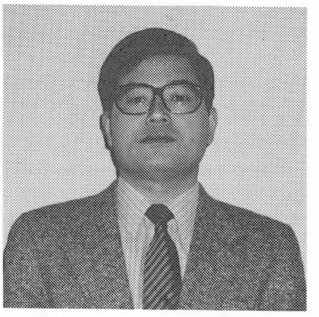
CONCRETE LIBRARY OF JSCE NO. 11. JUNE 1988

FUNDAMENTAL EXPERIMENTS ON COMPACTION OF EXTREMELY STIFF CONSISTENCY CONCRETE BY SURFACE VIBRATOR

(Reprint from Transaction of JSCE, No.384/V-7, 1987)





Makoto KAGAYA Hiroshi TOKUDA Makoto KAWAKAMI

SYNOPSIS

The compaction mechanism was examined based on the vertical movements of each constituent material which were found by mix analysis test results of concrete in prismatic specimen during the vibration process. Both water cement ratio W/C and air content α were pointed out as the important internal composition factors influencing on mechanical properties, and the relation between a parameter (W/C+k α) and compressive strength was obtained. Furthermore, since the compaction degree could be evaluated by the parameter, this was applicable to compaction control as a quality characteristic. This was designated as compaction factor CF, and relations between CF and compacting conditions such as vibrator weight, vibrating frequency, amplitude and specimen size were examined.

M.Kagaya is a research associate, Department of Civil Engineering, Akita University, Akita, Japan, where he received his M.Eng. in 1975. He is engaged in experimental study on the vibrating compaction. He is a member of JSCE, JCI and ACI.

H. Tokuda is a professor, Department of Civil Engineering, Akita University. He received his Dr. Eng. from Hokkaido University, Sapporo, Hokkaido, in 1973 and has published numerous papers on thermal properties and other properties of concrete. Dr. Tokuda is a member of JSCE, JSMS, JCI and ACI.

M. Kawakami is an associate professor, Department of Civil Engineering, Akita University. He received his Dr. Eng. from Hokkaido University in 1974. He is a member of ACI committee 548, Polymers in Concrete, JSCE and JCI.

---

1. INTRODUCTION

Recently Roller Compacted Dam(RCD) construction method has been used to construct gravity dams[1]. In this method extremely stiff consistency and lean mix concrete is used and compacted by vibratory roller.

The test data[2]-[4]considered on the materials, mix design and construction method and the results[5][6] on the compressive strength test of cores sampled from site have been reported. The reports[7]-[12] point out some unclarified problems such as compaction mechanism, the causes of the heterogeneity of compressive strength distribution in the height direction of one lift and the relationship between surface vibrator characteristics and operation efficiency.

Shimazu et al.[13] stated that the increase in amplitude of the vibrator had positive effect on the compaction, and the correlations between compaction energy and compressive strength and unit weight of the concrete were observed. Nakauchi et al.[14] reported that the correlation between compaction energy and amount of concrete surface settlement was observed and the latter value could be an index of compaction effect. Although these results give valuable suggestions to the compaction character of this concrete, above mentioned problems are not clarified satisfactorily.

In order to make clear these problems in this study, the variation degree of constituent materials in each layer of prismatic specimen was measured by mix analysis test during the compaction process. From this result, the compaction mechanism was examined based on the vertical movements of each constituent material. As the variation influences on the mechanical properties, both water cement ratio W/C and air content a were pointed out as the important internal composition factors, and the relation between a parameter ($W/C+k \cdot a$) and compressive strength was obtained. Furthermore, since the compaction degree could be evaluated by the parameter, this was applicable to compaction control as a quality characteristic. The relations between this parameter and compaction conditions such as vibrator weight, vibrating frequency, amplitude and specimen size were examined. Thin mortar layer is placed on a hardened lift surface before spreading the regular RCD mixture by bulldozer and the mixture is compacted by vibratory roller in the practical case. In this study, the mixture was compacted immediately after placing into prismatic mould, and the effects of thin mortar layer and the preceding compaction due to bulldozer were not considered. However, it seems that the results of this study must be basic data to make clear above mentioned problems on RCD construction method.

