초청강연

Investigation of Korean Asphalt Pavement and Its Failure

한국 아스팔트포장과 파손사유 조사

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I、 Introduction

Failure is the mother of invention, in Japan

- Solution by experiental methods better than theoretical method in practice.
- Experience is gotton by good failure(mistake).
- Failure of Pavement(Damage) is important indexes.
- I think and I hope,Our failure (mistake) will help to your pavement technologies,iven if in different circumstance from ours.

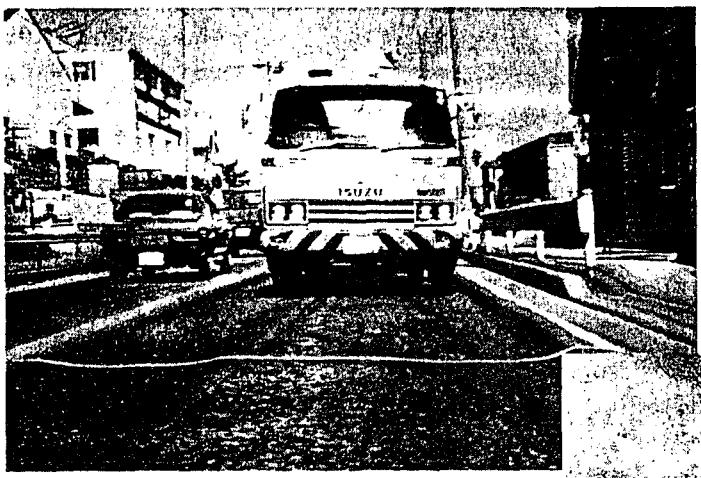


Fig.1-1 Example of Heavy rutting
(ex.RD≧30mm)
<in Japan>

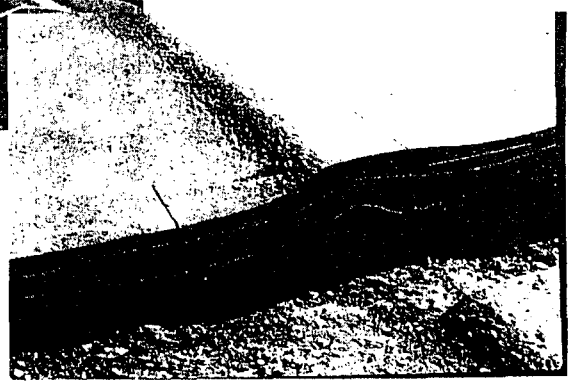


Fig.1-2 Cross Section of rutting
<in Japan>

------- The current state of pavements

(1) Fundamental points

----- Asphalt pavement failure (damage) and its causes(Table 1-1 and 1-2,1-3)

Table 1 1 Classifications of asphalt pavement damage

Classification of Damage			Main Causes
Damages mainly due to surface characteristics	Local crack	Hairline crack	Poor mixture quality. Incorrect temperature during early stages of compaction
		Linear crack Longitudinal crack Transverse crack	Improper construction. Uneven subsidence at the joint of cut and embankment. Cracks in the subbase and subgrade layers Uneven bearing capacity of the subbase and subgrade layers
		Construction joint crack	Improper spreading and compaction
	Faulting	Irregularity in the vicinity of structures	Poor compaction of the subbase, subgrade and asphalt mixture. Unevenness due to uneven subsidence of the ground
	Deformation	Rutting	Excessive traffic of heavy vehicles. Poor mixture quality
		Longitudinal roughness	Poor mixture quality. Uneven bearing capacity of subbase and subgrade
		Corrugation, Hollow, Swell Flush	Improper construction of prime coat or tack coat Improper construction of prime coat or tack coat. Poor mixture quality (especially poor quality of asphalt cement)
	Abrasion	Raveling	Use of tire chains and studded tires after snow has been removed
		Loss of skid resistance	Poor quality of mixture or aggregate in the mixture
		Exfoliation	Poor mixture quality. Improper compaction
	Disruption	Pot holes Stripping	Poor quality of mixture. Improper compaction Lack of adhesion between aggregate and asphalt cement. Water broken into the mixture
		Aging	Aging of bituminous materials in mixture
	Others	Tire marks	Extraordinary high temperatures. Poor mixture quality
		Surface swelling	Poor mixture quality. Swelling of air trapped under the surface layer
Structural damage	Wide range of cracks	Alligator crack	Lack in thickness of pavement. Improper construction of subbase or subgrade. Excessive traffic volume. Presence of groundwater
	Others	Frost heave	Lack in thickness of the pavement or antifrost layer. Presence of groundwater

(Manual for Asphalt Pavement,1989 Japan Road Association)

