide on Pavement Construction		South Africa		
Type of mixture	Dense graded	Dense graded	Continuous graded	Continuous graded	Continuous graded
Maximum grade size(mm)	20	13	20	14	10
28			100		
26.5	100				
25					
20			80-100	100	
19.0	95-100	100			
14			-85	80-100	100
13.2	75-90	95-100			
12.5					
10				-85	80-100
9.5					
7.1					-85
4.75	45-65	55-70			
2.36	35-50	35-50			
2			23-49	29-58	32-67
0.6	18-30	18-30			
0.3	10-21	10-21			
0.15	6-16	6-16			
0.075	4-8	4-8	2-8	2-10	2-10

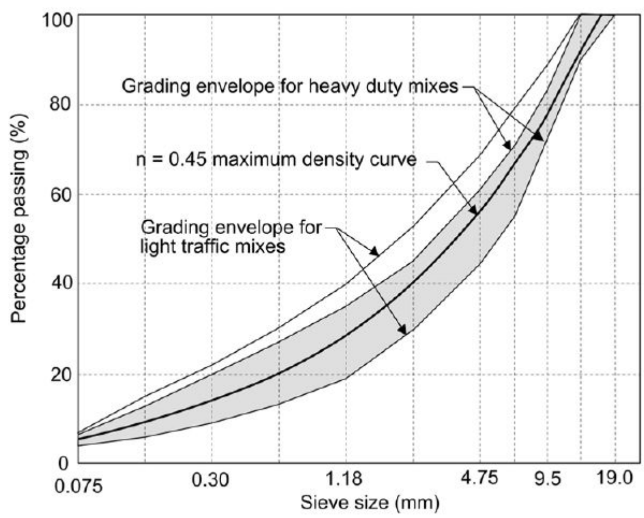


Figure 1.4.1 Dense grades in Australia(continuous grades, maximum grade size 14mm)

(2) Material tests

The tests indicated below are prescribed for material testing for asphalt mixtures in the respective countries.

Table.1.4.4 Material tests for asphalt mixtures

Name of standard	Guide on Pavement Construction (2006)	South Africa	Australia
Asphalt	Asphalt test for penetration grade Modified asphalt test	Penetration Grade Test PG Test	60℃の粘度で分類 改質アスファルト試験
Aggregate	Gradation test Specific gravity test for absorption rate Test for rate of wear Stability test	Hardness/Toughness Soundness Durability Shape/Texture Water absorption Cleanliness	Particle size and grading Particle shape Surface texture Resistance polishing Abrasion resistance Durability Strength Cleanliness Particle density Absorption
Filler	Gradation test Test for specific gravity	Sieve Density Methylene blue	Particle size distribution Moisture content Particle shape Water solubility Loss on ignition Clay content Plasticity index Compacted void content

With grant aid projects, as generally the contractor conducts daily quality control, construction costs are calculated on the premise that a laboratory is constructed for daily quality control. However, in cases where special tests or test numbers are few or in case of approval tests for materials, testing duties are sometimes consigned to another party. In a lot of developing countries, test centers are not obliged to provide certification for measurement and problems with the accuracy of the testing equipment exist. Therefore, there are cases where even though testing conducted through a testing center during construction showed results in line with the respective specification, testing with a different party made it clear that the standard requirements were not met. In such cases where testing is to be entrusted to another party, prior checking should be conducted over various options and the duty assigned to the party with the highest reliability. Alternatively, testing can be consigned to multiple parties and double checking conducted. Also in some cases, for example in Ghana, the consultant as well as the general contractor are obliged to set up a laboratory.

1.4.2 Points of consideration for mix design and testing

(1) The method of mix design (Marshal mix testing)

Although hot mix asphalt is mostly used for the surface course in asphalt pavements, it is standard to ensure that the surface has sufficient qualities for resistance to rutting due to plastic deformation. Therefore, in determining the qualities of asphalt mixtures, mix design is very important. Mix design is the process of determining the contents of asphalt and aggregate necessary to secure the required resistance to rutting due to plastic deformation and other qualities. In Japan, the Marshal mix testing method is applied. Standards for pavement design applied in developing countries also apply the Marshal mix testing method, although the Marshal test standards during testing and the evaluation methods at the testing stage for the effect of compaction due to passing traffic upon opening to service vary with the applied standard.

Table1.4.5 Outline of the Marshal mix testing method

Design method	Marshal Method
Outline	The type of mixture as well as the materials to be used are selected in accordance to the conditions of climate, traffic, etc and the content of aggregate determined accordingly to satisfy the gradation standard. Under various amounts of asphalt, after subjection to a number of compaction blows corresponding to the traffic conditions, a test cylinder is prepared and subjected to Marshal testing. The design asphalt content is then set to a value within the range that satisfies the mixture standard (usually the median). This method is prescribed in the Guide on Pavement Construction, ORN19 and other places worldwide.
Selection method of the materials to be used	1) Asphalt: Determined in accordance with climate, region, traffic conditions, area of application etc. 2) Aggregate: Should satisfy the respective standard; stable and obtainable.
Evaluation method of the aggregate	1)coarse aggregate: cleanliness, gradation, particle shape, strength, abrasion, polishing, water absorption, stability, content of contaminants, resistance to peeling (Guide on Pavement Construction, ORN19 etc) 2)Fine aggregate: Cleanliness, stability, gradation (ORN19, etc)
Selection method of amount of asphalt	Mixture standard：Asphalt content selected from the range that satisfies the required standard(air voids, voids filled with bitumen, voids in mineral aggregate, stability, flow value). This value is usually the median. Standard items and values vary with different organs. (Guide on Pavement Construction, ORN19)
Final evaluation method	The number of turns necessary for plastic deformation to occur determined if necessary(Guide on Pavement Construction, ORN19)
For heavy traffic roads	Polymer modified asphalt is selected, subjected to a number of compaction blows in accordance with the stability standard, and performance tested by determining the number of cycles for plastic deformation.(Guide on Pavement Construction)
Consideration of climate factors (hot or cold)	Adaptation for hot climate is similar to adaptation for heavy traffic. Adaptation for cold weather is accounted for in the selection of asphalt and types of mixture (Guide on Pavement Construction)

Diagram: mounting equipment for Marshal stability testing (with automatic recorder)

Used in determining the stability of the composite materials in an asphalt mixture as well as the flow value. It is used in measuring stability and resistance to plastic deformation for asphalt mixtures of maximum grade size 25.4mm and below.

Marshal compaction test equipment (Crank type)

This equipment is used in preparation of a test cylinder for Marshal testing. A rammer is let down from a regular height over a mold placed on the compacting stand for a specific number of turns to compact the mold content.

The Marshal test standards for each pavement design standard are as shown below:

Table1.4.6 Outline of the Marshal test

Type of mixture		Dense grades(20)	Dense grades(13)
Number of compaction blows	1,000≦T	75	75
	T＜1,000	50	50
Air voids ratio (%)		3-6	3-6
Voids filled with asphalt (%)		70-85	70-85
Stability (kN)		4.90 (7.35)	4.90 (7.35)
Flow value (1/100cm)		20-40	20-40

1. T refers to the pavement planning traffic volume (vehicles/day/direction). Pavement planning traffic volume is an average value of heavy traffic over the design period. T=1,000 corresponds to about 2.7×10^6 ESALs[3]
2. The value of stability indicated in parentheses is the standard when 75 blows are administered for compaction.
3. Volume of voids in mineral aggregate of 15% and above is desired for maximum aggregate size of 20mm and 16% and above for 13mm. Stability/flow value should be in the range of 2,000 to 4,900kN/m for a typical region.
4. The design asphalt content for the surface mixture in a typical region where plastic deformation is feared should be set below the median value in the range shown for Marshal standard testing.
5. Measures against plastic deformation are conducted by performing wheel tracking tests to determine dynamic stability through which resistance to plastic deformation is evaluated. Target DS, as shown in Table1.3.5, should be set to at least 1,500 turns/mm for pavement planning traffic (T) of less than 3,000 vehicles/day/direction and to 3,000 turns/mm for T≧3,000 vehicles/day/direction.

Table1.4.7 Marshal test standards（Reference：ORN）

a. For 80kN ESALs＜5×10^6 (98kN ESALs が 2.2×10^6)

Category and design traffic （$\times10^6$ esa）	Marshal compaction blows	Least stability (N)	Flow (mm)	Voids filled with asphalt (%)	Air voids at optimum asphalt (%)
Heavy(1-5)	75	8000	2-3.5	65-75	4
Madium(0.4-1)	50	5300	2-4.0	65-78	4
Light(-0.4)	33	3300	2-4.5	70-80	4

Note 1. Air voids at optimum asphalt of 4% is applied regardless of the traffic level.

Source：ORN19 P20 Table6.3

b. For 80kN ESALｓ≧5×10^6 (98kN ESALs が 2.2×10^6) (ORN19)

Category and design traffic （$\times10^6$ esa）	Marshal compaction blows	Minimum stability (N)	Flow (mm)	Voids filled with asphalt (%)	Air voids at optimum asphalt (%)
Very heavy(>5)	75	9000	2-3.5	65-73	5

Source：ORN19 P20 Table6.4

[3] Engineering standard for pavement structures (Japan Road Association, July 2001. On P57 Fig.2-5, the 49kN conversion wheel turns was set to 1,200,000 wheel turns each ten years, for 1,000 vehicles of heavy traffic. By applying the fourth power law, the number of axles equivalent to 80kN axle load, by calculation yields 2.710^6 ESALs)

(2) Points of consideration for mix design

The points of consideration during mix design for asphalt are as follows:

1) Laboratory mix design: Aggregate and aggregate content
   a. Do the aggregate qualities satisfy all of the required specifications?
   b. Do the coarse aggregate have all the required fractured surfaces?
   c. Isn't there excess of natural sand used?
   d. Isn't there excess of aggregate passing through the 0.075mm sieve?
   e. Are there contaminants of organic matter or clay?
2) Laboratory based mix design; bitumen (asphalt)
   a. Has the right type of asphalt in terms of grade (penetration) been chosen in consideration of climatic conditions, traffic?
3) Laboratory based mix design; bitumen (asphalt)
   a. Does the type of mixture fit the specifications of the respective design standard?
   b. Do the aggregate in the mixture fit the gradation range specified? Has the availability of the aggregate as well as variation during manufacturing of the mixture been properly accounted for?
   c. Has the design method been stipulated?
   d. Have traffic conditions been properly accounted for in setting the conditions for preparing the test cylinder to be used in mixed design?
   e. Does the design standard of the mixture apply for the respective layers and traffic conditions? What are items and their specification according to the standard?
   f. Have the methods been stipulated for mix testing, data compilation or setting of the optimum asphalt content?
   g. Have tests been stipulated for particular site conditions, such as submerged Marshal stability testing for water tightness?
4) Trial mixing at the asphalt plant to be used in construction, trial construction
   a. Is there a plan in place by which mixture qualities set through laboratory tests can be verified to check that they satisfy the requirement of the respective standard?
   b. Is the scale of trial construction indicated? Can a working standard be prepared for the equipment to be used in actual construction?
5) Gradation control for the asphalt mixture
   a. Have sieve sizes as well as allowable range of grades that apply to gradation control been specified. Have the contents for the aggregate passing the sieve sizes of 2.36mm and 0.075mm, most vital for the mixture quality been specified?
   b. For the start of works and when the construction process has attained normal stability, is there setting for the frequency of testing, the use of control charts, correcting devices, etc, for gradation control?

Other points of consideration include the following:

1) For cases where plastic deformation is a threat, such as areas with a high volume of heavy traffic

In recent times, due to a rapid increase in the number of vehicles on the roads as well as larger vehicle sizes, pavements designed by Marshal stability tests tend to cause premature failures such as rutting. One effective measure against this problem is the use of pavement with high resistance to plastic flow. The points of consideration for Marshal stability tests performed for the mix design of such types of pavement are as shown below:

a. General thinking on the setting of target gradation

The points of consideration for the setting of target gradation include:

A. Gradation range indicated in the specification.

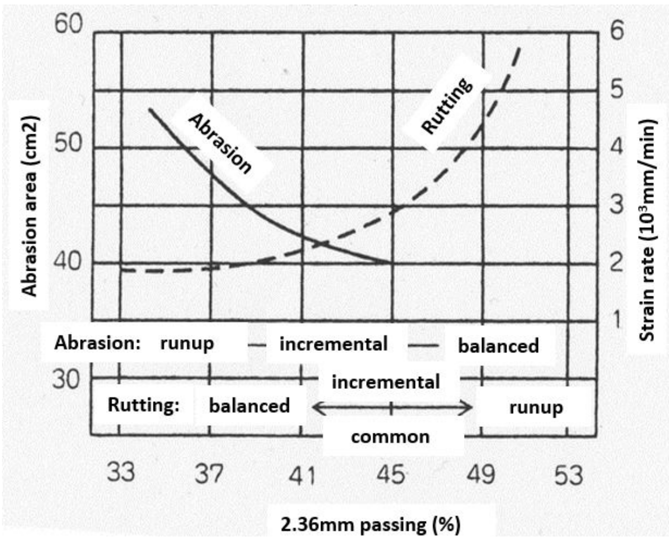
B. Condition of the construction site (traffic, climate conditions)

C. Economic factors (availability of the intended materials of use)

D. Workability

Even though the requirement that condition A is met is obvious, it is desirable that the other conditions are considered collectively in accordance with the scale of works and reference to previous cases.

The durability features of resistance to plastic deformation and abrasion of an asphalt mixture change greatly in accordance with the composite gradation. The graph below shows the relationship between the "content of aggregate passing the 2.36mm" and durability.



Source: Engineering memo (1998 Japan Highway Public Corporation research)

Figure 1.4.2 relationship between resistance to plastic deformation, abrasion and the content of aggregate passing the 2.36mm sieve

When the content of aggregate passing the 2.36mm sieve is:

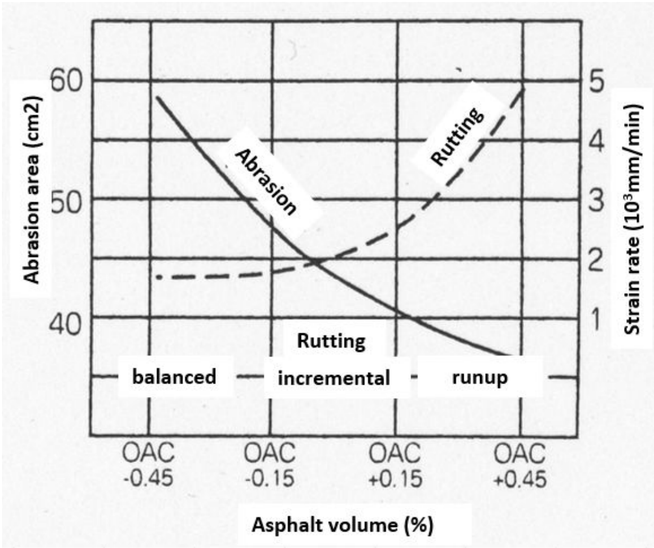
1) Smaller (coarse gradation) ⇒resistance to plastic deformation GOOD, resistance to abrasion POOR

2) Larger (Fine gradation) ⇒resistance to plastic deformation POOR, resistance to abrasion GOOD

Also, although the thinking that the median value of the gradation range is ideal for target gradation is common, from Fig.1.4.2, it is clear that in most cases, this is not always necessarily true.

b. Setting the optimum asphalt content in accordance with the target gradation

The content of asphalt (bitumen), similarly to the aggregate content passing the 2.36mm sieve greatly affects the durability of the mixture. Fig.1.4.3 shows the relationship between the content of asphalt and the durability of the mixture.



Source: Engineering memo (1998 Japan Highway Public Corporation research)

Figure 1.4.3 relationship between resistance to plastic deformation, abrasion and the content of asphalt

When the asphalt content is:
Smaller:⇒ resistance to plastic deformation GOOD, resistance to abrasion POOR
Larger ⇒ resistance to plastic deformation POOR, resistance to abrasion GOOD

The median value in the allowable range (the asphalt content mid value of the range that satisfies all the standards) is generally taken as the design asphalt content. However regarding item B “condition of the traffic site”(traffic volume, climate conditions), for roads where the traffic volume is high, a lower value than the median value can be adopted.

As shown above, mix design in regard to resistance to plastic deformation and to abrasion involves contrary conditions. A balanced mix design should therefore be conducted with consideration made for the climatic features of the respective region and traffic volume.

Table1.4.8 factors affecting resistance to plastic deformation, abrasion

Resistance to plastic deformation	Factor	Resistance to abrasion
Less is GOOD	Content of aggregate passing the 2.36mm sieve (fine aggregate)	More is GOOD
Harder is GOOD (40-60＞80-100)	Penetration grade of asphalt	Softer is GOOD (40-60＜80-100)
Less is GOOD	Asphalt content	More is GOOD
-	Quality of coarse aggregate	Harder is GOOD
Sharper edges GOOD	Shape of fine aggregate	-

This marks the theoretical thinking and measures for resistance to plastic deformation of asphalt pavements.

In cases where plastic deformation is a threat, such as when the volume of heavy traffic is high, the following considerations ought to be made during mix design:

a. Is the framework of the design standard about to be applied have respectable?

b. In case of performance of mix design by the Marshal method, is there direction that specifications for heavy and very heavy traffic be applied? Is there consideration for the use of the mid value or the lower limit of the gradation range (conversion of the content passing the 2.36mm sieve)? Is the number of blows specified in accordance with the traffic level; are the volumetric properties (volume of air void, VMA, voids filled with asphalt)?

c. Is the grade (type) of asphalt to be used obtainable, with the lowest penetration grade and the highest clay grade in light of the considerations of item c above?

d. For verification and correction for the optimum asphalt content (OAC) obtained from the Marshal test, in case the refusal density method is to be used, are previous examples of its application indicated?

e. Has planning been made for wheel tracking tests to verify dynamic stability (DS)?

2) Points of consideration in cases where variation of the specific gravity of aggregate is feared

Variation of the specific gravity of aggregate during the manufacture of the asphalt mixture causes irregularities to arise. If the specific gravity of aggregate from trial mixing becomes larger, the amount of asphalt binder increases making the mixture more vulnerable to rutting. On the other hand, smaller specific gravity of aggregate results in poor adhesion of the asphalt mixture. This phenomenon can also be deduced from contemporary theories on volumetric mixing. Therefore, it is desirable that a steady range of specific gravity of aggregate is kept as much as the aggregate source is constant.

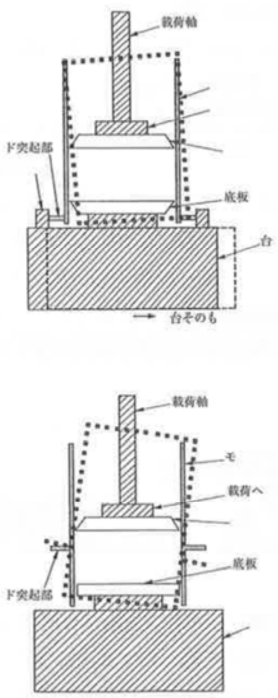
3) Points to be considered when variation of the aggregate gradation is feared

The gradation distribution of aggregate greatly affects the asphalt content. If there is a possibility of the stone material used for crushed stone or the grade distribution of sand changing (due to change in layer or location for the aggregate source, change in the equipment for the crushing plant, etc), such means as increasing the frequency of conducting sieving tests should be taken and proper control maintained. If the gradation distribution significantly changes such that it can be thought to affect the asphalt content, mix design for a different composition of the mixture becomes necessary.

(3) Application of new knowledge on mix design

Marshal mix design conducted worldwide to determine the proportions of the components of an asphalt mixture involve determining the aggregate grade and preparing several test cylinders under varying proportions of asphalt. However, a number of study reports indicate the problem that certain features as volume of air voids obtained from test cylinders prepared by compaction with a Marshal rammer do not represent the true qualities of asphalt concrete. This is because, while the load applied by compaction with a Marshal rammer is one of shock, the load applied by a compacting roller or by passing vehicles is one of kneading and the two are different.

As a counter measure to this challenge, determining the mix proportions by management of gradation range, aggregate integration, voids by application of a gyratory compactor has been suggested. In this compaction method, the test stand revolves and compaction is carried out at a steady angle of transverse. The Super Pave Gyratory Compactor used in the U.S.A is well known.



Source: Guide on pavement studies and test methods, Japan Road Association

Figure 1.4.4 Gyratory compactor

(4) Evaluation of aggregate integration（Bailey Method）

The Bailey Method is a system developed by Bailey of the U.S.A to determine aggregate proportions based on the aggregate’s structural framework. The method, by classifying 4 different ways in which aggregate fits together (packing), can make qualitative evaluation for the aggregate.

(5) Evaluation methods of asphalt mixtures

Evaluation of the performance of a finished asphalt mixture in the countries of this study is as shown in table 1.4.10.

Table1.4.10 Mix design／Evaluation at the construction stage

Item	Japan	Australia	South Africa
Evaluation method	Evaluation of resistance to plastic deformation is conducted by performing wheel tracking tests. Also, the following tests are conducted as per need; permeability tests, tests for wear, texture depth	Resistance to plastic deformation is evaluated by the volume of air voids after the maximum number of turns of the gyratory compactor. Performance of a pavement’s resistance to plastic resistance is tested by conducting wheel tracking tests. Other tests performed for resistance to peeling, resilient modulus, etc.	Hamburg wheel tracking test and MMLS (mobile load simulator) used for plastic deformation resistance tests. MMLS can be performed for several test cylinders of different mix proportions.
Trial construction	Trial kneading may be skipped for materials that have been certified in a system of prior examination. Trial construction is conducted in accordance with the scale of the construction and type only when necessary.		Mix design consists not only of laboratory tests, but also of kneading at the plant (full production) and confirmed by trial construction stretching over 200m, repeated until the specification is satisfied.

Also, standards for wheel tracking tests vary with country. For example the BS load standard is 520kN, smaller than the Japanese standard of 686kN and would thus yield a larger DS value.

The TR (transformation rate) =5.0mm/hr and less, specified in the British Standard, is equivalent to the DS value of 504 turns/mm. Even though the British Standard separates the testing temperatures of 60℃ and 45℃, both standards are milder than the Japanese standard.

Table1.4.11 BS wheel tracking test limit values as compared to the Japanese standard

Item	Japanese standard	BS
Method of analysis	DS（turns/mm)= 15 X 42/(d60－d45) d60：TR after 60minutes d45：TR after 45minutes	T_R (mm/hour)=3.6(rn－r(n3)+ 1.2(r(n－1)－r(n－2) rn：n TR after n minutes
DS conversion from T_R =5.0mm/hr	No. of runs for 60minutes = 60x42turns＝2520turns Mm/hr = 2520mm/turns Therefore,5mm/hr represents 5/2520mm/turns, the reciprocal of which yields DS = 2520/5 = **504 回/mm**	
Maximum rut ＝7.0mm	TR after 45minutes of passage	

1.4.3 Points of consideration for management of an asphalt plant

(1) Types of asphalt plant

There are two types of asphalt plants; batch and continuous types. An overwhelming majority of the plants in Japan are batch types. The different features of asphalt plants are as shown in table 1.4.12.

Table1.4.12 Type of the asphalt plant

Item	Batch plants	Continuous plants
Features	A measurement for each material is introduced to the mixer and mixing carried out for each batch.	A determined volume of the composite materials is introduced to the mixer and mixing performed continuously.
Advantages	1) Output materials of the cold bin are sieved with a screen and measured, generally making quality control easier. 2) Well suited to small quantities of different types of mixtures	Screen, hot bin, hot elevator are all unnecessary making it compact and inexpensive and easy to increase productivity. For the production of one type of mixture, steady production in large quantities is possible
Disadvantages	As compared to the continuous type, more equipment is required.	1)The quality of output materials is directly affected by control of the cold bin 2) Not suited to small quantities of different types of mixtures

※Some large pavement companies in Australia use continuous plants, although the disadvantages of this method are covered through detailed classification of the cold bin materials and installation of six storage silos.

(2) Points of consideration for plant quality control

The purpose for quality control of asphalt plants is to ensure a steady supply of uniform products that meet the respective standards. However, as shown in Table1.3.3, there are cases where improper control was observed.

Plant control is mainly classified into two types namely, periodic control and daily control. Periodic control involves the basic tests and inspection procedures taken at the plant for delivery of mixtures for which the mix proportions have been determined. Daily control involves the conduction of tests and inspection on the manufactured mixture to verify if it meets the requirement of a determined mix design. The former is conducted periodically (once per year or per month) at the establishment of the plant, before commencement of works, etcetera, when production has been halted whereas the latter is conducted daily during production.

In other words, control/management should be conducted with a proper understanding that, it is necessary first of all to conduct periodic control to ensure that the necessary conditions are set for a plant to provide a steady supply of mixture suitable to the respective works. Next, daily control is conducted based on the data obtained from periodic control to verify that the production rate, materials, kneading, etc of the mixture are within the allowable range, and there is no variation or defects. Examples of recommended periodic and daily control are shown in Tables 1.4.13 and 1.4.14.

Table1.4.13 Example of periodic control of an asphalt plant

Control Item	Area of control	Contents of the control	Recommended frequency
Plant facility	Scale *（Batch style）	Accuracy of measure	Before commencement of works Once per year
	Cold bin	Flow rate of aggregate and calibration of the feeder output.	Before commencement of works Once per year
	Thermometer	Time lag and error of the thermometer (temperature displayed)	Before commencement of works Once per year
	Asphalt discharging device	Amount of asphalt discharged.	Before commencement of works Once per year
Material	Aggregate	Gradation	During testing for the materials standard. During mix testing During test kneading
		Other aggregate properties	During mix testing About twice a year thereafter
	Filler, asphalt	Test of properties	Verification from the maker's test report During mix testing Frequency recommended by the maker thereafter
	Mixture	Mix testing	Before commencement of works
		Screening test of the hot bin (mix proportions of the hot bin and determination of the composite gradation)	Before test kneading During test kneading During test paving
		Extraction test (Amount of asphalt, verification of the mixture	During test kneading During test paving

		gradation)	
		Marshal test (standard density, air void ratio, stability)	Before test kneading During test kneading During test paving

Note：*It is desirable that a recording device of the measurements is installed. During inspection of the scale, records from the recording device are printed and verification made to check whether the values stipulated by the measure scale and the printed records match.

Table1.4.14 Example of daily control of an asphalt plant

Control Item	Area of control	Contents of the control	Recommended frequency
Aggregate at room temperature	Stock yard Cold bin	gradation	Every day materials are received Verify if there are no deviations from the record of periodic control
Heated aggregate	Hot bin	gradation Screening test of the hot bin	Every day of delivery
Mixture	Kneaded mixture	Extraction test	Every day of delivery Are the amount of asphalt and gradation of the mixture within the allowable range of the standard
		Marshal Test	Every day of delivery Are standard density, air void ratio and stability within the allowable range of the standard
	Operation board and an automatic recording device	Printed record	Every batch Is the measure (printed record)within the allowable range of the standard?

Note：It is desirable that control of gradation and the amount of asphalt is conducted by making use of the result of the printed record.

Screening test of the hot bin: Gradation should be checked for each hot bin (type of aggregate).

In case irregularity is found in the daily control, delivery should be immediately stopped and inspection carried out over the defective area. Also, depending on the extent of irregularity, it may be desirable to increase the frequency of the periodic control.

Although control of the hot bin mix proportions is typically conducted by use of a computer, (control by printed records), cases of irregularity in the actual mix have been observed. This is likely to be caused by disproponation of particle size in hot-bin due to a clogging of screen. In this case, an extraction test is required because a control by printing dose not correspond to this situation. And content of asphalt is not main concern. In such cases, it is necessary to clean up the plant’s screening device, re-conduct the screening test for each material, adjust the speed of the screen conveyor, check the source of material, etcetera. Figure 1.4.5 shows the flow of daily control for the asphalt plant of one construction project.

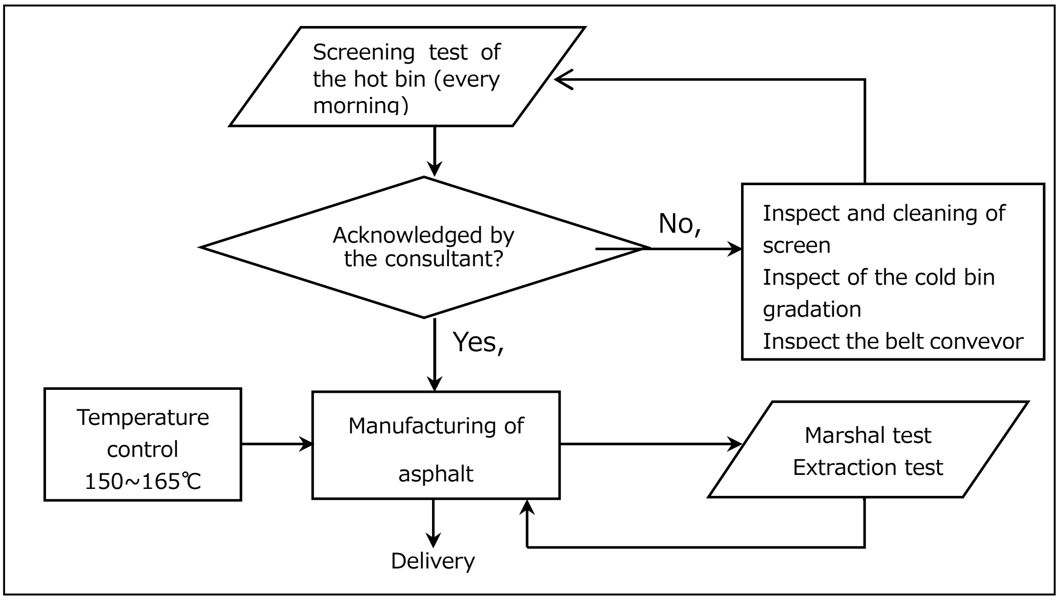


Figure1.4.5 Example of daily control at an asphalt plant

1.4.4 Attention points for construction and construction equipment

As an example of a project conducted in Cambodia with a Japanese grant, following construction equipment were utilized under proper management.

Construction of subbase course
Levelling: Motor grader
Rolling: 10t Vibration roller (vibration force of 17 to 25t), 16 turns (once one way)
Thickness of the finished layer: 200mm (finished in 2 layers of 400mm total thickness)

Construction of base course (mechanically stabilized aggregate course)
Levelling: Base paver (asphalt finisher)
Rolling: preliminary rolling by auxiliary use of a 10t Macadam roller
Initial rolling with a 10tvibration roller (vibration force of 17 to 25t), 16 turns (once one way)
Secondary rolling with a tire roller 12 to 16t, conducted until roller marks have disappeared
Thickness of the finished layer: 125mm (finished in 2 layers of 250mm total thickness)

Construction of base course (stabilization of asphalt)
Levelling: Asphalt finisher
Rolling: Initial rolling with a 10t Macadam roller (4 turns)
Secondary rolling with a 12 to 16t tire roller (18 times, once one way)
Finish rolling with a 7t tandem roller; conducted until roller marks have

disappeared

Thickness of the finished layer: 100mm

Generally, vibration rollers are rarely used for the construction of base courses in Japan. A general lack of versatility with pavement construction companies, higher cost than the Macadam roller, effect of vibration on the surrounding environment, etc are all possible factors responsible for this tendency. However, vibration rollers have the advantages of easy transportation to the site and good compaction ability.

Formation of construction, number of rolling turns, etc were determined by performing trial construction (sometimes conducted multiple times as par need) and were therefore suitable.

During construction, water was suitably applied to adjust the moisture content in consideration for compaction. As the strength and stability of base course crushed stone especially are improved by increase in density, this was noted as a good practice.

In another site (Mid country section), a base paver was used for levelling and a vibration roller used for rolling. The thickness at the construction time was 270mm (it is unclear whether the levelling thickness was equivalent to the finished layer thickness). Even though the standard thickness for a single layer of granular base course materials is up to 200mm, this formation is acceptable, as long as rolling ability can be confirmed by performing trial construction,

1.5 State of construction management and attention points

1.5.1 Structure and role of construction management

(1) Consulting services for construction management

A construction management consultant, in representation to the client, after agreements have been made between the client and the contractor, in reference to the design document, determines, approves, orders the contractor accordingly in order to ensure that various stipulations of the contract are fulfilled. It is also the consultant's role to ensure that the contractor faithfully executes the necessary work since, alongside the client, the consultant bears technical responsibility for the works upon completion. Concisely, the consultant performs the following duties as a representative of the client:

a) Formalities for bidding, evaluation and advice to the client

b) Selection of manpower for special works, and delivery of materials

c) Supervision of different works during construction

d) Response to any problems arising during construction

e) Point out technical faults to the contractor.

f) Provide certification in accordance with the terms of the contract

g) First point of reference in case of disagreement between the client and the contractor in regard to the contract terms.

The consultant conducts technical analysis of construction as it proceeds, and has the responsibility to make approval or deliver orders to the contractor regarding the items indicated below:

a) Approval for the personnel provided by the contractor.

b) Approval for the stages of construction as well as the time period.

c) Approval for the items of construction.

d) Approval for the amount of the money preliminarily paid to the contractor.

e) Delivery of certification for encountered expenses

f) Certification for completed works and the funds involved.
g) Certification for completion of works and construction period
h) Certification for unexecuted contract terms

(2) Details of the content of consulting services

The consultant, as one in charge of supervising the construction process, bears responsibility for quality control. Indicated below is the flow for pavement works. The consultant is responsible for making confirmation of the quality control conducted by the contractor at every stage of construction.

Flow of pavement works	Client	Consultant	Contractor	Manufacturer
Mix design of pavement ↓	◎	◎	○	○
Manufacture (at the plant) ↓	◎	◎	○	○
Paving works ↓	◎	◎	○	
Inspection	◎	◎	○	

◎ : **Supervisor （verifier）、○Executor**

Figure 1.5.1 Flow of the construction of pavement and approval

A management system where quality control during construction is conducted by the contractor and the consultant engineer has been adopted. “SAPEM” in South Africa stipulates the contractor’s role as “Quality Management” and the consultant’s as “Quality Control”.