2. EXPERIMENTAL OUTLINE

(1) Materials and Mix Proportions

Normal portland cement(NPC), moderate heat portland cement contained 30% fly ash(FAC), air entraining agent(AEA), and water reducing agent(WRA) were used. The principal gradients of each agent were natural regionate and lignino-sulphonic acid respectively. River sand(RS), river gravel(RG), crushed sand(CS) and crushed stone(CG) were used. Table 1 shows the physical properties of these aggregates.

Table 1 Physical Properties of Aggregates.

Kinds of Aggregate	Specific Gravity	Water Absorption (%)	Fineness Modulus F.M.
River Sand (RS)	2.54	2.71	2.61
Crushed Sand (CS)	2.57	2.67	2.62
River Gravel (RG)	2.56	3.30	7.28
Crushed Stone (CG)	2.59	2.16	7.35

Table 2 shows the mix proportions and

mechanical properties at the age of 28days. Mix No.1 and 2 concretes were designed referred to the reference[4]. First, the VC value and watercement ratio were decided as 20 5 seconds and 80% respectively following to the practical data, and the appropriate sand percentage was assumed and the unit water content was decided based on the VC value of the concrete with containing the constant cement content and changing the water content. Furthermore, the VC value test was carried out changing the sand percentage with constant unit water and cement content, and the sand percentage with the minimum VC value was used. Mix No.3 is the wet-screended concrete by the 40mm sieve, which was inner one in T dam. NPC, RS and RG were used in Mix No.1 and 2 and AEA was added tothe latter Mix. FAC, CS, CG and WRA were used in Mix No.3.

(2) Product of Test Specimen

Table 3 shows the type of specimen. Symbol S, P-1~3, and L show the standard specimen, small sized prismatic specimen with different height and large sized specimen. The samples for mix analysis test and the core specimens for mechanical properties were sampled from specimen P and L respectively as mentioned later. The forced mixing type mixer was used and its capacity volume was 50ℓ. The mixing time was 90 seconds after charging all materials.

The specimen S was compacted by vibrating rammer with frequency of 50Hz, amplitude of 0.25 cm and weight of 35 kg in accordance with the reference[4]. The specimen P and L were compacted in one layer by the surface vibrator of variable capacity type. The characters of the vibrator is shown in Fig.1 and table 4 and the appearance is shown in photo 1. The frequency N can be

Table 2 Mix Proportions and Mechanical Properties of Concrete.

Mix No.	Gmax (mm)	VC Value (sec)	Air Content (%)	W/(C+F) (%)	F/(C+F) (%)	s/a (%)	Unit Weight (kg/m^3)					Mechanical Properties (kgf/cm^2)		
							W	C | F / C+F	S	G	Ad-mix-ture	σc	σt	E
1	40	20±5	1.5±0.5	79.8	0	33.0	130	163 | 0 / 163	687	1361	——	136	15.3	2.14×10^5
2	40	20±5	5±0.5	79.9	0	33.0	115	144 | 0 / 144	679	1346	0.101	103	12.8	1.87×10^5
3	40	20±5	1.5±0.5	73.0	30	46.2	135	130 | 55 / 185	932	1096	0.463	135	20.0	1.98×10^5

Table 3 Kinds of Specimen.

	Specimen	Shape and Size
S	Standard Specimen	φ 15×30cm
P-1	Small Prismatic Specimen	15×15×25cm
P-2	Small Prismatic Specimen	15×15×33cm
P-3	Small Prismatic Specimen	15×15×40cm
L	Large Specimen	75×75×33cm

Table 4 Characteristic Ranges of Surface Vibrator.