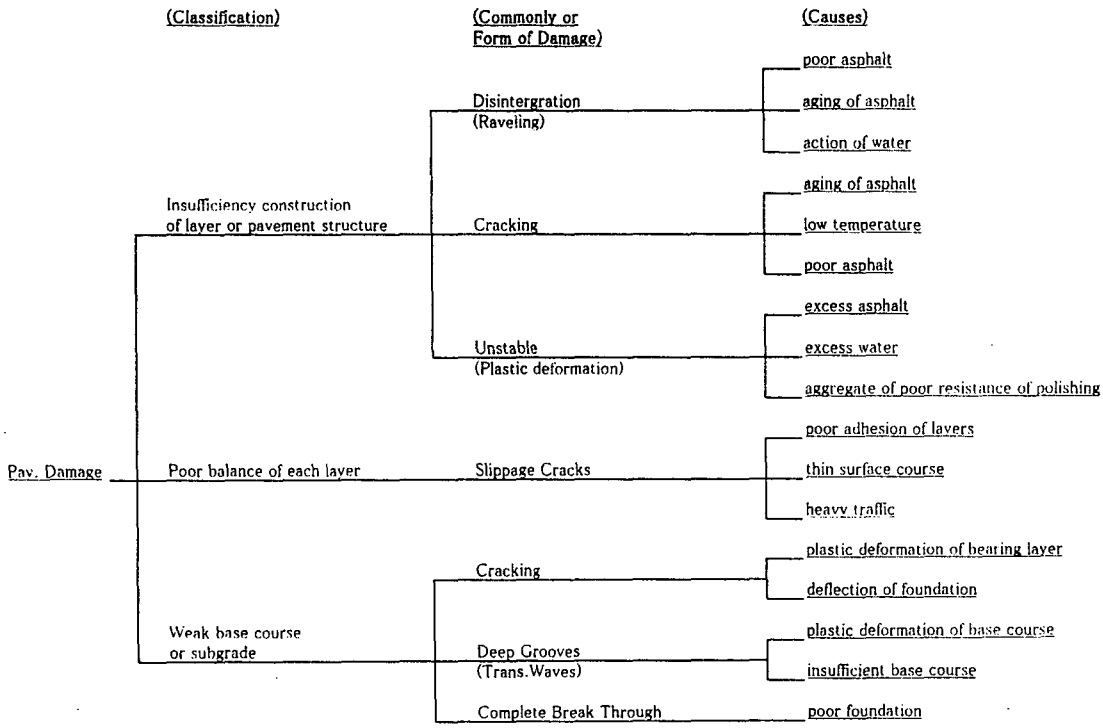
- Another example of Classification of asphalt pavement (Table 1-2,1-3)

- Photo 1-1~1-17, Typical Failure examples in Japanese pavements
- Photo 1-18~1-33, Several examples in Korean pavements (based on limited research)

Table 1-2 Classofication of Pavement failure
(by Yoder.E,1959)

Definition	Examples of failures mechanism
(a) Rupture	
1. craching	①excessive strain of load ②accumulated effects by repeated load(fatigue) ③thermal movements ④hydroscopic effects ⑤slippage by horizontal stress ⑥shrinkage
2.Spalling	①accumulated effects by repeated load ②others(ref.Disintergration)
(b) Distortion	
1.Plastic deformation	①excessive shear stress ②creep
2.Rutting	①densification ②consolidation
3.Faulting	①volume change of lower layer's materials ②lack of bearing capacity for surface ③others(ref.Plastic deformation and Rutting)
4.Differential volume change	①swelling ②densification ③shrinkage ④thermal changes
(c) Disintergration	
1.Stripping	①loss of adhesion between aggregate and binder ②chemical response of aggregate
2.Raveling,Sealing and loss of matrix	①thermal effects ②chemical reactivity ③lack of adhesion between aggregate and binder ④excussive stress in surface layer
3.Aggregate degradation	①unstable stone(rock) ②response for weathering ③excessive stress

Table1-3; Classification and Cause of failure to asphalt pavement(by Hveem.F.N. 1958)



(2) Classification of Failures

The Failures are classified as follow with those examples above.

	<Korea>	< Japan>
a	Crack	Crack
b	Pothole (Segregation) (Disintegration) etc.	Disintegration (Weathering) (Fretting) etc.
c	Bleeding (texture of tendermix) (Stripping) etc.	Deformation (Bleeding) (Corrugation) etc.
d	Rutting	Rutting

(3) Possible failure causes

Based on the surface investigation, the following reasons are though to be responsible for the failure.
However, asphalt pavement failure are usually caused by various factors, it is necessary to investigate core samples, analyze related data, including base layer and structure investigation as well. For reference, pothole failure related factors are indicated in Figure1-1.(Fish-bone chart pothole failure)

1) Inconsequence of materials management and mix design (presumption)

Development of material separation of pavement mixture, surface separation (aging and chapping) due to poor compaction , asphalt stripping due to water and potholes due to bleeding, is concerned with the incousequence of materials management and mix design.(need to be inspected correctly)

That is to say, if aggregates with irregular shape are used, the mixture will have high void ratio, leading to a rich asphalt content. In addition, if only one type of fine aggregate is used, the aggregate gradation will change greatly, leading to unstable for the mixtures.

With gyratory compaction test and/or wheel trucking test, the effect of materials used and mix design results can be inspected.

2) Inadequate mixing and manufacture management (presumption)

Surface separation of paved mixtures, bleeding and some other softening phenomenon are caused by inadequate of mixing condition in plants,manufacture management as well. (need to be inspected)

That is to say, under the condition that materials are wet, contaminated and with high water absorption, and materials are not dried sufficiently, and mixing is carried out under low temperature and with inadequate mixing time*, it will lead to inadequate mixing, Especially, when PMA is used, appropriate manufacture management is necessary.

The confirmation of the mixture quality in plant may be done by a comparison the density of the plant mixture, which is usually obtained by Marshall Compaction, with mix design density.

*Example (Counting back ward for drying time)
- mixing time:45sec(dry5,wet40)
- plant capacity:80battch/hr →2.0t/batt.×80=160t/hr
- Dryer capacity(Operation manual):120~150t/hr lower than plant capacity(160/hr)
  ——— Over carry from cold bin (cold aggregate)

3) Poor compaction during construction (nearly conclusive)

One of the main reasons is that the compaction by tire roller on the surface for sealing is not guaranted. This is closely associated with surface separation and pothole failure (damage),may be accelerated by water penetrating from insufficiently compacted cold joints and side.
That is to say, compaction of mixtures is hard when crushed stone with poor shape (elongated, flatted and maximum size 19m/m) is used as aggregates, so that materials separation is easy to happen.

The temperature condition of construction process is very important, for example, stuck mixture to tire roller, may be a reason of the delay of roller.

