QUANTITATIVE EVALUATION OF CONSTRUCTION PERFORMANCE OF HOT MIX ASPHALT

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ABSTRACT

By observing the degree of compaction determined on the cored samples taken from the hot mix asphalt (HMA) surface course placed at an airport, the quantification of the performance of construction work and the influence of the number of samples on the results of inspection on construction work were investigated. The following results were acquired.

(1) The construction performance of HMA could be quantified by the fatigue life.
(2) The change in the fatigue life is conspicuous compared to the change in the degree of compaction.
(3) The number of samples used in the inspection of HMA construction work greatly influences the quantification of the construction work. The inspection will be conducted almost correctly if ten samples are used.

KEY WORDS

hot mix asphalt, performance-based specification, compaction, pay factor, fatigue life

INTRODUCTION

Infrastructure must be designed and constructed so that its performance is sufficient for the predetermined period, as well as be maintained appropriately as needed. Attention has focused on the performance of infrastructure during its service life due to the deficits in budget.

In Japan, among the three phases of design, construction and maintenance, some performance-based procedures were developed for the design and maintenance phases. For the construction phase, however, generally the specification-based procedures in which all the sampled values of volume, size, quality, etc. of the construction work must satisfy the criteria at inspection have been adopted. Accordingly, the inspection results are either acceptable or unacceptable, and an interim result, i.e. that between them, does not usually exist. In the paving work of roads and airports in the U.S.A., the performance-based method of payment for construction work has been adopted.

The method of payment for the performance of paving work at airports is studied here by focusing on the density, one of the criteria in the inspection for paving work. First, the test data on the cored samples taken from the hot mix asphalt (HMA) surface course placed at an airport were collected, and the density, Marshall stability, etc. were reviewed. Next, the method of payment for the performance of paving work adopted in the U.S.A. was applied to this paving work. Then, the performance of the work was quantified based on the number of load repetitions to fatigue failure, that is, fatigue life, of HMA. In addition, the influence of the number of samples on the results of the inspection for the paving work was examined. [1), 2)]

PAYMENT CRITERIA OF PAVING WORK AT AIRPORTS IN THE U.S.A.

Many foreign countries including the U.S.A. adopt the payment system in which the amount of payment varies with the performance of the construction work. Namely, not only will the construction work be accepted even if it does not fully satisfy the criteria, but the amount of payment exceeds the pre-contracted amount when the performance is recognized to be much superior to the criteria. For example, the quality control and warranty system is introduced in U.S.A. road and airport pavements, on the premise that decreasing the variation in the process of material manufacturing and pavement constructing might improve the performance of the pavement's service and extent of its service life.

The amount of payment will be adjusted by quantifying the performance of the constructed pavement, that is, in construction work of HMA surface courses of airport asphalt pavement, as a pay factor. The pay factor is calculated by the density (the degree of compaction) and air void of HMA. **Table 1** shows the single-sided specification system (lower side), where LPF is the percentage of the contracted unit price (lot pay factor) and PWL is the percentage of material within specification limits. [3)] PWL is calculated from the quality index Q_L and the number of samples n using predetermined tables (not shown herein). Q_L is calculated using **Equation 1**.

$$Q_L = (X - L)/S_n \quad \textbf{(1)}$$

where,

X: sample average of sublot values in the set,
L: specification lower tolerance limit,
S_n: sample standard deviation of the number of sublot values in the set.

Table 1 Percent within limits and Lot Pay Factor

PWL (%)	LPF (%)
96-100	106
90-95	PWL + 10
75-89	0.5 PWL + 55
55-74	1.4 PWL - 12
Less than 55	Re-construction

Due to this procedure, not only does the amount of payment increase to 106% of the pre-contracted amount, but the work with PWL of 55% passes the criteria with the amount of payment being reduced.

PERFORMANCE EXAMPLE OF CONSTRUCTED HOT MIX ASPHALT SURFACE COURSE

Density

Thirty cores of HMA were extracted from the surface course of an airport asphalt pavement in Japan, for which the structure and material properties were identical irrespective of position, and their performance was assessed by applying the above-mentioned construction quantification system. Actually, the degree of compaction, which is the ratio of the density of the core to the standard density determined using the presently specified method, was used instead of the density.