Weight of Head(kgf)	38∿98
Frequency (Hz)	0∿75
Amplitude (cm)	0∿0.48
Centrifugal Force(kgf)	0∿560
Compaction Plate (cm)	14.5×14.5

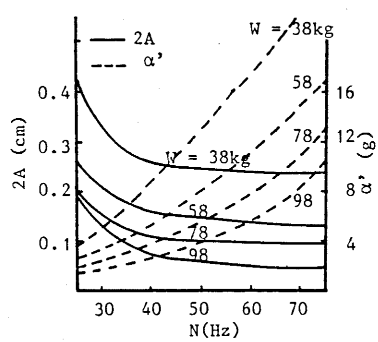


Fig.1 Characteristics of Surface Vibrator.

changed by inverter, the amplitude 2A by adjustment of angular of eccentric and the weight W by setting some weights with 2.5 kg per unit on the vibrator. N, 2A and acceleration were measured by indicator through acceleration transducer setting on the vibrator. Table 5 shows the compaction conditions. The vibrating characters in this table were decided based on those of the surface vibrator, and the range of frequency and the amplitude correspond to the character of vibratory roller practically used in RCD construction method.

The surface vibrator was moved methodically in the compaction of specimen L as shown in Fig.2. For example, if the vibrating time is 5 seconds in each position, the compaction time in the corner area(7.5x7.5cm) is 5 seconds, that in wall side area(7.5x60cm) is 10 seconds and that in another portion(60x60cm) is 20 seconds. The specimen L was compacted by the condition so that the vibrating time per unit area in another portion is the same as the case of the specimen P-2.

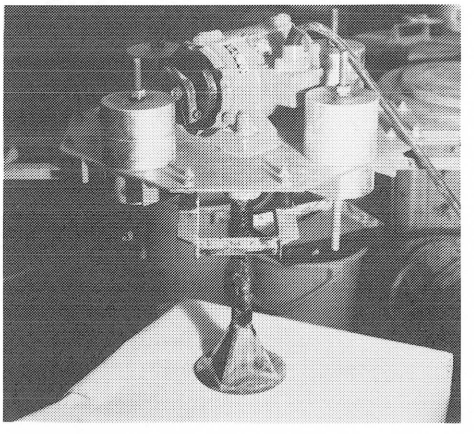


Photo 1 Surface Vibrator.

(3) Mix Analysis Test[15]

In order to measure the mix proportion in the each position of compacted specimen, two specimens were manufactured in the cases of P-1~3 and

Table 5 Vibrating Compaction Conditions.

No.	Vibrating Compaction Time (sec)	Weight W (kgf)	Frequency N (Hz)	Amplitude 2A (cm)	Layer Thickness H(cm)	Specimen Size
I	15,60,120,180,300	38	50	0.18	25	P-1
II	180	38,58,78	50	0.12	25	
III	90	38	25,50,75	0.18	25	
IV	90	38	50	0.15,0.20,0.25	25	
V	30,90,180	38	75	0.18	25,33,40	P-1,2,3
VI	15,60,180	38	50	0.25	33	P-2,L

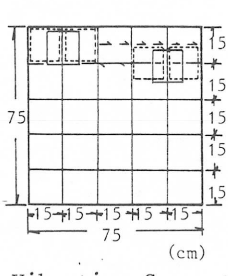


Fig.2 Vibrating Compaction of Specimen L.

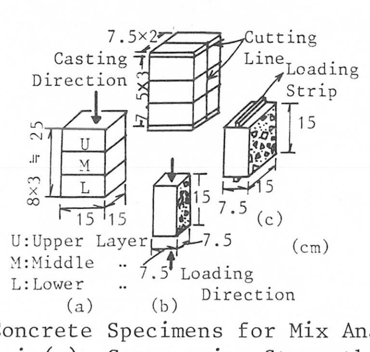


Fig.3 Concrete Specimens for Mix Analysis(a), Compressive Strength and Modulus of Elastisity Test(b) and Tensile Strength Test(c).

L. One was used to measure the unit content of each constituent material and another to the air content. Fig.3(a) shows specimen P-1 as an example. The concrete samples with about 15x15cm section and 8 cm layer-height were picked from upper, middle and lower layer in the specimen and then a small amount of mortar about 50 gr, was obtained by wet sieving using 5 mm sieve. The mortar was dehydrated by high frequency heating and the dried sample was dissolved in hydrochloric acid and the solution was tittrated with sodium hidroxide. This permitted determination of water cement ratio. Fine and coarse aggregate contents in the concrete samples were determined after washing of concrete sample using 0.088 and 5 mm sieve. The undisturbed samples were picked from the other test specimen to measure the air content from the positions corresponding to those used for wash analysis. Subsequently the sample was placed in the containner of Washington air meter filled with water. The amount of overflow water was measured to obtain the volume of the sample. Then the sample was stirred and air bubbles were removed. The reduction of the water level in the containner showed the absolute volume of air void in the sample. BY these procedures the mix proportion of the sample picked from each layer was determined. In the case of P-2 and 3, the same manner was used as P-1, and in the large sized specimen L the samples were taken out from center and wall side portion of the specimen, and the vertical distribution of internal composition was measured by mix analysis test.

