Research and Study on Effective Quality Control Method of Pavement Construction by Acceleration of Vibratory Roller

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ABSTRACT: Recently, information and communication technology rapidly have been developed. Especially, positioning technology by GPS and automated machine control technology have been applied for construction sites. However, quality control technology has not been developed for pavement constructions. Then, we focus that the behavior of the vibrating rollers changes according to the ground stiffness. We studied the method of quality control for asphalt pavements by acceleration of vibratory rollers. The accelerations of a vibratory roller were measured on subgrade, sub-base course, base course and surface course at the test construction yard. The ground moduli of each layer were calculated by acceleration data. The results showed that the ground moduli would be applied for the quality control of pavement construction. On the other hand, resilient moduli of each layer material were investigated at the laboratory. Resilient modulus can be used for the theoretical design method of asphalt pavements. We simulated the in-situ stress conditions of pavement structure with vibratory roller loading and estimated in-situ resilient moduli of each material. From results of laboratory tests and simulated estimation, the average modulus was calculated. Comparing ground moduli of field test with average moluli of laboratory test, we found the good relationship of both moluli. Finally, we suggested the method of quality control for asphalt pavements construction combined with theoretical design method of asphalt pavements.

KEY WORDS: Vibratory roller, roller accelerations, compaction control, quality control, resilient modulus.

1 INTRODUCTION

The information and communication technology in the construction work is progressing rapidly of sharing the computerization of information according to the spread of CALS/EC as the tool of the reliable design from the site measurement management etc. "Information - communication technology construction promotion strategy" was typed out by the Ministry of Land, Infrastructure and Transport in July 2008 when the introduction of ICT (information - communication technology) in the construction field was steadily advanced, and the policy of promoting a wide-ranging ICT construction work became clear. Recently, the execution management and the work progress control using the digital design data of three dimensions have entered a practical stage in the earthwork, too.

The spread and evolution of computers are assumed to be a base to these backgrounds, a computerization, various sensor technologies, and the site communication technologies of the drawing and specification by CAD play an important role, and the point that a highly accurate, real-time, positional measurement has become possible contributes greatly especially by rapid development of the positioning technology such as GPS (Global Positioning System) and the automatic tracking total stations. And, the automation of construction came to advance rapidly by combining an advanced oil pressure control technology of the construction machine with these technologies. The verification to have already turned such a system to not only the labor saving of construction but also the rationalization of the entire construction process of the investigation, design, construction, operation and maintenance in Europe and America.

The execution management, especially the technology of the work progress control advanced rapidly in Japan because it introduced these technologies into the earthwork. It is not applied for the quality control in the paving work and it exists in the current state that depends on the technique of the sample that measures the degree of compaction at each survey point. The system has already been put to practical use by location information of moving roller by GPS for the construction management. On the other hand, the project that rationalizes the improvement and the paving work of QC/QA by informationization is progressing by measuring, recording the material stiffness in the surface compaction and controlling roller automatically as Intelligent Compaction strategy plan (http://www. intelligentcompaction. com/).

Then, authors are working on the research and development of which it is the final target to base these situations, to combine the construction management technologies by the acceleration response of the vibratory roller and GPS, and to construct the system that achieves the whole of quality management in the paving work. This paper describes the result of examining the application of the construction management technology by the acceleration response of the vibratory roller to the paving work among those researches.

2 EVALUATION OF GROUND STIFFNESS BY VIBRATORY ROLLER

When the soil compaction of the ground is done with the vibratory roller, the acceleration waveform of the vibratory roller falls into turbulence by receiving repulsion from the ground as the rigidity of the ground increases by the progress of the compaction. It becomes possible to measure the change in the degree of compaction by analyzing the frequency. In the earthwork, the evaluation approach for the real time management of the entire degree of compaction by using this acceleration response has already been put to practical use.