Table1.5.1 Quality Management versus Quality Control

Quality Management (Contractor)	Quality Control (Engineer)
Prevents problems	Reacts to problems
Does the right thing	Does the right thing
Controls activity	Provides end inspection
Involves all people in the organization	Places reliance on quality control specialist
Places responsibility for quality with the people who do the work	Client supervision

Source : South Africa Pavement Engineering Manual

According to SAPEM, the role of the consultant as a representative of the client covers the following activities:

a) Client’s contract policy

b) Project organization

c) Responsibilities and authority regarding contract terms (setting and removing of hold points, management and inspection, removal of irregularity)

d) Procedure (contract management, disputes, changes in contract money, confirmation and correction of irregularity, supervision including inspection, site discussions, purchase and lease, hold points and witnessing, recording, training)

e)Time schedule required by all the concerned parties

f) Inspection schedule based on the contract.

Also, the importance of the role played by material supervisory staff participating in construction management conducted by the consultant is indicated and staff capable of conducting the following activities is required.

a) Knowledge of the specifications and demands of the project.
b) Characteristics of the raw materials and evaluation of their properties.
c) Selection and usage of materials
d) Assessment of materials and sensibility to changes
e) Proper plant management.
f) Thorough work process and technique
g) Consideration for the natural environment (weather and temperatures)
h) Visual verification of completed sections.
i) Material tests in suitable areas.
j) Flatness, width, management of layer thickness
k) Smooth surface finishing
l) Assessment of completed works and report of the results.
m) Knowledge of SANS17025 and ISO17025
n) Knowledge of the quality of the testing site and inspection of the procedures
o) Recording of work completion

(3) Structure of consulting services

Results of investigations on consultancy show that projects conducted under grants provided by Japan typically involve one or two Japanese personnel serving as resident construction supervisor alongside 2 to 4 of the local engineers.

However, pavement works in each of the countries looked at in this study showed that works involve highly experienced personnel working as resident supervisor, pavement engineer, quality control engineer, and a local engineer in addition, installed to conduct construction management.

Also, studies conducted heretofore show that irregularities of pavement works mostly arise from the use of poor materials and improper plant management (poor plant quality control).

Even today, there are consultancy firms that dispatch experts of pavement engineering for proper control of mix design and setting up a plant.

Since responsibility for verification of proportions lies with the consultant, quality control in accordance with the construction terms should not be left wholly to the contractor but, but instead there is need that the consultant works in collaboration with the contractor.

There should be collaboration with the contractor to solve any problems arising with the structure and the conditions.

There should be cooperation with the contractor in conducting mix design and plant control.

1.5.2 Guide on preparation of construction management plan

(1) Contents of the plan

For projects where a construction management plan has been adequately prepared, the consultant can conduct proper supervision by overseeing works from obtaining test samples to conducting tests. When the consultant prepares a construction management plan, it is necessary that the frequency of such tests or overseeing is stipulated in consideration for the importance of quality control. A good construction management plan should at the very least provide information regarding the terms indicated below.

Construction Management Plan (Example)

1. Project Outline

1.1 Overview
1.2 Location Map
1.3 Plan and Typical Cross Sections
1.4 Contents and quantities of major works

2. Specific Conditions (External conditions) (depending on project characteristic)

2.1 Work area and land acquisition
2.2 Utility relocation
2.3 Regulated area such as national park
2.4 Problem soil
2.5 Drainage plan and network
2.6 Detour

3. Policy and System of Supervision

3.1 Policy
3.2 Task (Responsibility)
3.3 Structure (Role and responsibility)
3.4 Role and responsibility of contractor

4. Supervision Method (Quality and process management)

4.1 Applicable standards
4.2 Rule of instruction and approval
4.3 Approvals
4.4 Inspection items, schedule and method
4.5 Timing of meeting
4.6 Recordkeeping
4.7 Construction schedule and schedule management

5. Safety Management Plan

5.1 Safety policy, system and management by consultant
5.2 Points of attention
5.3 Emergency communications

6. Environmental Management Plan

6.1 Environmental management plan
6.2 Environmental monitoring plan
6.3 Applicable standards
7. Others
7.1 Update of management plan
Attachment
- Quality control items (control items, measurement method, standard, frequency, report, etc.)
- Inspection (Frequency, reject and correspondence, recordkeeping, etc.)
- Measurement workmanship (control items, measurement method, standard, frequency, report, etc.)

Regarding JICA projects, for projects post November 2015 approved by Cabinet, preparation of a construction management plan in making the contract was made mandatory, and must be specified in the consultant's agreement.

(2) An example of a construction management plan

Overseas projects funded by other donors or by the local government refer to the construction management plan as "Quality Assurance Manual" (QAM) or "Quality Assessment Plan". Below, we show a typical construction management plan used overseas. As can be deduced from the table below, the responsibility of the consultant is specified and clearly indicated in the plan.

1. INTRODUCTION
2. OBJECTIVE AND SCOPE OF QUALITY CONTROL
2.1 General
2.2 PRE-REQUISITES OF EFFECTIVE QUALITY CONTROL
3. QUALITY MANAGEMENT FRAMEWORK
(Clear indication of the Consulting structure)
4. RESPONSIBILITIES of the CONTRACTOR and the CONSULTANT
4.1 Contractor's Responsibilities
4.2 Contractors Construction Activities
4.3 Consultant's Responsibilities (Stipulation of each engineer's role)
5. QUALITY ASSURANCE SYSTEM
5.1 General
5.2 Method Statement
(specification for the standard, test and pass mark for each work section)
- Clearing & Grubbing: Annex 1
- Earthwork: Annex 2
- Sub-base: Annex 3
- Base Course: Annex 4
- Asphalt Concrete: Annex 5

- Pipe Culvert, Drainage: Annex 6
- Bridge: Annex 7
- Fabrication of RC Pipe: Annex 8

5.3 Inspection and Test Plan (ITP)

5.4 Request for Inspection (RFI) Book

5.5 Support Documents (Same unique number as the RFI)

5.6 Other Means of Communication, Confirmation and Action

6. QUALITY CONTROL TEST PRO FORMA

6.1 Pro forma for QC Tests

6.2 Survey Strip Layer Chart - Key Plan

Also, as an example in a project funded by Japanese grant in Laos, “National Road No.9 (East west corridor for the Mekon region) development plan”, the four plans shown below were prepared:

- PRPJECT MANAGEMNT PLAN（PMP）
- PROJECT QUALITY CONTROL PLAN (PQCP)
- PROJECT ENVIRONMENTAL CONTROL PLAN（PECP）
- PROJECT OCCUPATIONAL HEALTH AND SAFETY PLAN (POHSP)

1.6 Condition and attention points of construction management

1.6.1 Structure and role of construction management

(1) Role of the contractor

Construction management involves the selection of the construction means for a project (personnel, materials, method, equipment, capital) from which a construction plan is made regarding the management of funds, time, quality control, safety management etc in order to achieve a particular objective (appropriate quality, construction period, cost).

The contractor, upon coming into agreement with the client, bears responsibility to conduct works in order to construct the structures indicated by the client under the given conditions.

(2) Strengthening of the structure of construction management

Rutting observed in road projects funded by Japan in recent times can be attributed to "the use of poor materials" and "Improper plant management (the plant's quality management). Therefore, although this factor may be influenced by the scale of the project, it is desirable that, at the very least, a pavement construction engineer, quality control engineer (mix design), plant engineer have sufficient experience and expertise. Though we do not stipulate that the personnel for this work are Japanese, it is important that the contract indicates that the engineer provided for this work needs to be familiar with pavement engineering.

Primary responsibility for quality control lies with the contractor, and there are only a few with good knowledge of mix design, plant management and familiar with the details of the condition of the materials in the area of construction. From that viewpoint, it is important that collaboration is made with local pavement professionals familiar with local materials. In addition, collaboration with consultant's pavement engineer is essential.

(3) Review of the pre-qualification condition

Currently, the PQ (Pre-qualification) stage for grant funded projects only considers a company's financial condition, background for construction projects, etc, taking into account only the management and background conditions of the company. However, the pavement problems discovered in this study occur regardless to the size or background of the company. Therefore, the following knowledge if required for an engineer undertaking pavement works (construction and quality control).

Construction management: Knowledge of management of construction period, product and quality control, money management, safety management is included.

Construction methods for various pavement works: This knowledge is vital as construction methods, equipment significantly vary with varying pavement methods.

Proportions and manufacturing methods of materials: There are several types of materials used in pavement. Good knowledge is required in order to select and suitably determine proportions of materials that can be obtained, in order to satisfy the requisite performances indicated in the design.

Therefore, further discussion for the following requirements to the engineers in Pre-qualification should be continued.

1) Supervision of pavement construction

a) Level One certification for supervision of pavement construction.

b) Experience of pavement works under similar climatic conditions (hot or cold region); Experience of at least one previous work in a similar region (within or outside Japan) is desirable.

2) Management of asphalt plant

Managerial experience of asphalt plants within Japan (at least once)

3) Quality control (personnel in charge of mix design)

Experience with mix design of pavement (at least three projects, within or outside Japan)

Evaluation at the point of bidding may be considered; however, as contract talks are held in order of the lowest bids and there is need for preparation of both cost and technical standards, it is thought appropriate to set the above discussed conditions at the PQ stage.

1.6.2 Guide on preparation of construction management plan

The contractor should consider the following items during formulation of a construction plan

1) Contract items specified by the client

2) Location of the site and constraining conditions

3) Basic period of construction

4) Structure of construction personnel

5) Construction method and procedure

6) Quality control plan

7) Selection of equipment

8) Selection of materials and delivery method

9) Installation of temporary structures

10) Management of daily health and safety; structure for emergency response

11) Traffic management

12) Measures for environmental protection (prevention of noise and vibration, measures against water pollution, measures for disposal of construction waste, etc)

Also, the contents and attention points for preparation of a construction plan (prepared by the contractor, agreed upon by the contractor and the consultant) are as follows:

a. Understanding the respective documents: Design documents, study of specifications and contract terms, and items found out by conducting field survey.

b. Basic principle of construction: The construction items for each section and the standards and quantities, construction method for each section, types and number of construction equipment, construction procedure.

c. Management of construction period: Collection of material from which the number of days of operation can be deduced such as weather conditions, equipment, materials, productivity, etc, calculation of work efficiency from which an operation plan can be set, time management for each work section, time management for the total construction work.

d. Plan for temporary facilities

e. Temporary primary works: Facilities that directly affect the work at hand such as a temporary route, electricity source, water supply, plant, storage facility.

f. Temporary secondary works: Facilities that do not directly affect the work at hand but are necessary for facilitation. These include, accommodation facilities, cafeteria, laboratory, warehouse, etc.

g. Plan for equipment: List up of information on equipment regarding type, model, dimensions, manufacturer, required number, etc, planning for usage and periods of restraint.

h. Plan for materials: Calculation for the quantities required for each type of work, usage plan for each work section and time period.

i. Plan for labor: Number of personnel required for each type of work, personnel in charge; Labor plan for various works involved and the periods of operation.

j. Transportation plan: Type and number of vehicles necessary for delivering materials, equipment, temporary materials; route of delivery and traffic safety; permit for transportation of special materials and equipment.

k. Site management plan: Work safety management plan, equipment management plan

l. Construction management plan: Management for construction period, product control plan, quality control plan, photographing plan

m. Labor management plan: Selection of personnel in charge of recruiting labor, guidance for the subcontracting body,

Source: pavement engineering library-7. Fundamentals of pavement engineering

Also, the points of attention for preparation of a construction plan are as follows:

a. Which standard to apply

b. Can each material to be used in the mixture be obtained in the necessary amounts?

c. Does each material satisfy the quality specification of the respective standard?

d. What's the mix design method of the selected mixture? Does the mixture meet the requisite quality standard?

e. Is management for the asphalt plant management proper? Does production at the plant fit the standard?

f. Is the construction method proper in regard to the equipment and formation?

g. Has a proper plan for quality control been set?

h. Have the above items been properly indicated in the construction plan?

1.7 Conditions that require particular consideration

1.7.1 Problematic Soil

(1) What is problematic soil

Problematic soil refers to the type of soil that presents difficulty during road works. This includes scattered soil (Cambodia, Laos, etc.), soil prone to expansive soil (South Asia, East Africa, etc), etc. As these types of soil greatly affect the quality of road work, proper response should be taken when encountered.

(2) Definition of problematic soil

Table 1.7.1 Definition standard of problematic soil for each country

Standard. Year of issue	Definition of problematic soil	Points of attention
Guide to Pavement Technology Australia	Although PI is a good indicator to a certain extent, it is desirable that a expansion test is conducted (refer to Table1.7.2)	Counter measures have been standardized as expansive soil exists in some states.
Guide on Pavement design, road works; Guide on measures in soft soil (Japan)	The guide for measures in soft soil lists highly organic soils, organic soils and clay soils with high moisture content such as volcanic ash clay soils. Moisture content, expansion rate and the N value are included. The counter measures suggested include consideration of subgrade stabilization from which the most cost effective subgrade improvement method can be determined.	The soil test methods for determining problematic soils in developing countries vary
South African Pavement Engineering Manual 2013	Expansive soil and scattered soil are listed as characteristics of problematic soils. Also, damage by soils of high salt content in dry regions is separately discussed.	Knowledge on problematic soils is well indicated.
Tanzania Pavement and Materials Design Manual 2001 CML Test 1.9	In addition to regular soil tests (of PI greater than 20), additional detailed expansion tests are conducted for soils for which expansion is feared such as black cotton (Table1.7.3). As a measure against expansion, in accordance to the severity, replacement is suggested with consideration of the cost.	Existence, types, determination terms of problematic soils is well listed. Also identification of scattered soil is indicated. Damage by soils of high salt content in dry regions as well as measures against high salt content also indicated

*Scattered soil has a high content rate of natrium which is highly soluble in water

Table1.7.2 Standard for determining expansive soil in Australia

Expansive nature	Liquid limit (%)	Plasticity Index	PI x % < 0.425 mm	Swell (%)*
Very high	> 70	> 45	> 3200	> 5.0
High	> 70	> 45	2200–3200	2.5–5.0
Moderate	50–70	25–45	1200–2200	0.5–2.5
Low	< 50	< 25	< 1200	< 0.5

* Swell at OMC and 98% MDD using Standard compactive effort; four-day soak. Based on 4.5 kg surcharge.

Source ：Austroads, Guide to Pavement Technology, Part 2 Pavement Structural Design

Table 1.7.3 Classification of expansive soil for Tanzania

Expansion rate $\varepsilon_{e\chi}$	Classification
< 20	Low
20 - 50	Medium
> 50	High

In South Africa, the following tests are stipulated for determining expansive soil. However, clear figures are not indicated to classify a soil sample as prone to swelling.

a) Grade distribution

b) PI (Plasticity Index)

c) Rate of expansion

(3) Scattering Soil

【What is scattering soil?】

Soils that carry a possible danger of scattering include white silt. When dry, silt forms a hard lump. This type of soil however dissolves in rainfall and is vulnerable to erosion. When road embankment is conducted with this kind of soil, erosion or subsidence (forming what is termed as “dragon hole” in Cambodia, also referred as tunnel erosion, sinkhole) may occur greatly affecting the quality of road works.

According to a survey conducted by JICA in Cambodia, cement stabilization is effective as a means against the scattering of soil.


Photo: Dragon holes

Cambodia and Laos are largely faced with “dragon holes” which are holes vertically developing in embanked soil. The hole of 20 to 50 com diameter vertically forms in the upper surface or the side of embanked soil. As dragon holes have ben forming regardless of the contractor in charge, it can be said that the properties of materials used is mostly responsible. It is thought that the use of scattering soil prevalent in both countries is responsible for this problem.

【Measures against scattering soil】

In case the embanked soil is thought to contain scattering soil, means should be devised to prevent water permeating through to the roadbed. Here, cement or good quality soil are applied near the surface to create a water impermeable layer.

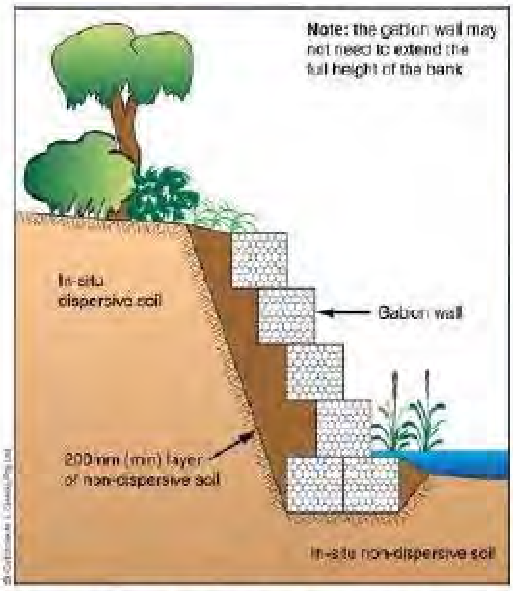


Figure 18 – Gabion stabilisation of gully banks containing dispersive soils

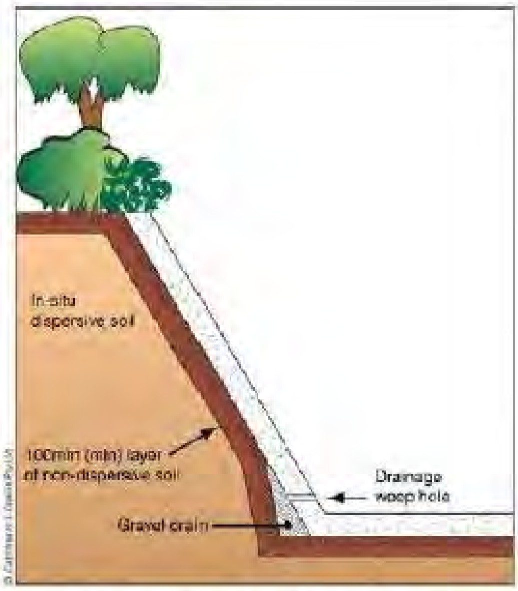


Figure 19 – Placement of hard linings over dispersive soils

Figure 1.7.1 Examples of measures against scattering: Installation of a gabion made of good soil, lining with concrete.

Photo：On site test for scattering clay soil measures

(4) Expansive soil（Black cotton soil）

【What is expansive soil?】

Represented mainly by black cotton soil, expansive soil is hard and has considerable bearing capacity when dry, but with increase in moisture content, the soil swells and loses the strength it had in the dry condition. From the wet condition when this soil type dries, contraction cracks develop presenting considerable difficulty in the construction of road.

AASHTO has classified swelling soils as A-7-6. Also, soils of high expansion rate, can have a change of volume rate of up to 30%. In terms of the features of the composite materials, despite the blackish grey color, there is little content of organic matter and a high content of swelling clay materials such as montmorillonite. Also, the soil has a high reactivity with alcohol.

Photo: Expansive soil in the wet condition (clay soil)

Photo: Expansive soil in the dry condition（CBR investigations may sometimes show high readings.）

However, road damage caused by expansive soil typically follows a particular pattern. A vertical crack develops at the edge of the pavement; and with the initial crack as a weak point pavement of failure proceeds. The pictures shown below are examples of pavement damaged by expansive soil.

Photo: Ethiopia; Main city road
Bearing capacity of the lower road section deteriorated by expansive soil（black cotton soil） leading to rutting of the surface.

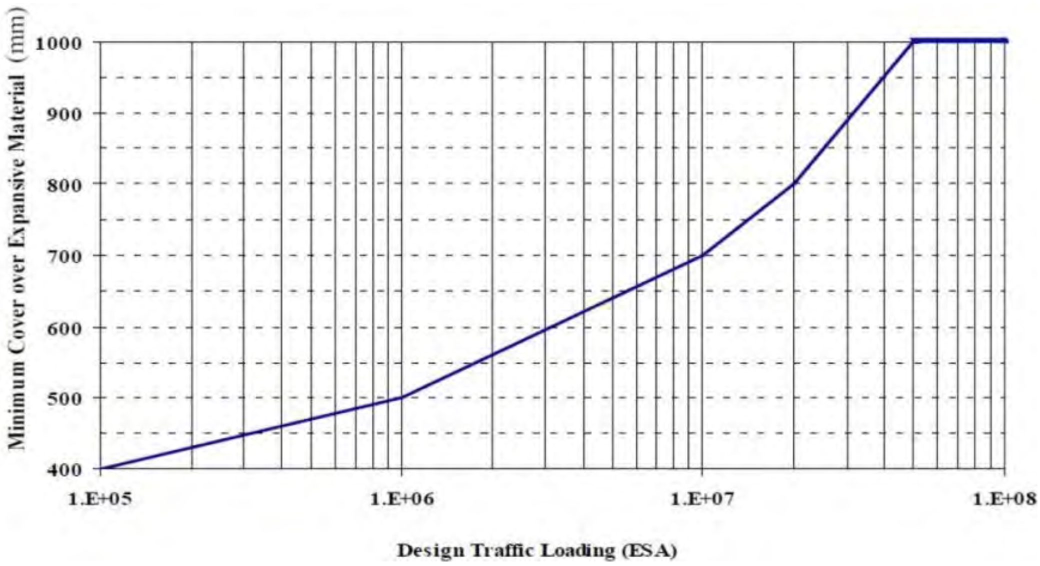
Photo: South Africa; Road surface over a culvert raised by expansive soil
Source：SAPEM Chapter-6

【Measures against expansive soil】

The measures taken by different countries faced with problems to do with swelling soil are indicated below.

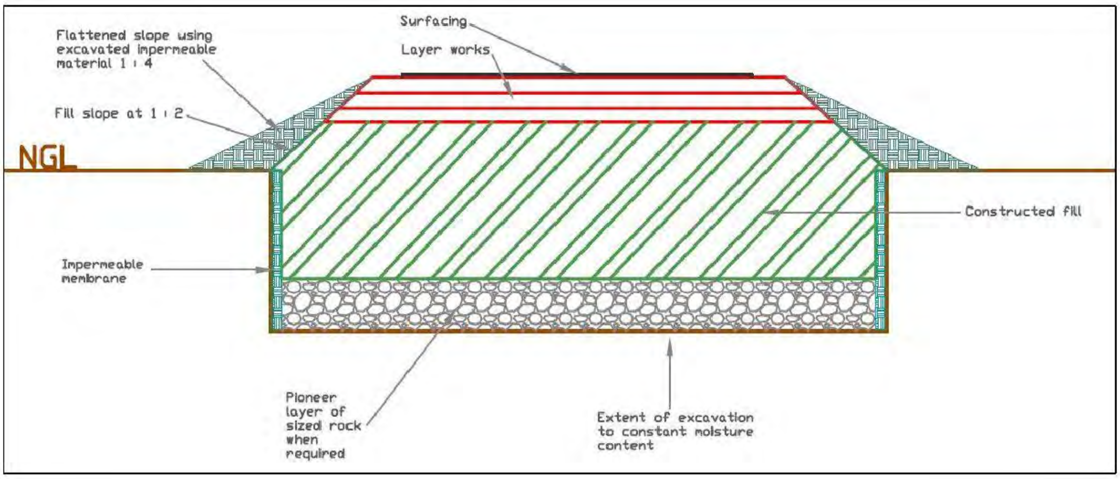
Table1.7.4 Standard measures against expansive soil

Country	Recommended measure
Australia	Setting a cap over 150mm. The thickness covered by a cap changes between 400mm and 1000mm in accordance with traffic
South Africa	Replacement (no information on the clear figure for thickness) Prevention of change in water content Replacement + water shielding
Tanzania	Replacement＋counter weight embankment
Ethiopia	Alternative alignment Cut and replacement Lime stabilization Minimizing water content、
Zimbabwean standard	Replace 700mm thickness
Kenyan standard	Replace 1000mm thickness
Indian case study	Replace 1000mm thickness
SATCC	Replace 1000mm thickness
United States of America	Replace layer up to a maximum 1500mm



Source：Austroads, Guide to Pavement Technology, Part 2 Pavement Structural Design

Figure 1.7.2 Capping layer thickness for expansive soil in Australia



Source：SAPEM Chapter-6

Figure 1.7.3 Measure against expansive soil in South Africa

In Tanzania, the following measures against expansion are indicated in the TANROADS pavement design manual

Table1.7.5 Measures by class

<table>
<tr><th rowspan="2">Expansion rate</th><th colspan="2">Measures</th></tr>
<tr><th>Main roads（paved roads）</th><th>Others（paved roads）</th></tr>
<tr><td rowspan="2">Low
$\varepsilon_{e\chi} < 20$</td><td colspan="2">Shoulder seal</td></tr>
<tr><td>Embankment slope 1:6</td><td>-</td></tr>
<tr><td rowspan="2">Medium
$\varepsilon_{e\chi} < 20 - 50$</td><td colspan="2">Refer to Fig. 1.7.4 (top)
Shoulder seal, embankment slope less than 1.6</td></tr>
<tr><td>Least embankment thickness：1.0m</td><td>Least embankment thickness：0.6m</td></tr>
<tr><td rowspan="3">High
$\varepsilon_{e\chi} > 50$</td><td colspan="2">Refer to Fig.1.7.4 (middle)
Thickness of replaced layer : 0.6m、least embankment thickness : 1.0m、shoulder seal、embankment slope：1:6 and below</td></tr>
<tr><td>Least shoulder width：2.0m</td><td>-</td></tr>
<tr><td>Alternative method：none</td><td>Refer to Fig.1.7.4
Shoulder seal, least shoulder width:2.0m, least embankment thickness:1.0m, embankment slope: 1:6 and below</td></tr>
</table>

Figure 1.7.4 illustrates the content of Table 1.7.5. The top most figure applies to low soil expansion and the embankment height is not considered. The bottom figure corresponds to swelling soil of medium and high rates of expansion. Specification for embankment height has been indicated elsewhere.

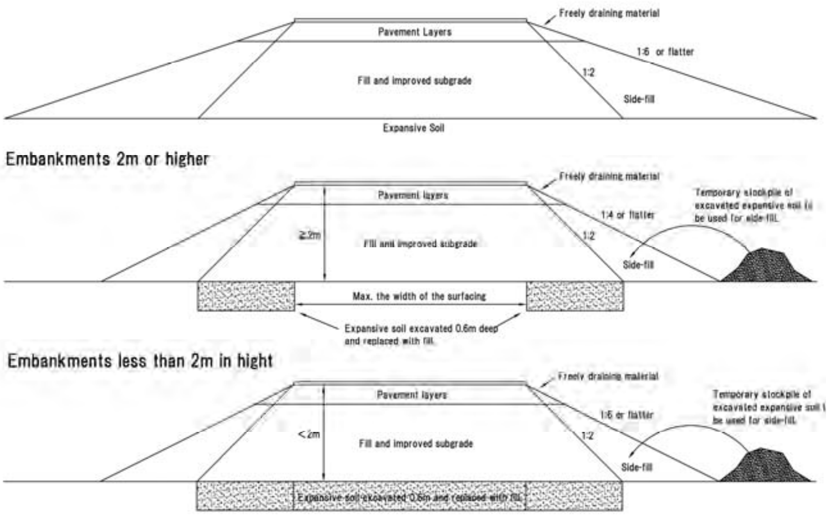
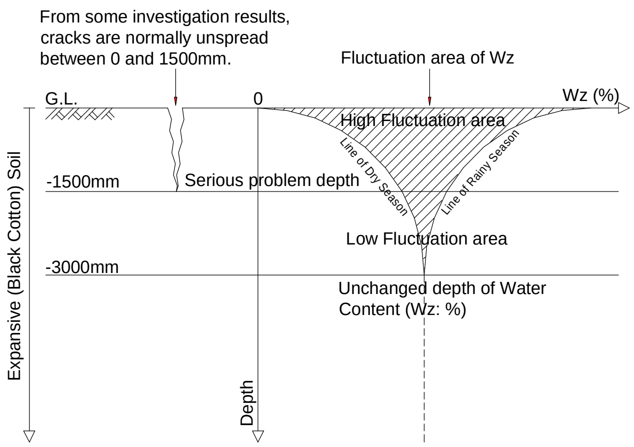


Figure1.7.4 Measures against expansive soil（TANROAD pavement design manual）

During the "Project for Rehabilitation of Trunk Road, Phase IV" funded with a Japanese grant, consultation was made with a professor of geotechnical engineering at the University of Addis Ababa. According to this discussion, variation of the moisture content of black cotton between the dry season and the wet season is severe up to 3m from the surface with the first 1.5m layer especially vulnerable (see Fig.1.7.5). From the knowledge obtained in this discussion, a water shielding sheet was installed up to 3m in sections prevalent with black cotton in this project to prevent variation of moisture content.



Source：Project for Rehabilitation of Trunk Road, Phase Ⅳ

Figure 1.7.5 Variation of moisture for black cotton soil layers

(4) Management of unusual soils during construction

It is desirable to note down in detail any measures taken against special types of soils arising during construction. Such a record is useful not only for the defective period, but also upon completion of work to enable appropriate response in case a problem arises at the section with problematic soil. Information regarding the following should be recorded:

1) Construction method

In order to show the validity of the construction method, it is important to keep a record of photographs taken for the works conducted. Particularly with black cotton soil and other clay soils prone to expansion, it is important that curing is done over the excavated section to prevent variation in the moisture content. For the same reason, it is desirable that backfilling works are conducted fast (as much is as possible, within a single day). In such cases, it is important that photographs are taken of the construction condition and preserved.

2) Volume of excavated soil

Regarding soil that has been determined to be problematic, records should be kept of the amount of excavated soil when replacement is carried out. As expressed above, in case there is need to quickly conduct backfilling after excavation, it may be difficult for the consultant or the client to oversee the process each time. Therefore, the amount of excavated soil can be determined by taking measurements, alongside photographs, for excavation cross-sections over a span of about 50m.

3) Quality control

Quality control involves indication of the quality of good soil used to replace the problematic soil (grade distribution, strength, coefficient of water permeability if necessary) and compaction management during construction (thickness, density management, etc). Particularly in cases where backfilling and compaction need to be conducted hurriedly and replacement by ordinary methods is time consuming, management by use of an RI measure is recommended.

4) Disposal of arising soil

The soil type considered problematic for road works may be useful for other purposes such as agriculture (black cotton soil for example). Discussion should be conducted with the local government or representative regarding the disposal of this kind of soil. Also, it is desirable that agreement on the method of disposal is noted.

1.7.2 Cement stabilized base course

(1) Cement stabilized base course standards by country

Application of cement stabilization for the base course requires attention to the plasticity index (PI) of the base course materials. There have been reports of insufficient strength and deterioration of cement stabilized base courses for projects funded by Japanese grants. In this section, we show aggregate standards and quality test regarding cement stabilized base courses.

Most standards discourage the use of materials with poor aggregate gradation and materials with large PI for application of cement stabilization. This is due to the characteristic difficulty in realizing the required strength as well as deterioration of the base course.

Table 1.7.5 Standards for aggregate used in cement stabilization of base courses

Standard・year	Specification	Attention points
Guide on Pavement Design (Japan)	「Regarding the subbase course」 Aggregate should be of PI at most 9 and modified CBR at least10 「Regarding the base course」 Aggregate should be of PI at most 9 and modified CBR at least20 Grade distribution (percentage by mass of aggregate passing) 53mm-100%、37.5mm-95～100%、19mm-50～100%、2.36mm-20～60%、75μm-0～15%	The specification considers cost (of cement).
Australia	Proportion of fine aggregate and PI are specified in relation to the cement stabilized base course material Proportion passing the 0.425mm sieve >25% PI≤10 For proportions passing the 0.425mm sieve less than 25%, PI of 10 and above is accepted	
South African Pavement	There are four specifications for cement stabilization C1 to C4, and standards for the mixture aggregate	Cement stabilization primarily, is not

Engineering Manual 2013	stipulated for each specification.	recommended.
ORN31 1993	Continuous gradation with containing some coarse aggregate is encouraged for cement stabilization. Cement stabilization is allowed in special circumstances for poorly graded aggregate and highly plastic materials. In such cases, from an increased content of cement, the risks of increased cost, cracking, development of reflection cracks, and deterioration due to neutrality of cement are acknowledged.	There is no clear specification for the allowable values for poor graded aggregate and PI. Selection of aggregate in consideration of the cost (of cement), and possible damage is indicated.
SATCC Pavement Design Guide 1998	Aggregate of uniform grade distribution and PI no greater than 10 is stipulated as suitable for cement stabilization.	Properties and performance should be checked in case of use of locally obtained materials. Suitable aggregate PI is specified.
Laos Road Design Manual 2003	Aggregate of PI no greater than 30 stipulated to be suitable for cement and lime stabilization of the subbase course. There is also further specification regarding gradation.	Relatively high plasticity soils tolerated. (This standard is based on the Thai Standard).
Cambodia	CBR ≥ 20% Aggregate passing the 0.075mm sieve <40% PI of aggregate passing the 0.425mm sieve PI <20	

PI* : Stands for plasticity Index. PI refers to the water content of soil or base course materials when the composite fine aggregate are in a state of plasticity. It is obtained from the difference between the moisture content at the liquid limit and the plastic limit.
Apart from classification of soil, this index is used also as a reference for the quality standard of base course materials. PI=WL-WP, where; PI：plasticity index (%),WL：Liquid limit (%),WP：Plastic limit (%). Plasticity index is zero for sandy soils and increases for increasing clay composition of soils.

Also, when locally obtained poor soils are used for cement stabilization it should be kept in mind that, in order to prevent problems occurring during construction due to an increase in the amount of cement, the following quality control tests must be satisfied.