(4) Mechanical Properties Test

Two specimens were manufactured for each P-1~3 and L, and one was used for measuring compressive strength and modulus of elastisity and another for tensile strength. The prismatic specimens were used to measure the variation in the mechanical properties of concrete in the vertical direction. Specimens were cut in 7.5 cm height from upper, middle and lower layer and two prismaticspecimens 7.5x7.5x15 cm were prepared for compressive strength and elastic modulus test as shown in Fig.3(b). Elastic modulus was measured by a wire strain gauge, and splitting test was conducted using 1x1x15 cm steel strips to measure the tensile strength as shown in Fig.3(c). Unit volume weight was measured by the weight and volume of specimen. In the case of P-2,and 3, the same manner was used as the case of P-1 and in the large sized specimen L, 10cm diameter cores were drilled from center and wall side portion of the specimen and each core was cut in 10cm height. The cutting and drilling were carried out at the age of 26 days and the tests were done at the age of 28 days after standard moist curing.

It should be cared that the section size of the specimen 7.5x7.5cm for compressive strength test was too small in relation to maximum size of coarse aggregate 40mm and the size effect influenced on the test value. However, preliminary test of this type of concrete showed the negligible size effect. The principle of the equation for splitting tensile strength calculation must be used for a circle section and line load, but steel strips were set on 7.5x15 cm section of specimen and loaded in this study. Suffice it to say that the measurement value is the reference data.

3. INVESTIGATION OF COMPACTION MECHANISM

In this chapter, first, the variation condition of constituent material in each layer of the specimen during compaction process is made clear by mix analysis test. Secondly, the movement trends of each constituent material in the vertical direction are grasped and some considerations on compaction mechanism are carried out based on these trends.

(1) Variation of Internal Composition During Compaction Process

Fig.4 shows the relationship between vibrating time and air content, water cement ratio and unit content ratios of internal constituent materials, such as water, cement, fine aggregate and coarse aggregate in each layer of specimen P-1 as an example. Mix No.2 concrete was placed into prismatic mould and compacted by compaction condition No.I. The unit content ratio is evaluated by the ratio of unit content of a material in each layer to that in specified mix.

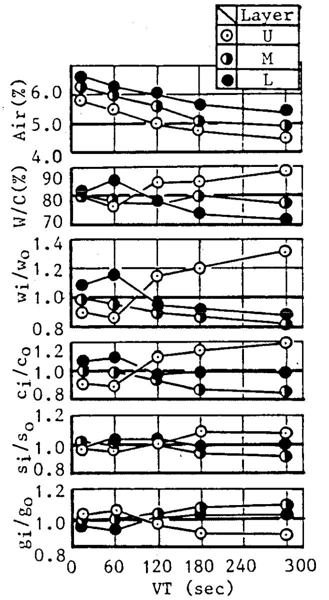


Fig.4 Variation of Composition in Each Layer with Change of Vibrating Time VT.

The air content in each layer decreases with increase in vibrating time, and the content in lower layer is about 1% higher than that in upper layer at each vibrating time. Water cement ratio in upper layer increases and that in lower layer decreases with increase in vibrating time. However, water cement ratio in lower layer is higher than that in upper layer up to about 90 seconds, and after this time the reversed trend can be observed and the difference between both ratios increases with the time. The water cement ratio in middle layer lies between the ratios in upper and lower layer. The variation trends of unit water content ratio and unit cement content ratio with vibrating time are almost similar. These ratios in upper layer decrease and those in lower layer increase up to about 60 seconds, and after this time increase rapidly in upper layer and decrease in lower layer up to about 90 seconds. Then the difference between both ratios increases with vibrating time. These ratios in middle layer show almost the same variation trend as those in lower layer, and the ratios become the minimum after 90 seconds.