In this study, the method adopted by this earthwork was applied to the paving work. It has aimed at the appreciable rationalization by using this acceleration response as the quality control of the paving work is real-time.

2.1 Principle of Evaluation Approach

The acceleration response measured in this study was converted into the ground stiffness (modulus of elasticity E) by theoretical formula (Fujiyama and Tateyama 2000).In this paper, ground stiffness E is shown E_{roller}.

Figure1 shows one example of the acceleration waveform and the frequency analysis result. As for the waveforms of the acceleration response of the vibratory roller, it falls into turbulence, and elements other than the vibration frequency of the vibratory roller are appeared in the frequency analysis as the ground stiffness increases by the progress of the compaction. "Turbulence factor" is defined by using this property. The formula for computation of the turbulence factor (Ft) is shown in equation (1).

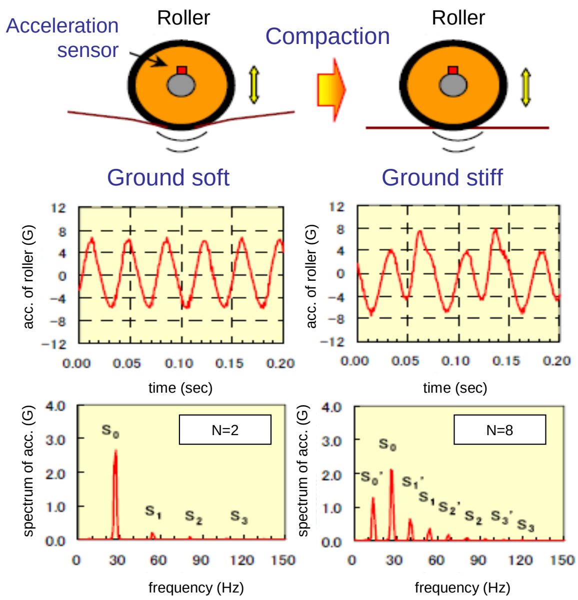


Figure1: Example of waveform and spectrum of acceleration

$$Ft = \frac{\dfrac{\sum_{i=1}^{3} S_i + \sum_{i=1}^{3} S_i'}{S_0 + S_0'}}{F/(m_1 + m_2)g} \tag{1}$$

where,

S_i, S_i' : spectrum of acceleration (G)

F : vibromotive force (kN)

m_i : mass(kg)

g : gravitational acceleration(m/s^2)

Ground elasticity E can be calculated by using, analyzing the numerical calculation model shown in Figure2, and using equation (2). E value obtained by this theoretical formula is assumed to be E_{roller}.

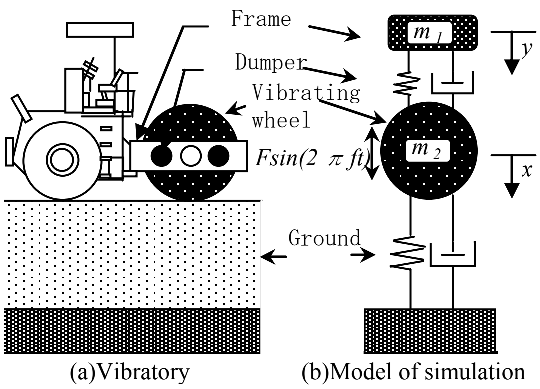


Figure2: Model of vibratory roller

$$E = \frac{2 \cdot (1-\nu^2)}{B \cdot \pi} \cdot \frac{\left(\frac{4}{3} Ft + 1\right)^2 \cdot (2\pi f)^2 \cdot m_2}{1 - 0.32\alpha + \sqrt{0.1024\alpha^2 - 1.64\alpha + 1}} \tag{2}$$

$$\alpha = 1 - \left(\frac{F}{(m_1 + m_2)}\right)^2$$

where,
v : Poisson's ratio
B : width of wheel (m)
f : frequency (Hz)

2.2 Field Test

In this study, it dug up the original ground, the 600mm subgrade was made from crushed sand , a 150mm subbase course was made from recycled crushed stone (top size 40mm), a 100mm base course was made from crushed stone (top size 30mm), a 50mm surface course was made from dense grade asphalt mixture and the pavement was constructed as shown in figure3.