Table1.7.6 maximum unconfined compression strength of cement stabilized base course, quality test method

Standard. Year	Features	Attention points/Weak points
ORN31 1993	The use of cement stabilizing materials of relatively high unconfined compression strength is accepted	The use of cement and lime separated from grade distribution and PI.(see

	（3.0-6.0MPa） The risks of increased cost, cracking, development of reflection cracks, and deterioration due to neutrality of cement are acknowledged. Wet-dry brushing stipulated for testing for deterioration.	Table1.7.7)
AASHTO Guide 1993	Wetting and drying tests（ASTM D559-96）、freezing and thawing tests （ASTM D560-96） are stipulated。	
SATCC Pavement Design Guide 1998	Maximum unconfined compression strength of 1.5 to 3.0MPa is recommended. Verification by laboratory tests (in consideration of cement and water content) is recommended. Wet-dry brushing test is stipulated for deterioration testing.	Even though the use of local materials is limited, there is still need for verifying properties and checking performance. Repeated deterioration tests for wet and dry conditions are stipulated to determine the limit cement content.
Laos Road Design Manual 2003	The qualities after stabilization are set at 60 and above for modified CBR (7 days of submersion in water) and 15 and less for PI	Deterioration due to continuing drying and wetting is not specified.
South African Pavement Engineering Manual 2013	Cement stabilization materials of unconfined compression strength of 6.0 to 12.0MPa and 3 to 6MPa are not used due to their proneness to cracking and development of reflection cracks. The upper limit for the unconfined compression strength of cement stabilization materials is 3.0MPa. As problems arising with cement stabilization are due to the requisite tensional strength not being realized, tensional strength testing is stipulated. Design that puts into consideration the fact that cement stabilization strength deteriorates is required (wet/dry brushing test, etc)	Even though the use of local materials is limited, there is still need for verifying properties and checking performance. Recent knowledge on cement stabilization(Compression strength, tensional strength, rate of deterioration) is required.
Guide on Pavement Design (Japan)	「Regarding the subbase course」 Unconfined compression strength (after 6 days of curing and 1 day submersion in water)：0.98Mpa 「Regarding the base course」 (after 6 days of curing and 1 day submersion in water)：2.9Mpa Verification by trial is required.	
Australia	0.7Mpa < UCS < 1.5MPa (28days of curing、4days of submersion in water)	
Cambodia	Specification for gradation(shown in the table) CBR ≥ 30% Aggregate passing 0.075mm sieve< 2/3 aggregate passing 0.425 sieve PI of aggregate passing 0.425mm sieve should be 20	

	or less.	

Table1.7.7 Efficient stabilization methods

Type of stabilisation	Soil properties: *More than 25% passing the 0.075 mm sieve*			*Less than 25% passing the 0.075 mm sieve*		
	PI≤10	10<PI≤20	PI>20	PI≤6 PP≤60	PI≤10	PI > 10
Cement	Yes	Yes	*	Yes	Yes	Yes
Lime	*	Yes	Yes	No	*	Yes
Lime-Pozzolan	Yes	*	No	Yes	Yes	*

Notes. 1. * Indicates that the agent will have marginal effectiveness
2. PP = Plasticity Product (see Chapter 6).

Source : ORN31 Table 7.2

(2) Japanese knowledge

Quick damage of a thin asphalt layer (no greater than 10cm) laid over a base course that was stabilized with cement was observed during road repair works funded by a Japanese grant. Even though it may be thought that knowledge of the problems arising with cement stabilization of base courses has not spread, the following knowledge from NEXCO (Japan) can be seen.

In NEXCO's Guide on Design, Volume 1, it is indicated that "the least thickness for an asphalt layer over a cement stabilized base course for a carriageway section should be at least 15cm". Even though evidence for this value of 15cm is not clearly indicated, can be said to be deduced in reference the following:

1) The results of the "studies on the serviceability of asphalt pavements applying soil cement" by the Civil Engineering Research Center in the old Ministry of Works

a) Failure is common with asphalt pavements where high cement content soil cement has been used.

b) Soil cement pavement with high compression strength is prone to failure. Therefore, the least required amount of cement should be used and compression strength kept to no more $30kg/cm^2$.

c) A thickness of at least 15cm is desirable for a soil cement layer. Road sections of soil cement of compression strength over $30kg/cm^2$ and a thin upper layer are prone to a large cross-sectional crack developing in the road surface. The upper surface of soil cement should comprise of at least 10cm layer of asphalt concrete.

From the above results, the Guide on Asphalt Pavement revised in 1967 stipulates that for base sections where cement stabilization is conducted, the treated section should be at least

10cm deep from the surface and the cement amount suitably adjusted to provide the equivalent of 30kg/cm^2 of unconfined compression strength.

Also, from data indicating that application of cement stabilization to a depth within 5cm depth from the surface increases the road surface's tendency to plastic deformation and that cracking in the soil cement appears directly in the surface, the standard stipulated application within 10cm depth.

1) From "Prevention methods of reflection cracks in overlaid concrete pavement";

a) Application of asphalt mixture over concrete pavement leads to the problem of the appearance of reflection cracks in the concrete slab's joint or the overlaid surface. This is thought to be similar to the case where asphalt pavement is applied over a layer of soil cement).

b) In that case, reflection cracks appear even for asphalt mixtures thickness of about 10cm constructed over concrete. As a result it is said that, asphalt mixture should be laid in three layers of about 15 cm thicknesses.

(3) Australian knowledge

The asphalt layer thickness when cement stabilization has been conducted for the base course in Australia is 175mm and above. A chip seal is often installed between the cement stabilized layer and the asphalt layer. This helps provide curing for the cement stabilized layer as well as prevent skidding and the development of reflection cracks.

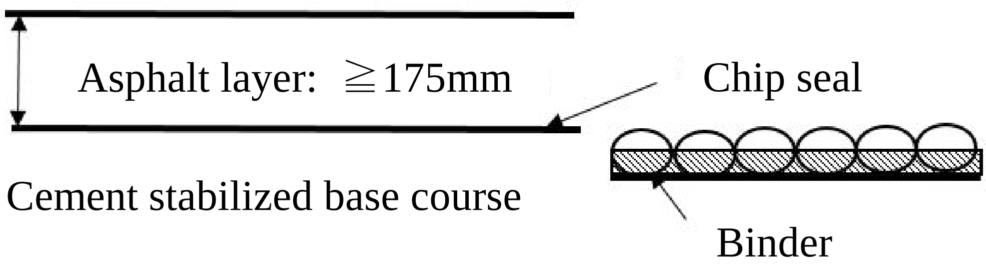


Fig.1.7.6 Asphalt layer on top of a cement stabilized base course

（４）South African knowledge

In South Africa, as shown in the table below, application of cement stabilization in the base course for road where heavy traffic is expected is mostly not recommended.

Table 1.7.8 Recommended Pavement Types for Road Category and Design Traffic Class

Pavement Type		Road Category & Design Traffic Class								Reasons for Exclusion
		A		B			C			
Base	Subbase	ES100	ES30	ES10	ES3	ES1	ES3	ES1	< ES0.3	
Concrete	Granular	×	×	✓	✓	✓	✓	✓	✓	Granular subbases prone to erosion at joints and cracks
	Cemented	✓	✓	✓	✓	✓	✓	✓	✓	
Granular	Granular	×	✓	✓	✓	✓	✓	✓	✓	Uncertain behaviour for high traffic demand
	Cemented	✓	✓	✓	✓	✓	✓	✓	✓	
Hot mix asphalt	Granular	✓	✓	✓	✓	×	✓	×	×	Cost effectiveness
	Cemented	✓	✓	✓	✓	×	✓	×	×	
Cemented	Granular	×	×	×	×	×	×	×	✓	Cracking, crushing, rocking blocks and pumping unacceptable
	Cemented	×	×	×	✓	✓	✓	✓	✓	
BSMs	Granular	×	✓	✓	✓	✓	✓	✓	✓	Cost effectiveness, permanent deformation

✓Can be used、 ×cannot be used

The aggregate specifications for application of cement stabilized are shown in table 1.7.9.

Table 1.7.9 TRH14 Classification of Cement Stabilized Materials

Class	C1	C2	C3	C4
Material Class Before Stabilisation	G2	G2/G3/G4	G5/G6	G5/G6
Aggregate Quality Before Stabilisation				
Grading (Sieve size, mm)	**Nominal Maximum Size of Aggregate (percent passing)**		Maximum size in place after compaction should not exceed two thirds of the compacted layer thickness, or 63 mm, whichever is the smaller.	
	38 mm	**28 mm**		
38 37.5	100 95 – 100			
28 26.5	90 – 100 78 – 98	100 88 – 98		
20 19.0	75 – 95 68 – 88	85 – 95 74 – 86		
14	65 – 85	71 – 84		
5 4.75	48 – 62 45 – 60	45 – 64 42 – 60		
2.00	41 – 53	27 – 45		
0.425	30 – 47	13 – 27		
0.075	5 – 12	5 – 12		
Crushing strength ACV (max) or 10% FACT (min)	29% 110 kN		Not applicable	
Flakiness Index	Max 35%		Not applicable	
Sand Equivalent	Max 30% for any sand added to correct the grading		Not applicable	
Design Strength of Stabilised Materials				
Class	C1	C2	C3	C4
Unconfined compressive strength: (UCS) at 7 days, 100% MDD	Min 6 Max 12	Min 3 Max 6	Min 1.5 Max 3.0	Min 0.75 Max 1.5
Atterberg Limits after Stabilisation	Not applicable		Max 6	

Also, regarding cement stabilization, as well as the quality control standards indicated below, a number of tests (deterioration test, indirect tension test, etc) have been suggested.

Table 1.7.10 Additional Standards for Cement Stabilized Materials

Classification	C1	C2	C3	C4
Material before treatment	At least G2 quality	At least G4 quality	At least G5 quality	At least G6 quality
PI after treatment	Non-plastic	Non-plastic	6 max [1]	6 max [1]
UCS (MPa) [2]	6 min	4 min	1.5 min	0.75 min
ITS (kPa) [3]	–	–	250 min	200 min
Wet/dry durability (% loss) [4]	5 max	10 max	20 max	30 max

Notes:
1. For materials derived from the basic crystalline rock group, the Plasticity Index after stabilisation shall be non-plastic.
2. Unconfined Compressive Strength @ 100% MDD.
3. Indirect tensile Strength @ 100% MDD.
4. Wet/Dry Durability according to SANS 3001-GR55.

1.8 Fundamentals of measures against plastic deformation

1.8.1 Mix design

(1) The concept of mix design

There are two methods of mix design taken as measure against plastic deformation; the empirical approach, and the theoretical approach (volumetric design method).

【Empirical approach】

（Method 1）Finer aggregate gradation is aimed at, by setting the target gradation at a value lower than the midpoint value of the grade distribution. Also, asphalt content and type, control of collected dust at a lower value than the highest limit, aggregate shape are all factors that are considered. However, the properties of hot mix asphalt (HMA) are maintained by the Marshal method (Guide on Pavement Design (Japan), etc).

（Method2）A target value of dynamic stability (DS, number of turns that lead to plastic deformation) is controlled by performing wheel tracking (WT) tests. In this case, verification of properties by Marshal testing is not mandatory. (MLIT; “Engineering standard on pavement structure” (2001))

【Theoretic approach】

（Method 3）Aggregate interlock to form a skeleton increasing its’s resistance against plastic deformation. A compaction mechanism that best represents the effect of vehicle loads on the surface is devised by conducting gyratory compaction and resistance to plastic deformation evaluated by control of the volume of air voids (VIM). (SUPERPAVE、Austroads: Guide to Pavement Technology, The South African National Roads Agency: South African Pavement Engineering Manual)

Reference 1 Two approaches around resistance to plastic deformation

1) Resistance to plastic deformation is achieved by providing mechanical resistance for the mixture (Marshal stability). Stiffness (stability/flow value) is concurrently secured.
2) Resistance to plastic deformation is achieved through the interlocking of aggregate. In other words, the asphalt content in the mixture need not exceed the volume of voids in aggregate after compaction; an extent of void is secured.

In the latter “interlocking of aggregate” method, compaction for mix design is conducted by use of a gyratory compactor and the calculation method applies volumetric design. In the United States of America for example, the very expensively developed SUPERPAVE employs this method.

1.8.2 Representation in a guide (proposal)

With the assumption that Japanese consultants and contractors typically conduct mix design and construction in projects funded by Japanese grants, we make the following recommendations.

(1) The basic structure

1) JICA projects that require particular consideration for rutting due to plastic deformation and the mechanism of rutting

2) The core technology examples of measures against rutting for JICA projects.

3) Reference technologies (introduction of measures taken in SUPERPAVE, Austroads, and South Africa)

(2) Detailed concept discussion of the main technologies

1) Rutting due to plastic deformation is caused by large vehicular loads (heavy traffic) as well as long duration of operation (low speed movement), environmental conditions such as high surface temperature which causes asphalt to soften, especially when aggregate interlocking is weak.

2) As a measure, finer aggregate gradation is used, by setting the target gradation at a value lower than the midpoint value of the grade distribution. Also, asphalt content and type, control of collected dust at a lower value than the highest limit, aggregate shape are all factors that should be considered.

3) A quantitative estimation of resistance to plastic deformation by the above method however is impossible. Therefore it is desirable that resistance to plastic deformation is verified through following methods. In some cases, these may be specified by the client.

a) Stipulating the dynamic stability (DS) of asphalt mixture for straight asphalt (1,500turns/mm for example) through performing wheel tracking (WT) tests (according to the Japanese specification) (see Fig.1.8.1).

b) Securing a constant void ratio of 2% under the ultimate number of traffic turns (N_{max}) by SGC (a compactor indicated in the American SUPERPAVE)

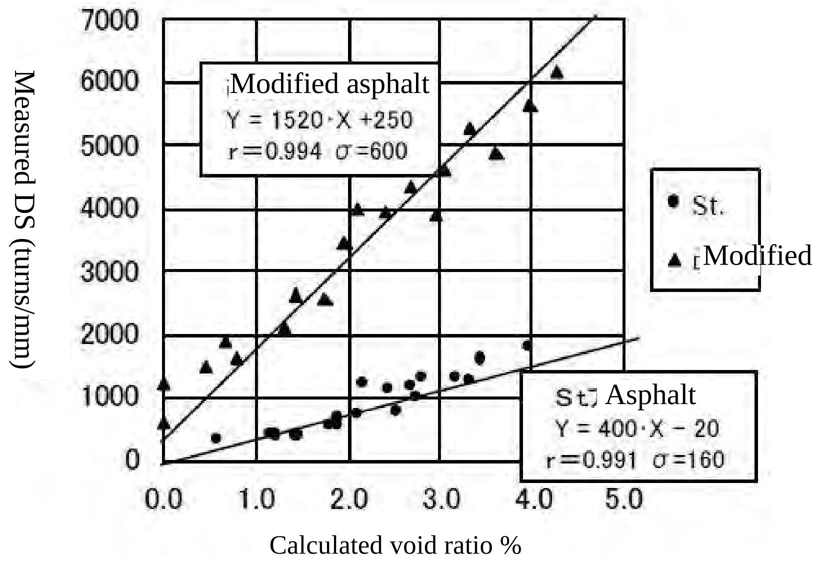


Figure 1.8.1 Relation between calculated air void rate

1) Source：Proposal of volumetric mix design method for hot mix asphalt based on aggregate void ratio (Japan Society of Civil Engineers (JSCE) Essay Collection on Pavement Engineering, No.5 Dec.2000 Yasuo Gunji, Takemi Inoue, Hirokazu Akagi)

１） If DS 1,500 turns/mm is deemed insufficient in sections of high elevation, sections of heavy traffic, etc and the target value cannot be achieved with straight asphalt (due to aggregate for example), the use of modified asphalt should be considered.

Chapter 2. Research in Asian Countries

2.1 Objectives and Discussion Items

2.1.1 Objectives

The objectives of research in Asian countries are to share knowledge and know-how based on data analysis and collection of pavement damage caused by improper construction works. In Australia, data collections on advanced pavement technology including design method and quality assurance procedure are discussed with related organizations. In Cambodia, actual works including plant and equipment control and mix-design/trial construction are researched through site visits and discussions.

2.1.2 Member

Table2.1.1 Mission Member

Position	Name	Responsible
JICA	Yukinari TANAKA	Deputy Director Financial Cooperation Implementation Dept.
JICA	Moriyasu FURUKI	Adviser Financial Cooperation Implementation Dept.
IDI	Kenko OKAMURA	Team Leader/Quality Control
IDI	Toshiya FURUKAWA	Construction/Equipment

2.1.3 Schedule

The schedule is shown in Table 2.1.2.

Table 2.1.2 Site Schedule in Cambodia and Australia

Date		Site and Purposes
1	3, April (Sun.)	Leave for Cambodia
2	4, April (Mon.)	Site visit to Korean section on NR21, Hearing to MPWT PWRC
3	5, April (Tue.)	Site visit to China section on NR6-A-8 and Crusher Plant operated by WKK
4	6, April (Wed.)	Hearing survey to NR1 KEI site office , site visit, TMC, Site visit to asphalt plant
5	7, April (Thu.)	Site visit to China section on NR5, hearing survey to NR5 KEI site office
6	8, April (Fri.)	Hearing survey on pavement at TSUBASA bridge, site visit to NR11 bridge
7	9, April (Sat.)	Leave for Australia
8	10, April (Sun.)	Arrive at Australia
9	11, April (Mon.)	Hearing survey and site visit to Downer pavement facility and plant on site
10	12, April (Tue.)	Hearing survey and site visit to Boral laboratory
11	13, April (Wed.)	Hearing survey to JACOBS (Consultant company)
12	14, April (Thu.)	Hearing survey to ARRB
13	15, April (Fri.)	Hearing survey to local office of Obayashi Corp. Leave at Australia
14	16, April (Sat.)	Arrival in Japan

2.2 Research Results

2.2.1 Discussion Items

The interviewees and hearing contents are shown as below;

Table2.1.2 Interviewees and hearing contents

Interviewees	Hearing contents
MPWT PWRC Mr. Khun Sokha (Deputy Director)、Mr. Hum VUTHY (Deputy Director)	・Constriction management system, quality control ・Application of laterite, cement stabilization ・Production of asphalt mixture, supervising materials ・Drainage issues
WKK Crusher Plant Mr. Piseth (Director), Mr. Sinal (Engineer)	・Crusher Plant facilities (crushed stone, washing stock yard) ・Produced coarse aggregate and fine aggregate ・Quality test
NR1 Site office (KEI) Mr. Morita (Director), Narikawa (Engineer), Mr. Anato (TMC Asphalt plant engineer)	・Constriction management system, quality control ・Construction plan, mixing design ・Cement stabilization ・CBR test before construction ・Mixing design ・Plant management ・Base course work ・Construction machinery ・Asphalt stabilization
NR5 South section office Mr. Mizuishi (Project manager)	・Pavement structure, drainage measures ・Comparison with China section ・Material procurement plan ・Traffic load, safety facilities etc. ・Considering laterite material as subbase course
Site office of TSUBASA bridge Sumitomo Mitsui Construction: Mr. Suzuki (Director) Chodai: Mr. Oyama OCG: Mr. Lee	・Constriction management system ・Procurement of materials ・Plant management ・Construction machinery ・Pavement structure, and construction ・Management of bridge deck pavement
Downer (Company for Asphalt material production and construction) Mr. Pat Capaan (NSW Client Relations Manager), Mr. Warren Carter (National technical Manager) , Mr. Paul Sherry (Assistant Production Manager), Mr. Dougall Broadfoot (State executive Officer-NSW, AAPA: Australian Asphalt Pavement Association)	・Mixing design, mixture testing equipment ・Gyratory compactor ・Screen for testing ・Using material (Crashed stone) ・Cold and hot bins ・Measures if flow resistance ・Stipulation of filler

Boral Materials Technical Services Laboratory Mr. Trevor Distin (National Technical Manager), Mr. Bob Bornstein (Manager), Dr. Alexandru Let, Mr.Georgr Calvar (Laboratory Manager)	・Aggregate test ・Gyratory compactor ・Wheel tracking test ・Other performance test ・CBR test
JACOBS (Consultant company) Mr. Branko Cerecina (Practice Leader Pavement Engineering)	・Technical standard of pavement in Australia ・Practical issues on pavement design standard ・Supervision by consultant ・Cement stabilization ・Measures for Black cotton ・Plant control
ARRB Dr. Michael Moffatt (pavement research general manager, PIARC pavement committee member), Mr. Kieran Sharp （REAAA technical committee chairperson）, Dr. Didier Bodin (Principal Research Engineer), Mr. Shannon Malone (Laboratory Manager)	・Technical standard of pavement in Australia ・Measures for Black cotton ・Pavement design method ・CBR test for subgrade ・Compaction standard of base course ・Usage of Natural Gravel as base course materials ・Cement stabilization ・Actual condition of modified asphalt ・Gyratory compactor ・Hard asphalt ・Supervision
Australia branch office for Obayashi Corp. Mr. Sadamatsu (Director), Mr. Tanaka (Deputy director), Scott Wright (Senior Manager)	・Contractors and paving company in Australia ・Consultant company

2.2.2 Discussion Results

(1) Cambodia

1) MPWT PWRC

- Road projects placing service for long period without serious damage was basically conducted by client, consultant, and contractor cooperating and understanding technically each other. These projects are often well-managed the quality. The materials are also managed severely by taking an approach to reject and exchange if problems found by testing.
- Application of cement stabilization for base course is currently prohibited. This rule was established because some Chinese projects in the past which were tried to be sustained by the strength of the cement stabilized base course on soft subgrade and subbase course Then after opening the projects, the base course was damaged in sections of heavy traffic volume and that maintenance was in great trouble.
- In the case that local laterite is used for subbase course, the standards on PI and CBR for the subbase course should be satisfied. If PI and CBR of the subbase course could

not be satisfied their standard, it should be treated by cement stabilization with material which is satisfied the standard for PI and CBR value after stabilization.

- More asphalt plant company expects more overlay projects in future. In case of great size project, some companies have a number of asphalt plants to transfer and set to the site.
- Characteristics of crashed stone for coarse aggregate defer depending on mountain locations of the crusher plant.
- River sand and crashed sand are used for fine aggregate. Cambodian river stone is fair condition and high in intensity in general. The method of crashed stone differs according to companies.

2) Crasher plant for WKK

- Crashed stone is produced by jaw crusher and cone crusher. The size of aggregate is basically 5 to 25 mm and 0 to 5 mm (mainly for concrete). Since impact crasher is not used, 20 to 30 % of Flat crushed stone is included.
- There is no facilities adding water or washing for management of moisture content. In the stock yard, crashed stone is piled up out in the open due to no roof and silo.
- Mixing crashed stone of the size 5 to 25 mm and 0 to 5 mm is baked mixed by pay loader. There is no mixing plant for mechanical stabilization crushed stones.
- The type of rock is “limestone” which is good quality and high density. There is no laboratory inside, therefore, samples are sent to MPWT’s laboratory or Japan for testing, if it is impossible to test in Cambodia.

3) NR1 site office

“Hearing survey”

- The assignment of well-skilled engineer (not limiting it to Japanese) is required in the tender document. Asphalt engineer is assigned from the beginning stage of asphalt stabilization for base course.
- Consultant supervises and inspects the CBR strength evaluation for subgrade, the base course construction and the test construction of asphalt stabilization. Since the contractors recently carefully work due to their well-understanding on the quality management, therefore, consultants are now reducing times for supervising inspections.
- CBR testing is required before commence of construction. The sample collected at the original location is conducted CBR test at laboratory. Consultants inspect in whole process from sample collection to the implementation of CBR

test. The design CBR is ensured 3.0% and over. The sampling interval is 200 m. 40 % of subgrade which is 500 mm depth is replaced. The replacement of material is river sand of Mekong River of 16% CBR.

- Contractor should carefully conduct proof loading during the construction and manage uniform strength on the road structure.

"Site visit"

- The mechanical stabilization crushed stones for base course is mixed by soil plant which is used mixing plant.
  Mixing ratio…M-30 : 20-10 : 5-0＝70 : 20 : 10
- The construction equipment for base course is indicated as below;
  Leveling: base paver
  Initial rolling: Macadam roller
  Secondary rolling: Vibration roller (10 ton, 16 pass)
  Finish rolling: Tire roller (12-16 ton)
- Used equipment and construction management for asphalt stabilization are indicated below;
  1. Used equipment (Leveling, surface rolling)
     Leveling: Finisher
     Initial rolling: Tandem roller and Macadam roller, 6 pass
     Secondary rolling: Tire roller (12-16 ton), 20 pass
  2. Targets of thermal management (Arrival temperature, labeling temperature, rolling temperature)
     Arrival temperature: 150 ± 11 ˚C
     Leveling temperature: 145 ± 11 ˚C
     Initial rolling: 135 ± 10˚C
     Secondary rolling: 110˚C and over
  3. Management of rolling degree (core cutting)
     Method: Management by core cutting
     Frequency: no information
     Standard: 95% and over (to the Marshall specimens)

"Asphalt plant"

- TMC's mixture plant is made by Niigata Iron Works Co., Ltd., unknown year of manufacture, and 60 ton / H.
  Fine aggregate: 20-13mm (25mm), equally No.5 crashed stone classified in JIS[1]

[1] JIS: Japanese Industrial Standards

13-5mm, equally No.6 crashed stone classified in JIS
Coarse aggregate: 5-0mm, river sand or screenings
Filler: Secondary dust collection of dust is discarded without using.
Asphalt: Commonly used 60/70 straight asphalt in Cambodia.

- Marshall stability is currently targeted 10kN under the high temperature of the tropics, however, the mix design is under consideration due to the management problem of flatness and fine fraction of the aggregate.
- The size of hot bin (mesh size of screen)
  The number of hot bin is five. Since the result of 2.5mm screening amount varies widely, the size was changed from 5-0 mm to 5-2.5 mm and 2.5-0 mm by Japanese engineer.
- Items and timing for plant inspection
  Items: Thermometer, meter, and aggregate flow rate
  Timing: Once before commencement of construction
- Particle size management and daily management for hot bin
  Hot bin: 1 time/day (in the beginning of the handling)
  Marshal test: 1 time/day
  Extractive tests: 1 time/day
- Quality control of asphalt mixture
  Visual confirmation of mixing material
  Confirmation of measurement by plant man
  Visual confirmation of control panel since there is no printing recording device

4) NR5 south section MPWT site office

- Pavement structure
  Subbase course: Crushed stone
  Base course: 20-25 cm thick and double layer treatment of mechanical stabilization crushed stones
  Binder course: 5x2=10cm thick
  Surface course: 5 cm thick
  No used late light as a subbase course.
  As Japanese ODA, high quality infrastructure development should be provided.
- Pavement structure for Chinese section
  Base course: late light
  Base course: 27 cm thick crushed stone and single layer treatment by vibratory roller of 25 ton power
  Surface course: 7 cm thick
- Candidates of stone pit and borrow pit are designated.

Bidding contractor considers the profitability and determines whether they use stone pit and asphalt plant in Phnom Penh.
General using straight asphalt of 60/70 is applied for bitumen.

5) TUBASA bridge

- Consultant allocates two pavement engineers during the construction for mixing design, test and pavement inspection. The pavement QC engineer of contractor is Pilipino.
- Paving contractor is selected from five dominant companies by questionnaire and hearing survey.
- Asphalt mixture plant is set moving paving contractor's plant to the site. Calibration of the plant is conducted after the relocation.
- Base course material is procured directory from supplier. Stone pit is located nearby NR3 and 4.
  Asphalt aggregate and asphalt are procured from the maker by LS.
  Asphalt of 60/70 is procured from TIPCO in Thailand.
- Vibratory roller of 25 ton power is used for the compaction of base course.
- The top of subgrade is treated by cement stabilization, mixing by bulldozer.
  Crushed stone of subbase course is treated by cement stabilization, 0 cm thick and 1 to 2 % cement.
  Since the strength was too high, the amount was adjusted the hard way into within the standard. Base course is applied 13 cm thick of mechanical stabilization crushed stones
- For bridge deck pavement, the water resistant layer under the binder course is carefully constructed especially adopting sheet system and application system.
- In Technical Specifications, it needs a high value of the figure below:

  Ratio Marshall Stability (KN) / Marshall Flow (1 / 100cm)

  If the value of formula above is high, it seems to be strong to flow rutting.

(2) Australia

1) Downer (Asphalt material maker, contractor)

- Volume design method using a gyratory compactor is mainly adopted as a mixing design and mixing test. The marshal test is used at rural road and some state governments.
  Number of turns of gyratory: 120 times (design), 350 times (refusal)
  Porosity: 3 to 6% (120 times), 2% ≤ (350 times)
  Angle of traverse: 2 ˚C (fixed)
- As a flow resistance measures, there are two methods to define a rutting

amount (5 mm) 12 months after opening service and to adopt 3 mm standard of rutting mount by repeating 10,000 times of the wheel tracking test.

- Modified asphalt (for only surface course) and hard asphalt (EME, enrobés à module élevé) is used in a limited way as flow resistance of the material.
- Content of the filler is 1 to 2 %. Collected dust is included in the fine aggregate not included in the filler.
- Number of sieve type for testing is greater than in Japan.

19mm, 13.2, 9.5, 6.7, 4.75, 2.36, 1.18, 0.6, 0.3, 0.15, 0.075
The number of hot bin is almost same as the one used in Japan.
4-5 bins: (28-20), 20-14, 14-5, 5-2.5, 2.5-0

2) Bora Materials Technical Services Laboratory

- The gyratory compactor is divided into gyro pack and servo pack.
  The standard diameter of gyro pack is 100mm. In case that the maximum particle size is 20mm and over, the diameter is 150mm.
- The test equipment of wheel tracking test is smaller and cheaper than the one in Japan.
- Flow resistance of the reference value is 3 mm against 10,000 times (repeating 4 hours, DS≒3,300time/mm)
  Testing temperature is basically 60 degrees. 70 and 90 degrees are also available.
  The porosity of the specimen for wheel tracking test is fixed 5%.

3) JACOBS

- Pavement design method is divided into Empirical design methods and Mechanical design method. Empirical design method is applied for only surface treatment of gravel road and asphalt road. The pavement of this road project is designed by Mechanistic design method. This method is different from “Mechanistic-empirical design method” in USA. The analysis program is called as CIRCLY.
  This country has decided to use the design about 20 years ago.
- The consultant conducts the verification, supervision, hold points, non-conformances and certification of the project as a supervisor.
  Hold point is specified in the agreement. The setting of hold point is discussed whether either quality or schedule should be prioritized.
  The cause of defect is divided into contractor’s fault and difference between the design and the practical situation.
  The defect caused by the design is discussed involving headquarters’ engineer.

In the case that the defect is occurred after opening service, the measures are discussed among three parties those are designer, contractor and supervisor. In case that repair work is needed, that cost burden is discussed among them. All three parties purchased bond insurance before signing the agreement.

- The materials for cement stabilization specified by the ratio of fine fraction (0.425 passing) and PI.

The thickness of asphalt pavement is 175 mm and over, in case that the base course is cement stabilized. Chip seal is often used between cement stabilization layer and asphalt layer. This is for curing of the cement stabilization process, anti-slip, prevention of reflection cracks.

- Black Cotton Soil frequently occurs in Victoria. Installation of capping layer is basic method as a countermeasure. At least 150 mm thick of capping layer should be installed. As necessary, drains are installed. The shoulder is sealed by impermeability layer.

4) ARRB

- The guideline of Austoroads is made by regional engineers and ARRB. There are general common clause and special clause which covers regional original material and condition.
- Black Cotton Soil frequently occurs in Queensland and Victoria. Technical specification of both state governments can be referenced.
- The theory design method in Australia is named as “Mechanistic design method”, been different from Mechanistic empirical design method in USA. It had been considered to adopt since 1980s. It had been tested from 1984 to 1987. Then it has been used broadly since 1990s. New method and materials can be easily tried to use. Their elasticity test and bending fatigue test are conducted.
- There are two types of compaction standard density, Standard and Modified (Large rammer mass). In case that the standard density is determined by those two, the compaction degree becomes more than 100%.
- The thickness of asphalt pavement is 175 mm and over, in case that the base course is cement stabilized. As necessary, 20 mm thick of chip seal and spray seal are applied between cement stabilization layer and asphalt layer for curing of crack.

  “Guide to Stabilization” issued by Aus+Stab association can be referenced.
- The gyratory compactor is divided into gyro pack and servo pack.

  Gyro pack: Angle of traverse is 2 ° (fixed and not been changed)

  Servo pack: Angle of traverse is 0.1 ° (adjustable by unit)

  * 2 ° for ϕ 100, 3 ° for ϕ for in laboratory of ARRB.
- Servo pack is more advanced method. Various options and more broadly

management can be conducted. They plan to migrate to the servo pack. The negative point is that Servo pack costs $20,000 to $25,000 and is more expensive than Gyro pack which costs $10,000 to $15,000.

2.2.3 Collected documents

(1) Cambodia

"Pavement design and construction standards in Cambodia"

- Road Design Standard, Part 2. Pavement, 2003, MPWT
- Construction specification, 2003, MPWT

(2) Australia

"Pavement design and construction standards in Australia"

- Guide to Pavement Technology (Part.1~10), Austoroads
- Guide to Project Delivery (Part.1~4), Austoroads
- New South Wales, Material, Pavement, QA specification
- Queensland, Contract administration, Technical specification
- Victoria, Code of Practice, Standard specifications
- Austoroads test method
- Roads and Maritime services(RMS), QA specification

"Pavement standards in Australia"

- Specification Framework for Polymer Modified Binders （AGPT-T190-14）
- Guide to the Selection and use of Polymer Modified Binders and Multi-grade Bitumens (AP-T235-13)
- EME technology Transfer to Australia：An Explorative Study (AP-T249-13)
- High Modulus High Fatigue Resisitance Aspahlt (EME2) Technology Transfer (AP-T283-14)
- Heavy Duty Dense Graded Asphalt (RMS R116)
- Open Graded Asphalt (RMS R119)
- Stone Mastic Asphalt (RMS R121) 等

2.2.4 Field survey photos

(1) Field survey photos in Cambodia

TMC Asphalt plant

WKK Crashing plant

Coarse aggregate

Fine aggregate

Base course work, NR1

Base course work, NR5 (by China)

Photo2.2.1 Field survey photos in Cambodia

(2) Field survey photos in Australia


Dynapak

Servo pack


Measuring device of aggregate profile


Aggregate peeling resistance test


WTtest


Asphalt truck

Photo2.2.2 Field survey photos in Australia

2.3 Findings obtained in the survey

2.3.1 Mixing design (Australia)

- Volume design method using a gyratory compactor is mainly adopted as a mixing design and mixing test. Number of turns of gyratory is 120 times for design and 350 times for refusal. Porosity is between 3 and 6% for the number of 120 times and 2% and over for the number of 350 times. Angle of traverse is fixed as 2 °C.
- The gyratory compactor is divided into gyro pack and servo pack.
  Gyro pack: Angle of traverse is 2 ° (fixed and not been changed)
  Servo pack: Angle of traverse is 0.1 ° (adjustable by unit)
- Servo pack is more advanced method. Various options and more broadly management can be conducted. They plan to migrate to the servo pack. The negative point is that Servo pack costs $20,000 to $25,000 and is more expensive than Gyro pack which costs $10,000 to $15,000.
- As a flow resistance measures, there are two methods to define a rutting amount (5 mm) 12 months after opening service and to adopt 3 mm standard of rutting mount by repeating 10,000 times of the wheel tracking test.
- Flow resistance of the reference value is 3 mm against 10,000 times (repeating 4 hours, DS≒3,300time/mm)
  Testing temperature is basically 60 degrees. 70 and 90 degrees are also available.
  The porosity of the specimen for wheel tracking test is fixed 5%.
- Modified asphalt (for only surface course) and hard asphalt (EME, enrobés à module élevé) is used in a limited way as flow resistance of the material.