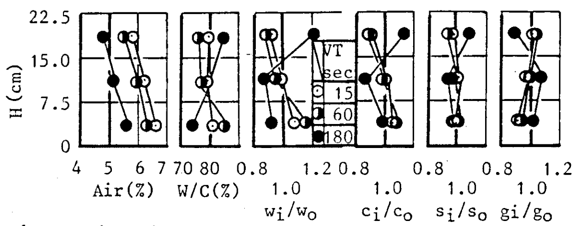


Fig.5 Distributions of Constituent Materials in the Vertical Direction.

The variation trend of unit fine aggregate content ratio with vibrating time is almost similar to the cases of water and cement, but the reverse trend can be observed in that of unit coarse aggregate content ratio. The variation ranges of unit content ratios of both aggregates are about from 0.9 to 1.1 and the value is smaller than those of another constituent materials.

Fig.5 shows the vertical distribution trends of air content, water cement ratio, and unit content ratios of internal constituent materials at each vibrating time. The air content increases downward at each vibrating time and the content in each layer decreases with vibrating time. Water cement ratio increases downward at the time of 15 and 60 seconds and decreases downward at the time of 180 seconds. The unit water content ratio and unit cement content ratio increase downward at the time of 15 and 60 seconds, and the ratios in upper layer is the highest and those in lower and middle layer in the order of their magnitude at the time of 180 seconds.

The vertical distribution trend of unit fine aggregate content ratio is almost the same as the cases of water and cement. The unit coarse aggregate content ratio decreases slightly downward at the time of 15 and 60 seconds, and this trend changes to increase downward at the time of 180 seconds.

(2) Considerations on Compaction Mechanism

Photo 2 shows the side view of specimen P-1 at the compaction time of 15,60 and 180 seconds. The honeycomb caused by unsatisfactory compaction can be observed on the lower half part of specimen at the time of 15 seconds and only on the bottom part at the time of 60 seconds, but no one can be observed at the time of 180 seconds. From this result, it can be turned out that the compaction effect of surface vibrator propagates from surface to lower part and the compaction time to obtain satisfactory compaction degree exists in the range of 60 to 180 seconds.

The qualitative considerations were carried out about compaction mechanism based on time dependent variation and vertical distribution of composition shown in Fig. 4 and 5. The air content in upper layer is higher than that in lower layer at each vibrating stage, and each content decreases gradually with compaction time. This is caused by the propagation of compaction effect from upper to lower layer. First of all, since the surface layer is changed to relatively dense, it is difficult to dissipate air bubbles passing through the dense layer, and some of them remain under the layer. As the thickness of the dense layer increases with vibrating time, dissipation of air bubbles under this layer is still difficult and the lower the layer the more the air content.

The movement of water can be observed conspicuously during compaction. The water moves downward remarkably at early compaction stage, after this time the moving direction changes to upward and then is proceeding gradually. This is explained as follows. In the early compaction stage, as the compaction degree of medium and bottom layer remained unsatisfactory and porous, the pressed water in upper dense layer due to compaction flows downward passing through the medium layer to the bottom easily. When the compaction effect reaches to the bottom layer, the water stayed there is pressed and moves upward. Further successive compaction cannot move it remarkably because of high compaction degree as a whole. Therefore, the water moves upward gradually in this stage. It is observed that the movement of cement is almost similar to that of the water. This means that cement particles are transported by upward or downward flow of water. The water and cement particles, that is cement paste, flow all together, and a portion of water is segregated from cement paste with high water cement ratio by compaction force. As the water is easy to flow for its low viscosity, the movement is more active than that of cement.