The average and sample standard deviation of the degree of compaction are 98.9% and 1.83%, respectively. Moreover, the minimum and maximum values of the degree of compaction are 94.4% and 101.8%, respectively. From **Figure 1,** which shows the histogram of the degree of compaction, about 1/4 of the data does not pass the criteria of degree of compaction of 98%.

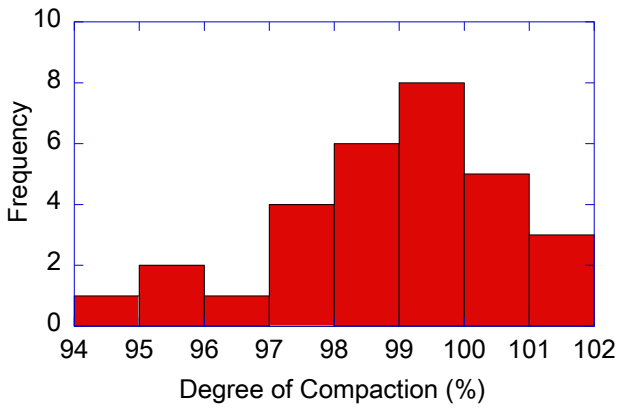

Figure 1 Frequency of Degree of Compaction for Cored Samples

Amount of payment

The influence of the performance of HMA on the amount of payment was then investigated. Namely, LPF was calculated at 98% of the specification lower tolerance limit of the degree of compaction. The table prepared for road pavements in USA was used for all thirty data since there is not a suitable one prepared for airport pavement. As a result, it was found that PWL and LPF were 69% and 85%, respectively.

Marshall stability

In addition to the density, the Marshall stability of cores was measured. **Figure 2** shows the relationship between the degree of compaction and the Marshall stability. The Marshall stability increases with the degree of compaction although the variation is somewhat large. Even given that the Marshall stability of cored samples is quite a bit lower than that of laboratory prepared samples, securing the degree of compaction is recognized to be highly significant for obtaining the higher Marshall stability; that is, the bearing capacity of HMA, a kind of performance, could be estimated by observing the degree of compaction.

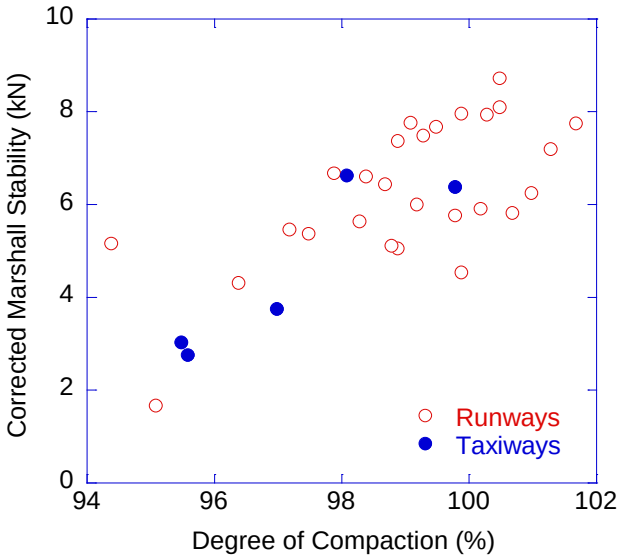

Figure 2 Degree of Compaction and Corrected Marshall Stability

RELATIONSHIP BETWEEN DENSITY AND FATIGUE STRENGTH OF HOT MIX ASPHALT

In order to grasp the influence of the degree of compaction of HMA on its performance, the bearing capacity was verified. Fatigue cracking was adopted as the checking item for bearing capacity, and the fatigue life was actually calculated; that is, as the fatigue life increases, the bearing capacity becomes higher.

The fatigue life of HMA was calculated using the following procedure. First, the stiffness of HMA was estimated from the degree of compaction, then the strains of aircraft placed on the pavement with HMA were calculated using this stiffness, and finally the number of loadings to fatigue failure of HMA, that is, the fatigue life, was assessed based on a fatigue strength equation. In this process, the fruits of the research of the University of Massachusetts were used for estimating the stiffness, and the equation contained in the airport pavement structural design manual in Japan was adopted to calculate the fatigue life. In addition, the strains of HMA were calculated using GAMES in the example described in the above-mentioned design manual (for B777-300D aircraft).