1) Mixing design and performance test
   The flow of mixing design (dense-graded asphalt)
   LEVEL 1 (Mixing design)
   I. Selection type of aggregate and binder
   II. Selection target particle size and the amount of the binder
   III. Formulation of the material
   IV. Adjustment by compaction temperature and the adjustment time
   V. Compaction of the test formulation

   A) Gyratory method
   ・ The porosity at the design turning number of 50, 80 and 120: 3-6%(NSW), 45(Victoria)
   ・ Volume characteristics: Porosity, density, VMA, degree of saturation and binder

film index, are decided.

- Additional test is conducted by changing t0.5% of the trial mix in order to decide appropriate asphalt amount by checking the volume characteristics.
- The porosity at the maximum turning number of 250/350: 2.5/2.0% and over is confirmed.

B) Marshal method

- Stability and flow value is defined.
- Volume characteristics: Porosity, density, VMA, Degree of saturation and Binder Film Index are decided.
- Additional test is conducted by changing ±0.5% of the trial mix in order to decide appropriate asphalt amount by checking the volume characteristics, stability and flow value.
- The porosity at the maximum turning number of 250/350: 2.5/2.0% and over is confirmed.

LEVEL 2 (performance test)

I. Resilient modulus (indirect tensile test)
II. Deformation resistance (wheel tracking test)
III. Peeling resistance (rate of tensile strength)
IV. Fatigue bending test: the minimum number of repetitions

2) Typical grading envelope for 14 mm dense graded mix

Grading envelope for heavy duty mixes is standardized as a target particle size of the aggregate (dense-14) in Vitoria.

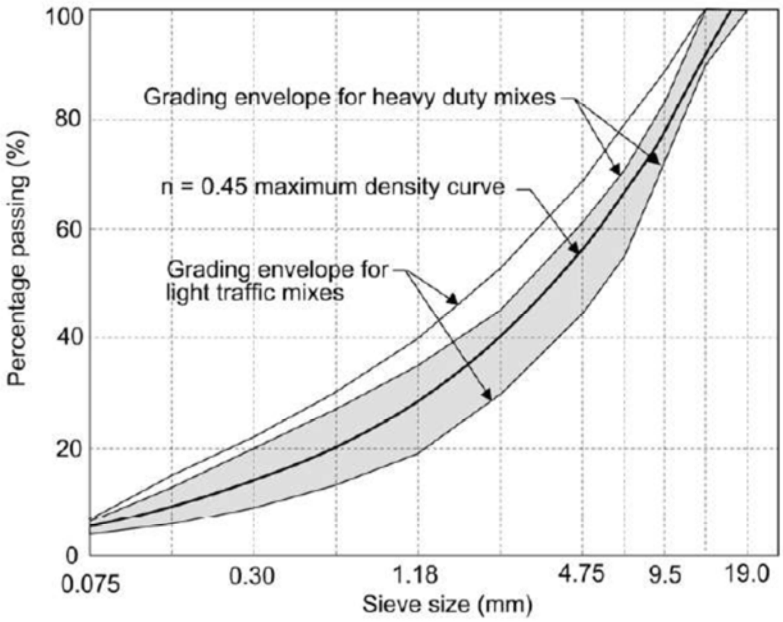


Figure2.3.1 Typical grading envelope for 14 mm dense graded mix

3) Voids of mineral aggregate and porosity

Porosity is an important parameter for mixing design. Especially, a heavy traffic mixture should not be less than a defined porosity after the maximum turning. In general, design engineer should design the mixture co all design parameters including voids on the most economical binder amount. Granularity mixture is located at the middle point of the envelope curve of specified particle size, provides a valuable starting point. Adjustment to increase or decrease the aggregate porosity and adjusting the amount of the binder to meet the target porosity include bellows;

- The mixture is made to rough granularity or finer or gap granularity. Generally, the middle point of the envelope curve of specified particle size provides the target value close to the maximum density curve. By roughening and fining a part of particle size, porosity increases in general. However, the attention to the impact to the texture of stiffness and the surface of the mixture should be paid.
- The proportion (%) of the fine fraction which is materials 2.36 mm passed is changed. In other words, the impact above is made.
- An increase or decrease of filler amount brings about a direct effect. Porosity decreases by increasing filler amount, and porosity increases by decreasing filler amount.
- The shape of the particles, particularly fine aggregate, is caused a changed. Smooth and round particles make the workability increased and the porosity decreases. In this case, it should be paid attention on decreasing the stiffness of mixture.
- Increase of natural sand content causes an increase of the porosity due to the void space that occurs between grains of sand.

4) Deformation resistance

Lack of deformation resistance causes rutting. Deformation resistance can be improved by methods as below;

- Select a mixture of-large nominal dimension
- Use the angular or rough aggregate
- Use a stiff binder
- Apply the coarse granularity
- Reduce the gap (however, it is on the condition that does not result in a void under the limit at the maximum cycle.)
- Increase the amount of filler

These factors influenced other properties. For instance, using more aggregate being rough angular causes less workability and more filler amount to produce more mastic lacking flexibility, therefore, the fatigue resistance is reduced.

5) Workability

Workability indicates the ease of spraying and compaction of the mixture. They are improved by methods below:

- Increase of aggregate porosity
- Using the high amount of the binder
- Using soft binder
- Decrease of filler amount
- Using round aggregate

Using high binder amount, soft binder and round aggregate tends to increase potential of rutting.

6) Moisture-sensitive (peeling resistance)

Resistance to damages caused by moisture can be improved by methods as below:

- Contain the 1 to 2 percent of the total slaked lime into the filler
- Decrease permeability
- Contain anti-stripping agent
- Use the aggregate of asphalt to an affinity
- Use clean aggregate
- Properly dry the aggregate
- Effectively mix and splay aggregate mixture
- Appropriate mixing time
- Appropriate binder / filler ratio
- Select compatible certain composition
- Manage contamination of additives
- Use hard granularity binder or resin

Non-quartz aggregate has usually a good affinity for asphalt. It reduces the potential that binder film is displaced on the surface of the aggregate.

Additional slaked lime, usually 1-2% in total mixture, is made clear to reduce the likelihood of peeling.

7) concept of volume design method

a) Maximum density

Density that does not take into account the gap

b) Aggregate porosity

Compaction characteristics of the particle size distribution, the shape of the bone material, textured surface and aggregate particle.

Aggregate porosity should be appropriate value as 13-20% according to the maximum grain diameter.

- Secure enough asphalt amounts to obtain durability of the mixture.
- Secure enough porosity after compaction to obtain safety of the mixture

The impact of aggregate porosity is indicated as below:

Excessively small aggregate porosity:

- Flash queuing and bleeding are unstable due to excess asphalt to the void.
- Adhesion shortage and lack durability due to inappropriate asphalt amount.

Excessively large aggregate porosity:

- Large porosity.

The method to increase aggregate porosity is indicated as below:

- Vary the grain size distribution to leave the maximum density curve and move to rough elements of the maximum density. Maintaining a uniform grain size distribution is better than taking in the gap granularity.
- Decrease elements for less than 0.075 mm filler in order to increase binder film index, however, it decreases the rigidity of the mixture.
- Obtain different compaction characteristics by some changes of the shape of the fracture surface such as a characteristics of different shapes of aggregate and/or texture of the surface

The method to decrease aggregate porosity is indicated as below:

- Increase asphalt amount in order to satisfy the required porosity.
- Vary the grain size distribution to close the maximum density curve and move to fine elements of the maximum density.
- Increase the filler amount.
- Obtain different compaction characteristics by some changes of the shape of the fracture surface such as a characteristics of different shapes of aggregate and/or texture of the surface

c) Porosity

The porosity of mixture is indicated as functions below:

- Voids in the Mineral Aggregate (VMA)
- Asphalt amount
- Compaction degree

The porosity of the mixture affects the stiffness of the mixture, the fatigue resistance and the durability. In general, a mixture design should be minimized in order to decrease characteristics below:

- Degeneration or oxidation of asphalt
- The possibility of water penetration and peeling of the asphalt from the aggregates involved.

If the void of mixture is extremely low such as approximately under 2%, flushing, bleeding and rutting are occurred due to the plastic flow.

The maximum density of the mixture reaches (minimum porosity) during opening to public is by the compaction of the maximum number of turns of the gyratory compactor.

Minimum porosity in the maximum number of turns of the heavy traffic mixture is based on the 250 or 350. The value of the minimum porosity of the maximum number of turns is applied to the asphalt of the design under heavy traffic.

d) Asphalt amount

Generally, an appropriate asphalt amount is calculated by the balance the amount necessary to ensure the durability and longevity of the pavement and the amount reduced in order to not become unstable.

Asphalt amount highly influences the volume characteristics and mechanical properties of the asphalt mixture.

Appropriate design asphalt amount is decided by following elements.

- Type of aggregate
- Particle size distribution of the aggregate
- Compaction of the mixture -
- Design porosity

The performance of the asphalt is decided by effective asphalt content Except for the asphalt amount that is absorbed into the aggregate. It differs from total asphalt amount.

Asphalt amount that is absorbed into the aggregate is decided by the measured maximum density and aggregate mixture, filler, the theoretical maximum density which is determined from the bulk density of the asphalt.

Accurate measurement of density for aggregate and filler is an important part on the estimation of asphalt absorption amount. The negative value of the asphalt absorption amount shows density determination and the error to be used in the calculation. The proportion of asphalt amount that is absorbed into the aggregate depends on the type of permeability and asphalt aggregate.

In general, asphalt absorption of aggregate is from 0.3 to 0.7 in the water absorption of the aggregate.

e) Voids filled with bitumen (VFB)

Saturation is the ratio of the VMA occupied by effective asphalt content. This is generally in the range between 65 and 80%. For low saturation (VFB) in about 60%, the mixture is dried, and adhesion, durability and fatigue resistance are insufficient. If the saturation of more than 85%, the mixture is at risk of rutting become unstable. If the target value of the porosity is given, high degree of saturation is obtained from a high aggregate porosity (VMA), low degree of saturation is the value of the low aggregate porosity. Method of adjusting the aggregate porosity can be referred to the section of bone material porosity of the above-mentioned.

f) Binder Film Index

Binder Film Index is a function of the surface area and the filler and an effective asphalt content of aggregate. Calculation of Film the Index is by standardized surface area coefficients of each particle diameter. In fact, Surface area is affected by the texture of the aggregate shape and surface. Binder Film the Index is an index which does not indicate film thickness accurate asphalt.

Considering the minimum Binder Film Index at the stage of volume design method, can be the guide to incorporate appropriate adhesion to the asphalt mixture, a sufficient amount of asphalt to ensure the resistance to durability fatigue resistance and moisture effect.

Binder Film Index can be increased by the methods below:

- Vary the particle size distribution and increase the proportion of coarse-grained material for fine-grained material.
- Reduce the amount of filler.
- Increase the aggregate porosity by increasing the aggregate porosity for the same porosity.

Other reference value for securing the asphalt amount is the minimum asphalt rate, or the percentage of saturation.

2.3.2 Plant management

(1) Case of Cambodia

- In the high temperatures of the tropics, it aims to achieve 10kN as Marshall stability, however, the flatness and the fine fraction management of aggregate are problems. (NR1)

- General crushing plant in Japan has an equipment configuration to crush to a predetermined size by the primary and the secondary crushing, and to improve the shape of the bone material in the tertiary crushing. Types and specifications of the crusher in Cambodia are shown as below:

  Primary crushing: jaw crusher
  Secondary crushing: cone crusher,
  Granulator: None

  Flat coarse aggregate tends to be increased. Typical lithotripsy machine are shown below:

  Jokes La Shah: easy to produce an elongated shape.
  Cone Kura Shah: easy to produce an elongated shape.

Impact class Shah: easy to produce the shape of a cube.

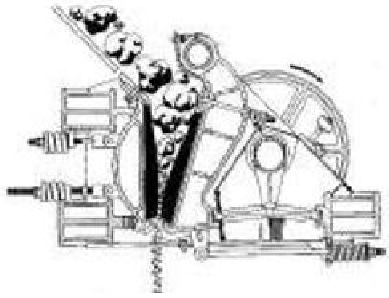
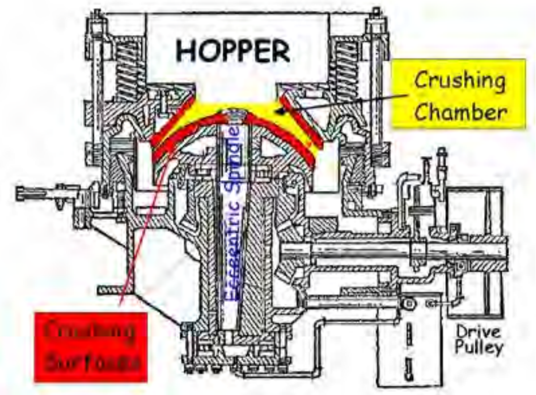
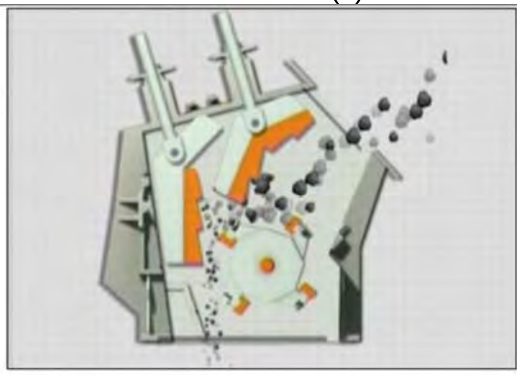
	
Jaw Crusher (1)	Jaw Crusher (2)
	
Cone Crusher	Impact Crusher

Figure2.3.2 Typical Types of Crusher

- Since Crusher plant demand is often for concrete, the particle size distribution of the fine aggregate (0-5 mm) is not often managed for asphalt concrete.
- Asphalt is imported from Thailand or Singapore and 60/70 are commonly used. In consideration, such as the above, it is necessary to carry out the mixing design and plant management.
- Considering point on plant management
  - Method of storage aggregate is mainly silo dumping without roof.
  - No cleaning equipment of aggregate
  - The minimum size of hot bin is mainly 0 - 5mm.

(2) Plant Management

Method of plant management using for NR1 is indicated as below:

1) Item and frequency of plant inspection

- Item: Thermometer, meter, aggregate flow rate
- Frequency: Once before the start of construction

2) Position of the temperature management

- Aggregate heating temperature: (the outlet of the dryer) hot shot, Hot bin (1 bottle)
- Asphalt: asphalt tank

3) Granularity management and daily management of Hot bin and cold bin

- Hot bin: once a day at beginning of production
- Marshal test: once a day
- Extraction test: once a day

4) Quality management of asphalt mixture

- Visual confirmation of mixing material
- Confirmation of measurement by plant man

Visual confirmation of control panel since there is no printing recording device

2.3.3 Cement stabilization

- Cement stabilization for base course is currently prohibited in Cambodia.
- In case of cement stabilization for base course in Australia, the thickness of asphalt pavement should be more than 175 mm. Chip seal is mainly installed between cement stabilization layer and asphalt layer. This is for the curing of cement stable processing and the prevention of anti-slip and reflection crack.

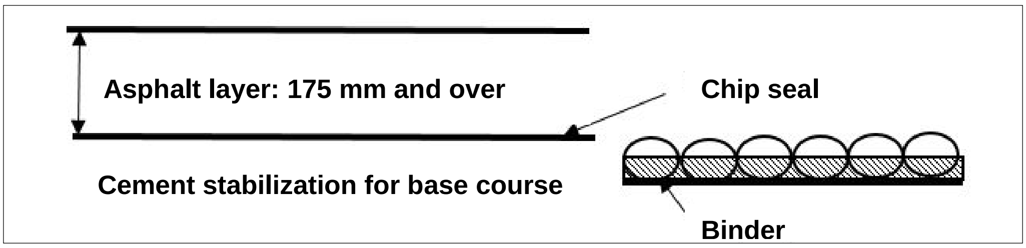
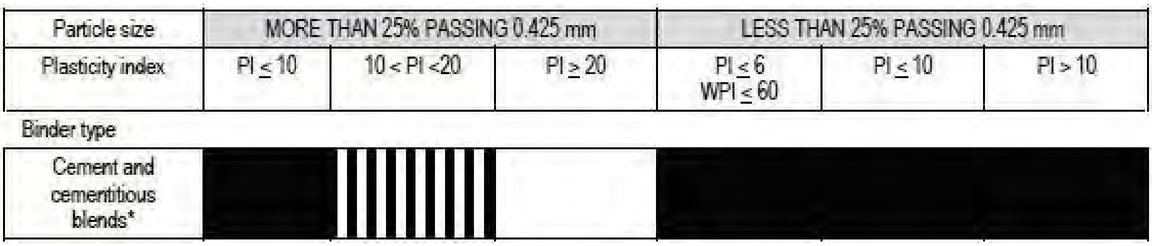


Figure2.3.3 Cement stabilization in Australia

- In Australia, desirable qualities of the cement stabilization material as the subbase course materials are defined by the proportion of fine fraction (0.425mm passing amount) and PI.



Black: desirable quality

Figure2.3.4 Desirable qualities of the cement stabilization material

<u>Cement stabilized base course</u>

0.7 MPa < UCS*

Unconfined compression strength < 1.5 MPa

*)28 days curing, 4 days drench

2.3.4 Application criteria of laterite

- CBR value of laterite produced at local has variation in production area. In case that it is applied to the subbase course, the material that satisfied criteria for PI and CBR should be used.
  - Standard in Cambodia:

    The provisions of the particle size, CBR ≥ 30%

    0.075mm passing <2/3 * 0.425 passing, 0.425mm passing PI <20
  - Pavement construction handbook in Japan

    CBR ≥ 20%, PI < 6
- In case that the criteria of the lower layer subgrade is satisfied, cement stabilized, however, high enough quality material for the particle size and the PI of the stabilized material is used.
  - Standard in Cambodia:

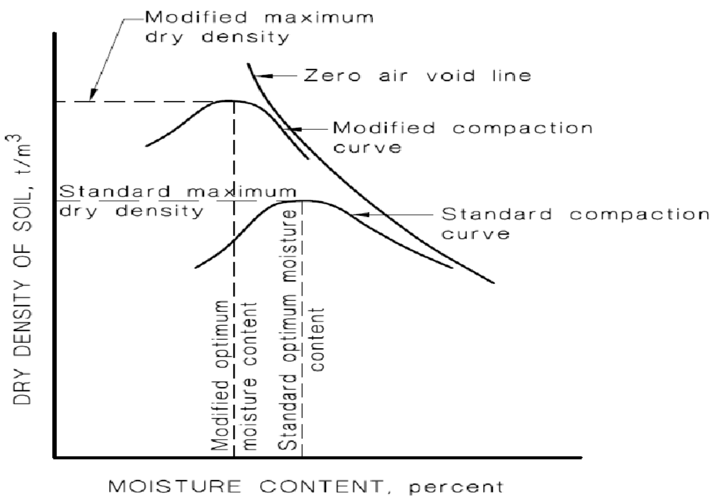
    CBR dard , 0.075mm passing <40%, 0.425mm passing PI <20
  - Pavement construction handbook in Japan

    CBR Ja10%, PI < 9

2.3.5 Compaction standard of base course

- Compaction standard density in Australia has two types, "Standard" and "Modified" which is large rammer mass as indicated as below:

  In case that standard density is decided by "standard", compaction degree criteria may exceed 100%.



Source: AS1289.0-2000

Figure2.3.5 Standard and modified compaction curves

In the JIS, the optimum moisture content (OMC) and the maximum dry density (MDD) for the embankment and the base course material are decided by "Soil compaction test by JIS A 1210 compaction (Pavement research and test method Handbook F007, E011)". Based on calculated MDD, the compaction degree is managed on site.

Five types of method, A to E, of compaction test are classified as two types by impact load (Ec).

A, B in JIS: "Standard Proctor" Ec≒550kj/m3

C, D, E in JIS: "Modified Proctor" Ec≒2500kj/m3

$$Ec = \frac{W_R \cdot H \cdot N_B \cdot N_L}{V} \quad (\mathrm{kJ/m^3})$$

Formula2.3. 1

Here by W_R : The weight of the rammer (kN)

H : Drop height of the rammer (m)

N_B : Number of compaction times per layer

N_L : Layer number

V : The volume of the mold(Volume of specimens compacted) (m3)

Table2.3.1 Five types of method of compaction test

Types	Mold diameter (mm)	Mold depth (mm)	Mold volume (cm3)	Rammer weight (kg)	Drop height (cm)	Compaction number of time	Layer number	Maximum permissible (mm)	Ec (kJ/m³)
A	100	127.3	1,000	2.5	30	25	3	19	552
B	150	125	2,209	2.5	30	55	3	37.5	549
C	100	127.3	1,000	4.5	45	25	5	19	2,482
D	150	125	2,209	4.5	45	55	5	19	2,472
E	150	125	2,209	4.5	45	92	3	37.5	2,481

Depending on method type of compaction test, the standard density defers.
In the case that the compaction of the reference density carried out in the rammer mass small way, compaction criteria should be more than 100%.

2.3.6 Construction management

(1) Cambodia

- According to the result of hearing survey at the site of NR1, the following matter is critically important for quality management of pavement work at the stage from the mixing design and the construction management.

  "Although the tender documents are not described as the Japanese, requiring the placement of skilled technicians who are familiar with the pavement at the specification"

- Regarding the plant management of asphalt mixture, in case that the plant management of the local paving company does not manage (NR1 case), Japanese pavement engineer of the contractor is assigned. In case that local pavement company manages the plant (TSUBASA Bridge case), Japanese pavement engineer of the consultant is assigned.

- At the NR1 site in Cambodia, consultant supervises and inspects the CBR strength evaluation for subgrade, the base course construction and the test construction of asphalt stabilization. Since the contractors recently carefully work due to their well-understanding on the quality management, therefore, consultants are now reducing times for supervising inspections.

  From this point, it is found an importance to implement an efficient witness examination at a certain stage equipped with a guide to quality.

(2) Australia

In Australia, "design" and "verification" are important role of consultant.

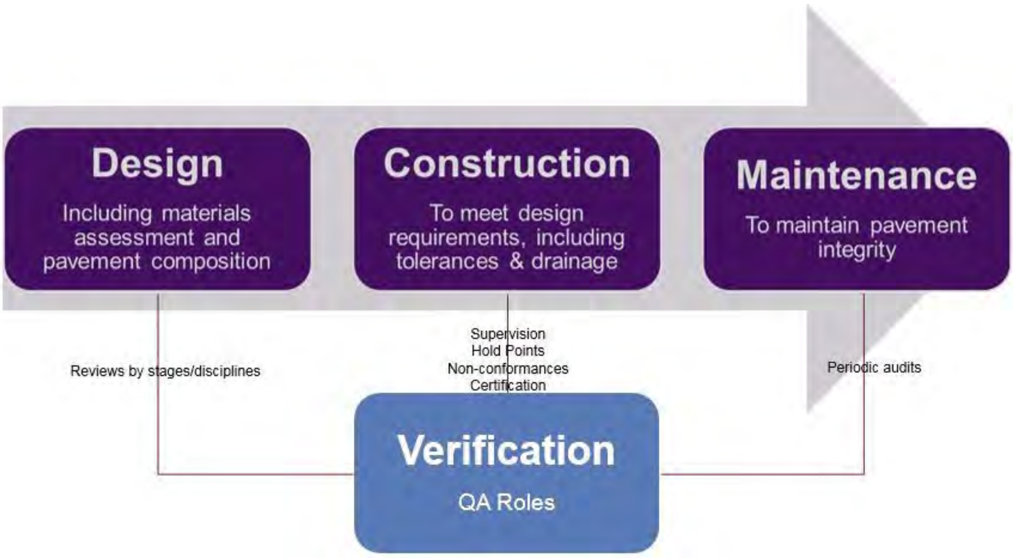


Figure2.3.6 Role of consultant in Australia

Verification is conducted at each stage of design, construction and maintenance. At the stage of construction, the consultant supervises the standard for allowable values in order to meet the design requirement including drainage systems. The breakdown of verification for the construction stage is as shown below:

- Supervision and inspection of construction
- Inspection and approval of hold points
- Attendance to irregularities (by the contractor or design)
- Issue of certification

In the case that the defect is occurred after opening service, the measures are discussed among three parties those are designer, contractor and supervisor. In case that repair work is needed, that cost burden is discussed among them. All three parties purchased bond insurance before signing the agreement. The defects period is two years.

2.3.7 Method of CBR test

- Water immersion conditions of CBR test depends on the specification. It is tested accordingly. (Boral)

Table2.3.2 CBR specimen compaction method in Australia and Japan

	Australia	Pavement Investigation and test methods Handbook in Japan
Compaction condition	25 times×3 layers Drop height 30cm weight 2.7kg Mold 1,000cc (Equally to A method in Japan)	67 times ×3 layers Drop height 45cm weight 4.5kg Mold 2,209cc
Moisture content	Optimum moisture content	Natural moisture content
Testing condition	4-10 days water immersion	4 days water immersion

- Water immersion conditions of CBR test of subgrade change by the state. Some state use the 10 day water immersion. Australian standard is obtained by reflecting the reference for each state. (ARRB)

■ CBR specimen compaction method in Queensland

Table2.3.3 Typical wet conditions CBR test inside

Point / wet conditions	Test condition
Annual rainfall ≤ 800mm Good surface drainage Good underground drainage Subgrade is not affected by the underground water level, ponding Subgrade is not affected by the flood Empirically not waterlogged place	not waterlogged
The Cut, spring water below Underground water level Place to more than 10 days of water immersion	waterlogged for 10 days
Places not meet the above conditions and to occur water immersion for four days.	waterlogged for 4 days

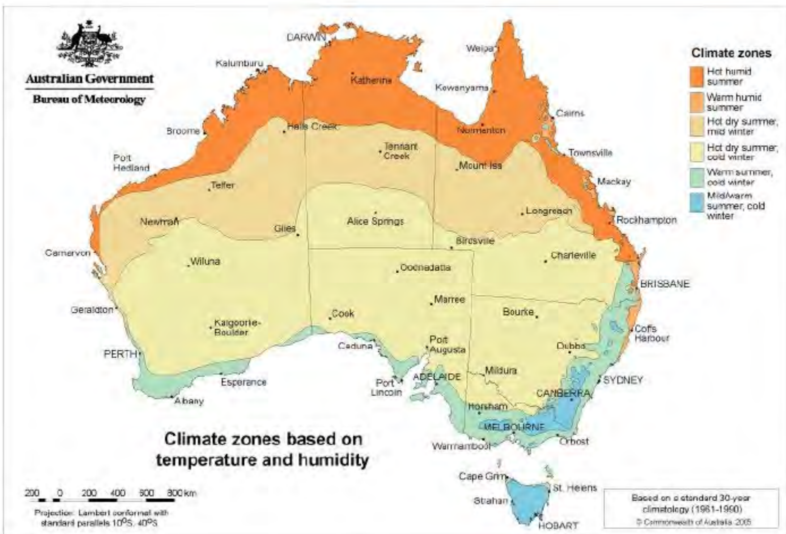


Figure2.3.7 Australian climatic zones

■ CBR specimen compaction method in NSW

Fine-grain material should be tested in 10 days water immersion conditions due to wetting by capillary action in the high rainfall areas. In the arid regions of the inland, the tests are conducted without water immersion by creating a test sample in the field water content ratio (the equilibrium moisture ratio).

The standard of CBR test in laboratory in NSW is shown as below:

Table2.3.4 The standard of CBR test in laboratory in NSW

Annual rainfall (mm)	The water content ratio of the test specimen	Test condition	
		Fair drainage	Poor drainage
<600	OMC	0 day Soaked	4 days Soaked
600 - 800	OMC	4 days Soaked	10 days Soaked
>800	OMC	10 days Soaked	10 days Soaked

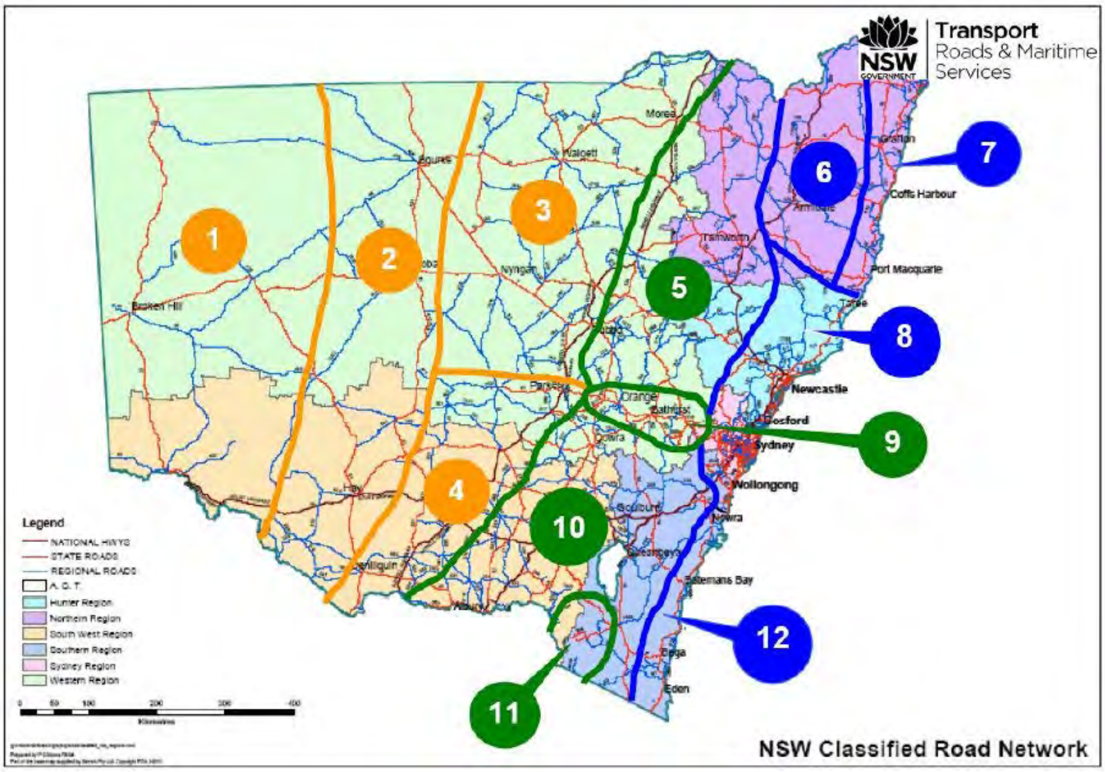


Figure2.3.8 NSW climatic zones defined Roads and Maritime

Table2.3.5 Average rain fall and temperature in 12 climatic zones

N0.	Minimum average temperature (˚C)	Maximum average temperature (˚C)	Annual average rainfall (mm)
1	12.1	26.5	261
2	12.7	25.1	408
3	9.9	24.7	561
4	9.9	23.2	487
5	10.8	25.9	616
6	7.2	20.1	857
7	15.6	23.1	1493
8	12.3	21.4	1036
9	16.5	16.5	1072
10	7.2	20.6	649
11	0.6	10.3	1947
12	11.3	20.4	963

2.3.8 Measures of concerned soil (expansive soil)

- Expansive soil which is called "Black cotton soil" is appeared often in Queensland and Victoria. Black cotton soil can be determined by the PI, however, it is better to determined by expansion test if the test machine is available. The measures are described in technical specifications.

Table2.3.6 Determination of "Black cotton soil"

Expansive nature	Liquid limit (%)	Plasticity Index	PI x % < 0.425 mm	Swell (%)*
Very high	> 70	> 45	> 3200	> 5.0
High	> 70	> 45	2200–3200	2.5–5.0
Moderate	50–70	25–45	1200–2200	0.5–2.5
Low	< 50	< 25	< 1200	< 0.5

* Swell at OMC and 98% MDD using Standard compactive effort; four-day soak. Based on 4.5 kg surcharge.

- The measures should be based on the method of providing a capping layer of 150 mm thick. The thickness is decided by the weight.