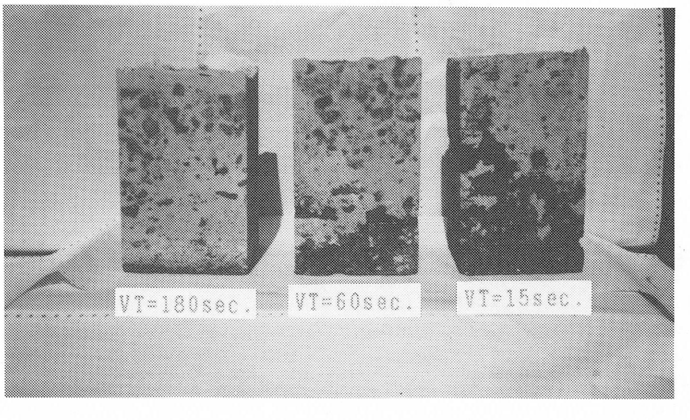


Photo 2 Side View of Specimen P-1.

In case of fine aggregate, the similar movement with the case of cement paste can be observed, but the degree is lower than the paste. This means that fine aggregate particles are transported by upward or downward flow of cement paste.

On the other hand, the reversed movement to the cases of cement paste and fine aggregate can be observed in case of coarse aggregate. The unit content of coarse aggregate increases with decrease in cement paste content in upper layer and decreases with the increase in cement paste in lower layer during the early compaction stage. Therefore, the coarse aggregate moves upward apparently. Subsequently, the coarse aggregate particles settle slightly with the vibrating time and cement paste or mortar part in concrete are replaced by coarse aggregate particles. The coarse aggregate content decreases in upper layer and increases in lower layer. The water moves downward rapidly during early compaction stage and then changes to move upward. It is considered that the motions is changed by the settlement of coarse aggregate particles.

As above mentioned, the closely relation can be observed between the behaviors of water, cement, fine aggregate and coarse aggregate during compaction. However, air bubbles move upward always independently of the behaviors of other materials.

4. EVALUATION OF COMPACTION DEGREE

First of all, effect of vibrating time on mechanical properties was made to clear. The next, with due regard to compressive strength which is the most important property, the consideration on the relationship between the internal composition and compressive strength was carried out. Furthermore, the compaction factor CF which is a measure of compaction degree was suggested.

(1) Relationship Between Vibrating Compaction Time And Mechanical Properties

Fig.6 shows the relationship between vibrating time and compressive strength, tensile strength, modulus of elasticity and unit volume weight in each layer of prismatic specimen P-1 used concrete Mix No.2. The compaction condition was No.I. The horizontal bold lines show the values measured from standard specimen.

Compressive strength, tensile strength and modulus of elasticity in upper layer are higher than those in middle and lower layer at the time of 15 seconds. These values in each layer increase with vibrating time and the differences between these values decrease. The values reach the maximum at about 120 to 180 seconds, after this time they turn to decrease and those in upper layer come to be lower than those in middle and lower layer. Unit volume weight in upper layer is higher than those in middle and lower layer up to about 180 seconds and the difference between the values in these layers decreases with the time. After this time the value in upper layer decreases slightly and those in middle and lower layer show increasing trends.

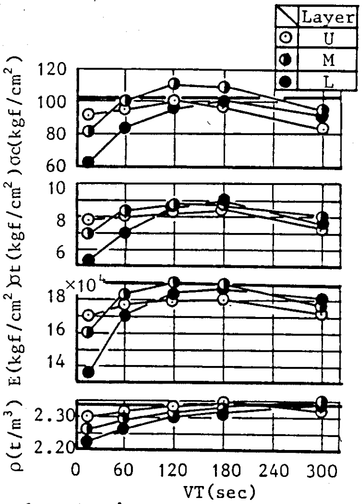


Fig.6 Relations between Vibrating Time VT and Mechanical Properties in Each Layer.

There are some different points between this experiment and practical construction such as mix proportions and construction conditions. Although the exact comparison between them cannot be done, the vibrating time corresponding to practical energy by vibratory roller is about 60 to 120 seconds. It can be judged to attain to the satisfactory compaction degree from Fig.6.

Fig.7 shows the vertical distribution trends of compressive strength, tensile strength, modulus of elasticity and unit volume weight at each vibrating time. Compressive strength, tensile strength and modulus of elasticity decrease downward at the time of 15 seconds and these values in middle layer are higher than those in upper and lower at the time of 60 and 180 seconds. Unit volume weight decreases downward at each vibrating time. Although the variation degrees of these values in upper layer are very small, the lower the layer the higher these values for the vibrating time ranged from 15 to 180 seconds.