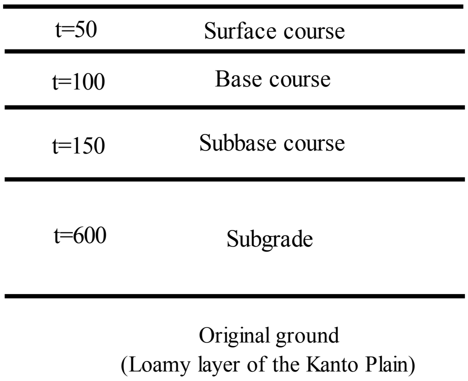
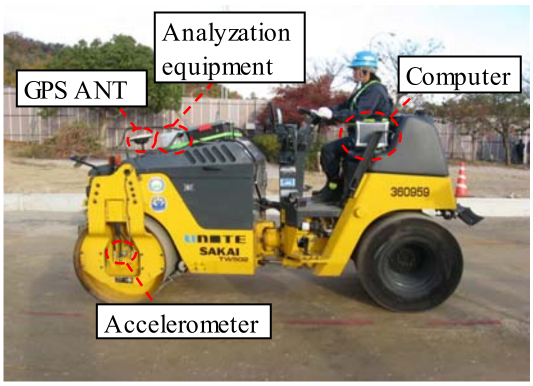


Figure3: Pavement for field test

The vibratory roller is 4tonne combined roller shown in the photograph1, and the one generally used by the paving work in Japan. The accelerometer was installed on the axle on the iron wheel of the roller, and the acceleration response was measured.



Photograph1: Vibratory roller

Figure4 shows the relation between number of compaction and E_{roller} (Data shows three mean values.). E_{roller} tends to increase with number of compaction on each layer. E_{roller} tends to increase with construction stage without surface course. The asphalt surface layer is remarkable to increase, and seems to have received the influence of the viscosity of asphalt by the reduction in temperature remarkably.

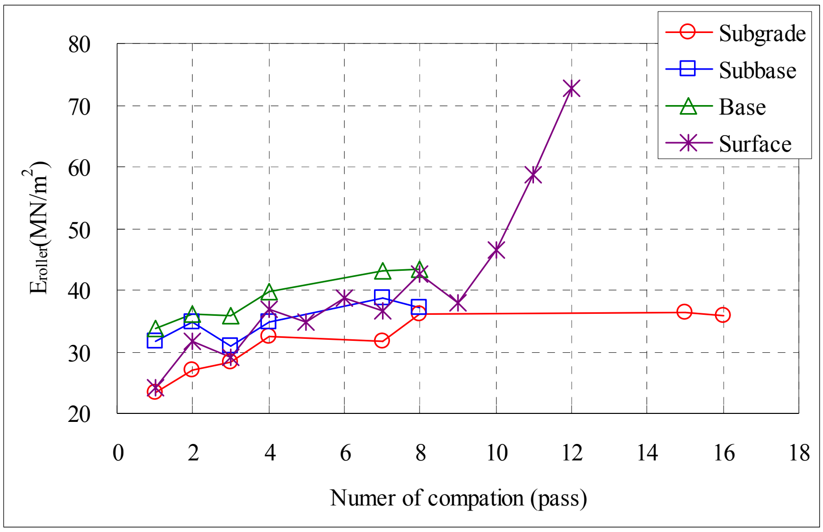


Figure4: Number of compaction vs. E_{roller}

Table1 shows Eroller at last compaction of the subgrade, the subbase course, the base course, and surface 8 passes and 12 passes.