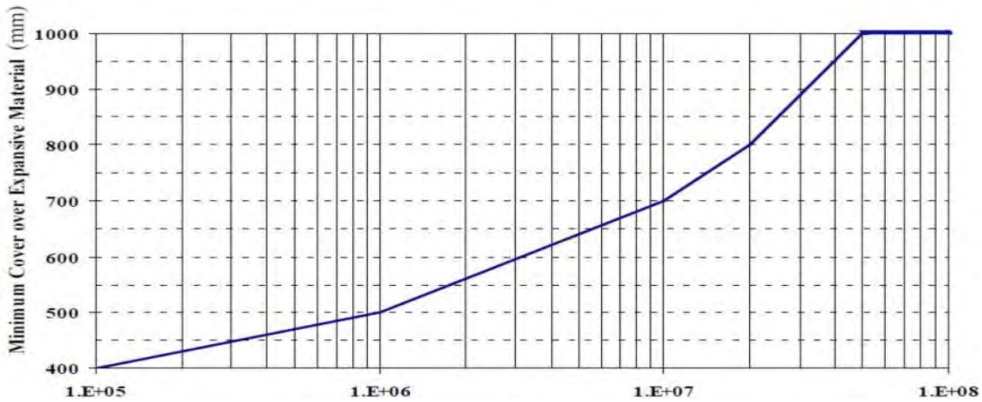


Figure2.3.9 Design traffic loading (ESA) and thickness of capping layer

- Drains should be installed as necessary as below:

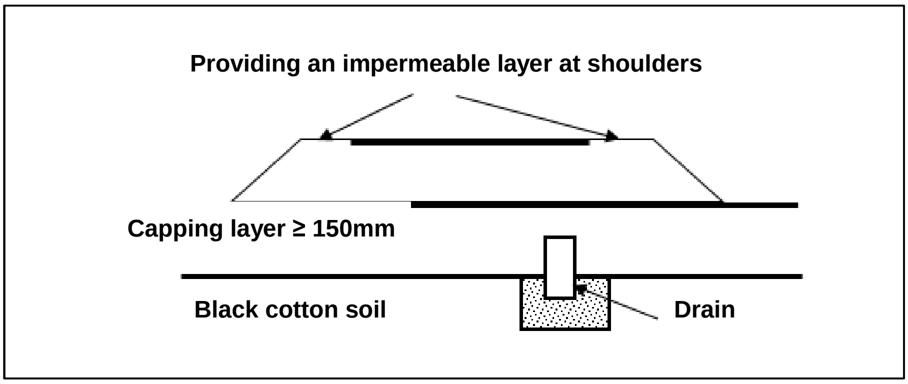


Figure2.3.10 Typical road prism on expansive soil

Chapter 3. Research in African Countries

3.1 Objectives and Discussion Items

3.1.1 Objectives

Information to update the handbook is collected in South Africa as developed on the pavement skills and Zambia which was a developing country conducted road projects by Japanese ODA. In South Africa, information for the latest pavement design, the trend of asphalt mixture design, standards and cases on quality management was collected. In Zambia, information of the cause of unique defects or damages was collected by hearing to local company concerned and site visit.

3.1.2 Objectives

Table 3.1.1 Mission Member

Position	Name	Responsible
JICA	Yuichi ICHIKAWA	Grant Aid Project Management Division 1, Financial Cooperation Implementation Dept.
JICA	Kotaro Nagasawa	Adviser Financial Cooperation Implementation Dept.
EJEC	Satoshi MIZUNO	Pavement Design/Supervision
EJEC	Tomohiro FUJINAGA	Material/Mix Design

3.1.3 Schedule

The schedule is shown in Table 3.1.2.

Table 3.1.2 Site Schedule in South Africa and Zambia

Date		Site and Purposes
1	4, April (Mon.)	Leave for SA
2	5, April (Tue.)	Hearing to Agencies concerned
3	6, April (Wed.)	Team meeting, Site visit
4	7, April (Thu.)	Hearing to Agencies concerned
5	8, April (Fri.)	Ditto
6	9, April (Sat.)	Leave for Zambia
7	10, April (Sun.)	Site visit to Livingstone
8	11, April (Mon.)	Ditto
9	12, April (Tue.)	Hearing to Agencies concerned, Site visit to Tokyo Way
10	13, April (Wed.)	Hearing to Agencies concerned
11	14, April (Thu.)	Hearing to Agencies concerned
12	15, April (Fri.)	Hearing to Agencies concerned
13	16, April (Sat.)	Leave at Zambia
14	17, April (Sun.)	Arrival in Japan

3.2 Research Results

3.2.1 Discussion Items

The interviewees and hearing contents are shown as below;

Table 3.2.1 Interviewees and hearing contents

Interviewees	Hearing contents
Much Asphalt (Material supplier) Mr. Herman Marais Group Technical Director of Materials	・Material / Plant management ・Constriction system / supervision ・Quality management / Inspection ・Defect Site visit (2 locations)
South African National Roads Agency (SANRAL) Mr. Lonw kannmyer Road Network Manager	・Supervision / management standards ・Construction quality assurance ・Responsibility of client on defect
University of Pretoria Dr. James Maina Department of Civil Engineering	・Direction of design method ・Evaluation of asphalt and material ・Construction quality assurance
JICA South Africa office Mr. Kinomoto (Resident Representative) Mr. Ishigame (Deputy Resident Representative), Mr. Mochiduki (Resident Officer)	Interim reporting the study result
CSIR Dr. Morris De Beer Eng. Julius Komba	・ Situation and direction of revised design ・ Compounding test / materials evaluation ・ Asphalt evaluation ・Construction quality assurance
IGEROP (Consultant) Mr. Ian Fitz General Manager Operations	・Construction management plan ・Supervision system ・Quality management / Quality assurance ・Defects / defect insurance
BCHOD (Consultant) Eng. George Sitali: Director Eng. Tresphor K. Musonda	*Supervised repairing work of Livingstone Rd. ・Issues on Livingstone Rd. ・Construction management plan ・Supervision system ・Quality management / Quality assurance ・Defects / defect insurance
JICA Zambia office Mr. Fujiie (Deputy Resident Representative), Mr. Sunohara (Resident Officer)	Interim reporting the study result
Scirocco Enterprises Ltd., ORIENTAL (Material supplier) Mr. Moustafa S. Y. Saadi: Managing Director	・Materials / Plant management ・Quality management / Inspection
Zule Burrow (Consultant) Mr. Levi Zule: Managing Director	・Pavement design standards ・Construction management plan ・Supervision system ・Quality management / Quality assurance ・Defects / defect insurance
Road Development Agency (RDA) Eng. Agustin Mwwinga: Principal Engineer Maintenance	・Issues on Livingstone Rd. ・Supervision / Standard management ・Construction quality assurance ・Responsibility of client on defect
BCHOD (Consultant) Eng. Tresphor K. Musonda	・Provided rerated documents on repairing design of Livingstone Rd.
Ecofor (Zambia Ltd.) (Construction company) Mr. Gasore Ildeponse: Director	・Material / Plant management ・Quality management / Inspection

3.2.2 Summary of result of hearing survey

3.2.2.1 Much Asphalt (Asphalt supplier in South Africa)

Interviewees: Mr. Herman Marais (Group Technical Director of Materials)

Items for hearing: Materials/plant management, construction system/supervising, quality management/inspection, defects and plant visiting (2 locations)

Result of hearing survey: The result is indicated as below;

- **Quality management**

  Pre-qualification system does not exist. The mix test is conducted at each site. The quality management office in the plant controls following items.

  Mixture: Sampling testing every 100 tons

  Aggregate: Testing every 200 tons

  Asphalt: Every carrying by tank lorry

  All sampled mixture is stored during the defect period. For asphalt, it is supposed to store more than three years.

- **Evaluation of asphalt mixture**
  - The evaluation of mixture is conducted by a mobile simulator, a Hamburg test, a dry and wet test, a wheel tracking test and a creep test etc.
  - Test by SGC is conducted although it is not standardized. This is specified in "Special Specification" of construction. It secures at least 2% porosity at turn number 300 for a high standard road, although it differs for each road standard.
  - SGO adopts the method of AASHTO. Comparing the method for Europe countries, AASHTO method is more used in South Africa.
  - In South Africa, after mix designing, the test on rutting resistance is examined in laboratory before a test construction is conducted on site. In the test construction, it is verified by a simulator as necessary.

- **Measures against rutting**
  - As a measure against a rutting, modifying material is used in general. It used for 20 to 30 % road in Pretoria. Modified asphalt concrete is 20 % more expensive than ordinal asphalt concrete.
  - Methods to prevent rutting are also used by asphalt with penetration of 10/20. (EME in France)
  - Amount of asphalt and porosity are important parameters for rutting, however, an use of modified asphalt is the most efficient.

3.2.2.2 SANRAL (Road authority in South Africa)

Interviewees: Mr. Lonw kannmyer (Road Network Manager)

Items for hearing: Construction system/supervising, quality management and Client's responsibility/defects.

Result of hearing survey: The result is indicated as below;

- **Design / construction guarantee**

  - Security deposit should be accepted for consultants and contractors. Defect guarantee is required during the design life in the range from 5% of contract amount up to a ceiling of 15 million Rand. It is as specified in FIDIC.
  - Defect liability period of the design is basically a year. It may be three years and five years depending on the importance.

- **Management of construction**

  - Contractors take responsibility for "Process Control" and consultants take responsibility for "Quality Control".
  - A team to manage integrally two controls above is formed in order to build a system to promptly share necessary information between the team. This intends to streamline and speed up on the work on site.

- **Contract of consultant**

  - SANRAL holds a matrix on consultant structure that includes project scale and content.
  - Construction supervision plan by consultants indicates on stuff allocation and quality control warranty plan etc. This is proposed at the tendering stage by consultants and will be a part of contract document.

- **Construction plan**

  - Construction plan by contractor may be required to indicate details regarding an implementation method, a safety management and environmental considerations. This plan will be a part of contract document.

- **Pavement design in South Africa**

  - In South Africa, software for road design will be made the shift to "SARDS (South Africa Road Design Software)" as new software. This new system can perform a series such as pavement design, mix design, pavement performance curve and economic analysis.

3.2.2.3 University of Pretoria

Interviewees: Dr. James Maina (Department of Civil Engineering)
Items for hearing: Concept of design method, evaluation on asphalt and material and quality management of construction.

Result of hearing survey: The result is indicated as below;

- **Pavement structure in SA**

  - Pavement structure in South Africa is composed manly a base course and a subgrade unlike asphalt layer in Japan.

- **Pavement design in SA**

  - Standard of pavement design in South Africa will be made the shift to SARDS instead of TRH-4. TRH-4 is not useful due to over-designing and mismatching to the local condition. In this system, actual grounding shape of tires and elastic modulus of material (Ev, Eh) can be considered. Theory of viscoelasticity is also incorporated.
  - The load condition is used “Traffic Axle Load Spectrum” rather than E80. This data can be obtained from the system of weigh-in-motion. Due to the observed value, possibility of cover loading is considered.

- **Mix design in SA**

  - For mix design in South Africa SGC is used for its optimization, although the new system above can work as well. It has the feature of good reproducibility. The standard of asphalt will be completely changed to PG type near future. This change will spread to all Africa.

- **Defect examples of Japanese ODA project**

  - According to the defect situations of Japanese ODA project, an asphalt mixture that does not match the local conditions such as a climate condition (high temperature), materials and traffic condition, seems to be adopted. In the urban area of Tanzania, the influence by low speed driving of heavy vehicles should be considered since the port area is close to. Also, in Durban in South Africa one road project was repaired their rutting every six months. This problem was solved by using HiMA which is by French technology.
  - The most important thing in the pavement design including mix design is the condition setting on material test and traffic conditions.

- **Others**

  - Cement stabilization is not adopted for the base course. Cement stabilization of Laterite should be referred to Chapter 14 and 15 in SAPEM. It covers almost experiences of road projects in SA.
  - The criterion for crushing base course uses shear. The criterion for cement stabilization uses crack.

3.2.2.4 CSIR (Council for Scientific and Industrial Research) University of Pretoria

Interviewees: Dr. Morris De Beer, Eng. Julius Komba (Transport Infrastructure Engineering)

Items for hearing: Revision of design standard/its direction, mixing test/material evaluation, asphalt evaluation and quality management of construction.

Result of hearing survey: The result is indicated as below;

- **Pavement design in South Africa and Africa region**

  - SARDS currently advances by SANRAL in South Africa This considers Empirical-Mechanical-Probability being an effective design tool in other African countries as well.

- **Countermeasure against rutting**

  - Mix design and required tests are divided in to each level of traffic volume such as Low, Middle and High. On Marshall, there is no problem for roads of low traffic volume, although it has low reproducibility in heavy traffic.

- **Paving in high rainfall area**

  - In high rainfall area such as Durban, 150 mm asphalt Base, asphalt surface course of 40 - 50 mm, subbase course cement stabilization treated, are adopted. On the groundwater etc, its problem can be solved by develop drainage facilities corresponding to the water level.

- **Cement stabilized base course**

  - Cement stabilization had been accepted for a base course in South Africa between 1970’s and 1980’s. However, the use was stopped due to significant defects of pavement. The cause of defects is vulnerability at the top of the base course due to heavy traffic and chemical change (carbonization). For using this, it is necessary to conduct Brush Test, wheel tracking, Hamburg test etc.

- The cement stabilization treatment is suitable for the subbase course even though it considers the construction and maintenance of the platform.

- **Standard to use modifying materials**

  - It is not regulated. It is important to select binders considering regional conditions (climate and traffic conditions). Workability and durability are first considered for testing a mixture. Several tests were conducted depending on whether the problem assumed for that road was crack or rut thereafter. Rutting test is for rutting, and then beam test, fatigue test and stiffness etc are for cracks.

- **Improvement of strength without using modifier**

  - There are two methods. One is to use High Modulus Asphalt, another is to adopt aggregate interlocking test by Bailey Method (US). This is the test to conduct before asphalt mixing being attached to the end of TRAB-8 of SABITA.

- **Others**

  - Each parameter are important for mix design, however especially a porosity has great influence.
  - For evaluation of subgrade, not only CBR but also PI (Professional Indemnity Insurance) is important parameter.
  - At the design stage, the elastic modulus is also considered to change.
  - Important matters to determine the structure thickness and materials of each layer in pavement design are to consider the balance. For instance, when G1is used for base course, cement stabilized base course which is a good platform is effective.

3.2.2.5 INGEROP

Interviewees: Mr. Ian Fitz (General Manager Operations)

Items for hearing: Construction system/supervising plan, quality management and defects/ defect insurance.

Result of hearing survey: The result is indicated as below;

- **Insurance for consultants**

  - Insurance for consultants is responded by PI. It is comprehensive insurance that the premium is changed depending on the scale of the contract amount. Even if the project requires separate insurance, insurance for the project is made with PI insurance. The cost is included in the contract fee.
  - Some insurance are required against the design life or the life period of structure.

- **Defects on design / supervision**

- Consultants have a responsibility of design errors found during construction. It is in the object of design flaw. Defect caused by construction is basically not the responsibility of consultant, depending on the level of construction supervision by contract (once a week or residing on site etc). The role of consultant is monitoring for process control and quality control.
- For instance, the responsibility of the concrete quality is the contractor who ordered. Generally, laboratory test is not conducted by consultants. Each test is regulated in the specification document, and not proposed by consultant. Therefore, consultant seems not to have responsibility on those qualities.
- For the conflict on defects, it mediates the dispute by the National Judicative System.

➢ **Scope of supervising by consultant**

- This is determined by discussion and request of the client.

➢ **Others**

- Separating design and construction supervision has a great risk, and it is discouraged.
- Basically consultant does not directly access and check materials. In this regard, however in case that material engineer is adopted and the material quality checking is included in the contract, it should be done by the consultant.

3.2.2.6 BCHOD

Interviewees: Eng. George Sitali (Director), Eng. Tresphor K. Musonda
Items for hearing: Issues on Livingstone Road, construction system/supervising plan, quality management and defects/ defect insurance.

Result of hearing survey: The result is indicated as below;

➢ **General method of pavement design**

- Current design method consists of the design method from Zambia and SATAC from South Africa It is currently under revision.
- As the output above, it aims for a new catalog method revising old catalogs rather than a formula.

➢ **Responsibility of pavement construction**

- Process control is 100% responsibility by the contractor
- Quality control is 50% responsibility by the contractor and the consultant each. Supervising consultant has an obligation to check it PI is needed for design defect.

➢ **Formation of supervision team**

- The client dedicates the formation of supervision team.

➢ **Designer and supervisor**

- It determines on a case-by-case basis whether these are implemented in the same company or not for the projects by EU and AfDB, consultant services include the feasibility study, detail design and supervising.
- As a unique way of Zambia, supervising consultant checks the detail design having a responsibility for its design defect.

➢ **Supervising / management plan**

- Supervising consultant should submit “Construction Management Plan” after signing the contract before beginning the work. On the other hand, the contractor has an obligation to submit “Method Statement” to the consultant.
- On “Quality Assurance Plan”, the both have an obligation to submit from the contractor to the consultant and also from the consultant to the client. However, these are for after signing the contract, not required submission at the bidding or using for qualification review.

3.2.2.7 Scirocco Enterprises Ltd. (ORIENTAL)

Interviewees: Mr. Moustafa S. Y. Saadi (Managing Director)
Items for hearing: Materials/Plant management and quality management / inspection

Result of hearing survey: The result is indicated as below;

➢ **Quality management of asphalt mixture**

- Consultant conducts sampling test each truckload, if the client requires.
- There is no quality control for the construction by Chinese contractor since detailed quality management is not regulated in the contract.

➢ **LABO and mix design**

- Lab installation and dispatch of engineers will be carried out, if it is requested by the client. Asphalt mix design is conducted in the installed laboratory.
- The mixture is adopted by Marshall. The result should be approved by the consultant.

3.2.2.8 Zule Burrow

Interviewees: Mr. Levi Zule (Managing Director)
Items for hearing: Pavement design standard, construction supervising plan,

construction system, quality management and defects/ defect insurance

Result of hearing survey: The result is indicated as below;

- **Pavement design in Zambia**
  - As a design standard, SATCC is normally adopted. All projects must need traffic volume survey and axial weight survey. Over loading and design load are considered depending on the discussion with the client. This has great impact on the cost.
- **Supervising road construction**
  - According to RDA's standard for road construction, nine staffs including 1)PM, 2)RE, 3)Assistant RE, 4)Inspector, 5)Material engineer, 6)Surveyor, 7)Quantity staff, 8)Laboratory technician and 9)CAD operator should be assigned at the project site. Material/Pavement Engineer is normally in charge of the assistant RE above.
- **Design defects / defect insurance**
  - In general, RDA separately orders FS-DD and DR-SV. Design responsibility of DR covers only modification from the original design. Consultant for DD has a responsibility for the part without modification by DR.
  - Due to extremely short period for DR (for a few month), the inspection scope is limited
  - Defect insurance is an inclusive insurance using PI, therefore the insurance premium is differ depending on scale of the company. Consultant and contractor are obligated to submit the certificate of insurance enrollment at the submission of the proposal.
  - For the design of special or mega structure, the insurance for such specific projects is required in rare cases. This insurance premium is included in the contract.
- **Construction supervising plan**
  - Consultant for service contract has an obligation to submit Quality Management Plan and Environmental Management Plan.
  - Contractor for works contract has an obligation to submit Construction Plan
  - Normally, the plans that consultant produces should be included in the contract being a part of a tender document.

3.2.3 Data collection

The collected data in this study is listed as below:

Table 3.2.2 List of data collection

Name of data	Issued by	Year	Provided by
Standard specification for road and bridge works for state road authorities	Committee of Land Transport Officials	1998	Much Asphalt
User guide for the design of hot mix asphalt	Sabita	2001	Much Asphalt
Hot mix asphalt trouble-shooting guide	Society for Asphalt Technology	2005	Much Asphalt
Interim guideline for the design of hot-mix asphalt in South Africa	Sabita	2001	Much Asphalt
Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses	Sabita	2014	Much Asphalt
Guidelines for the manufacture and construction of hot mix Asphalt	Sabita	2008	Much Asphalt
Technical guideline The use of modified bituminous binder in road construction	Sabita	2014	Much Asphalt
Technical guideline The introduction of a performance grade specification for bituminous binders	Sabita	2016	Much Asphalt
Design and use of asphalt in road pavements	Sabita	2016	SANRAL
The rehabilitation of approximately 13km of mosi oa tunya road Detailed assessment and design report	RDA	2013	BCHOD

3.2.4 Photos on the site survey


SA: Continuous plant for Much Asphalt (the largest asphalt supplier in SA)


SA: Much Asphalt Laboratory


SA: Sampling from dump truck bed in Much Asphalt


SA: AS MIX sample storage in Much Asphalt


Zambia: Condition of "Tokyo way" in Lusaka (Fair)


Zambia: Condition of "Tokyo way" in Lusaka (Fair: Repaired section after 7 months (a rainy season))


Zambia: Condition of "Tokyo way" in Lusaka (Fair: Repaired section after 7 months (a rainy


Zambia: Condition of "Tokyo way" in Lusaka (Stone collected here by local people caused the

season))

repairment)

Zambia: Livingstone Road before repairment (Extreme rutting)

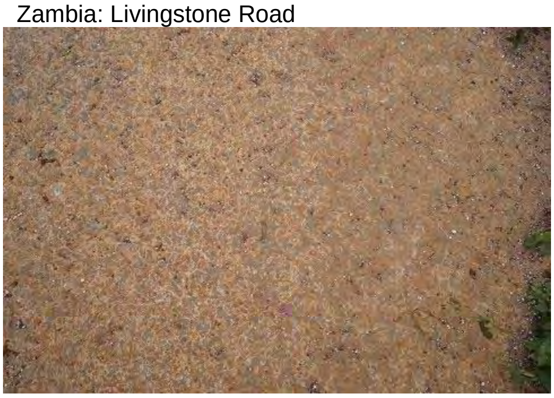
Zambia: Livingstone Road before repairment (Extreme breathing)

Zambia: Livingstone Road after repairment (beginning point)

Zambia: Livingstone Road after repairment (rutting at the intersection)

Zambia: Livingstone Road

Zambia: Tokyo Way



Zambia: Tokyo Way

3.3 Knowledge obtained in the study

3.3.1 Pavement design

The standard of pavement design in South Africa is currently under preparation of the revision as a progress below; to pursue the operation after three years.

Table 3.3.1 Pavement design methodology in South Africa

<table>
<tr><th colspan="3">Pavement design method in South Africa</th></tr>
<tr><th>Current situation</th><th>Coming 2 to 3 year</th><th>After 3 years</th></tr>
<tr><td>Main method
TRH (Technical Recommendations for Highways)4, 1996
Empirical (trial) Method
Catalogue method</td><td>Main method
TRH (Technical Recommendations for Highways)4, 1996
Empirical (trial) Method
Catalogue method</td><td rowspan="3">Main method
SANRAL leads to make the shift to SARDS as new software.
This new system is considered Empirical- Mechanical-Probability.
Pavement design, compound design, compound design, pavement performance curve, economic analysis can be carried out in a series. In this system, it is possible to consider the actual ground contact shape of the tire and the elastic modulus (Ev, Eh) of the material.
Also, the theory of viscoelasticity is incorporated.
Traffic axle load spectrum is used as the load condition instead of E80.
This data is obtained from the weigh-in-motion system. Due to actual measurement, overloading is also taken into consideration.
This will be an effective design tool in other Africa regions as well.
To develop this system, SANRAL has signed a contract of about 1.5 billion yen with Pretoria University for two years.</td></tr>
<tr><td>Consideration of physical method
Pavement structure for the section having heavy traffic volume is verified by M-E (Mechanical- Empirical) in South Africa.

Design Soft-ware
“MePAD” (Multilayer elastic theory + Empirical method) is currently updating.</td><td>Consideration of physical method
The natural conditions of the area such as climate (temperature) is considered on the elastic modulus used in the M - E method.

Design Soft-ware
Upgraded “MeGAMES”will be released before the end of 2016.</td></tr>
<tr><td>Issues
TRH-4 is over-designed and mismatching to the local condition (Difficulty to obtain material such a G1. Expensive cost)</td><td>–</td></tr>
</table>

3.3.2 Mix design and evaluation

The newest mix design and asphalt evaluation in South Africa is conducted as below:

1. MIX TYPE SELECTION
2. BINDER SELECTION
3. AGGREGATE SELECTION
4. MIX DESIGN

3.3.2.1 MIX TYPE SELECTION

The type of asphalt mixture in South Africa is selected from three types below:

Mix Types: SMA, Coarse, Fine

3.3.2.2 BINDER SELECTION

Suitable asphalt binder for the area to use is selected depending on maximum asphalt temperature and minimum asphalt temperature in the figure below: This is the same idea as USA's PG (Performance Grade). The PG specification of South Africa is still in the trial stage.

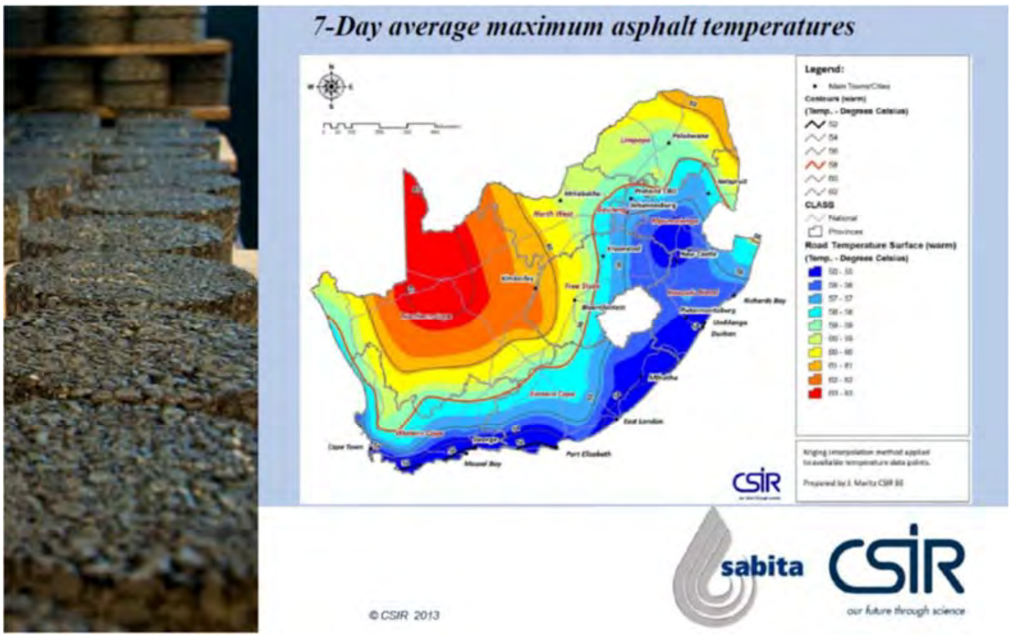


Figure 3.2.1 7-Day Average Maximum Asphalt Temparatures

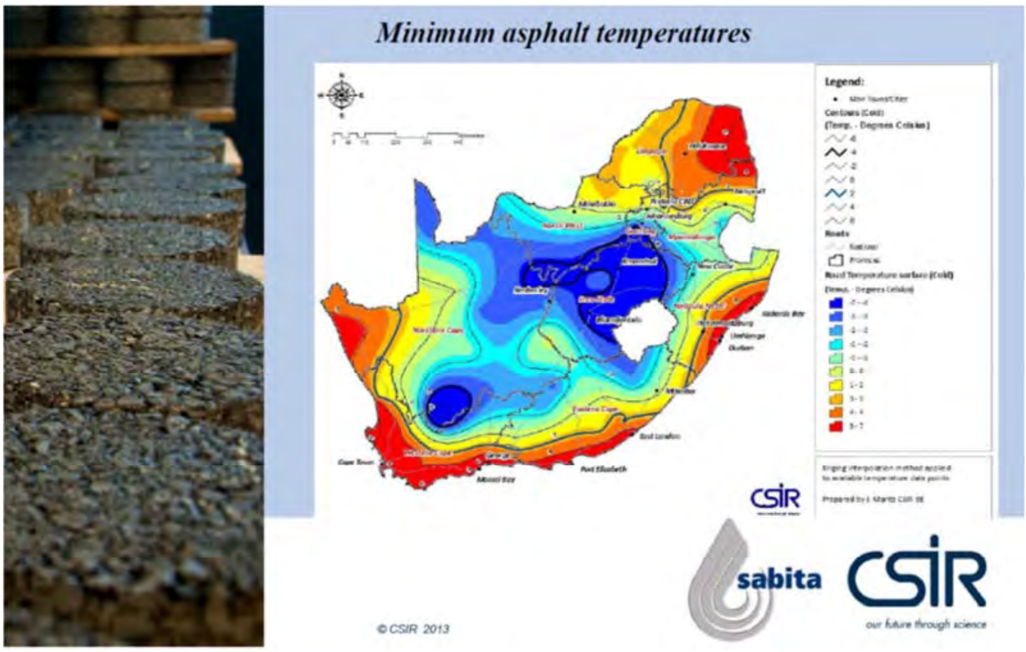


Figure 3.2.2 Minimum Asphalt Temperatures

3.3.2.3 AGGREGATE SELECTION

Aggregate framework is formed by its particle size using Bailey Method as a reference.

Bailey method – grading and packing analysis

Criteria are set based on unit weights, coarse and fine aggregate ratio.

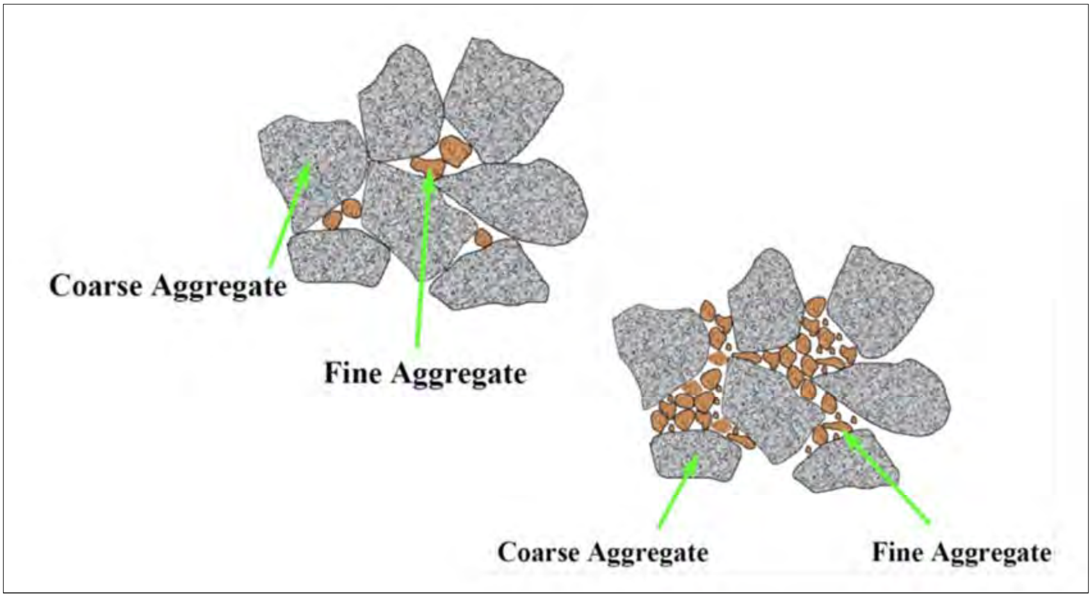


Figure 3.2.3 Aggregate Formulation

3.3.2.4 MIX DESIG

Mix design is categorized three levels depending on traffic volume for the target section, and then it is conducted using the method indicated as below;