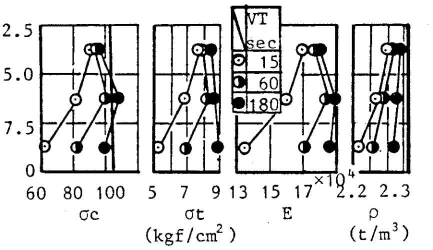


Fig.7 Distributions of Mechanical Properties in the Vertlcal Direction.

These phenomena are resulted from the fact that compaction effect propagates from upper part to lower part of the specimen. Namely, in the initial stage of vibrating compaction the unit volume weight in surface layer is higher than those in middle and lower layer, and air void content increases downward. Therefore, the upper the layer, the higher the mechanical properties. The cause of small variation of mechanical properties in upper layer at the range of vibrating time from 15 to 180 seconds is that the compaction degree has be already attained to near the peak value. The decreasing trends of mechanical properties in each layer beyond the time of 120 to 180 seconds are caused by higher water cement ratio in upper layer and less cement paste content and more air void content in lower layer as shown in Fig.4. The reason why the compressive strength in middle layer come to be the highest beyond the time of 60 seconds is not clear, but it seem to closely relate to the internal composition. The decreasing trend of unit volume weight in upper layer beyond the time of 180 seconds is caused by the subsidence of coarse aggregate particles replacing the mortar.

It was carried out to examine the relations between compressive strength and tensile strength, and modulus of elasticity of concrete Mix No.1 and 2 in each layer of prismatic specimen compacted by conditions I to V . The increase in tensile strength and modulus of elasticity with increase in compressive strength could be observed with somewhat scattering. Since the both properties can be estimated by compressive strength to some degree, the following considerations on experimental results are made on the basis of the compressive strength and the relation between the strength and internal composition is proved.

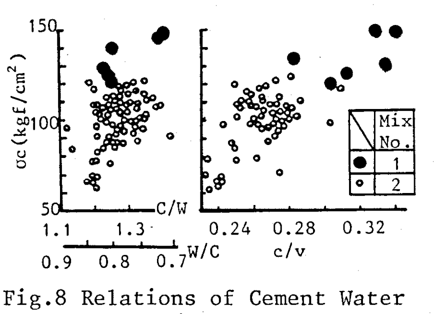


Fig.8 Relations of Cement Water Ratio C/W and Cement Void Ratio c/v versus Compressive Strength σc.

(2) Effective Factors Influenced on Compressive Strength

The generally used rules giving the

relation between internal composition and compressive strength are cement water ratio theory and cement void ratio theory. Fig.8 shows the relation between cement water ratio or cement void ratio and compressive strength measured in each layer as mentioned above section. The correlation coefficient of each relation was 0.38 and 0.48 respectively, and the close relations between them can not be recognized from these results.

The unit volume weight has been used as compaction control factor in the construction field. As observed in Fig.6 this is correlative with the strength in a certain degree up to the time of 120 to 180 seconds, but the correlation cannot be observed beyond this time. Therefore, it can be thought that the estimation of compressive strength from the unit volume weight is not available during excessive compaction stage.

In order to obtain the higher precise relation, the constituent material changed remarkably during compaction should be chosen as the factor influenced on the strength. The variation ranges of the unit content ratio of air, water, cement, fine aggregate and coarse aggregate are about 0.9 to 1.3, 0.8 to 1.3, 0.8 to 1.2, 0.9 to 1.1 and 0.9 to 1.1 respectively as shown in Fig.4 and the ranges of formers three are among them relatively large. Fig.9 shows the relationship between water cement ratio and unit content ratio of water and cement in each layer measured by mix analysis test. Certain correlations between these values can be observed. From these results,the air content and water cement ratio are chosen as the effective factors influenced on the strength.

(3) Evaluation Method of Compaction Degree

Popovics[16] suggested the strength equation modifying the Abrams' one in terms of the air content and water cement ratio

$$\sigma c = A/B^{(W/C)} \times 10^{-ra} \qquad (1)$$

where σc= compressive strength (kgf/cm^2), W/C= water cement ratio and a = air content (%). W/C and a are measured from fresh concrete samples. A and B are experimental parameters depending on air content, type of cement, age of testing, curing conditions, and other factors influenced on strength of concrete, and r is an experimental parameter that depends on the material in question.