Figure 3 shows the situation where the stiffness and the maximum principal strain change with the degree of compaction of HMA. Along with the decrease in the degree of compaction, the stiffness decreases and the maximum principle strains increase.

By using this data, the difference in the fatigue life arising from the degree of compaction could be grasped, as shown in **Figure 4**. The fatigue life in the case of 98% degree of compaction falls to about 90% of that in the case of 100% degree of compaction, and the fatigue life in the case of 95% degree of compaction falls to about 80% of that in case of 100% degree of compaction. It is clear from the figure that the change in the fatigue life is conspicuous compared to the change in the degree of compaction; that is, the difference in one point of degree of compaction corresponds to a difference of about three points of fatigue life.

When applying this result to the above-mentioned thirty core samples, since the average, minimum and maximum values of the degree of compaction are 98.9%, 94.4% and 101.8%, respectively, the average, minimum and maximum values of the fatigue life will be 93,000 times, 76,000 times and 109,000 times, respectively.

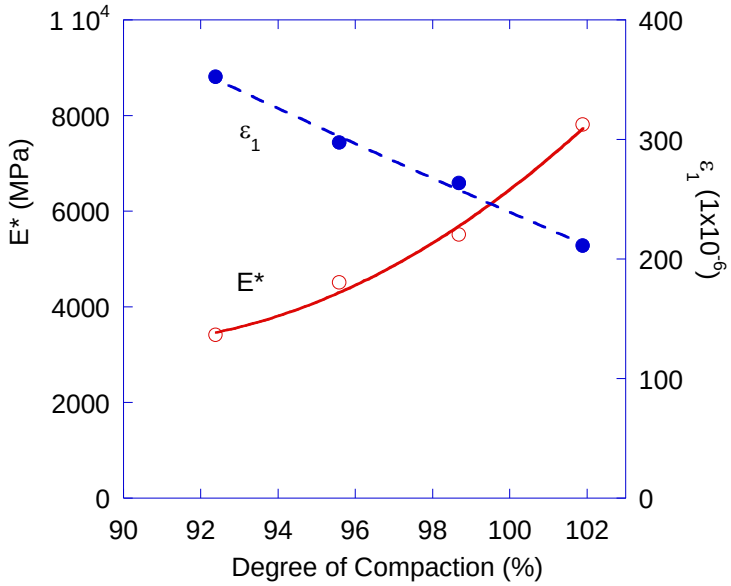

Figure 3 Degree of Compaction, Stiffness and Maximum Principle Strain

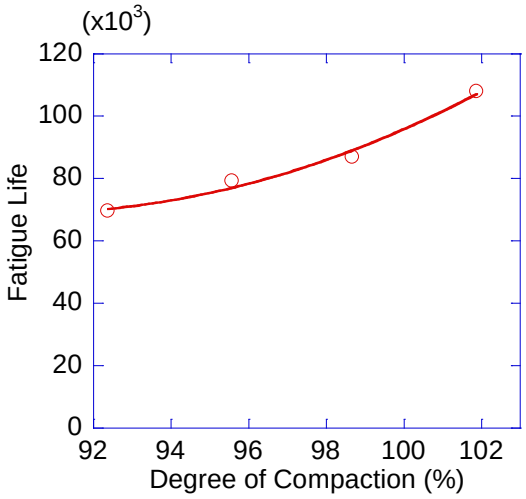

Figure 4 Degree of Compaction and Fatigue Life

INFLUENCE OF NUMBER OF SAMPLES ON CONSTRUCTION PERFORMANCE ASSESSMENT

PWL varies with the number of samples even if the quality index Q_L is identical, as explained above. In order to obtain the basic data for determining the number of samples necessary for appropriately assessing the construction performance, the influence of the number of samples on the degree of compaction, LPF and the fatigue life were investigated.

Five and ten data were arbitrarily taken as a set of data samples from the above-mentioned thirty data, the data populations were estimated, and then the average value and population standard deviation of the degree of compaction, LPF and the fatigue life were calculated. The data populations with normal distribution for which the average and standard deviation coincide with the above-mentioned values were assembled, and the values having 90% reliability were used in the following analyses.