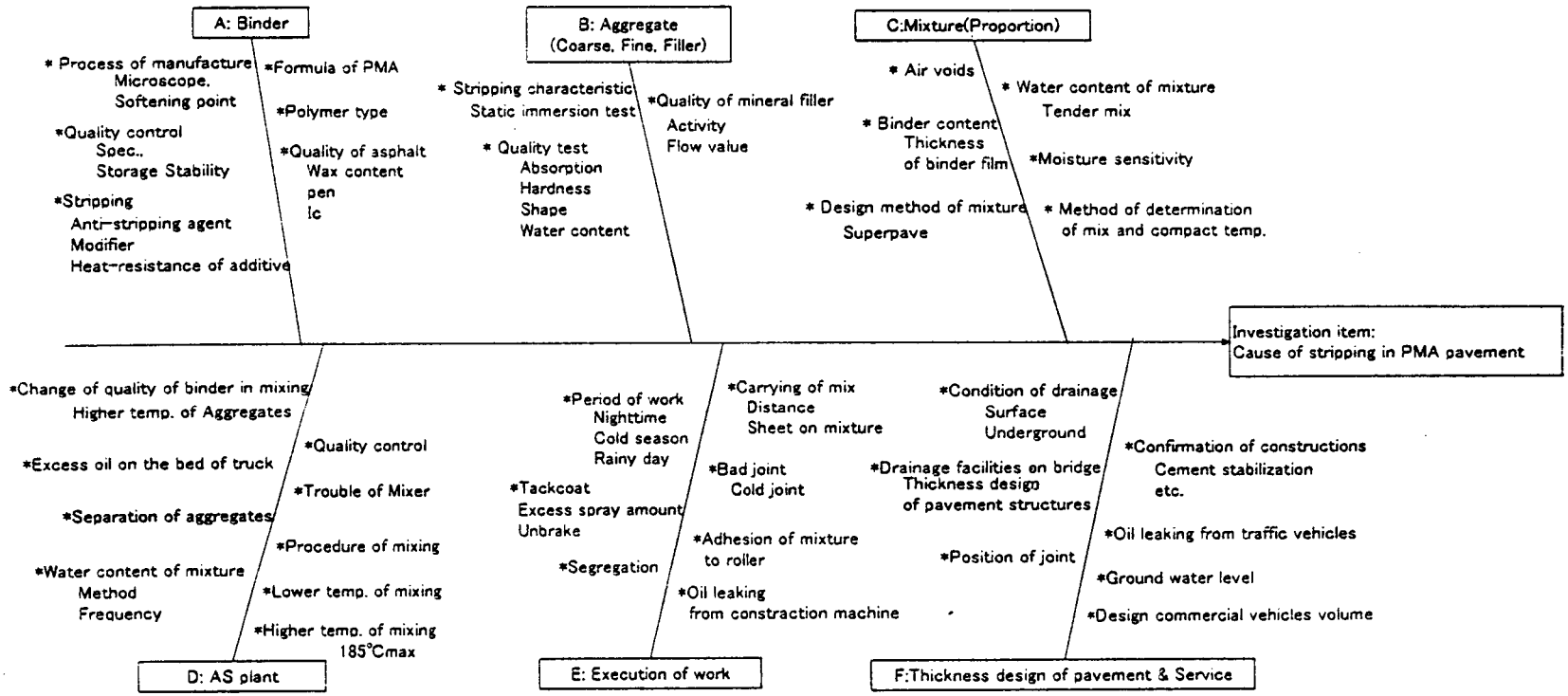


Figure Fish bone chart about the pothole damage

Figre1-1,Fish bone chart pothole damage of asphalt pavement

2 Asphalt pavement technology, fundamentals(A) and actuality (B and C)

——— Good(B) and Wrong(C)point of Design,Materials,Plant and Construction site in Korea

(1) Design (Maintenance)

A. 1) Important pre-investigation for existing pavement (road surface and pavement structure) (Fig 2-1,2-2)

B. 1) (not clear)

C 1) Even maintenance design is performed with standard specification, rutting is occurred in short period(case of heavy rutting), which take notice to do with the properties of underlayer mixture (maybe soft)

2) If high quality materials are used, (for example PMA), poor pavement structure has still no problem.<Misunderstanding ①>

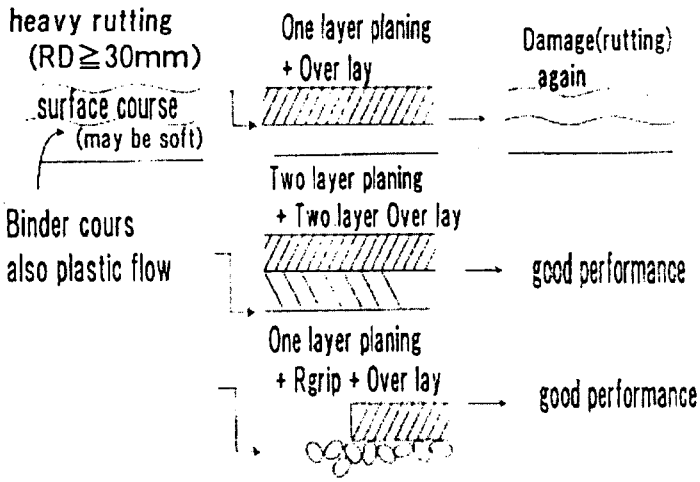


Fig.2-1 Suirability of Binder course Regrip Method (case of heavy rutting)