Table1: E_{roller}

	E_{roller} (MN/m^2)
Subgrade	36.0
Subbase	37.1
Base	43.3
Surface(N=8)	42.6
Surface(N=12)	72.8

The degree of compaction and the water content of the each layer by the field density examination result are shown in Table2 and the degree of compaction in the cutout core on the surface is also shown.

Table2: Degree of compaction

	Degree of compaction(%)	Water content(%)
Subgrade	97.7	5.2
Subbase	97.6	4.3
Base	97.2	4.5
Surface	98.2	—

3 RESILIENT MODULUS OF PAVEMENT MATERIALS

The materials used by the field test were examined the resilient modulus at the same conditions of field test.

3.1 Resilient Modulus of Subgrade, Subbase and Base Course Materials

The test pieces were made by the degree of compaction and the water content of the site that had been shown in Table-2, and examined by triaxial compression test equipment. Figure 5 shows the results of the resilient modulus tests.

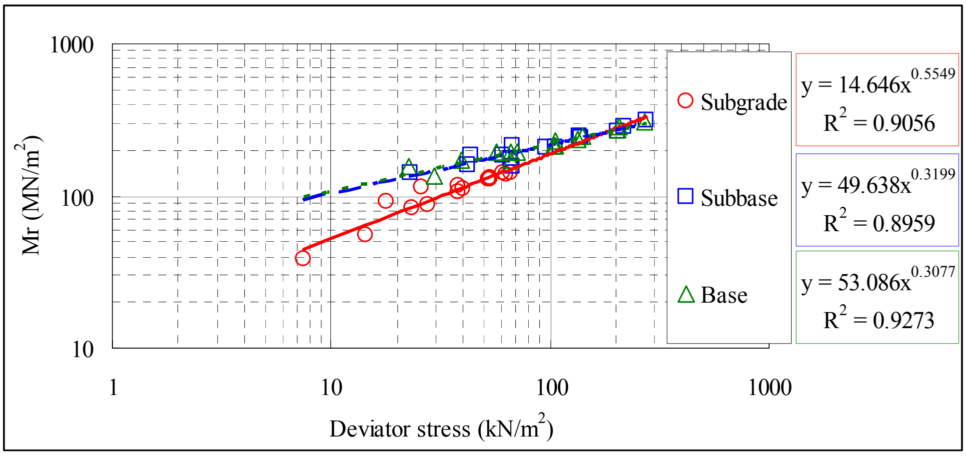


Figure5: Resilient modulus of subgrade, subbase and base course materials

3.2 Resilient Modulus of Surface Course Material

Resilient modulus of asphalt concrete at cold temperature was examined by indirect tension test with the core from the actual field. Figure6 shows the result of the core resilient modulus.

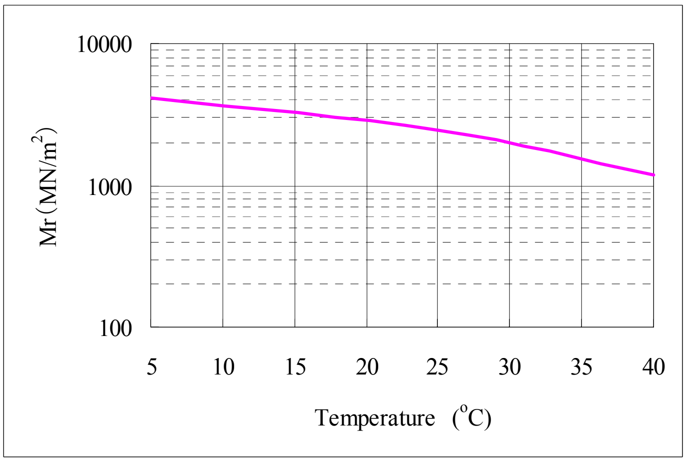


Figure6: Resilient modulus of asphalt concrete

Resilient modulus of asphalt mixture at hot temperature was examined by triaxial compression test equipment. However, the test equipment can not work at hot temperature. So, motor oil and glycerin were used for binders in stead of hot asphalt. Their viscosity at normal temperature is same as the viscosity of asphalt at hot temperature. Figure7 shows the comparison of viscosity.