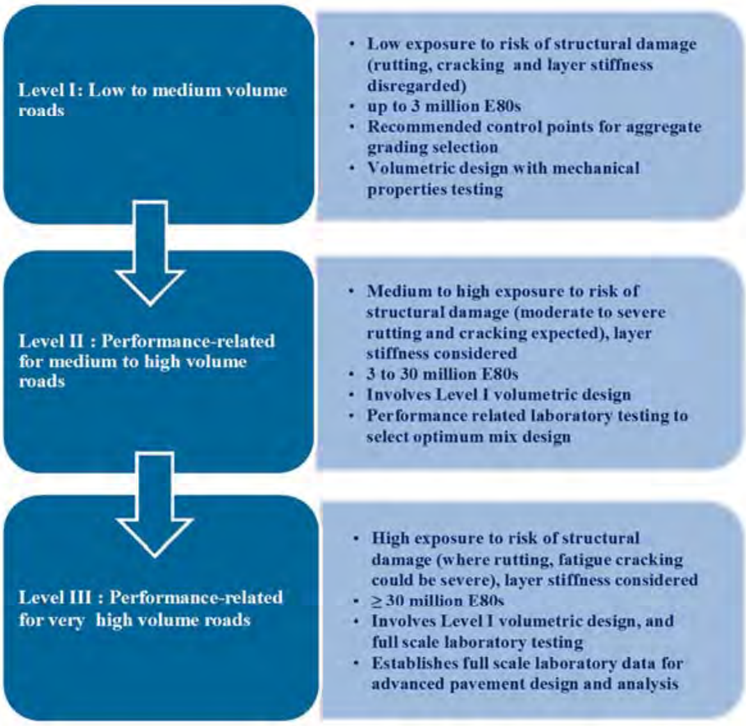


Figure 3.2.4 Mix Design Method 1

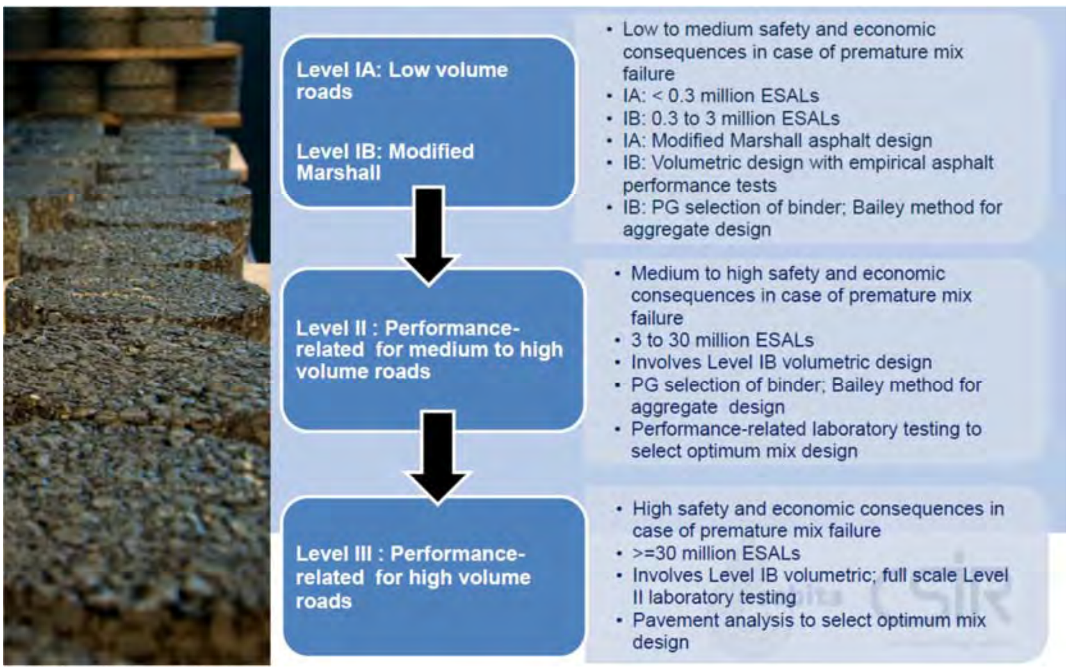


Figure 3.2.5 Mix Design Method 2

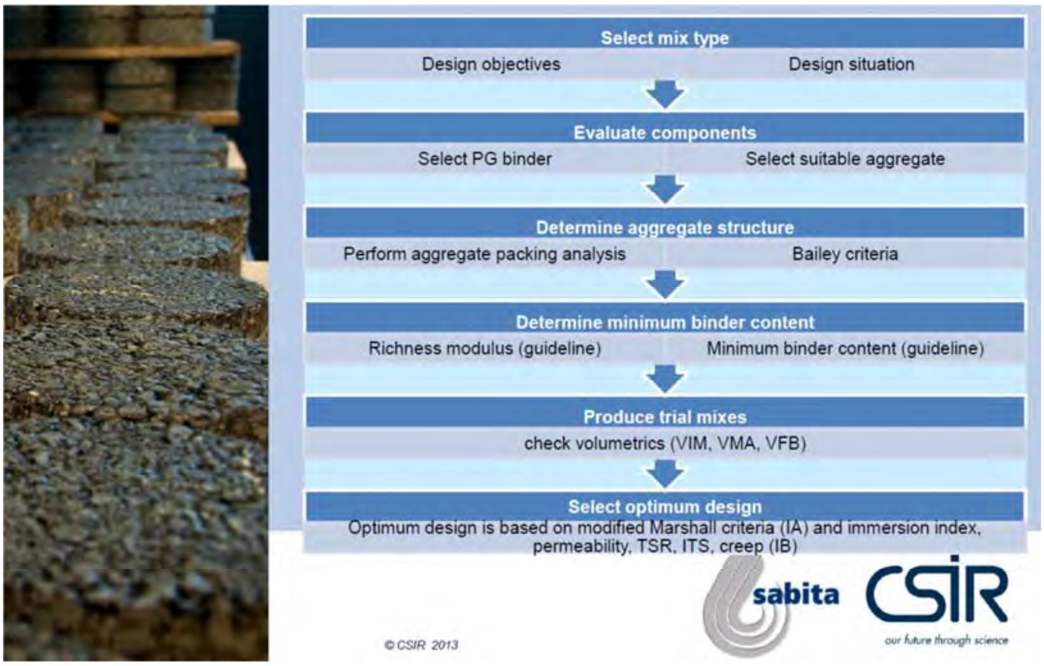


Figure 3.2.6 Method for Level I

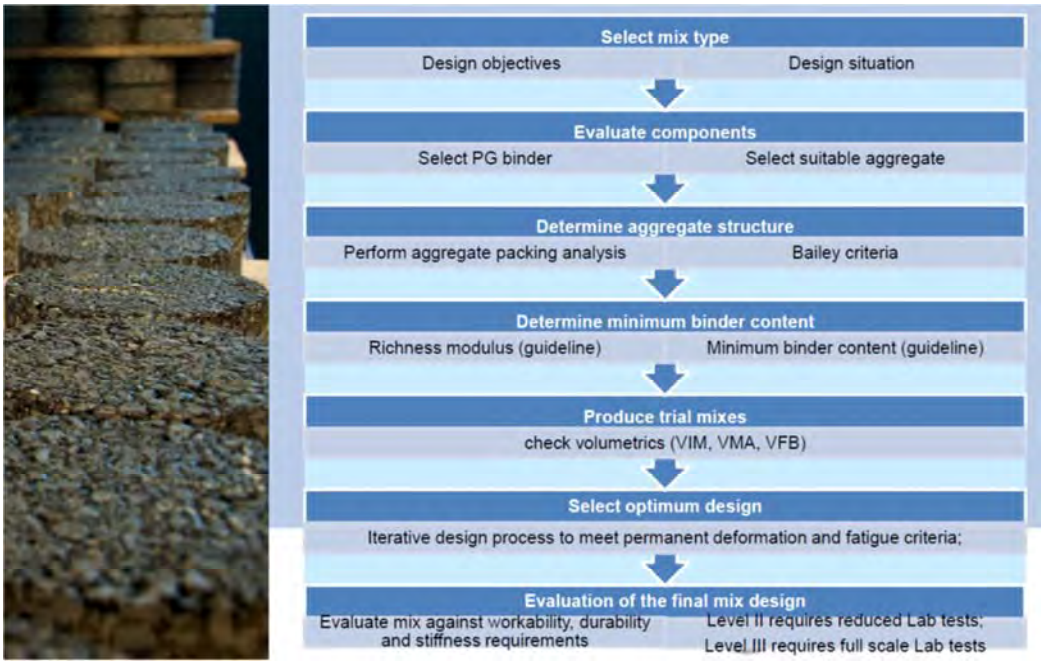


Figure 3.2.7 Method for Level II

3.3.3 Countermeasure against rutting

“Trouble Shooting Guide” issued by Asphalt Association in South Africa indicates a countermeasure against problems related to asphalt pavement that occurred on site.

Table 3.3.2 Shooting Guide

PROBLEM	POSSIBLE CAUSES	Pr.	Im.	SUGGESTED SOLUTIONS
Rutting: Deformation in wheel tracks under traffic (often accompanied by bleeding).	**1. Bitumen:**			**1. Bitumen:**
	a. Too soft for the application.	M	H	a. Use correct grade or modify for ambient temps and traffic.
	b. Contaminated, causing softening.	L	H	b. Check properties of samples from mixing plant.
	c. Compositional balance of bitumen.	L	H	c. Check for compliance with specs, but note that spec tolerances are wide. Can be big differences in properties of bitumen of same penetration grades.
	2. Asphalt Design:			**2. Asphalt Design:**
				Note: Any mix revisions suggested below must ensure that design requirements for the job are still met.
	a. Bitumen content too high.	H	H	a. Revise design for stiffer mix.
	b. Very rounded aggregates.	L	M	b. Change aggregate source if possible and practical.
	c. Grading close to maximum density line.	M	M	c. Revise grading curve to achieve a harsher mix.
	d. High filler content acting as a bitumen extender. (causing excess mastic).	M	H	d. Check filler properties; redesign mix with reduced filler and suitable VIM's. (But see 2e below for the opposite effect of another type of filler).
	e. Filler/binder ratio too low, causing tender mix.	M	H	e. Increase filler content but don't make mix uncompactable.
				Note: This filler is doing the opposite of fillet in 2d above.
	3. Asphalt mixing and transport:			**3. Asphalt mixing and transport:**
	a. Contamination in plant (unburnt fuel etc).	L	H	a. Check temperatures, air feed, burners, nozzles, fuel quality.
	b. Excess release agent in hot bins.	L	M	b. Consider use ofnon oil-based release agent.
	c. Excess release agent (diesel?) on trucks.	L	M	c. Consider use ofnon oil-based release agent.
	4. Construction:			**4. Construction:**
	a. Excessive release agent (diesel?) in paver hopper.	L	L	a. Consider use of non oil-based release agent.
	b. Over-compaction (only if mix VIM's are too low).	L	H	b. Rather revise the mix design than reduce compaction effort.
		H	H	c. Consider using a stiffer or modified bitumen.
	5. General:			**5. General:**
	a. Heavy traffic or accelerating/decelerating traffic (at intersections).	H	H	a. Re-design a rut resistant mix (maybe with stiffer or modified bitumen) but make sure it is still compactable.
	b. Fuel and/or oil spills from traffic	H	M	b. Repair. Note that EVA modified asphalt is resistant to these spills.

The Probability (Pr) of the problem's occurrence is indicated in the central column, with probability rated High (H), Medium (M), Low (L).The Impact (Im) on final product is shown in the central column, evaluated as High (H), Medium (M), or Low (L).

HOT-MIX ASPHALT TROUBLE SHOOTING GUIDE: Society for Asphalt Technology April 2005

Chapter 4 Subcontracted Test in Japan

4.1 Purpose of the Test

(1) Purpose

The purpose of the indoor mixing test under the present Study is to make proposals designed to reduce the occurrence of early defects originating from flow rutting, especially in hot tropical regions.

In Japan, the reference DS value is set at 3,000 or higher as the performance indicator for pavement bearing heavy traffic. Even though a high DS value is occasionally achieved with the dense graded type depending on the quality of the base rock used as coarse aggregate, this reference value is mostly met by the use of modified asphalt. In developing countries, however, the use of modified asphalt may not be easy because it may be difficult to secure a supply of modified asphalt or the cost of the modified asphalt mixture is approximately 20 ~ 30% more expensive than the cost of ordinary asphalt mixture.

Because of this, a possible way to improve the flow resistance using straight asphalt is examined in this Study. The findings of this examination regarding the following issues will then be compiled in a handbook to be produced under the Study.

- Listing of the causative factors of deterioration of the flow resistance and listing of particularly important points to manage the elimination or alleviation of these factors at the time of mixing, plant mixing and actual paving work
- Factors believed to be particularly effective to improve the flow resistance
- Test method other than the Marshall stability test to confirm the flow resistance of a mixture

There is concern regarding the non-applicability of the above findings due to specific external and internal factors in individual target countries. Examples of external factors are (i) there are road sections where a road surface temperature exceeding 60°C lasts for a long time, (ii) there are road sections subject to extremely heavy traffic and (iii) there are road sections requiring special measures for slow-moving heavy vehicles (steep gradient sections, inside intersections and sections requiring preparatory measures for the previously mentioned two types of sections). Examples of internal factors are (i) quality and domestic production capacity of coarse and fine aggregate and (ii) few options for procurable materials. Because of these possibilities, the measures to be compiled in a handbook will be presented as suggestions rather than concrete proposals.

(2) Basic Principles of Testing

The Paving Work Handbook (published by the Japan Road Association in Japanese) recommends the following measures to combat flow rutting.

- The target grain size of aggregate should be the median value or smaller and the volume of grains passing through a 75 μm sieve should be kept small.
- The asphalt content should be the median value in the common range. It must be noted that a lesser asphalt content could lead to proneness to peeling depending on the type of aggregate.
- The target Marshall stability and stability/flow value should be 7.35 kN or more after tamping for 75 times and 2,500 or more respectively.

- Of those passing through a 75 μm sieve, the volume of dust for recovery should not exceed 30%.

- The bituminous coal to be used should be re-examined and should be replaced by another bituminous material offering a high DS value if necessary (reformed As or low penetration As).

As the above important points are commonly known, this Study verifies the correlation between the porosity and a DS value at the maximum number of gyrations using the wheel tracking test (Japanese specifications) and SGC (compactor with Superpave specifications) based on knowledge (importance of the porosity in flow resistance) obtained by field studies conducted by other advanced countries than Japan. Because of concern that too much emphasis on flow resistance could lead to a decline of the weatherability, both the peeling resistance and crack resistance are checked by the immersion wheel tracking test and bending test respectively.

4.2 Testing Plan

4.2.1 Setting-Up of the Testing Conditions

(1) Configuration of Basic Mixture

Table 4.2.1 shows the commonly known factors (parameters) contributing to the flow resistance of a mixture.

Table 4.2.1 Parameters contributing to flow resistance

Category	Item	Parameter	Impact on DS Value
Internal Factors (Parameters)	Aggregate	Grain size	The smaller the volume passing through a 2.36 mm sieve is, the better.
		Structure	The greater the volume of coarse aggregate, such as gap-grade aggregate, is, the better.
		Shape (fine aggregate)	Artificial sand rich in sharp corners is better than almost spherical natural sand.
		Shape (coarse aggregate)	Aggregate with low flat and elongated contents and with a rectangular shape is better.
		Maximum grain size	The larger the size is, the better.
		Recovery dust	The smaller the mix rate of dust for recovery is, the better.
	Asphalt	Penetration	The lower the penetration is, the better.
		PMB	Modified asphalt is better.
		Asphalt content	The smaller the asphalt content is, the better.
External Factors	Outdoor temperature	Tropical region	The flow resistance conspicuously deteriorates when the road surface temperature exceeds 60°C.
	Travelling speed	Congestion; slow moving vehicles	The phenomenon of flow is more conspicuous at sites of congestion.

In this Study, the typical mixture to be used is decided to be the dense graded type (13) [75 times] 60/80. To make the porosity a parameter, the wheel tracking test and mixture compacting test using a SGC were conducted with changing porosity values.

As there is no way to change only the porosity while making the grain size and asphalt content constant, the following options were used in the Study.

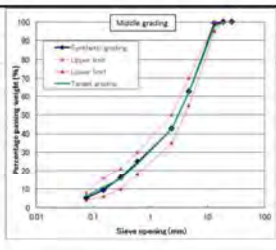
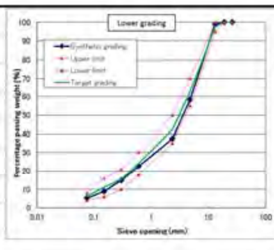
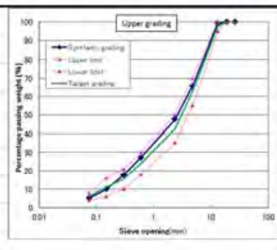
① Change of the content of dense graded asphalt (13)
② Change of the content of dense graded asphalt (13) passing through a 2.36 mm sieve

Using the results of ① and ② above, a correlation diagramme was created with DS plotted for the axis of ordinates and porosity, asphalt content, passing volume through a 2.36 mm sieve, compaction degree and maximum porosity plotted for the axis of abscissas.

The asphalt content in ① was set at ± 0.3 and 0.6% of the optimum asphalt content (OAC) in the typical mixture. In the Study, the asphalt content was only changed with the median grain size and lower passing rate grain size.

For the passing volume through a 2.36 mm sieve in ②, three percentage volumes, i.e. 37.5%, 42.5% and 47.5%, were used based on the range of the standard grain size of the dense graded asphalt mixture (13). These were then considered to represent the lower passing rate grain size, median grain size and higher passing rate grain size. Table 4.2.2 summarized the mixture contents at three different grain sizes.

Table 4.2.2 Summary of mixture contents (median, higher and lower passing rate grain sizes)

		Mix type		
		Middle grading	Lower grading	Upper grading
Mix proportion(%)	№6 Crushed ston	37.5	41.8	35.4
	№7 Crushed ston	15.0	17.0	11.0
	Crushed sand	37.5	31.2	43.6
	Fine sand	5.0	5.0	5.0
	Stone powder	5.0	5.0	5.0
Passing percent weight(%)	19.0	100.0	100.0	100.0
	13.2	99.1	99.0	99.2
	4.75	62.6	58.3	65.5
	2.36	42.5	37.5	47.5
	0.600	24.8	22.4	27.2
	0.300	16.2	14.8	17.6
	0.150	9.4	8.9	10.0
	0.075	5.2	5.2	5.1
Grading curve				

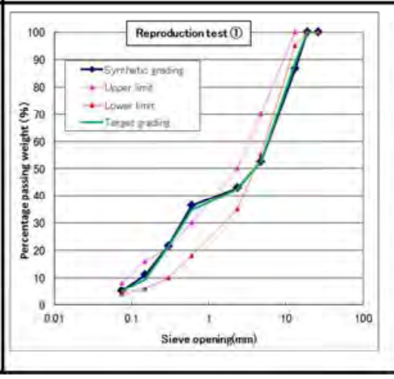
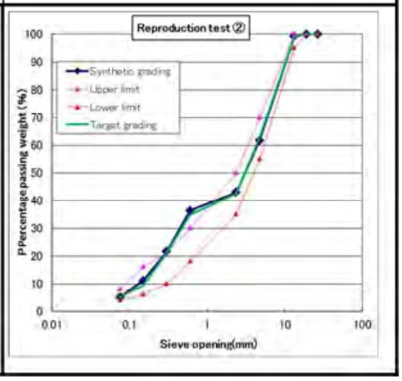
(2) Examination of Causative Factors of Rutting with in-Situ Pavement

The phenomenon of early rutting was observed with pavement in a hot tropical area. Checking of the grain size with the mixture sampled in-situ revealed that the grain size of the sampled mixture was outside the standard range of grain size for dense graded asphalt mixture (13) in most grain size categories. The reproduction test was then conducted to verify the properties of the in-situ mixture. The following two grain sizes of mixture were tested, referring to the grain size of the in-situ mixture.

- Reproduction test ①: The grain size of both coarse and fine aggregate are outside the appropriate range.
- Reproduction test ②: The grain size of only fine aggregate is outside the appropriate range.

Table 4.2.3 summarized the mixture contents at each grain size. To maximize the reproducibility of in-situ mixture, crushed sand classified by sieve opening was used for the reproduction tests ① and ②, while No.5 crushed stone was used for the reproduction test ①. For the asphalt content, OAC of the median grain size referred to in (1) above was adopted.

Table 4.2.3 Summary of mixture contents (Reproduction Tests ① and ②)

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="4">Mix type</th></tr>
<tr><th colspan="2">Reproduction test ①</th><th colspan="2">Reproduction test ②</th></tr>
<tr><td rowspan="10">Mix proportion (%)</td><td colspan="2">№5 Crushed ston</td><td colspan="2">14.0</td><td colspan="2">0.0</td></tr>
<tr><td colspan="2">№6 Crushed ston</td><td colspan="2">36.0</td><td colspan="2">38.0</td></tr>
<tr><td colspan="2">№7 Crushed ston</td><td colspan="2">5.0</td><td colspan="2">17.0</td></tr>
<tr><td rowspan="5">Crushed sand</td><td>2.36</td><td rowspan="5">35.0</td><td>10.0</td><td rowspan="5">35.0</td><td>10.0</td></tr>
<tr><td>0.600</td><td>15.0</td><td>15.0</td></tr>
<tr><td>0.300</td><td>35.0</td><td>35.0</td></tr>
<tr><td>0.150</td><td>25.0</td><td>25.0</td></tr>
<tr><td>0.075</td><td>15.0</td><td>15.0</td></tr>
<tr><td colspan="2">Fine sand</td><td colspan="2">5.0</td><td colspan="2">5.0</td></tr>
<tr><td colspan="2">Stone powder</td><td colspan="2">5.0</td><td colspan="2">5.0</td></tr>
<tr><td rowspan="9">Passing percent weight (%)</td><td colspan="2">26.0</td><td colspan="2">100.0</td><td colspan="2">100.0</td></tr>
<tr><td colspan="2">19.0</td><td colspan="2">100.0</td><td colspan="2">100.0</td></tr>
<tr><td colspan="2">13.2</td><td colspan="2">86.7</td><td colspan="2">99.1</td></tr>
<tr><td colspan="2">4.75</td><td colspan="2">52.5</td><td colspan="2">61.7</td></tr>
<tr><td colspan="2">2.36</td><td colspan="2">42.9</td><td colspan="2">42.9</td></tr>
<tr><td colspan="2">0.600</td><td colspan="2">36.4</td><td colspan="2">36.4</td></tr>
<tr><td colspan="2">0.300</td><td colspan="2">21.6</td><td colspan="2">21.6</td></tr>
<tr><td colspan="2">0.150</td><td colspan="2">11.1</td><td colspan="2">11.1</td></tr>
<tr><td colspan="2">0.075</td><td colspan="2">5.2</td><td colspan="2">5.2</td></tr>
<tr><td colspan="3">Grading curve</td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

4.2.2 Setting-Up of Test Items

Table 4.2.4 Proposed test items

No.	Test Title	Test Method	Remarks
①	Test for density and water absorption of aggregate	JIS A1110	Calculated value of maximum theoretical density
②	Marshall stability test	Testing Method Handbook B001	Determination of OAC
③	Wheel tracking (WT) test	Testing Method Handbook B003	Dynamic stability
④	Immersion wheel tracking (WT) test	Testing Method Handbook B003	Peeled area ratio
⑤	Bending test	Testing Method Handbook B005	Bending strength; bending strain
⑥	Maximum density test	Testing Method Handbook G027	Measured value of maximum theoretical density

⑦	Mixture compacting test using SGC	SHRP	Maximum porosity

1) Tests ① and ② are conducted in the manner of the conventional Marshall stability test to determine the relation between the asphalt content and porosity.

2) Test ③ is conducted to determine the DS

3) Tests ④ and ⑤ are conducted to confirm the peeling resistance and cracking resistance in view of concern that too much emphasis on the flow resistance could damage the weatherability.

4) Tests ⑥ and ⑦ are conducted to determine the workability, design porosity and maximum porosity by means of establishing the degree of compaction and porosity at a number of gyrations (Nini, Ndes and Nmax) under heavy traffic conditions in line with SHRP. Here, the maximum density to be used to calculate the porosity shall be the value obtained in Test ⑥.

4.3 Test Results

4.3.1 Materials Used

Tables 4.3.1 and 4.3.1 list the types of aggregate and asphalt used in the Study. The appearance of the aggregate used is shown in Photo 4.3.1.

Table 4.3.1 Aggregate used

			№5 Crushed ston	№6 Crushed ston	№7 Crushed ston	Crushed sand	Crushed sand for Reproduction test	Fine sand	Stone powder	Grade
Manufacturer			Orisu					Hagurosizai	Ryokosekkaikougyou	
Locality			Kasama city	Kasama city	Kasama city	Moriya city		Utsunomiya city	Ouse city	
Materials			Hard Sandstone					Sand washing	Calcium carbonate	
Test item	Passing percent weight (%)	19.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
		13.2	10.7	97.6	100.0	100.0	100.0	100.0	100.0	
		9.5	0.5	66.0	100.0	100.0	100.0	100.0	100.0	
		4.75	0.5	10.4	74.8	100.0	100.0	100.0	100.0	
		2.36	0.5	3.7	0.0	83.0	90.0	100.0	100.0	
		1.18	0.5	2.4	0.0	59.3	-	97.6	100.0	
		0.600	0.5	1.9	0.0	39.3	75.0	87.7	100.0	
		0.300	0.4	1.6	0.0	22.9	40.0	39.3	100.0	
		0.150	0.4	1.4	0.0	9.5	15.0	6.7	99.8	
		0.075	0.4	1.0	0.0	0.0	0.0	1.6	94.1	
	Density	Surface dry density [g/cm^3]	2.675	2.653	2.650		2.619	2.590		Coarse aggregate: Over 2.45 Fine aggregate : -
		Apparent density [g/cm^3]	2.689	2.682	2.693		2.680	2.631	2.710	
		Bulk density [g/cm^3]	2.666	2.636	2.625		2.530	2.546		
	Absorption[%]		0.32	0.65	0.97		3.51	1.76		
	Abrasion[%]		11.9	12.2						Coarse aggregate: Over30.0 Fine aggregate : -
	The amount of loss[%]		0.1	0.3	0.1		0.6	3.6		Coarse aggregate: Over12.0 Fine aggregate : -
	Soft fragments[%]		2.7	2.2						Coarse aggregate: Over5.0 Fine aggregate : -
	Flat rate[%]		0.2	0.8						Coarse aggregate: Over10.0 Fine aggregate : -
	Static peeling rate[%]			12.0						
	Plasticity index					NP		NP		
Remarks										Pavement construction standard

Table 4.3.2 Asphalt used

Product name			Straight Asphalt 60/80	
Manufacturer			JX energy	Grade
Test item	Ductility	[cm]	100(+)	Over 100
	Flash point COC	[℃]	362	Over 260
	Kinematic viscosity（120℃）	[mm^2/s]	834	
	Kinematic viscosity（150℃）	[mm^2/s]	190	
	Kinematic viscosity（180℃）	[mm^2/s]	64.0	
	Softening Point	[℃]	46.0	44.0～52.0
	Penetration（25℃）	[1/10mm]	71	60～80
	Penetration after evaporation	[%]	102	Over110
	Toluene soluble	[mass%]	99.97	Over99.0
	Density（15℃）	[g/cm^3]	1.036	Over1.000
	Thin film heating mass rate of change	[%]	(+)0.15	Under0.6
	Thin film heating penetration residual rate	[%]	70.3	Over55
Remarks				Hosou Sekou Binran (H18)

Photo 4.3.1 Appearance of aggregate used
(Top Left: No. 5; Top Right: No. 6; Middle Left: No. 7 crushed stone; Middle Right: crushed sand; Bottom Left: fine sand; Bottom Right: stone dust)

4.3.2 Subject Mixtures for Evaluation

Table 4.3.3 lists the subject mixtures in the Study.

Table 4.3.3 List of subject mixtures for testing

Mix name	2.36mm passing sieve[%]	Asphalt content
Middle grading OAC+0.6%	42.9	OAC+0.6%
Middle grading OAC+0.3%		OAC+0.3%
Middle grading OAC		-
Middle grading OAC-0.3%		OAC-0.3%
Middle grading OAC-0.6%		OAC-0.6%
Lower grading OAC+0.6%	37.5	OAC+0.6%
Lower grading OAC+0.3%		OAC+0.3%
Lower grading OAC		-
Lower grading OAC-0.3%		OAC-0.3%
Lower grading OAC-0.6%		OAC-0.6%
Upper grading OAC	47.5	-
Reproduction test ①	42.9	Middle grading OAC
Reproduction test ②		

4.3.3 Implemented Test Items

Table 4.3.4 lists the items tested in the Study. Table 4.3.5 shows the correspondence between the type of test and mixture. The mixture compacting test method using a SGC is described separately.

Table 4.3.4 Test items

Test name	Test method	Application
Test for density and water absorption of aggregates	JIS A 1110	Design of mix
Mashall test	Test method manual B001	OAC and standard density of each mixture
Wheel tracking test	Test method manual B003	plastic deformation resistance
Water immersion wheel tracking test	Test method manual B004	Stripping resistance of mixture
Bending test	Test method manual B005	Deflectio following of mixture
Maximau density test	Test method manual G027	Measured value of theoretical maximum density
Mixture compaction test by SGC	To be Written	V_{ini}, V_{des}, V_{max}

Table 4.3.5 Correspondence between type of test and mixture

No.	Mixture name	Mashall test	Wheel tracking test	Water immersion wheel tracking test	Bending test	Maximau density test	Mixture compaction test by SGC
①	Middle grading OAC+0.6%	○	○	○	○	○	○
②	Middle grading OAC+0.3%	●	○	○	-	○	○
③	Middle grading OAC	●	○	-	-	○	○
④	Middle grading OAC-0.3%	●	○	-	-	○	○
⑤	Middle grading OAC-0.6%	●	○	○	○	○	○
⑥	Lower grading OAC+0.6%	○	○	○	○	○	○
⑦	Lower grading OAC+0.3%	●	○	○	-	○	○
⑧	Lower grading OAC	●	○	-	-	○	○
⑨	Lower grading OAC-0.3%	●	○	-	-	○	○
⑩	Lower grading OAC-0.6%	●	○	○	○	○	○
⑪	Upper grading OAC	○	○	-	-	○	○
⑫	Reproduction test ①	●	○	-	-	○	○
⑬	Reproduction test ②	●	○	-	-	○	○

●:Do only the set asphalt content, evaluate the standard density
○:Test method of Table 4-6
ー:Do not test

< Mixture compacting test using a SGC >

A SGC (superpave gyratory compactor) is a testing machine which is used on the basis of the Superpave mixture design. One characteristic of this testing machine is that it provides the relation between the number of compacting gyrations by the SGC and height of the mixture. Fig. 4.3.1 shows an example of a correlation diagramme.

Using this correlation, it is possible to calculate the apparent density and porosity at a given number of gyrations.

The compaction parameter N is defined as follows based on the number of gyrations and mixture density.

Nini : Number of gyrations which can be used as the parameter for the workability during paving work and for the avoidance of an unstable mixture

Ndes : Number of gyrations required to provide a specimen of the same density as the on-site density under an estimated traffic volume

Nmax : Number of gyrations to obtain the indoor density which never exceeds the on-site density to avoid flow rutting.

Table 4.3.6 shows the set value for the compaction parameter (N) depending on the traffic volume. The porosity of the mixture obtained from each compaction parameter is defined as follows.

Vini : Initial porosity
Vdes : Design porosity
Vmax : Maximum porosity

As the Study assumed a route with an ultra-heavy traffic volume, the compaction parameter selected corresponds to the design ESAL of 30 x 10^6 or higher.

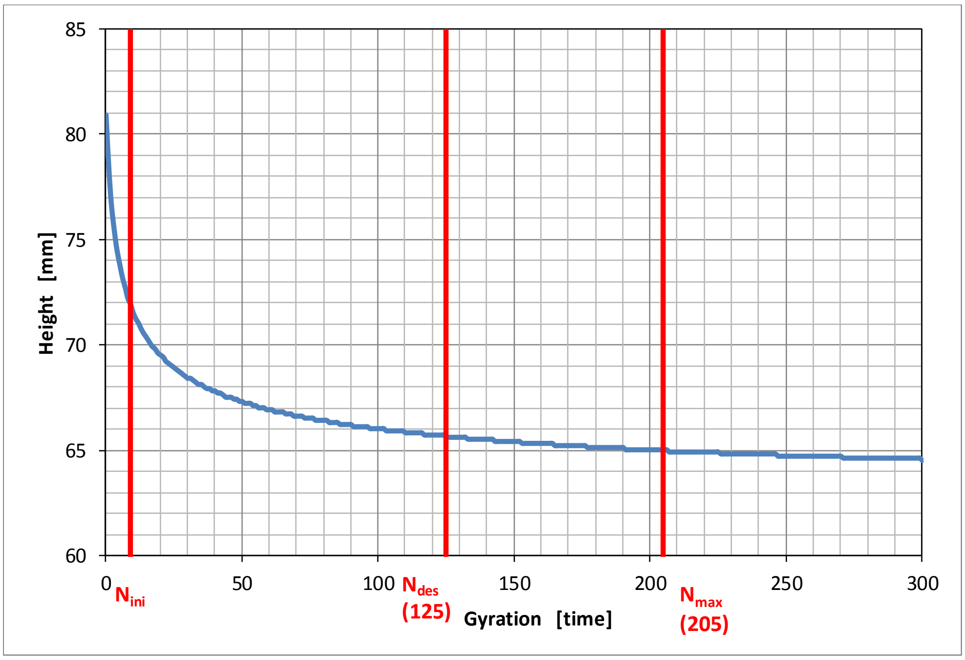


Fig. 4.3.1 Correlation between the number of gyrations of the SGC and height of the specimen mixture (Example)

Table 4.3.6 Compacting energy of a superpave gyratory compactor (AASHTO R35-09)

ESAL x 10^6	Compaction Parameter		
	Nini	Ndes	Nmax
< 0.3	6	50	75
0.3 to < 3	7	75	115
3 to < 30	8	100	160
> 30	9	125	205

The test was conducted in accordance with the Superpave (MixDesign) Superpave Series No. 2 (SP-2). The actual steps are described below.

① The aggregate and asphalt are cured in a circulating type drying furnace with a set temperature of 165°C.

② The aggregate and asphalt are mixed together until the former is completely covered by the latter.

③ The mixture is spread over a vat with a thickness of 25 ~ 50 mm.

④ The spread mixture is then cured in a circulating type drying furnace with a set temperature of 145 ± 3°C.

⑤ The mixture is taken out of the furnace every 60 minutes for further mixing.

⑥ After curing for two hours, the temperature of the mixture is checked using a bar thermometer to verify that the temperature has reached the temperature for rolling.

⑦ The mixture is poured into a mould which has been kept warm inside the circulating type drying furnace and is compacted by a SGC.

⑧ Based on the obtained number of gyrations and height of the mixture, the Vmax, Vdes and Vini values are calculated.

4.3.4 Test Results

(1) Mixture Design

The mixture design was conducted for three types of grain size, i.e. median, lower and higher passing rate grain sizes. Table 4.3.7 shows the test results.

Table 4.3.7 Marshall test results

	OAC %	TMD g/cm3	SD g/cm3	Void Ratio %	Saturation Degree %	VMA	Stability kN	Flow 1/100cm	S/F kN/m
Particle size (Upper)	4.7	2.495	2.409	3.4	76.2	14.5	15.4	35	4,400
Particle size (Middle)	4.8	2.492	2.409	3.3	77.2	14.5	14.3	36	3,972
Particle size (Lower)	4.8	2.492	2.403	3.6	75.5	14.6	15.0	38	3,947
Standard	-	-	-	3 - 6	70 - 85	>16	>7.35	20 - 40	>2,500

< Asphalt content and standard density in each type of mixture >

Based on the OAC for three grain size types, the asphalt content was determined in each mixture. Moreover, using the curve indicating the correlation between the asphalt content and density obtained from the mixture design, the standard density of each type of mixture was calculated. Table 4.3.8 lists the standard density for each type of mixture. The following evaluation test was conducted using a mixture with a compaction degree of 100 ± 1% against each standard density.

Table 4.3.8 List of asphalt contents and standard densities

Mixture name	Asphalt content[%]	Standard density[g/cm^3]
Middle grading OAC+0.6%	5.4	2.422
Middle grading OAC+0.3%	5.1	2.416
Middle grading OAC	4.8	2.409
Middle grading OAC-0.3%	4.5	2.400
Middle grading OAC-0.6%	4.2	2.392
Lower grading OAC+0.6%	5.4	2.416
Lower grading OAC+0.3%	5.1	2.409
Lower grading OAC	4.8	2.403
Lower grading OAC-0.3%	4.5	2.386
Lower grading OAC-0.6%	4.2	2.373
Upper grading OAC	4.7	2.409
Reproduction test ①	4.8	2.421
Reproduction test ②	4.8	2.408

(2) Marshall Stability

Table 4.3.9 shows the Marshall stability test results.