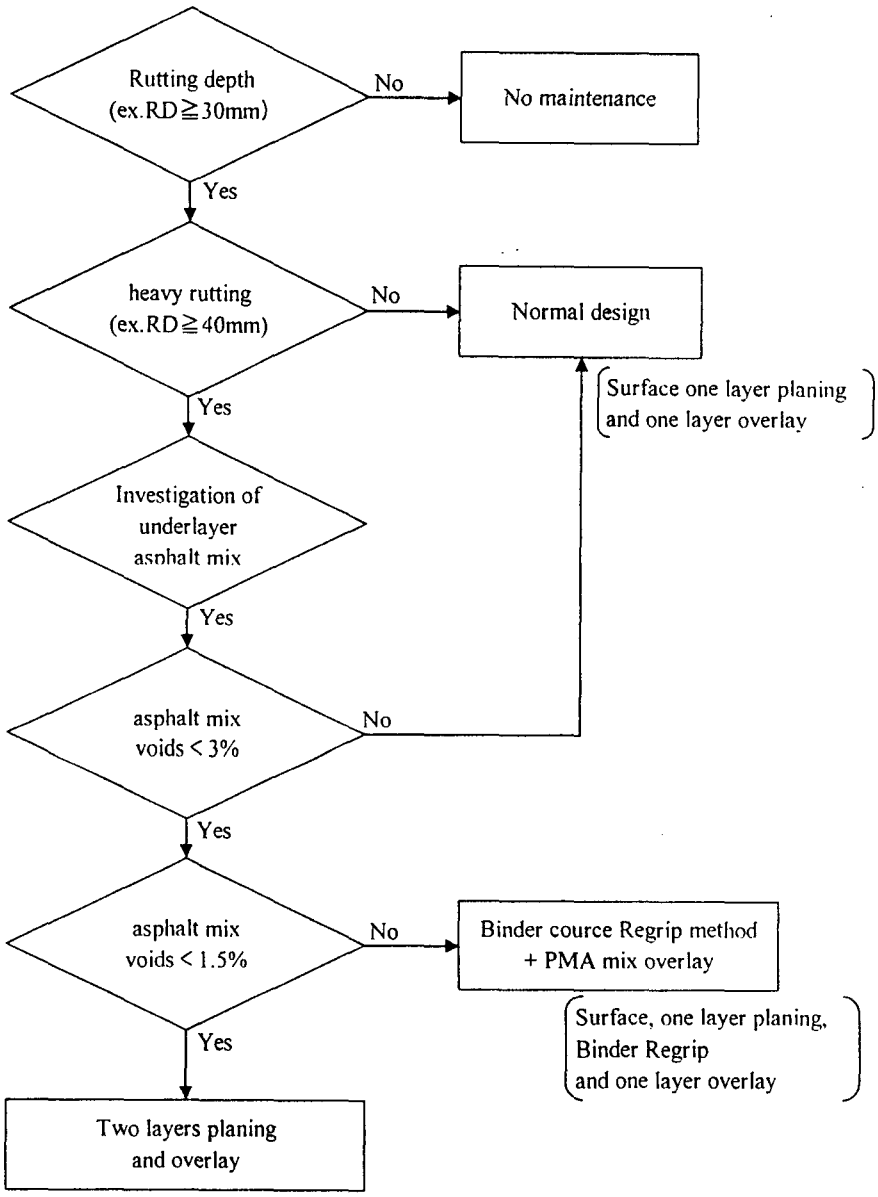


Fig.2-2 Selection flow of maintenance method for rutting

(2) Materials and mix design

A. 1) Crushed stone should be clean, dry, low water absorption, not stripping and no elongated and flatted<misunderstanding⑥>.

2) Asphalt cement is important a relationship of temperature –viscosity (to determine construction temperature (Fig.2-3), and attention of effective deadline should be paid to PMA. (usually about 14 days)

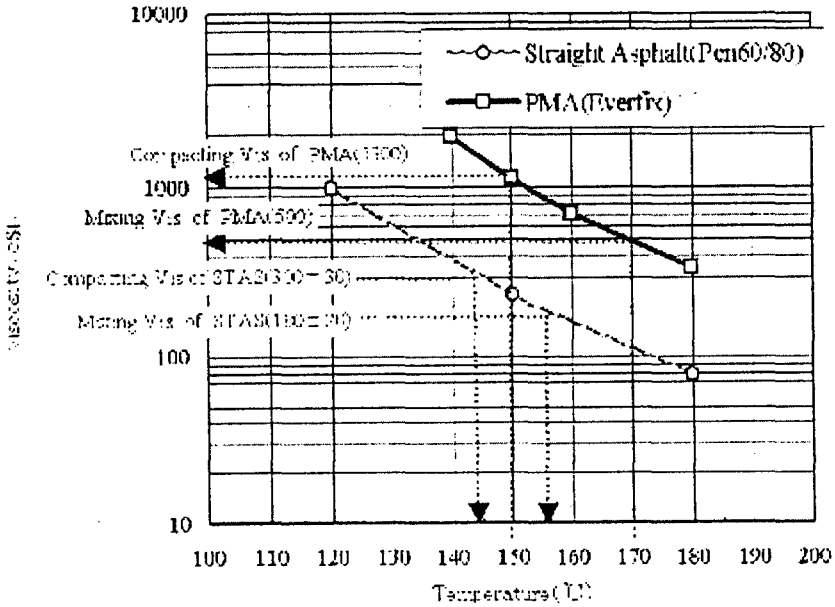


Fig. 2-3① Viscosity-Temprature curve of asphalt binders

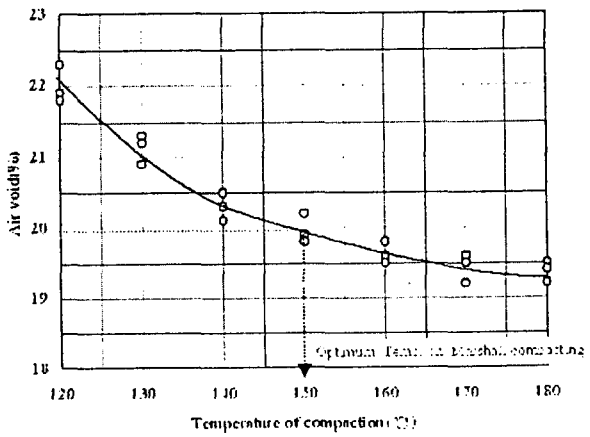


Fig. 2-3② Relationship of Air void-Temperature of compaction about porous asphalt (Marshall test pieces of porous asphalt mix used PMA)