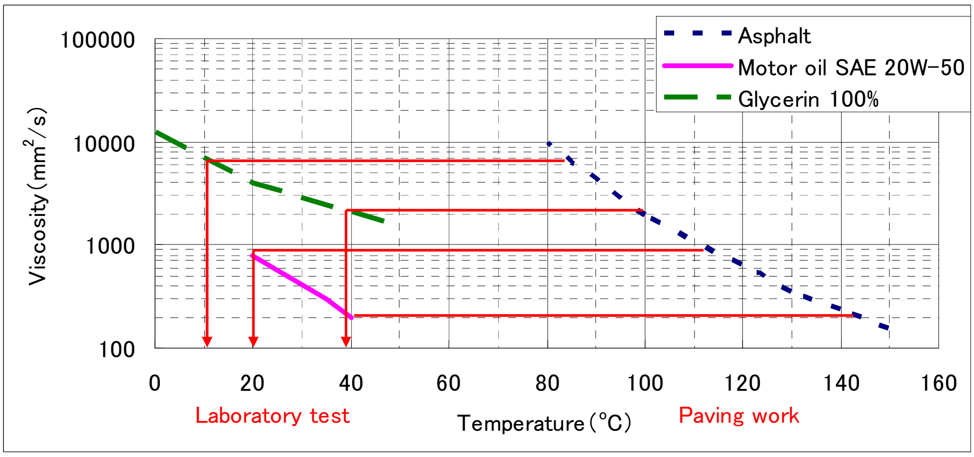


Figure7: Viscosity of binder

145°C and 115°C asphalt viscosities are same as 40°C and 20°C motor oil viscosities.100°C and 85°C asphalt viscosities are same as 40°C and 10°C glycerin. The test specimens were made in order to change the degree of compaction. Figure8 shows the results of resilient modulus of asphalt mixture at 145°C simulation. The degree of compaction affects the resilient modulus.

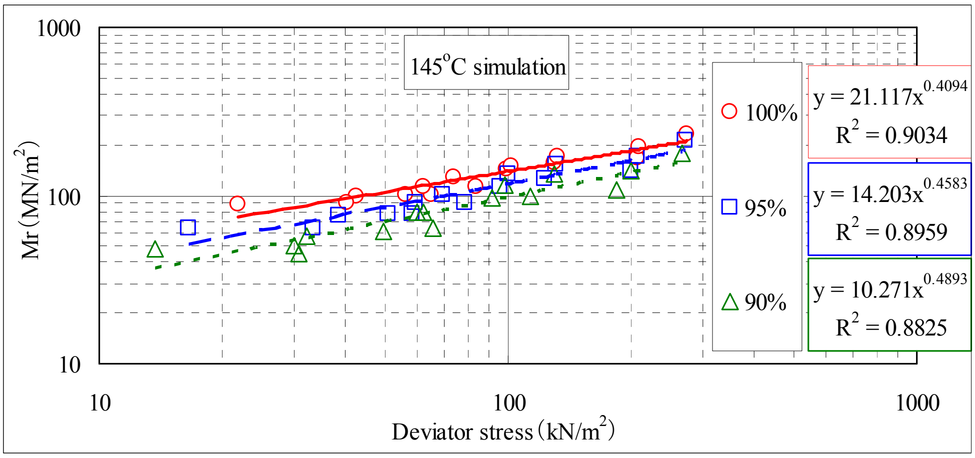


Figure8: Resilient modulus of asphalt mixture at 145°C simulation

Figure9 shows the results of resilient modulus of asphalt mixture at 115°C simulation. Figure9 is similar to Figure8.