As shown in **Figure 5** with regard to the degree of compaction, the average almost remains constant irrespective of the number of samples, and the variation becomes smaller as the number of samples increases. Incidentally, when the data population is estimated using all thirty samples, the average and standard deviation is 98.9% and 1.83%, respectively, and the degree of compaction with 90% reliability becomes 96.6%.

Next, LPFs calculated using both five and ten samples with 98% of the specification lower tolerance limit of the degree of compaction are shown in **Figure 6** as a histogram. The figure indicates that in the case of five samples, the frequency of rejection of the construction work is about 18% and the frequency of the construction work obtaining 106% of the pre-contracted amount of payment is about 15%, with reference to **Table 1**. On the other hand, in the case of ten samples, the frequency of rejected construction work and construction work obtaining a higher amount of payment is about 8% and 3%, respectively.

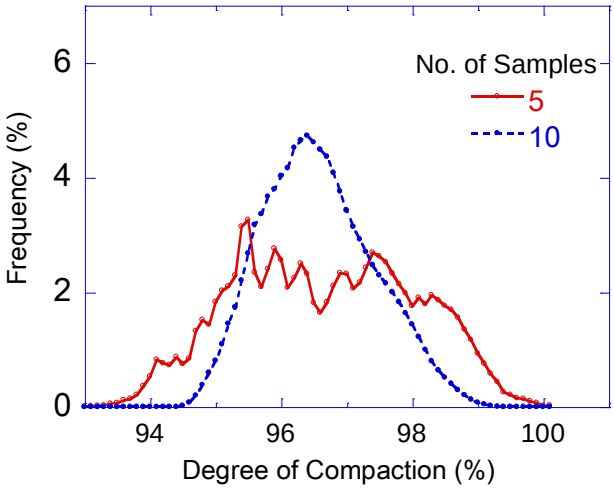

Figure 5 Frequency of Degree of Compaction (90% Reliability)

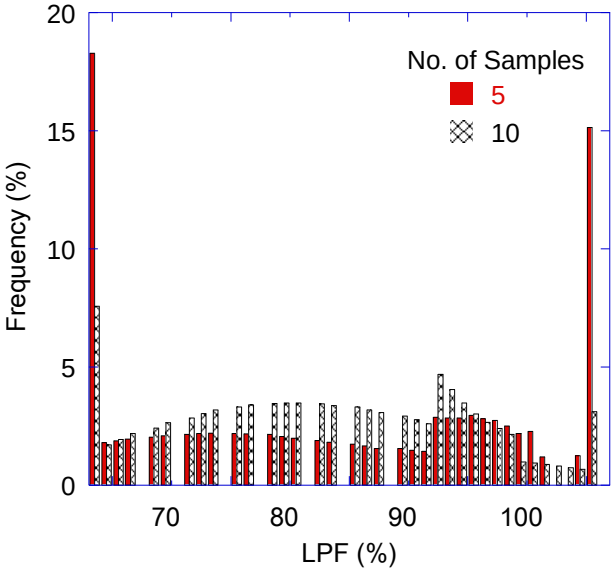

Figure 6 Frequency of Lot Pay Factor

From **Figure 7** that shows the cumulative frequency of LPF, with regards to the frequency of the construction work obtaining 65 - 105% of the pre-contracted amount of payment, the frequency for ten samples is found to be larger than the frequency for five samples. The risks for both the agencies and contractors might increase as the number of samples decreases. Incidentally, when the data population is assembled using all thirty samples, PWL is calculated to be about 83%.

The performance of pavement could be quantified by using the fatigue life, as mentioned above. To apply this procedure to these five and ten samples cases, the fatigue life in the case of the degree of compaction, with 90% reliability, was first calculated, and then the ratio of the number against the fatigue life in the case of 98% degree of compaction used as the criteria was calculated, which are hereafter referred to the relative fatigue failure repetition. The histogram of the relative fatigue failure repetition in the case of five samples is summarized in **Figure 8**. According to this, the average, minimum and maximum values are 94%, 82% and 111%, respectively. In addition, the relative fatigue failure repetition for 100% degree of compaction used as the criteria is also shown in this figure, where the average, minimum and maximum values are 84%, 74% and 100%, respectively.