3) Experience (previous result) should be used for mix design(test).<misunderstanding⑧>

B. 1) Adopting PG grade spec.(AASHO NP-1)and Supperpave mix design methods. (In Japan, it has not been adopted because no problem is occurred using current standards)
2) Using screenings (crushed sand) · But in generally,only one aggregate is not used for fine aggregate. <misunderstanding⑦>
3) In cold area, SMA is a good choice for pavements.

C. 1) Properties of mixture is affected by the aggregate quality.
2) If screenings is used only as fine aggregate, quality variation of the mixture will be problems.
3) As for coarse aggregates, it is not always true that the bigger the maximum size of the aggregate(ex.20m/m), the bigger the stability. It will be difficulty for coarse aggregates to be compacted.(Fig.2-4)
The allowable maximum aggregate size is determined by construction thickness. And a coarser aggregate is usually used in binder course. <misunderstanding③、④>

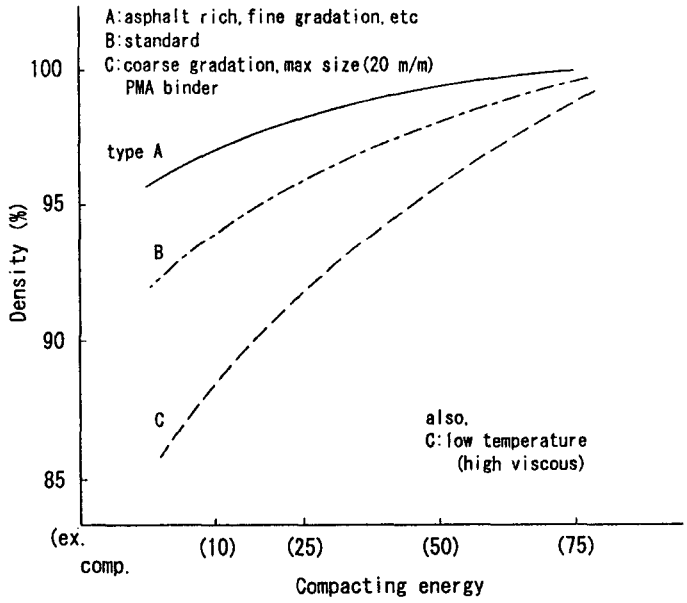


Fig.2-4 Relationship of compaction energy and density for several asphalt mix (schematic)

(3) Manufacture at asphalt plant

A. 1) It is important to manage mill sheet of arrival of materials and to check by eye(especially about crushed stone and sand).
2) Coarse aggregate should be dried thoroughly
3) Reasonable self-management based on" Pre-Check and Examination System of Asphalt plant"(in Japan) should be used.

B. 1) Operation standard manual of asphalt plant should be set up (for example, mixing time)
2) It is not clear whether management basing on operation standards manual has been producted.
_____Quality management is not only test. It is important to totally product quality control.
3)The aggregate stock have the roof.

C. 1) the same as B,2)
For example, aggregate gradation control is performed by the relationship between cold bin and hot bin.

(4) Paving at construction site

A. 1) Performing trial construction (before and the first day).
2) Fundamental point for construction in cold weather.
(Fig. 2-5)

B. 1) Protection measures for mixture adhering on tire roller using not vegetable type oil in Japan(using silicon-hydrate type)

C. 1) Compaction is by tire roller at high temperature is insufficient. Tire roller must move continuously ,don't rest. <misunderstanding②>
------- It could not be anticipated that densification on surface can be made by traffic load, especially when PMA mixture is used.
2) It is not true that the variation in construction is small for high quality material. Neither is for rough construction.

(5) Others

1) Pavement technologies include design, construction and service, so it's overall problem, therefore, it is a system need feedback in design again.
(Fig.2-6)

The total management, which is related from selection of every kind of materials to roller compaction in site, is very important.

Theoretical considaration is important .It is the bridge between the experimental consideration and practise(design ,construction and performance).
It also contributes to verification of technical solution by experimental method.

The various test results that have errors should be actively used.