Table 4.3.9 Marshall stability and flow value

Mixture name	Marshall stability[kN]	Flow value[1/100cm]
Middle grading OAC+0.6%	13.0	37
Middle grading OAC+0.3%	13.4	35
Middle grading OAC	14.3	36
Middle grading OAC-0.3%	13.1	34
Middle grading OAC-0.6%	13.3	35
Lower grading OAC+0.6%	14.4	39
Lower grading OAC+0.3%	15.6	37
Lower grading OAC	15.0	36
Lower grading OAC-0.3%	13.3	38
Lower grading OAC-0.6%	12.5	36
Upper grading OAC	15.4	35
Reproduction test ①	17.5	38
Reproduction test ②	18.1	37

(3) Wheel Tracking Test

Table 4.3.10 shows the wheel tracking (WT) test results.

- There is a tendency for the DS to increase with every grade size category when the asphalt content is decreased (Fig. 4.3.2).
- There is a tendency for the DS to increase with a larger porosity.
- The impact of an increase/decrease of the asphalt content and porosity on the DS is larger with the median grain size than the lower passing rate grain size (Fig. 4.3.3).
- When compared in terms of OAC, the DS in Reproduction Tests ① and ② is lower than that of every grain size category in dense graded asphalt mixture (13). The DS in Reproduction Test ② where only fine aggregate is outside the appropriate range is lower than the DS in Reproduction Test ① (Fig. 4.3.4).

Table 4.3.10 WT test results

Mixture name	Void[%]	d_{45}[mm]	d_{60}[mm]	d_0[mm]	DS[time/mm]
Middle grading OAC+0.6%	2.4	5.85	6.85	2.85	630
Middle grading OAC+0.3%	3.0	3.51	4.03	1.95	1212
Middle grading OAC	3.7	2.36	2.69	1.38	1909
Middle grading OAC-0.3%	4.0	1.68	1.89	1.04	3000
Middle grading OAC-0.6%	5.6	1.84	2.05	1.23	3150
Lower grading OAC+0.6%	2.2	4.29	4.87	2.57	1105
Lower grading OAC+0.3%	3.4	3.40	3.85	2.03	1370
Lower grading OAC	3.4	2.57	2.94	1.46	1703
Lower grading OAC-0.3%	4.2	1.97	2.22	1.23	2520
Lower grading OAC-0.6%	6.0	2.32	2.62	1.43	2100
Upper grading OAC	4.1	3.18	3.56	2.05	1658
Reproduction test ①	3.6	3.13	3.73	1.44	1050
Reproduction test ②	4.0	3.94	4.78	1.43	750

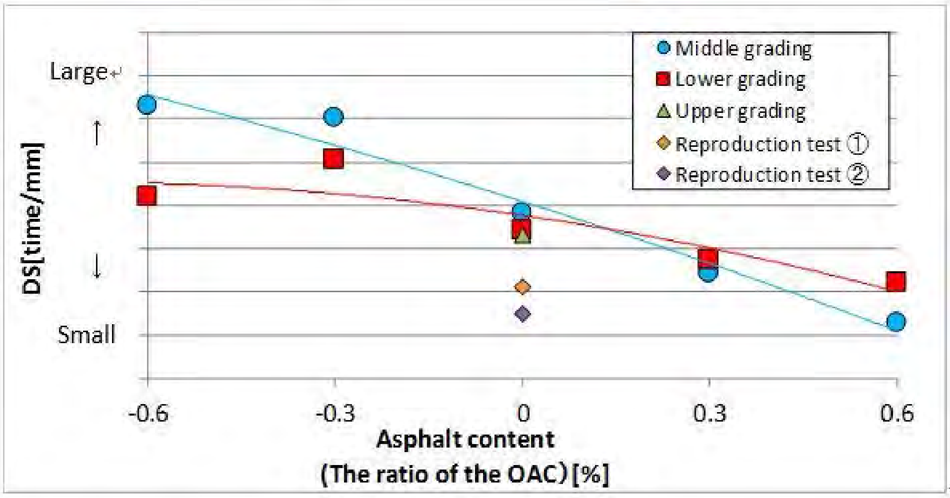


Fig. 4.3.2 Correlation between asphalt content (difference from OAC) and DS

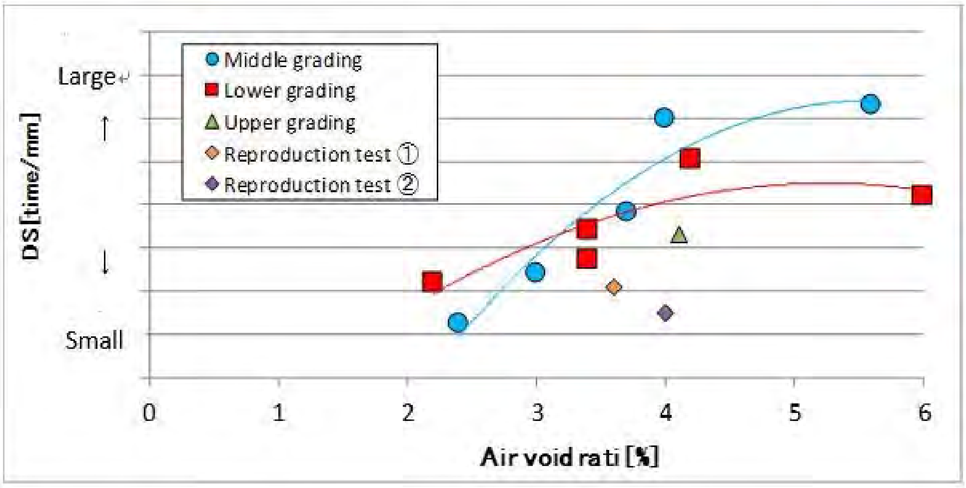


Fig 4.3.3 Correlation between porosity and DS

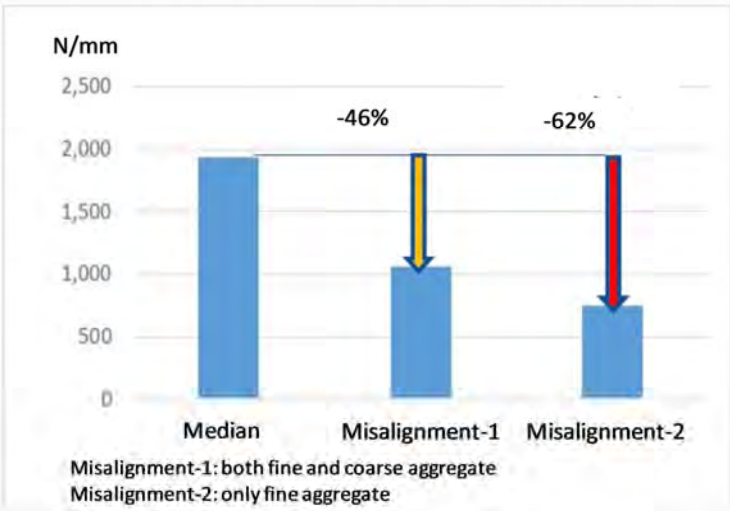


Fig. 4.3.4 Correlation between porosity and DS

(4) Immersion Wheel Tracking Test

Table 4.3.11 shows the immersion wheel (WT) tracking test results.

Table 4.3.11 Immersion WT test results

Mixture name	Void[%]	Stripping[%]
Middle grading OAC+0.6%	2.4	8.1
Middle grading OAC	3.7	4.7
Middle grading OAC-0.6%	5.6	4.7
Lower grading OAC+0.6%	2.2	3.5
Lower grading OAC	3.4	3.5
Lower grading OAC-0.6%	6.0	6.1

(5) Bending Test

Table 4.3.12 shows the bending test results for mixtures.

Table 4.3.12 Bending test results

Mixture name	Void[%]	Bending strength[MPa]	Bending strain [×10^{-3}cm/cm]
Middle grading OAC	3.7	6.27	3.87
Middle grading OAC-0.6%	5.6	8.14	4.57
Lower grading OAC	3.4	8.36	5.20
Lower grading OAC-0.6%	6.0	7.82	4.54
	※The void is value of the mixture before cutting		

(6) Maximum Density Test

Table 4.3.13 shows the maximum density test results. The actual measured values in this maximum density test were almost identical to the maximum theoretical values calculated.

Table 4.3.13 Maximum density test results

Mixture name	Measured maximum density [g/cm3]	Theoretical maximum density[g/cm^3]
Middle grading OAC+0.6%	2.472	2.470
Middle grading OAC+0.3%	2.484	2.481
Middle grading OAC	2.493	2.492
Middle grading OAC-0.3%	2.504	2.503
Middle grading OAC-0.6%	2.515	2.514
Lower grading OAC+0.6%	2.467	2.470
Lower grading OAC+0.3%	2.484	2.481
Lower grading OAC	2.491	2.492
Lower grading OAC-0.3%	2.503	2.503
Lower grading OAC-0.6%	2.517	2.514
Upper grading OAC	2.495	2.495
Reproduction test ①	2.493	2.490
Reproduction test ②	2.489	2.490

(7) Mixture Compaction Test Using a SGC

Table 4.3.14 and Figs. 4.3.5 through 4.3.8 show the results of the mixture compact test using a SGC. These results indicate the following tendencies.

- All of Vmax and Vdes tend to increase when the asphalt content decreases.
- At each grain size category, there is no distinctive difference between Vmax and Vdes at OAC.
- The difference between Vmax and Vdes tends to become larger with a decrease of the asphalt content.
- Vini for the lower passing rate grain size tends to be large compared to the other grain size categories at every asphalt content level.

- There is no clear correlation between the passing volume through a 2.36 mm sieve and Vmax.
- There is a clear correlation between Vmax and DS at every grain size category and a larger Vmax tends to increase the DS.
- There is a large difference between appearance density by SGC and bulk density using standard method. Hence evaluation of density by SGC should be carefully considered.
- The Vmax in the reproduction test is 3.7% for Test ① and 4.1% for Test ②, indicating a lower DS when compared with the corresponding Vmax of the dense graded asphalt mixture (13).

Table 4.3.14 Results of mixture compaction test using a SGC

Mixture name	2.36mm passing sieve[%]	DS [time/mm]	V_{ini}[%]	V_{des}[%]	V_{max}[%]
Middle grading OAC+0.6%	42.5	630	10.6	2.6	2.0
Middle grading OAC+0.3%		1212	11.9	3.7	2.9
Middle grading OAC		1909	12.2	4.2	3.2
Middle grading OAC-0.3%		3000	13.9	5.4	4.4
Middle grading OAC-0.6%		3150	14.6	6.2	5.2
Lower grading OAC+0.6%	37.5	1105	12.0	2.8	1.9
Lower grading OAC+0.3%		1370	13.2	4.0	3.0
Lower grading OAC		1703	13.1	4.4	3.5
Lower grading OAC-0.3%		2520	14.9	5.9	4.8
Lower grading OAC-0.6%		2100	15.5	7.0	5.9
Upper grading OAC	47.5	1658	12.3	4.5	3.6
Reproduction test ①	42.9	1050	11.6	4.7	3.7
Reproduction test ②		750	12.0	5.0	4.1

Table 4.3.15 Density, void ration and correction coefficient at Nmax

Mixture name	Density[g/cm^3] (N=205)		Correction factor "C"	V_{max}[%] (N=205)	
	Appearance	Bulk		Appearance	Bulk
Middle grading OAC+0.6%	2.414	2.455	1.017	2.3	0.7
Middle grading OAC+0.3%	2.387	2.444	1.024	3.9	1.6
Middle grading OAC	2.415	2.467	1.022	3.1	1.0
Middle grading OAC-0.3%	2.381	2.444	1.027	4.9	2.4
Middle grading OAC-0.6%	2.366	2.430	1.027	5.9	3.4
Lower grading OAC+0.6%	2.392	2.447	1.023	3.1	0.8
Lower grading OAC+0.3%	2.384	2.447	1.027	4.0	1.5
Lower grading OAC	2.394	2.457	1.026	3.9	1.4
Lower grading OAC-0.3%	2.368	2.448	1.034	5.4	2.2
Lower grading OAC-0.6%	2.349	2.430	1.034	6.6	3.5
Upper grading OAC	2.407	2.458	1.021	3.5	1.5
Reproduction test ①	2.408	2.451	1.018	3.4	1.7
Reproduction test ②	2.389	2.448	1.025	4.0	1.6

Table 4.3.16 Appearance density and bulk density for each number of gyration

Mixture name	V_{ini}[%] (N=9)		V_{des}[%] (N=125)		V_{max}[%] (N=205)	
	Appearance	Bulk	Appearance	Bulk	Appearance	Bulk
Middle grading OAC+0.6%	12.5	11.1	3.4	1.8	2.3	0.7
Middle grading OAC+0.3%	14.2	12.1	5.1	2.8	3.9	1.6
Middle grading OAC	12.5	10.6	4.1	2.0	3.1	1.0
Middle grading OAC-0.3%	14.4	12.1	5.9	3.4	4.9	2.4
Middle grading OAC-0.6%	15.6	13.3	7.0	4.5	5.9	3.4
Lower grading OAC+0.6%	13.7	11.7	4.2	2.0	3.1	0.8
Lower grading OAC+0.3%	14.5	12.2	5.2	2.7	4.0	1.5
Lower grading OAC	14.0	11.7	4.9	2.4	3.9	1.4
Lower grading OAC-0.3%	15.5	12.7	6.6	3.4	5.4	2.2
Lower grading OAC-0.6%	16.4	13.6	7.7	4.5	6.6	3.5
Upper grading OAC	12.5	10.6	4.5	2.5	3.5	1.5
Reproduction test ①	11.5	10.0	4.3	2.6	3.4	1.7
Reproduction test ②	11.9	9.7	4.9	2.6	4.0	1.6

< Considered items >

Appearance density, appearance void ration and bulk density, bulk void ration are led base on mmaximum number of gyration (Nmax) of 250. Definitions for each technical term in the Study are as follows:

Appearance density: calculated based on a sample weight in air and a sample volume ($\pi R^2/4$ x h:cm3)

h: height of displacement of testing machine

R: inner diameter of mold

Appearance density (g/cm3) = weight in air/sample volume

Bulk density: based on "Pavement testing manual, B008-1: Density test for dense asphalt concrete"

Bulk density (g/cm3) = weight in air/ (saturated surface dry weight – weight in water) x water density (≑ 1.0)

*specific weight of water: 1.0

Appearance void ratio: led from appearance density

Bulk void ratio: led from bulk density

Void ratio (%) = (1 – density (g/m3) / maximum density (g/m3)) x 100

*Value of maximum density for the calculation is derived from test result for "maximum density test".

Correction factor "C" is derived from correlation between appearance void ratio and bulk void ratio at Nmax. Bulk void ratios at Nini and Ndes are calculated using "C".

Correction factor "C" = bulk density/ appearance density

Value of correction factor "C" for superpave is value after Ndes, however value of "C" at Nmax is applied in the Study.

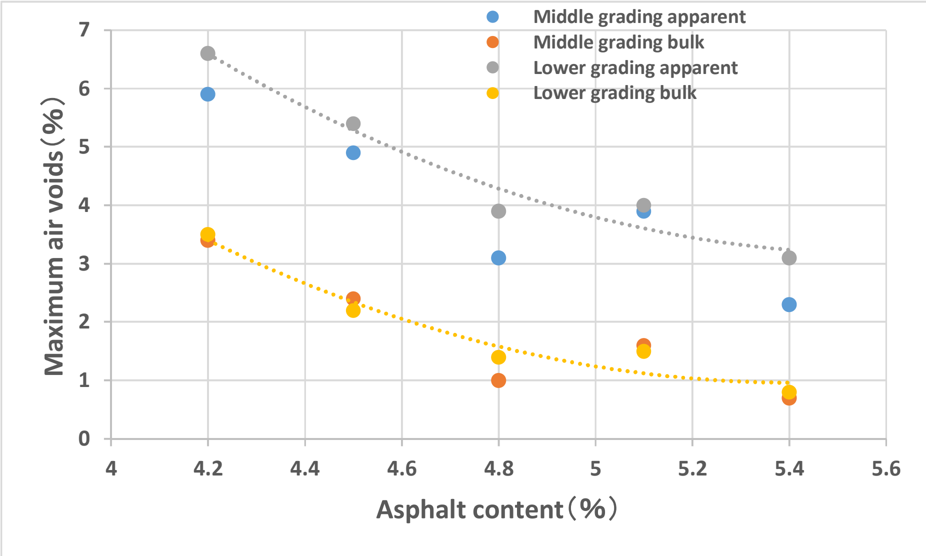


Fig. 4.3.5 Correlation between asphalt content and Vmax

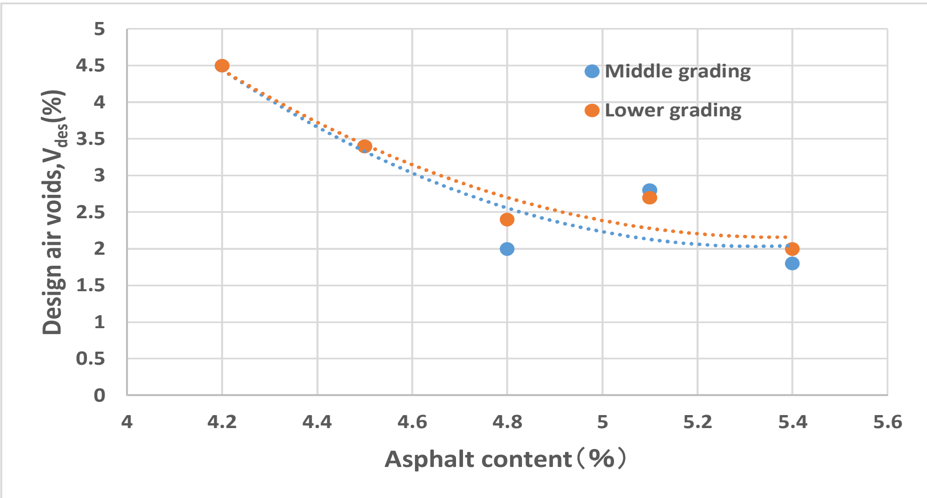


Fig. 4.3.6 Correlation between asphalt content and Vdes

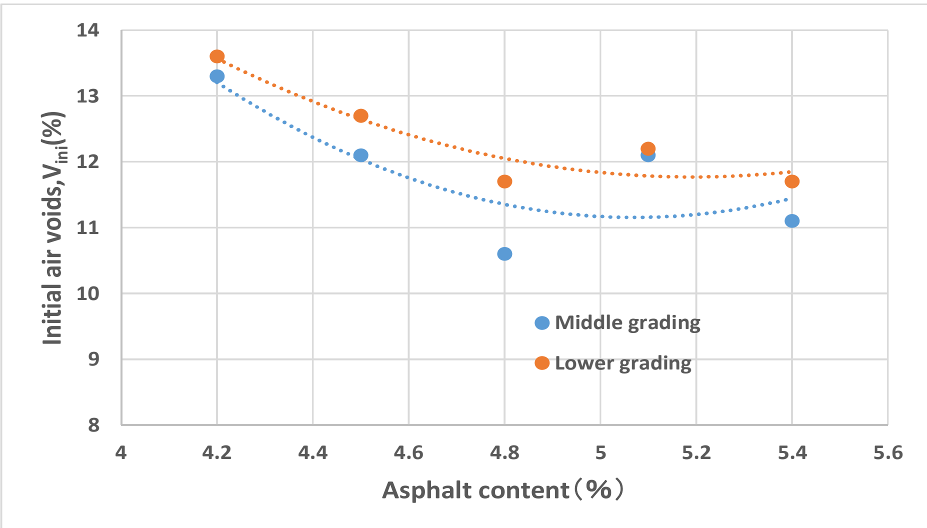


Fig. 4.3.7 Correlation between asphalt content and Vini

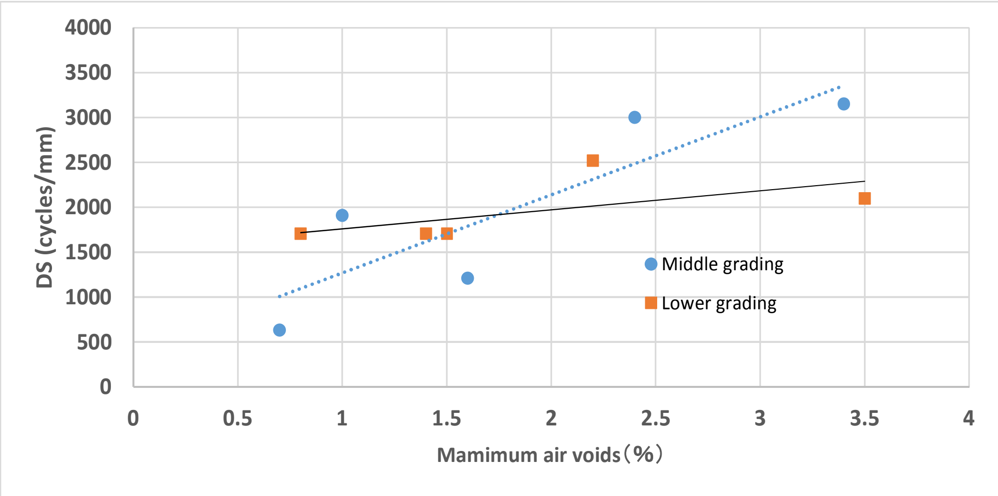


Fig. 4.3.8 Correlation between Vmax （bulk density） and DS

4.4 Key Findings of the Study

The key findings of the Study are described below.

(1) Parameters Originating from Plastic Deformation Resistance

The parameters originating from the plastic deformation resistance of mixture are described below.

- As far as the tests under the Study are concerned, it was possible to increase the plastic deformation resistance without damaging the peeling resistance or deflection follow-up performance by means of increasing the porosity (meaning reduction of the asphalt content in the range of OAC– 0.6%). However, as pointed out by the Paving Work Handbook, it is preferable for the asphalt content not to be reduced by 0.5% or more of OAC.

- Based on the comparison results between the median grain size and lower passing rate grain size, it is preferable to use the median grain size as it is more effective when the asphalt content is reduced.

- As a reduction of the asphalt content lengthens the time required for the asphalt covering of the aggregate (mixing time), it is necessary to check any impacts on deterioration of the thin film at the time of plant production.

- In this test, even though the final void ratio was less than 2%, high DS value was resulted. For this reason, it is inferred that the combination of good-shaped, high quality coarse aggregate and crush sand successfully led to the formation of a highly desirable aggregate structure.

(2) Parameter Inferred to be a Causative Factor for In-Situ Damage

The parameter inferred to be a causative factor for in-situ damage is described below.

- Even if the porosity and Vmax remain almost constant, there is a likelihood that damage in-situ is attributable to a certain grain size of the mixture as the DS in the reproduction test is lower than that of the dense graded asphalt mixture (13).

(3) Parameter Originating from the Compaction Performance (Workability) During Construction Work

The parameter originating from the workability of the mixture is described below.

- There is a possibility for improvement of the workability in proportion to an increased passing volume through a 2.36 mm sieve.

4.5 Conclusions

The Study are only based on one Japanese material. From the findings of the test, parameters which influence a resistance to plastic deformation are an asphalt volume and a void ration, however material quality is one of the important factors as well. Therefore, it is necessary to accumulate further data for different types of aggregate, including coarse aggregate with different lithological characters and natural sand and other fine aggregate.

Careful consideration is desirable prior to the implementation of a compaction test and mixing test using a SGC, as there are few engineers with the necessary skills and experience even among Japanese engineers.

For in-situ paving work, the following requirements must be met without fail.

- To verify the reproducibility of the results of the present Study, it is essential to confirm similar results in advance with a local material.

- Even if a good material is used, the final paving result can be poor depending on the quality of the paving work. Very careful work management and quality control systems are, therefore, important to ensure a high standard of in-situ paving work.

Chapter 5 Consultants' Defects

5.1 Consultants' Defects

5.1.1 Scope of liabilities for defects

(1) Consultants' roles

Construction consultants' roles in the construction industry in Japan consist mainly of "survey work such as program evaluation and F/S (feasibility study)," designing, and "preparation of design drawings required for site acquisition and ordering, calculation of construction quantity, and other services" at the bid/contract stages. Construction consultants are rarely involved the construction phase in general, but there are increasing cases where the three parties: the orderer, the constructor and the designer participate in the initial stage of construction and its implementation to share design intentions, and discuss and coordinate appropriate design and construction methods in response to the institutionalization of a tripartite technical liaison meeting. Although construction consultants' roles at the construction stage tends to be increasing, their contractual responsibilities are not yet stipulated despite their functional and moral responsibilities.

On the other hand, it is common to carry out the services of "preparing tender documents," "bidding support," and "supervising the construction" in addition to the above-mentioned roles in overseas operations. Under the contract clause of the International Federation of Consulting Engineers (FIDIC), the construction consultant is given the role of the "engineer (administrative agent) in addition to the "orderer" and the "contractor" that are the parties to the construction contract, where her/his authority and obligation are stipulated. In general, the construction consultant does not only play the role as the orderer's agent such as the construction planning, the approval of materials, etc., the direction of changes in the construction plan, the quality control, and the management of progresses in construction, designated by her/him, but is also given a strong authority to certify performances and make assessments and decisions against complaints, and is responsible as a judge from a fair and neutral standpoint, playing an important role in smoothly carrying out the construction in accordance with contracts along with a greater range of her/his responsibilities.

(2) Consultants' defects

Consultants' defects are considered to be the violation of "a duty of due care (the attention just as generally required by the obligor's occupation and the social and economic position to which s/he belongs)", and the "decrease in the value of an object due to the lack of the property that it is usually expected to have or the one whose existence the parties to the contract particularly guarantees." Because there are no provisions concerning the contents of defects with no definition and classification of them in the Civil Code, there are no legally clear judgment criteria for defects. In Japan, defects often refer to design defects with consultants' roles.

There are cases where their supervision responsibilities are also called into questions with regard to their defects at the time of construction in foreign countries, because consultants play the roles in surveys, designing and furthermore construction supervision work there. However, there are various ways of thinking about consultant defects (excluding design defects) at the stage of construction supervision even abroad.

Table 5.1.1 Results of interviews on the scope of defects

Services in Japan	Overseas services (interview results)
Design work A state in which a serious defect occurs at the target structure due to the incompleteness of the design document prepared by a consultant (Violation of a duty of due care).	**Design work** A state in which a serious defect occurs at the target structure due to the incompleteness of the design document prepared by a consultant (Violation of a duty of due care). A case where pavement is damaged at an early date because the prediction of a planned traffic volume is greatly divergent. None of the companies answered (could not answer).
Construction supervision There are no cases	**Construction supervision (design defects)** (1) Integrated contract for designing and construction supervision All of the design defects are attributed to the consultants in charge. (2) Separated contract for designing and construction supervision (with no design review) All of the design defects are attributed to the consultants in charge of designing. (3) Construction supervision with design review Any problems within the scope of the implemented design review (reviewed design) are defects of the company responsible for construction supervision. In other words, it is generally considered that there is their defect liability only within the scope of their design review. (The interview in Zambia demonstrated that the responsibilities against all design defects would be shifted to a company responsible for construction supervision in the case of construction supervision with design review there). **Construction supervision (defects of construction supervision)** **Opinion 1:** Opinion 1: The consultant's role is monitoring. Management of progresses and quality control is the construction contractor's responsibilities. When work is subcontracted, for example, a consultant does not directly monitor subcontractors, but rechecks whether or not an original contractor properly checks subcontract work. Resident supervisors need to prove that they do such work properly. **Opinion 2:** Consultants' responsibilities depend on types of construction supervision. They take no responsibilities for quality control with their sporadic contracts such as those several times per week or month. However, they are considered to share some responsibilities morally in the case of resident supervision. **Opinion 3:** Progress management is the whole responsibility of the construction company. Quality control appears to be shared equally by the consulting company and the construction company. It is because construction supervision consultants are also obliged to perform checking work.

5.1.2 Delinquency and indemnity liabilities (cases)

We have compiled several typical cases of indemnity liabilities for engineers (or architects). (Source: Engineering Law and ICE Contract, Max W Abrahamson, 1978)

(a) Consultants' failure to take appropriate procedures and approaches as professionals while being required to do them falls into the delinquency. For example, if a consultant fails to take a prescribed procedure when making an additional payment to the contractor or when s/he is requested to get permission from the orderer, it becomes her/his delinquency subject to the liability for compensating the orderer for any damages. Courts or arbitrators tend to strictly judge engineers' roles with respect to such procedures, and there are many cases where the engineers are determined to be negligent if damages to orderers or contractors are caused by mistakes in or omission of procedures, etc., and thus the engineers shall assume indemnity liabilities. Furthermore, decisions that do not go through the procedures prescribed in the contract are considered invalid (as they are against the procedural justice).

(b) The failure to perform or the inability of performing ordinary engineering work becomes the delinquency. The determination of the degree of performance of ordinary engineering work depends on what position the engineer took or what kind of risk s/he was supposed to bear. Furthermore, it is generally supposed that orderers cannot demand any compensations for damages caused by engineers' genuine mistakes or errors.

(c) There is a provision for paying additional costs to deal with difficulties not anticipated in the construction contract, and thus the more likely it is to happen, the more sufficiently engineers have to investigate their sites before designing to plan and design the construction. They tend to make an excuse that as the additional cost is not included in the bid price (contract amount), paying it should not cause any damages to the orderers, but it can be said to be a mistake. This is because the price becomes competitive at the time of bidding and it is much lower than the price presented by the contractor after making a contract, and thus the difference between them is a loss to the orderer. In order to avoid such a situation, therefore, the engineers are supposed to duly conduct thorough investigations at the designing and bidding stages, and to indicate the difficulties of future construction work in their contract books to the extent that it can be predicted (For the clarity of risk sharing). The engineers become liable for their defective surveys or their failure to identify risks.

(d) If an engineer declares that s/he is a specialist in a certain field, he must have usual skills and expertise that a professional should have in that position. In addition, it is determined that if s/he states her/his skills, s/he should not undertake work that goes beyond the scope that can be covered by such skills.

［Phillip & Leslie vs Transvaal Gold Field Ltd (1898)］

The architect supervising the construction work issued a certificate of completion of the electrical plant to his contractor, and the orderer made a payment accordingly. After that a defect was found in the installation of the plant, and it became useless. Moreover, it was found that the defect could be discovered only by a real expert. Before issuing the certificate, the architect is obliged to convince himself that the installation was done correctly with his expertise or an expert report. Therefore, the architect is liable for any damages caused to the orderer due to the failure to do so.

(e) If the engineer neglects the actions stipulated as necessary for construction supervision, it becomes the delinquency subject to the liability for compensating the orderer for any damages caused to him.

［Florida Hotels Pty Ltd vs Mayo (1965-66)］

When dismantling molds before the specified date of dismantling the elevated concrete floor slab, the floor slab collapsed and the workers were seriously injured. The cause of the collapse was not the earlier dismantling of the molds than prescribed, but it was judged to be a mistake in bar arrangement in the reinforcement of the floor slab. It was assumed that the erroneous placement of the reinforcement in the direction of a horizontal axis of the floor slab though it should have been placed in the direction of its longitudinal axis resulted in the lack of its strength, causing its collapse. The architect inspected the molds and rebars with an architect (who was an orderer and had directly managed its construction using a foreman and laborers) two days before concrete placing. However, the rebars were not yet installed at that time. The architect's foreman admitted the concrete placing without notifying him about the rebar inspection and the concrete placing. The architect insisted that the collapse of the floor slab was attributed to the foreman's failure to notify/inform him about concrete placing, as he could be expected to make such communications. However, the court's adjudication said, "The architect is obliged to ensure that his foreman always contacts him, not expecting a contact and notification from him, and also obliged to inspect the reinforcement installation before concrete placing. Because neglecting these two obligations, the architect is liable for making a compensation for this collapse accident."

(f) Since the engineer/architect undertakes the designing of the entire construction and his remuneration is determined accordingly, he cannot delegate part of the designing to the third party. However, he can delegate it if approved by the orderer.

［Moresk vs Hicks (1969)］

An architect delegated the designing of reinforced concrete frames to a nominated sub-contractor, approving his drawing, and this nominated subcontractor constructed it.

Two years after completion the girder part could no longer support the roof due to its insufficient strength, and the building could not be used any more. The court said, "The architect has no implied authority to delegate his design work to a nominated subcontractor and to rely on it. Therefore, he has the liability to the orderer."

(g) The engineer is liable for any damages if her/his negligence causes physical damages to contractors, workers, other persons and the property. It is applied irrespective of whether or not there was a contract with the engineer, and the law imposes this liability on the engineer.

(h) Negligent misrepresentations and advice are subject to the liability not only when a person is hired by anther but also when there is a special relationship. Those who know that special skills and competence are required to give advice or those who claim that they are equipped with such capabilities know that their descriptions and advice will be relied upon, and they are liable for damages unless they warn that others should be responsible for such descriptions/advice.

(i) The engineer could avoid his liability if promoting the bidder's/contractor's awareness by stating that he is not liable to the contractor for any information to be provided at a prominent portion in a bidding book. However, if the engineer makes a false or careless misrepresentation (a description made without discerning the truth) and the contractor is in a situation where s/he relies on it and actually relies on it, and consequently suffers damage due to it, then the engineer becomes liable to the contractor. It is said in such a case that the engineer should assume the liability no matter what kind of responsibility avoidance or waiver is taken.

5.2 Insurance for Consultants' Defects

According to the standard agreement clause in Japan ("standard contracting agreement clause for public civil engineering design services and others," May 1993), the ordering party can request the compensation from the construction consultant for damages when a defect occurs in a deliverable. Because neither the Commercial Code nor the Civil Code generally stipulates any particular limits on the amount of damages in the responsibility of warranty against defects (compensation limits may be set in private contracts), there are cases where construction consultants assume excessive responsibilities against the fees for of their services. In addition, the orderer is even more and more inclined to seek the compensation for damages if there are defects in consultants' deliverables.