To investigate the influence of the number of samples on the performance quantification, relative fatigue failure repetition for 98% and 100% degree of compactions used as the criteria were examined in the case of ten samples in accordance with the above-mentioned procedure. **Figure 9** shows the comparison between the case of five and ten samples, showing that as the number of samples increases the variation of the relative fatigue failure repetition decreases and the accuracy of the performance quantification increases. This clearly implies the importance of determination of the number of data in the quantification of the construction performance.

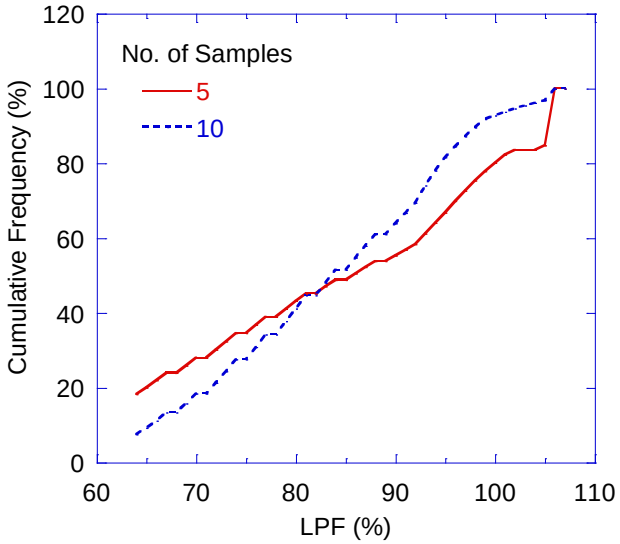

Figure 7 Cumulative Frequency of Lot Pay Factor

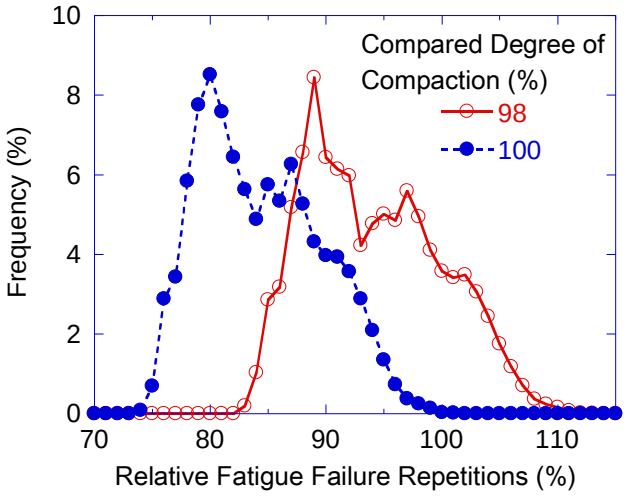

Figure 8 Frequency of Relative Fatigue Failure Repetitions

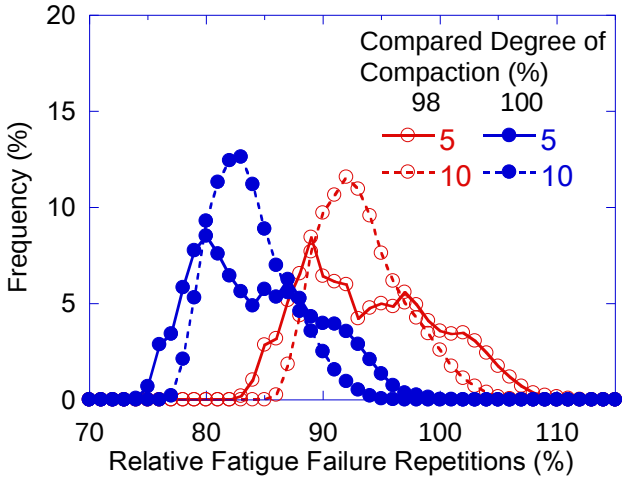

Figure 9 Influence of Number of Samples on Relative Fatigue Failure Repetitions

INFLUENCE OF NUMBER OF SAMPLES ON CONSTRUCTION PERFORMANCE ASSESSMENT FOR CRITERIA SATISFIED DATA

Only the data for which degrees of compaction pass the criteria, namely 98%, were used to investigate the influence of the number of samples on the construction performance assessment in the same way as mentioned above. The number of data used was twenty-two, and among them five and ten samples were arbitrarily selected.