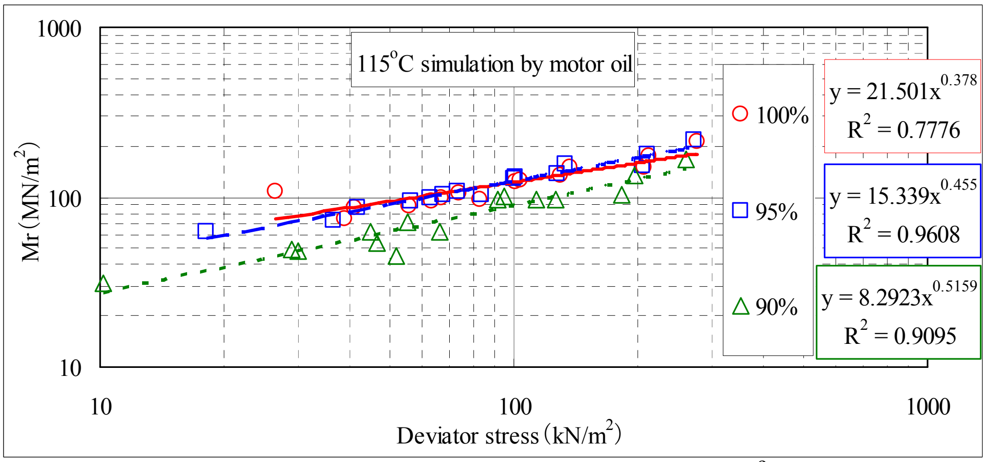


Figure9: Resilient modulus of asphalt mixture at 115°C simulation

Figure10 shows the results of resilient modulus of asphalt mixture at 100% of degree of compaction. From Figure8 to Figure 10, resilient moduli of asphalt mixture at more than 100°C are almost same values.

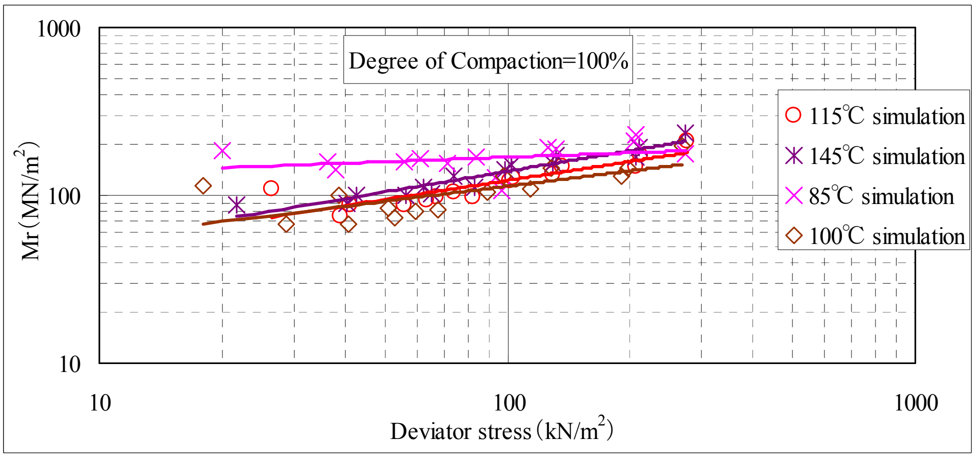


Figure10: Resilient modulus of asphalt mixture at hot temperature simulation

Table3 shows the resilient modulus of each material tested by field test conditions. The resilient modulus is shown by the equation of deviator stress (σ_d).