On the other hand, the compensation for damages due to defects in overseas design work are outside the scope of the damages insurance system of the Construction Consultant Association. However, seeing that the cases where subscribing for damages insurance is a prerequisite at the time of contracting are common abroad as seen in the case of the World Bank, the actual situation is that each company addresses it independently. Regarding the Professional Indemnity Insurance (PI Insurance) for overseas design work, there are not many domestic insurance companies on the recipient side, and currently the upper limit of insurance money is very small in actual, and so overseas insurance companies may be used. Apart from it, the orderer may withhold 5 - 10 % of the payment (Retention) abroad for dealing with the latent defect. There are some ways of thinking for it such as for a period of one to two years or over a rainy season.

Table 5.2.1 Damages compensation insurance scheme for design defects

Service in Japan	Overseas service
Obligation for policy application There is no obligation for policy application (optional).	**Obligation for policy application** As typified by the World Bank and others, it is common that the policy application becomes a prerequisite for contracts. (Loan aid cooperation: with an obligation for policy application) (Grant aid cooperation: with no obligation for policy application (the system is under revision))
Compensation insurance system (comprehensive contract) "The damages insurance system" was established by the Construction Consultant Association, and it is common that the construction consultancy companies generally pay damages due to defects through joining this system.	**Compensation insurance system (comprehensive contract)** There are two ways: for making comprehensive contracts for the entire overseas operations handled by consultants and making individual contracts for individual projects. In the case of individual insurance, insurance premium rates are very high because insurance companies must bear the risk on a project basis. Addition of defect insurance premiums is often allowed in the estimation of outsourcing expenses. However, it is up to consultants' judgments as to whether the insurance premiums are suitable for the risk. In addition, there are many cases where domestic insurance companies are requested to be used (for protection of domestic insurance companies). **Insurance amount (amount of a compensation limit)** The incorporation of the PI insurance is often included the standard contract with its maximum amounts not exceeding the contract amount in its contractual provisions. However, it is not a standard. The World Bank allows the decision on the surcharge for the contract amount in a target country. In the case of loan aid, the contract amount or 300 million yen is set as a maximum.
Period of defects (compensation) (1) The request for repair of defects or compensation for damages shall be made within three years from the day on which the delivery was received under the provisions. In the event that such defects are caused by the deliberate or serious negligence, however, the period during which such a request can be made shall be ten years. (2) The request for the repair of defects or the compensation for damages shall be made within one year from the day on which the delivery was received under the provision.	**Period of defects (compensation)** Although it varies among the target countries, the period is normally either 2 years or 10 years in many cases. Recently, there are cases where it is requited to be set according to the service life of a structure. It is set as one year in the case of loan aid or grant aid.
Contents of compensation A policyholder pays for damages as insurance claims when s/he is requested by the ordering party or a third party to be legally liable for them due to defects of her/his deliverables submitted to the orderer during her/his "civil engineering work," "geological survey work," and "surveying work" conducted within Japan.	**Contents of compensation** Payments are made for damages as insurance claims when a policyholder is demanded by the ordering party or the third party to assume the legal liability for damages due to defects of her/his deliverables submitted to the orderer in her/his overseas service (regardless of whether

Target services （1） Design work related to civil engineering structures in Japan (civil engineering design work) are covered by the insurance, excluding construction management work (However, the design work ordered in the construction management work are covered). （2） Civil engineering work does not include building design work, but as an exception, the designing of buildings (machine buildings, administrative buildings, etc.) subordinate to civil engineering structures subject to work is covered. （3） Members who register their geological survey operations with the Ministry of Land, Infrastructure and Transport under the "Geological Survey Registration Rules" together with the Construction Consultant Registration can also cover their geological survey work for insurance. （4） If the insurance is applied for surveying operations as well, the surveying work entrusted independently such as 1) – 4) below can also be covered in the insurance: 1) Basic survey (Article 4 of the Survey Act); 2) public survey (Article 5 of the Survey Act); 3) Surveys other than the basic survey and the public survey (Article 6 of the Survey Act); and 4) Local survey or the survey not requiring a high level of accuracy (Article 1 of the Order for Enforcement of the Survey Act) **Target deliverables** (1) Deliverables for the "civil engineering design work" Design documents such as preliminary design, outline design, detailed design, etc., for which the contract between the policyholder and the ordering party is intended (2) Deliverables for the "geological survey work" The geological survey report and the survey report on underground buried objects for which the contract between the policyholder and the orderer is intended (3) Deliverables for the "surveying work" The survey report for which the contract between the policyholder and the orderer is intended **Examples of damages to be paid for** (1) Liability to the "ordering party" 1) The construction cost when design defects are discovered during the construction or after the completion of a civil engineering structure and the structure has to be reworked or reinforced. 2) 2) The design cost for additional construction work in the case where the strength of a civil engineering structure is insufficient due to defects in the design and reworking or reinforcement work is required. (2) Liability to the "third party"	the orderer is within Japan or a foreign organization). The PI insurance for consultants covers a wide variety of targets, while the construction insurance to which the construction company subscribes is only for bodily injuries and property damages. This is because a consultant runs a greater risk while receiving a smaller amount of contract than a construction company. **Target services** All of the overseas consulting services performed by consultants, including MP and FS, are covered. (1) Survey work (2) Geological survey work (3) Civil engineering/construction planning/design work (4) Construction management work **Examples of damages to be paid for** (1) Liability to the "ordering party" Construction costs when design defects are found during the construction of or the completion of the civil engineering structure and the structure is reworked or reinforced. * While the above construction costs are covered by the insurance, redesign costs and design costs for reinforcement work are not covered. (2) Liability for the third party Same as liabilities in services within Japan. (3) In addition to them, the costs incurred when taking measures to reduce damages, the situations that could lead to damages, and the costs required to avoid such damages are also eligible for compensation.

1) A civil engineering structure were broken because it was insufficient in strength due to design defects, and the third person who was in the vicinity was injured or dead (During the construction and after the completion). 2) An adjacent house was damaged by the civil engineering structure that was collapsed due to design defects (During the construction and after the completion). 3) A civil engineering structure under construction was broken due to design defects and employees of the construction contractor under operation were injured or dead. **Cases where the payment cannot be allowed** (1) Liabilities arising from facilities/equipment at which the policyholder performs her/his services (2) Liabilities arising from an aircraft, an elevator and a vehicle (3) Liabilities due to criminal acts by policyholders or their employees (4) Liabilities arising from the infringement of intangible property rights (fishing rights, water use rights, etc.) (5) Liabilities caused by the noise/vibration or the dust (6) Liabilities for damages to the environment (7) Liabilities based on the allegation that the landscape is bad (8) An accident caused by errors in a survey or lack of surveying when entrusted as a task of surveying alone (9) Liabilities relating to expenses required for repairing or rebuilding the deliverable of the work itself. However, the insurance money is paid for design costs related to additional construction when the strength of the civil engineering structure is insufficient due to defects of the deliverable (design), and reinforcement work, etc. is required for it. (10) Liabilities arising from the failure to perform services or construction work or delay in their performance (11) Liabilities arising from wars, disturbances, insurgences, riots, labor disputes, etc. (12) Liabilities caused by earthquakes, eruptions and tsunami (seismic sea waves) (13) Liabilities caused by waste water or exhaust (including smoke) (14) Liabilities caused by excessive design (15) Liabilities arising from defects in the survey work reports including for maintenance inspection surveys, risk assessment and overview surveys, etc. However, insurance money is paid when there are defects in the survey work carried out as part of civil engineering design, and legal liability is incurred for deliverables of civil engineering design. (16) Liabilities attributed to surveying work conducted in violation of the Survey Act (in the	**Cases where the payment cannot be allowed** (1) With respect to Services (1) to (5), (7) and (13) of the domestic services in Japan as described on the left, even the secondary damage is also insured when the legal liability is required based on the laws in a target country. (Events that become pure economic losses are covered in a legal point of view). However, in order to be able to cover the pure economic losses as well, it is imperative to add an insurance by paying to the PI insurance for additional insurance premiums.) (2) Environmental damages for Service (6) described on the left are usually treated as a special contract provision in a regular contract, and the rates are higher when including them. (3) Regarding Service (8) described on the left, those for which legal liabilities are claimed are covered. (4) Service (9) on the left is not eligible for the insurance as well as redesign work is not covered. (5) Delay in the construction period in Services (10) and (17) on the left may not be covered by some insurance companies. (6) Conditions abroad are the same those in Japan for Service (11) on the left. (7) Out of the conditions in Service (12) on the left, earthquakes can be covered by the insurance (Seismic resistance required for designing is requested to be secured). (8) Service (14) on the left is eligible for the insurance if the legal liability is claimed for it. (9) Services (15) and (16) on the left are not covered in overseas operations. Exemption clauses of liability insurances in Japan are defined under the initiative of insurance companies and important provisions (e.g. fishing rights, water rights, drainage, etc.) are excluded as compared to those of overseas insurances.

case of incidental warranties for surveying operations) (17) Liabilities arising from the impossibility or delay of performance Source: JCCA Compensation Indemnity System for Construction Consultants	

Supplementary items concerning the PI insurance are listed below.

- The PI insurance covers damages caused by faults, omissions, inactions or negligence in the survey and design work of design professionals, not covering damages arising from the breach of duty.
- However, the PI insurance can cover prevention measures and remedy costs for insurance relief in repairing or modifying actually defective portions even though there are no damages or when there is a possibility of damages or deterioration if left undone.
- However, because the current PI insurance does not cover liabilities for damages when completed work objects (completed structures) are not suitable for the purpose or use of ordering, it is essential to purchase an extra PI insurance for it or add it to the current insurance by paying an additional premium.
- Insurance period and claim period
  - ✓ The most important point in the insurance period is that claims for liability insurances are made on a claim-made basis. In other words, it is supposed to be valid at the point of claiming (when a defect is found), regardless of the time of negligence. However, it is mandatory to take out the PI insurance at the time when the negligence is considered to have occurred. Therefore, we have to renew this PI insurance definitely every year, and thus the insurance premium becomes an annual premium. When consultants newly take out the PI insurance, s/he cannot claim the compensation due to the negligence in the previous year before taking out the insurance. There is a big difference in premium (guarantee fee), depending on the reliability, credibility and performances of each company (2.5 % to about 15%).
  - ✓ Separate purchasing of the PI insurance on a project basis is intended only for the project without covering other projects, and so the premium per item is very high and the insurance needs to be renewed continuously for a while after the completion of the construction.

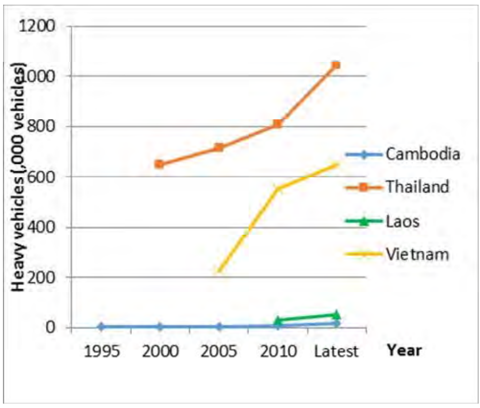
Chapter 6. The 2nd IRF Asia Regional Congress

An outline of the Japan Session on overloading and road management

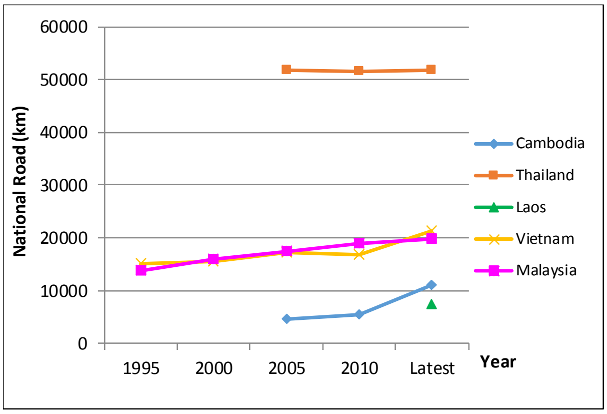
6.1 Responses to question items and contents of presentations

6.1.1 Basic data

Although there are differences in development among the target countries, the increase in large trucks and the development of national road networks can generally be confirmed there.



Number of vehicles owned (heavy vehicles)



Changes in length of national roads

Figure 6.1.1 Basic data of the target countries

6.1.2 Crackdown on overloading

(1) Results of surveys on overloading and axle weight distribution

Overloading is seen in each of the countries, but the conditions on overloading is being improved through legislative preparations against it there.

- 1,000 to 2,000 overloaded vehicles per year were observed. Many of the overloaded vehicles detected exceeded the regulatory value by about 5 – 10 % (Thailand).
- In the measurement on Route 9 in 2013/2014, 19.3% (2,996/15, 536) were overloaded vehicles (Laos).
- Overloaded vehicles on federal roads exceeded the regulatory value by 10 - 55.7% (Malaysia).
- Overloaded vehicles were reduced by approximately 91.5% through the strengthening of legal regulations (penalty provisions) (2016). Reinforcement measures were taken such as the multiplication of fines for drivers and owners by several times and the confiscation of drivers' licenses (Vietnam).
- Overloaded large freight vehicles were reduced significantly with the penalties strengthened by the 1994 law and regulations. Enhancement of penalties were expanded not only to drivers and forwarding agents but also to shippers (Japan).

(2) Legal support against overloading

Legal support such as regulations and penalties on axle weight with respect to overloading is shown in the table below.

Table 6.1.1 Legal support on overloading

	Legal support
Cambodia	・LAW ON ROAD (esp. Article no. 26 and 60) ・LAW ON ROAD TRAFFIC (esp. Article no. 78, 78, 80 and 82) ・SUB-DECREE no. 141 dated August 31, 2009 Established Overload Committee ・INTER- MINISTERIAL PRAKAS no. 536. dated December 22, 2010：**Set the Fine** ・PRAKAS no. 411 dated Sep. 02, 2009 ：**Limited Weigh**. ・Restructure of Permanent Coordination Committee. (May 2016)
Thailand	・Highway Act 1992 ・Highway Agency Announcement 2009 (according to the section 61 of Highway Act
Lao PDR	・Regulation for Overloading Control (Ref No.13848/MPWT on 16/Sep/2013)
Vietnam	・CIRCULAR No. 07/2010/TT-BGTVT, MOT, 2010 Regulations of axle weight, gross weight and road etc. ・CIRCULAR No. 03/2011/TT-BGTVT, MOT, 2011：Minor revision of the Circular No. 07/2010/TT-BGTVT ・DECREE No. 171/2013/ND-CP, 2013 Regulations for fine of violation and etc. ・CIRCULAR No. 84/2014/TT-BGTVT, MOT, 2014：Minor revision of the Circular No. 07/2010/TT-BGTVT ・CIRCULAR No.: 46/2015/TT-BGTVT, MOT, 2015 The total renovation of the Circular No. 07/2010/TT-BGTVT ・DECREE No. 46/2016/ND-CP, 2016 The total renovation of the Decree No. No. 171/2013/ND-CP
Malaysia	・Road Transport Act of 1987 (Act 333) ・Land Public Transport Commission (SPAD under Act 714) of 2010 ・APAD 2010 (Act 715).
Japan	・10-day vehicle suspension under Act on Service of Cargo Transportation（1994,5） ・Reinforcement of regulation(Implementation of personal visit) (2011)

■ Regulations on maximum (allowable) axle weight and gross weight

Regulatory values for the maximum (allowable) axle weight and the gross weight in each country are shown in the table below.

Table 6.1.2 Regulatory values for axle weight and gross weight

Target country	Axle weight	Gross weight
Cambodia	10 t	40 t
Thailand	11 t	
Lao PDR	9.1 t (11 t only for designated routes)	
Vietnam	10 t	48 t
Malaysia	12 t	53 t
Japan	10 t	20 t (25 t only for designated routes)

■ Legal regulations for penalty provisions

Penalties for violation on overloading in the countries are shown in the table below.

Table 6.1.3 Penalties for overloading

Target country	Penalty for violation
Cambodia	・Unloading, detainment for a certain period; ・Imposing a fine ・Confiscation of a driver's license for a certain period
Thailand	・a 10,000-baht fine or a 6-month sentence
Lao PDR	・Impose a fine
Vietnam	・Impose a fine ・Confiscation of a driver's license for a certain period
Malaysia	・Detain for a certain period of time ・Impose a fine
Japan	・Detain for 10 days

(3) Method for detecting overloaded vehicles

With regard to the control of overloaded vehicles, the following static and dynamic weighing methods are adopted:

Static method: Stationary weigh station

Static method: Stationary weigh station

Static method: Mobile-type

Dynamic method: Weigh in motion (WIM)

Dynamic method: WIM (travel speed 10km/h)

Mobile WIM

Figure 6.1.2 Control methods for overloaded vehicles

Table 6.1.4 Types and quantities of weigh stations in the countries

	Type	Quantity
Cambodia	・Dynamic method (9) & static method	27 stations
タイ	・Dynamic method (screen) & static method (recognition)	70 stations
ラオス	・static method (mobile type)	25 stations
ベトナム	・Dynamic method (mobile WIM)	64 stations
マレーシア	・Static method (RTD weigh station) & dynamic method (enhancement plan)	46 stations (stationary)

[Thai weighing system]

The dynamic method (selection of suspicious vehicles) and the static method (accurate measurement at measuring stations) are utilized together. Seventy stations are established across the country and monitored at the central stations.

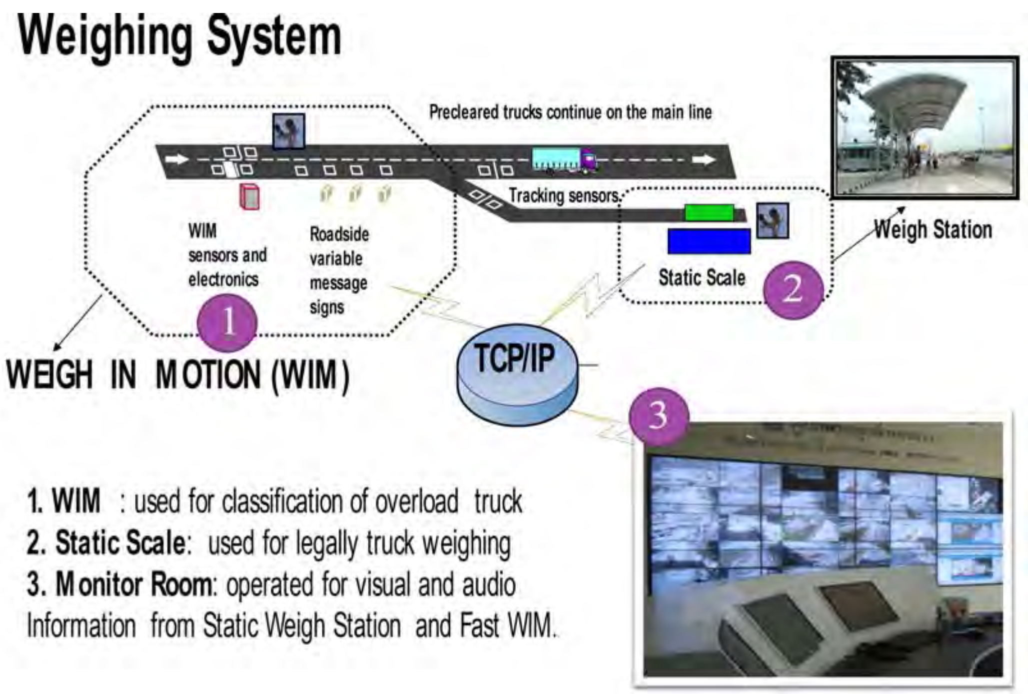
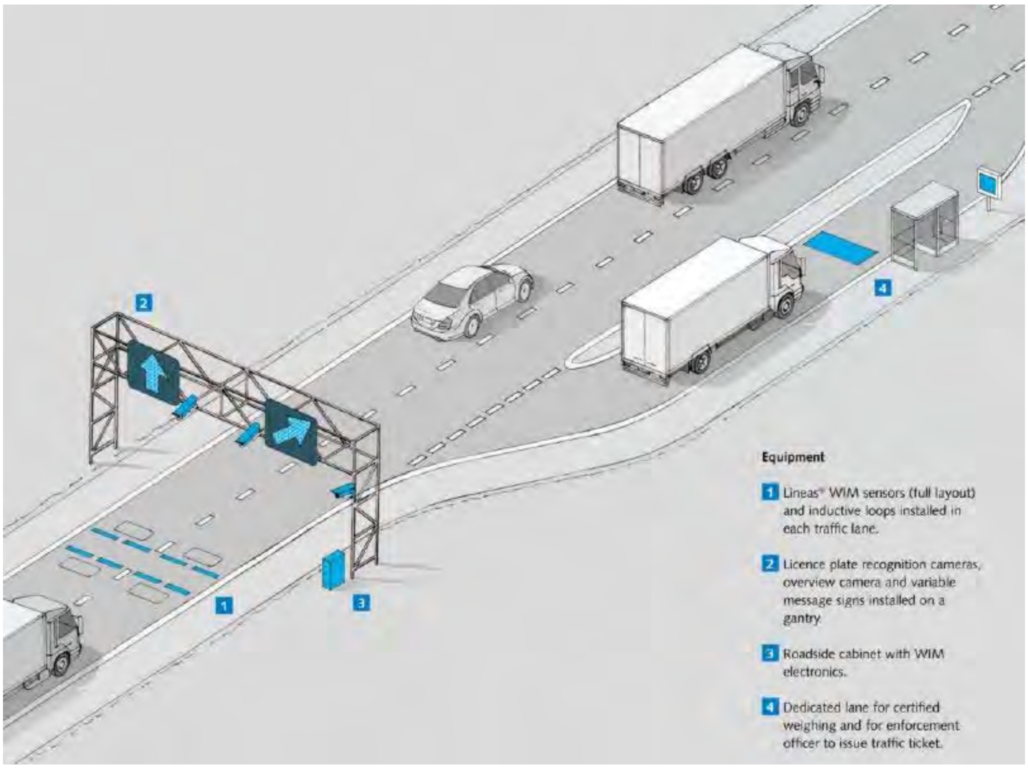


Figure 6.1.3 Weighing system in Thai Land

[Future development plan for a weighing system in Lao PDR]

Control of overloading (legal support, weighing, and penalties) is inadequate in Lao PDR. We are preparing a plan to improve the weighing system there with the support of JICA.



WIN and Static Axle Scale

Output of a WIN System

Figure 6.1.4 Weighing system in Lao PDR

[Weighing system in Vietnam]

- Mobile WIM systems have been set up at 63 locations (63 districts) across the country until now.
- Stationary weigh stations are being set up at 45 locations between 2012 and 2030

Mobile WIM Stationary weigh station

Figure 6.1.5 Weighing system in Vietnam

[NEXCO's new weighing system]

Features of NEXCO's new weighing system

- A variety of measurement/weighing functions (axle weight, gross weight, number of axles), measurement/weighing accuracy is up to ± 5%
- Long service life (1 million axes or 10 years after installation)
- Compact structure: 300 mm in width
- Utilize information on these overloaded vehicles for road management (database)

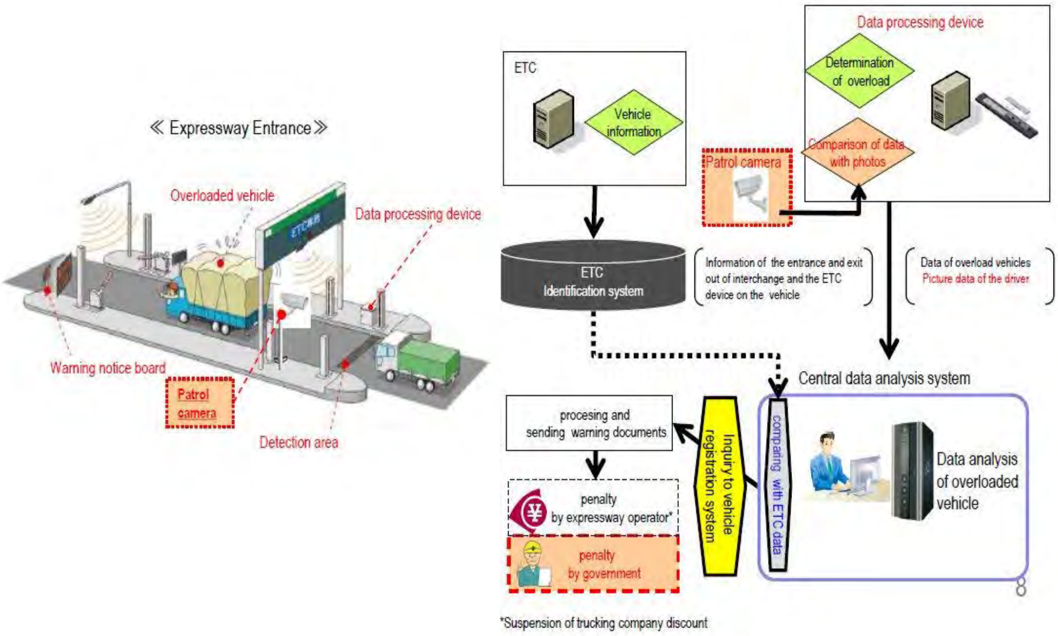


Figure 6.1.6 Weighing system by NEXCO

[Weighing system in Malaysia]

a) Stationary weigh station

- Stationary weigh stations under the jurisdiction of RTD (Road Transportation Department) were set up at 46 locations across the country.
- The stations were established on major federal roads with many freight vehicles.
- There are ten data collection centers across the country: one data collection center in each state.

b) Research study

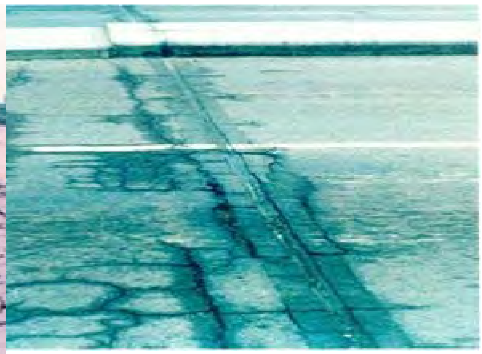
- Investigate the axle weight distribution at 8 locations for road asset management, including the federal roads with many motor trucks, the roads connecting the ports, etc.
- Establish B-SiWIM (Bridge-Weigh in Motion) for measuring axle weights on 25 bridges.
- We are trying the method of automatically detecting overloaded vehicles using the WIM.

(3) Actual conditions and cases of damages to pavements and bridges caused by overloaded or large vehicles


Rutting caused by overloaded vehicles


Pothole caused by overloaded vehicles


Cracking and rutting due to the lack of pavement thickness


Fracture of joints; cracking of floor slabs and beams


A pothole in a concrete slab


A bridge collapsed due to the overloading

Figure 6.1.7 Examples of road damages caused by overloaded vehicles

(4) Cases of road management and technical measures as countermeasures against overloading

Item		Case of technical measure
Pavement	Change in design method	・The routes where the ESAL is large (including overloading) are designated as heavy-traffic routes and designed to have appropriate strong pavement structures (Thailand) ・Designate the routes that adopt larger reference values according to the maximum axis weight and adopt a road pavement design that is reasonably strong for them (Lao PDR) ・Revise the design standard so that it can cope with cumulative axle weights exceeding 50 MSA (million standard axle) (Malaysia)
	Material and construction	Introduce the following technical measures as the countermeasures against rutting: ・Adoption of asphalt with penetration of 40/50 (Vietnam) ・Adoption of polymer modified asphalt (Malaysia, Vietnam) ・Adoption of SMA (Stone mastic asphalt mixture) (Malaysia) ・Road roadbed reproduction method (Malaysia) ・Adopt a wheel tracking test for the performance evaluation of rutting (Japan) ・Gyratory compactor and wheel tracking test are effective for the mix design that is resistant to rutting (JICA) Review of concrete pavement standards (Lao PDR, Malaysia)
	Methods of maintenance/ repair	Introduce the following technical measures: ・Pavement management: Prepare and implement a low-cost repair plan based on road pavement conditions (Thailand) ・Adopt a new contract system (performance code) (Malaysia)
Bridge	Change to the design method	・Construction of new bridges as well as replacement and reinforcement of existing bridges are carried out with new design standards (Malaysia) ・Adopt larger maximum axle weights for border bridges (Lao PDR)
	Method of maintenance/repair	Introduce the following technical measures: ・Implement bridge maintenance/repair programs based on bridge management systems and annual bridge inspection (Malaysia)
Designated heavy-traffic route		Introduce the following technical measures: ・Guide large vehicles to the routes designated as the heavy-traffic routes (Lao PDR) ・Impose a weight restriction by route: all of the routes cannot be compatible with the axle weight of 12 t (Malaysia)
Other Topics		Transportation companies are dissatisfied with the strengthening of overload crackdown. However, this complaint can only be solved little by little over time (Vietnam)

[Case of changing pavement design methods]

- Pavements that support heavy traffic exceeding normal traffic loads are made using the mechanic design methodology. Furthermore, polymer modified asphalt that can withstand heavy traffic, cement stabilization treatment of crushed granular roadbeds, semi-flexible pavements, etc. will be considered (Malaysia).

[Case of introducing pavement materials and construction methods]

- Introduction of polymer-modified asphalt, SMA (Stone mastic asphalt mixture), and the road roadbed reproduction method (Malaysia)
  - Polymer modified asphalt: Used to improve the resistance to rutting, etc. Because it is more expensive than the previous pavements, it will be used to a limited extent (e.g. climbing sections and sections with frequent excessive loading etc.).
  - SMA (Stone mastic asphalt mixture): Used to improve the resistance to rutting, etc. Because it is more expensive than the previous pavements, it will be used to a limited extent.
  - Road roadbed reproduction method: Used to repair pavements in the case of the pavements subject to the damages such as fatigue cracks, thermal cracks and refraction cracks and that cannot be repaired through overlaying.

[Case of a technique for introducing a pavement maintenance and repair plan]

- Investigate road pavement conditions on a regular basis, and implement and prepare a low-cost repair plan based on it (Thailand)

Figure 6.1.8 A case of the technique for introducing a plan to maintain and repair pavements in Thailand

(Reference 1: An excerpt from the criteria for reviewing the pavement design standard in Malaysia)

Pavement design for withstanding the ESAL exceeding 50 MSA (Million Standard Axles) is done using the mechanical design methodology. The design calculation program uses the following programs and the like.

- Pavement Design : A guide to the Structural Design of Road Pavements, STANDARDS
- AUSTRALIA and AUSTROADS, 2004, in conjunction with CIRCLY version 5.0

Source: Pavement design for heavy-traffic routes (Manual for the structural design on flexible pavement,2013)

(Reference 2: An excerpt from the modified asphalt in Malaysia)

It is recommended that the modified asphalt be used at the locations where the stress is high such as climbing lanes and those on which excessive axial loads act. Because it is more expensive than straight asphalt, it should not be used without careful considerations.

Source: Pavement construction standard (Standard specifications for road works (Sec.4 Flexible pavement, 2008)

6.2 Panelists' comments

6.2.1 Utilization of WIM for controlling the overloading

In consideration of the situations where heavy traffic including overloading is damaging pavements and bridges, each country is strengthening its legal penalty provisions and improving its weighing methods. There are differences in technical measures among the countries depending on the situations, such as Malaysia and Thailand where heavy traffic is apparent, Vietnam where it is becoming visible, and Cambodia, Laos etc. where it is expected to become apparent in the future. For example, taking the adoption of modified asphalt criteria as an example, the modified asphalt is standardized in Malaysia and Thailand. Its adoption is being considered in Vietnam, whereas Cambodia and Laos will be subject to its future considerations.

With regard to the measurement of axle weight and gross weight, the conventional static stationary weighing method in particular would have problems such as traffic congestion and unmeasured overloaded vehicles (avoiding the weighing) on routes with heavy traffic volume. A moderator asked a question of the panelists from Vietnam, Thailand, Malaysia, and NEXCO about the effect of utilizing WIM for data collection, and there was the following comment from each of them:

[Vietnam]

We are currently utilizing the mobile WIM. We are continuing to improve this mobile WIM, but the Government of Vietnam does not think that this method is adequate. We are proceeding with setting up stationary WIM systems at 45 points.

[Thailand]

We have 70 stationary weigh stations. WIMs on the lanes and static weigh stations have been set up at these weigh stations. WIM is used for screening overloaded vehicles. We use static weigh stations to take legal actions (impose penalties) against offending vehicles, because they ensure highly accurate measurements.

[Malaysia]

Various kinds of WIM systems are being developed all over the world. The crackdown on offending vehicles using static stationary weigh stations is now becoming more and more difficult, and the development of WIM that automatically controls offending vehicles without stopping them is a challenging task.

[NEXCO-West]

The WIM technology developed by NEXCO-West can efficiently detect overloaded vehicles without affecting the traffic flow. This WIM is an exquisite solution to the problem of overloading in this respect.

6.2.2 On the adoption of modified asphalt to cope with the rutting

The moderator asked the panelists about the opinions on the use of modified asphalt to cope with the rutting. The panelists from Vietnam and the National Institute for Land and Infrastructure Management (MLIT) of Japan made the following comments:

[Vietnam]

Modified asphalt has not yet been adopted so much in Vietnam. The notice was issued by the Government of Vietnam to recommend expressway companies to adopt modified asphalt, but it has not yet been a standard. The biggest problem of adopting the modified asphalt is a cost. It is necessary to show that its adoption is reasonable from a long-term perspective. We are creating a pavement management system and plan to calculate life cycle costs including modified asphalt pavements in our department.

[Japan]

The problem of rutting has almost been resolved in Japan by strengthening penalties and adopting modified asphalt. I have the following opinions on the use of modified asphalt in Vietnam and Africa:

- Vietnam

There are problems with the construction of modified asphalt: inadequate temperature control, the lack of rolling compaction, etc.

- Africa

Modified asphalt with poor quality is used. There are problems with the quality control of mix design, especially the control of particle size.

In Japan, we have a standard for using modified asphalt widely. On the other hand, we also do introspection on the fact that we rely too heavily on modified asphalt and that the quality management abilities such as the mix design of dense-grade asphalt using straight asphalt tends to decline. Therefore, it is imperative to understand basic technologies of asphalt pavements and proper construction methods.