Figure 10 shows a histogram of the degree of compaction with 90% reliability. The danger in rejecting the construction work varies with the number of samples, as well as the above analysis using all the data (30), but most sets of data samples will satisfy the criteria if ten samples are used. However, about 5% of all sets of data samples will be rejected when five samples are used.

Figure 11 shows the relative fatigue failure repetitions calculated in the same way as mentioned above. The number of samples affects the inspection results, showing that the relative fatigue failure repetition will increase to about 99% if ten samples are used. In addition, focusing on the average of the relative fatigue failure repetitions, there is about a ten point increase from 94% in the case of five samples to 103% in the case of ten samples.

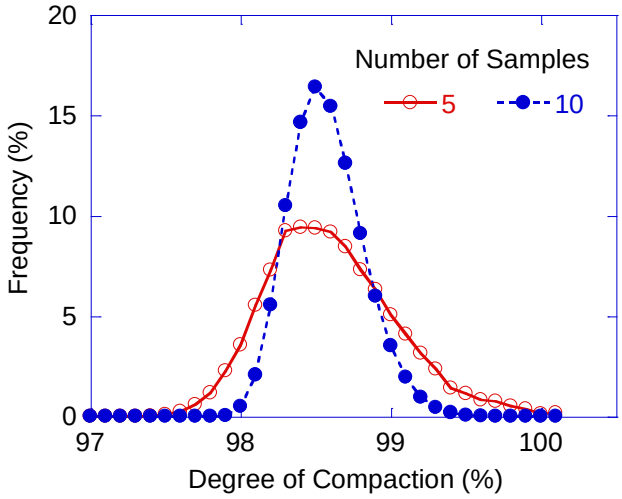

Figure 10 Frequency of Degree of Compaction (Criteria-Satisfied Data)

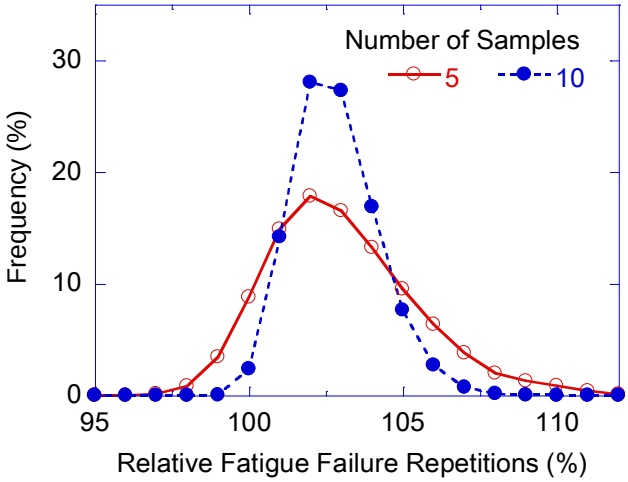

Figure 11 Influence of Number of Samples on Relative Fatigue Failure Repetitions (Criteria-Satisfied Data)

CONCLUSIONS

By observing the degree of compaction determined on the cored samples taken from the hot mix asphalt (HMA) surface course placed at an airport, the quantification of the performance of construction work and the influence of the number of samples on the results of inspection on construction work were investigated. The following results were acquired.

(1) The construction performance of HMA could be quantified by the number of load repetitions to fatigue failure, that is, the fatigue life, which is a quantification indicator of the bearing capacity.
(2) By using the relationship between the degree of compaction and the fatigue life of HMA, the performance of construction work could be quantified using the density of cored samples (the degree of compaction). The change in the fatigue life is conspicuous compared to the change in the degree of compaction, that is, the difference of one point in degree of compaction corresponds to a difference of about three points in the fatigue life.
(3) The number of samples used in the inspection of HMA construction work greatly influences the quantification of the construction work. Based on the criteria of LPF, the frequency of rejecting the construction work decreases from about 18% in case of five samples to about 8% in the case of ten samples.
(4) The inspection on construction work will be conducted almost correctly if ten samples are used, based on the analysis of the data satisfying the criteria on the degree of compaction.

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