Table3: Resilient modulus of pavement materials

	Mr(MN/m^2)	Remarks
Subgrade	$Mr=14.646\sigma_d^{0.5549}$	Figure5
Subbase	$Mr=49.638\sigma_d^{0.3199}$	Figure5
Base	$Mr=53.086\sigma_d^{0.3077}$	Figure5
Surface(95%,115℃)	$Mr=15.339\sigma_d^{0.455}$	Figure9
Surface(98%,38℃)	1,358	Figure6

4 QUALLITY CONTROL MEYHOD BY E_{roller}

The theoretical pavement design method sets the modulus and the Poisson's ratio of the pavement materials, calculates the fatigue fracture, and decides the pavement thickness. Therefore, it is thought that E_{roller} as the ground elasticity is reasonable for the execution management of the pavement construction designed by the theoretical method. Then, the quality control method using the relation between E_{roller} and resilient modulus of the pavement materials was devised.

4.1 Elastic Modulus of Compaction Plane

E_{roller} shows the elastic modulus of compaction plane on the ground. Therefore, the elastic modulus on the surface is necessary to use it for the quality control. Theoretical average elastic modulus (E_h) in the multi-layer structure can be calculated by equation (3). E_{roller} should be corresponding to E_h.

$$E_h = \left(\frac{H_1 E_1^{1/3} + H_2 E_2^{1/3} + \cdots + H_n E_n^{1/3}}{H_1 + H_2 + \cdots + H_n} \right)^3 \tag{3}$$

where,
E_h : average elastic modulus (MN/m^2)
E_n : elastic modulus of n layer (MN/m^2)
H_n : thickness of n layer (m)

4.2 Elastic Modulus of Each Layer

For calculating E_h, elastic modulus of each layer is needed. In this study, resilient modulus is used for elastic modulus of each layer. However, the value of resilient modulus changes by the stress conditions. Then, the stress conditions of pavement were calculated by the Boussinesq theory. Figure11 shows the conceptual diagram of Boussinesq theory. Stress can be calculated by equation (4), (5), (6).

$$\sigma_z = \frac{3Pz^3}{2\pi R^5} \tag{4}$$

$$\sigma_r = -\frac{P}{2\pi R^2}\left[-\frac{3r^2 z}{R^3} + \frac{(1-2\nu)R}{R+z} \right] \tag{5}$$

$$\sigma_t = -\frac{(1-2\nu)P}{2\pi R^2}\left[\frac{z}{R} - \frac{R}{R+z} \right] \tag{6}$$

where,
σ_z, σ_r, σ_t : Stress (see Figure11)
P : Load (see Figure11)
R, r, z : Distance (see Figure11)
v : Poison's ratio

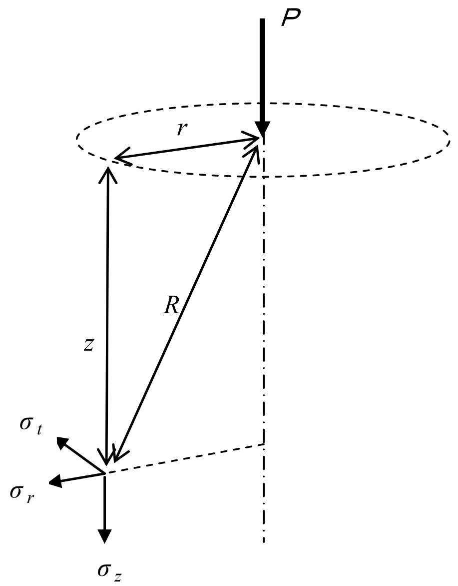


Figure11: Boussinesq theory

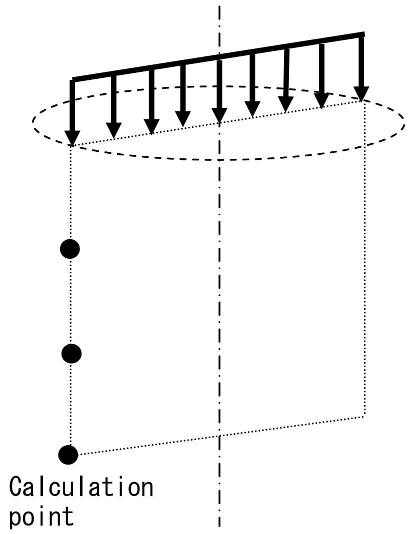


Figure12: Calculation point

In this study, the stress was calculated as a line load that showed the load by roller in Figure12.