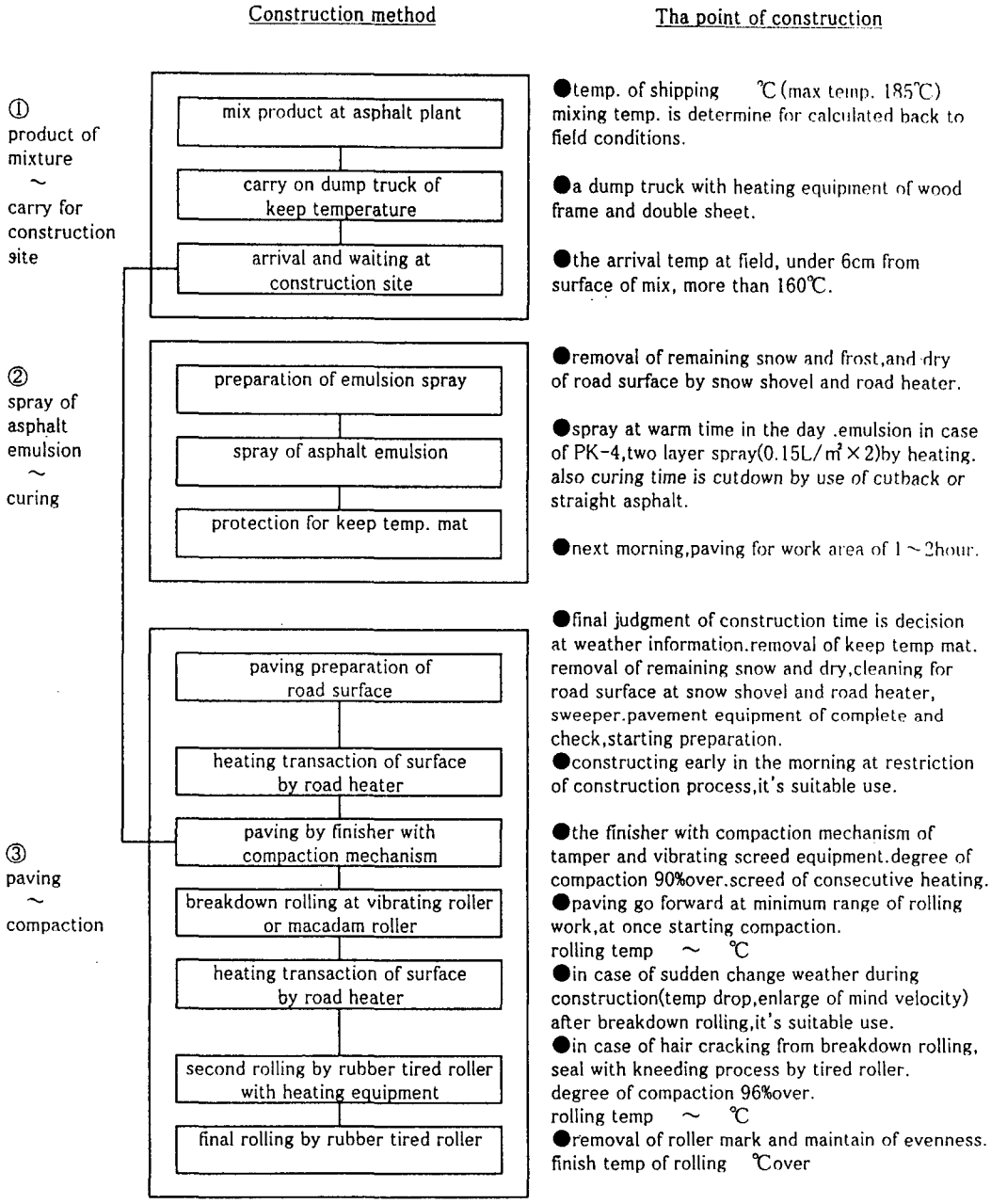


Fig2-5; Construction method of asphalt pavement for a cold period

(Nagumo.S and Yamanokuchi.H. editor
Question and Answer Vol.3, Kensetu Tosho co.ltd ,1977 <in Japanese>)

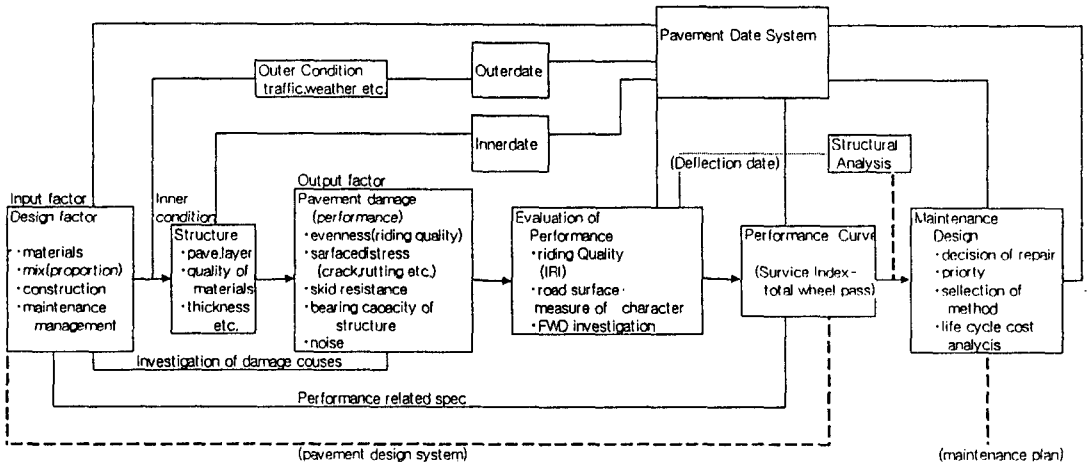


Fig.2-6 Situation of Maintenance Design for Pavement Meintenance Management System(PMMS)

(Yamanokuchi.H.and Maruyama.T.:Asphalt Pavement Technology for maintenance,Sankaido.co.ltd,197 <in Japanese>)

(6) References

1) Manual for Asphalt Pavement,1989
Japan Road Association (in English)
2) Manual for Asphalt Pavement,1992
Japan Road Association (in Japanese)
3) Technical Standards for Pavement Structure,2001
Japan Road Association (in Japanese)
4) Technical Guideline for Pavement Design and Construction,2001
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5) Pavement Construction Manual,2001
Japan Road Association (in Japanese)
6) Technical Guideline for Porous Asphalt Pavement(tentative),1996
Japan Road Association (in Japanese)
7) Matuno.S,Nagumo.S,Miura.U and Yamanokuchi.H:Test method for Asphalt Pavement, Kensetu Tosho.co.ltd.1983.8th.ed. (in Japanese)
8) Road Reserch Laboratory ,DSIR:Bituminous Materials in Road Construction. H.M.S.O.1962
9) Highway Reserch Board: Factors involved in the design of asphalt pavement surfaces NCHRP Report 39,1967
10) PIARC,Technical Committee on Flexible Roads: Bituminous Materials with a High Resistance to Flow Rutting, 1995

3 Examples of the solution scheme

Based on the foregoing section 2 and considering the cause of failure, the following matters are suggested as the solution scheme.

1) The steel wheeled roller in paving work should start immediately and advance closer to asphalt finisher and so. --- the mixture should be compacted immediately after spreading. (especially during cold period, temperature fall). A reference to standard construction procedure of pavements in cold period is shown in Fig. 2-5.

2) Do not delay introduction of a pneumatic tire roller. Compaction temperature (for PMA 125°C or above) should be maintained compaction carried over the whole surface.

3) Take necessary measures to prevent adhesion of asphalt mix the tire roller.
For example, the present vegetable type oil is replaced with silicon hydrate type like" nepparan-W"(commercial name).

4) When settled compaction is not getting,it is tender mix phenomena.
Problems related to moisture should be considered.

for example:
①Aggregates (especially crushed stone) should not be left to soak in water for a long period (they should always be properly stored in a shelter or covered)
② Usd aggregates should be changed (the quality properties should be examined).
③ Time in the drier should be lengthened (cold bin materials should be reduced to supply).
④ Near side screen of plant should be opened.
⑤ Addition of silicone oil should be evaluated.
⑥ Amount of asphalt should not be reduced. Compaction should continue until the mixture stabilizes (settled)by correct (high) temprature.

5) In the design of mix proportion, dense graded mixture with 13mm maximum size, which gives better compaction and finising than 19mm size.

6) The following is an example of methods which should be adopted detailed examination:

① Adoption of the impact crusher and sieving correct crucher etc. for improving the shape of aggregates.
② Investigations of present condition of various typical aggregates (quality, specification etc.).
③ The quality assurance (setup of pull-date) of PMA, and verification of quality of the tank at the asphalt plant
④ Examination of materials used as well as PMA mixture against stripping by water.
⑤When a mixing temperature (170 degrees C or more) of PMA cannot be secured, semi-hot mixing technology should be considered.

4 Possible investigation for improuving pavement technologies

(1) Basic investigations for examinnig pavement technologies

①Various quality and properties tests for aggregates and their influence on the properties of mixture (the quantitative influence of the poor aggregate on the mixtures, influence of the variation of screenings, water content in mixture etc.)
②Investigation of representative aggregate exploring, such as crushing stone plant
③Mix design using Marshall test (comparison to Surperpave, Gyratory compaction)

④Determination of plastic deformation resistance of mixture by wheel tracking test etc.
⑤Quality control of material measuring (in asphalt plant)
⑥Equipments specification examination (drier, mixer etc.)
⑦Typical site investigation of pavement construction

(2) Field investigation for the reasons caused the pavement failure

①Production storage properties (deadline) and storage properties when it is transported to the mixing plant (storage aging) should be understood for PMA
②Durability tests should be carried out for mixtures, such as aggregate stripping resistance(water-immersed wheel tracking test etc.)
③Confirmation of mixdesign, and its characteristic values (OAC ,VMA etc.)
④Marshall density sampling in plant(compared mix design's density)
⑤Core boring in site (extend to lower layer), (for Binder course re- grip method)

(3) Others, related data

① Relationship between temperature-viscosity for PMA
②Aggregate quality specifications (course aggregate , filler etc.)
③Types of anti-stripping additives
④Design document and plant hotbin measure and standard density(plant marshall density)
⑤Plant specifications (plant examination manual)
⑥Operation standard manual in plant (mixing temperature and time etc.)
⑦Operation standard manual in paving site (construction planning document)
⑧Pavement structure design condition
⑨Others, traffic and climate conditions,etc.

5 Examples of misunderstanding for asphalt pavement technology

Some of misunderstanding(misconceptions) about asphalt pavement technology can be listed as follows:

1) Even when constructed poorly and/or on a weak foundation (bigger deflections, cracks), PMA, which is expensive, will be more durable than a straight asphalt pavement.
   - Construction of PMA is difficult (construction nature).
   - It is not an answer to all the problems.
   - Requires an advanced level of management.
   - Material, mix design and construction method that considers PMA properties is necessary.
2) Asphalt pavement compaction and preservation of surface sealing will be performed by traffic load.
   - To some extent this may be true in case of straight asphalt pavement constructed during warm season. However, this phenomenon will not hold for a high viscosity PMA. The pavement should immediately and sufficiently be roller compacted by steel and tire.
3) Coarse graded asphalt pavement is more durable (plastic deformation) than a dense graded asphalt pavement.
   - Generally, coarse graded mix has good flow resistance because it has small percentage passing 2.5mm (higher percentage of coarse aggregates). However, construction is difficult for coarser mixture. It is more difficult to use high viscous asphalt (PMA).
4) A mixture with maximum size of 19 mm is more durable (plastic deformation) than that of 13 mm.
   - If the percentage passing of 2.5 mm is the same, they may practically be equal. However, very strict construction management is required because construction is difficult and may result in bad workmanship.

5) Superpave design is the excellent mixture.
   - That is still Unproven. In Japan, evaluation is not yet well established. Because,Aggregate gradation and mix design is not a critical matter. However, SMA is more suitable for your country.
     As for the pavement surfaces I observed a little cases, I noticed a lack of enough mortar in the mixture. I believe there is a need for further investigation and researches.
6) There is nothing to can do about crushed stones.
   - Modifications that take into consideration properties of PMA may be necessary. That is possible and I have already seen some positive signs towards this goal.(for example,impact crusher etc.)
7) We do not want to use river sand. It is expensive.
   - Only one type of screenings can be affected by variation in the fines. Furthermore, it may be better to evaluate a combination of 2-3 types because fines can significantly affect the quality (whenever necessary more tests should be performed).
8) In order to shorten the time which experience takes, theory is important and very helpful.
   - Theory is not useful to realistic solution. Theory is effective to verify and back up the solution.
9) Special medicine to solve problems
   - Problems related to asphalt pavement technology are quite diverse.(overall problem)
     A lot of pavement Failures are caused by a combination of several factors. Although there are factors with high weights, there are no absolute ones at present. Moreover, experiments (by many kinds of test) should not be trusted very much. They include errors. It is important to strike a balance between pavement design and construction.