And the deviator stress (σ_d) was calculated by (σ_z-σ_r). However, the stress occurred by vibratory roller load is not clear. Then, the calculated σ_d was modified, 0.4 was multiplied to the calculated σ_d for the subgrade and 0.2 was multiplied to the calculated σ_d for multi layers. Table4 shows calculation point z, deviator stress, Mr and E_h.

Table4: Calculation of Mr and E_h

Plane	Material	Z (cm)	σ_d (kN/m^2)		Mr (MN/m^2)	h (cm)	E_h (MN/m^2)
			Calculated	Modified			
Subgrade	Subgrade	60	10.0	4.0	31.6	60	31.6
Subbase	Subbase	15	39.0	7.8	95.8	15	33.7
	Subgrade	60	10.1	2.0	21.5	45	
Base	Base	10	61.5	12.3	114.9	10	43.3
	Subbase	25	22.5	4.5	80.3	15	
	Subgrade	60	10.1	2.0	21.5	35	
Surface 95%,115°C	Surface	5	134.5	26.9	66.4	5	45.1
	Base	15	39.0	7.8	99.9	10	
	Subbase	30	19.0	3.8	76.1	15	
	Subgrade	60	10.1	2.0	21.5	30	
Surface 98%,38°C	Surface	-	-	-	1,358	5	71.3
	Base	15	39.0	7.8	99.9	10	
	Subbase	30	19.0	3.8	76.1	15	
	Subgrade	60	10.1	2.0	21.5	30	

4.3 Comparison of E_{roller} and E_h

Modified σ_d was input to the equation in Table3. Then, calculated resilient modulus was input to equation (3) for theoretical average elastic modulus. Figure13 shows the relation of calculated E_h and E_{roller}. E_h is almost equal to E_{roller}.

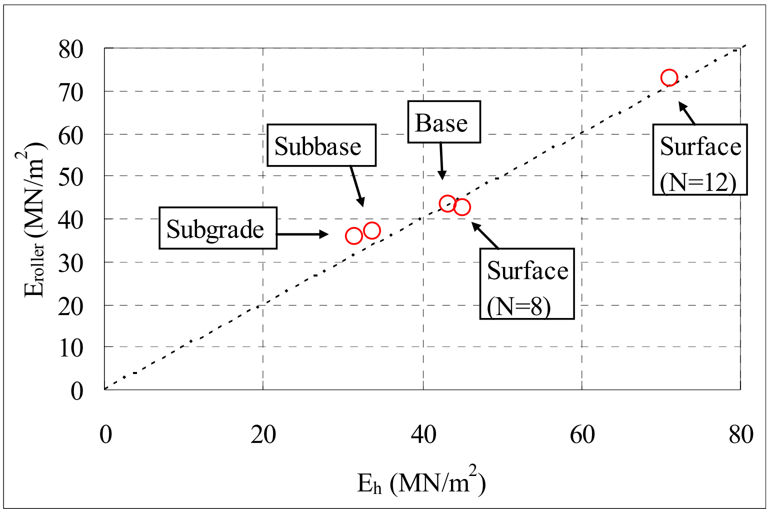


Figure13: E_h vs. E_{roller}

5 CONCLUSIONS

In this study, the quality control method of the paving work that used the acceleration response of the vibratory roller was devised. The stress obtained from the Boussinesq theory should be calculated for stress condition of roller loading. The calculated deviator stress should be modified for calculating resilient modulus of each layer. The resilient modulus of each layer should be combined for average elastic modulus (E_h). E_h will be value for the quality control. E_h and E_{roller} have the correlation, so that E_{roller} can be used for quality control on real time at all compaction area in effectively.

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