6 Others(for reference)

Pavement and Failure

(The New-Pavement Discussion.No.29,2001.7,Japan Road Contractors Association)

In recent years there have been a series of failure(mistake)committed by young professionals in Japan that Japan road contractors association organized a kind of panel discussion on failure in road construction projects. Most of the panelists were people with vast experiences on the road construction projects and have had some first hand experiences with failure committed on the field. I would therefore wish to share with you some of the basic issues raised during this discussion.

Failure by earlier engineers

Most of the failures committed in early days appeared to be purely technical. The whole pavement construction industry was at the development stage, where there was enough time to spend on the job and everybody on the client's side as well as contractor's side was aiming at a product of high technological quality. This was an era where people hardly took responsibilities for their failures neither were they worried about inconveniencing their clients.

However, situations have now changed quite considerably. There is very little room for obvious failures. You will not be forgiven in case you do not meet job specifications, but it is allowed to present an alternative design. During those old days the technology was still developing, and people were very keen on learning from senior professionals (like site representative) on how to carry out the works and it was common to develop an alternative design. In recent years, there is a decline in alternative designs. One reason for the decline is the absence of young engineers (on the client side too) with sound technological experience to present alternative designs. Furthermore, other reasons attributed to refusal to allow design changes is people being busy to meet strict accounting inspections as well as decrease in job size.

Moreover, shifting from a common goal of "constructing" to "buying" for the part of client and "selling" for the

part of contractor has not been successful. A contractor is always supposed to construct and not so sell a product. Furthermore, the high level of technology is moving from the public to private sectors, which suggests that the contractor should be responsible for the workmanship (including durability). Most people have enthusiastically welcomed performance specification, which has only penalty and no bonus. Furthermore, there is no rationale for a warranty period of 2 to 3 years. It is too short. Government responsibility in terms of accountability (disclosure of information) is treated separately.

After passing the catch up period, we had developed several special methods for pavement constructions, though we were still faced with a lot of challenges. To give an example, during the 80's there was one porous pavement construction project where fretting (loss of binder and aggregates) had occurred 1 month completion of works. Spike tires were still allowed and Tohoku region had already experienced similar problems (weakness of porous pavement to spike tires) but unfortunately this information was not available to the contractor. One young engineer was asked to search for information on similar project, but he was not thorough enough. That was a good reminder to the whole society that we still needed to be vigilant so that we do not repeat past failures. Moreover, failures at initial stages of the project like decrease of temperature of materials due to traffic congestion or failuren selection of a compaction roller may cause very serious problems later. I think the young generation is failing to listen or pay attention what the older generation is saying or doing. This may not be failures of the older generation, but in discipline and education is not going in the right direction. I also regret that the failure to strongly scold our children may also be a factor.

Good failures and bad failures

I would like us to talk a little bit about good failures (necessary failures) and bad failures. In my opinion, the example given earlier falls into the good failures category. Having realized the fretting problem in porous pavements, high viscosity binders as well as top coat method for porous pavements have been developed to tackle this problem. This was after tedious researches on porous pavement materials and after almost giving up on the use of porous pavement. Currently, there is a wide use of porous pavements.

Accumulation of knowledge from very few personal failures and some few more typical failures by others may be enough to prevent most of the failures being committed. This is to say, as professionals we should be aware of the fact that pavement technology is a combination of several technologies. Most of failures committed due to ignorance, carelessness, lack of proper investigation or evaluation, misjudgment are preventable.

There are also problems, which may be attributed to quality management and evaluation. Quality management at the project site as well as asphalt plant has merely been a formality. To give an example, quality investigation (Manual for asphalt pavement 6-5-3: Investigation of management data) is not for quality assurance but rather for preparation of management data. There is a need for strict quality management and assurance, and in case a failure or omission is found, the responsible party should be penalized. In case of exemplary workmanship, there should be a reward. There should also be a third party to evaluate companies, and only those with proper technology and qualified staff should be allowed to work. This will show benefits of performance specification where the contractor is given all the responsibility for the work and given overall evaluation.

Advices to young professionals

Ignorance should never be used as an excuse. What is important is to prevent all failures caused by lack of knowledge of things that are well known already. One should not be afraid of making failures but should always be well prepared. Older professionals should be ready to scold young ones whenever a failure is made. We should learn from our failures and make use of this experience.

If a warranty period is extended to, say, 7 years, I believe there will be an allowance for failures and a chance to learn from these failures. I am hopeful that performance based specification will revolutionize the construction industry.

Most of accidents in civil engineering works are caused by failures. I would like to give a list of 10 items that may be helpful in reducing failures by young professionals.

1) Should be courageous to postpone or evacuate. Perplexity may increase the extent of Failure.
2) Should assume the worst scenario and make sure whether its human life or property that is in danger.
3) You are responsible to defend your own site. Daily check and training will serve the site.
4) There are signs to most accidents. Do not overlook any small changes at your site.
5) Pay attention to section boundaries and their respective changes.
6) You should not relax because there is alarm equipment. Make sure it functions properly.
7) Accident management is the responsibility of every one involved with the site.
8) A professional who can predict accidents in his project plan as well as manage the site is normally strong at a crisis.
9) Never despise experience and common sense
10) There is a solution to failures. Listen to veteran professionals.