The equation (1) can be written in the following form

$$\log\sigma c = \log A - \log B(W/C + r\cdot a/\log B) \qquad (2)$$

This means that the relation should be a straight line with -logB slope in the $\log\sigma_c$ versus $(W/C+r\cdot a/\log B)$ semi-log system of coordinates. Measured compressive strengths, air contents and water cement ratios in this study are substituted into equation (2) and following equation (3) is obtained.

$$\log\sigma c = 2.384 - 0.227(W/C + 0.168a) \qquad (3)$$

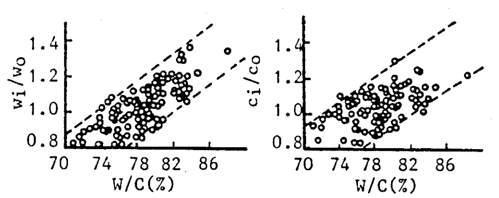


Fig.9 Relations of Unit Water Content Ratio wi/wo and Unit Cement content Ratio ci/co versus Water Cement Ratio W/C.

Fig.10 shows the relationship between

(W/C+0.168a) and σc. The strength increases with decrease in the term (W/C+0.168a). This means that the strength increases provided that both the water cement ratio and air content decrease at the same time or either of two decreases remarkably but another increases. The coefficient of correlation is -0.88 and this equation is more precise than the case of equation in terms of cement water ratio or cement void ratio.

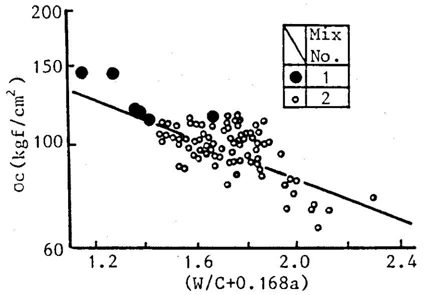


Fig.10 Relations between (W/C+0.168a) and Compressive Strength σc.

If the air content 5% and water cement ratio 0.799 in specified mix of concrete Mix No.2 are substituted into the term (W/C+0.168a), the value equals 1.639 and the strength equals 103kgf/cm^2 from equation (3). The strength corresponds to the average value measured by standard specimen. Therefore, if the term decreases with increase in vibrating time and reaches about 1.64, the compaction degree is judged to be sufficient. Consequently the compaction degree can be evaluated by the term and this is called compaction factor CF in this study.

Fig.11 shows the relationship between vibrating time and the factor CF, as an example. Concrete Mix No.2 and compaction condition I were used and this figure corresponds to the results shown in Fig.4 and 6. The factor CF in each layer decreases with vibrating time, and the lower layer the more the rate of decrement. The factor in upper layer is almost unchanged beyond the time of 60 seconds. On the other hand, the compressive strength reaches to the peak at the time of 120 to 180 seconds, and the strengths are about 95 to 110 kgf/cm^2 as shown in Fig.6. These values are more than 93 kgf/cm^2 which is lower limit value of 2σ control limit measured by standard specimen. This strength range corresponds to the factor CF of 1.65 to 1.8 in Fig.11. Thus, this factor range is available for compaction control to obtain the sufficient compaction all over the height.

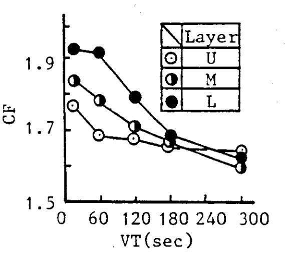


Fig.11 Relations between Vibrating Time VT and Compaction Factor CF.

Fig.12 shows the vertical distribution patterns of air content, water cement ratio, compressive strength and the factor CF. The compaction conditions are divided into 5 patterns. The pattern I shows the factor CF not attained to required value all-over the height and patterns II , III and IV shows the factor attained to the value in upper layer, upper and middle layer and all layers respectively. The pattern V shows the excessive compaction. From this figure, the variation trend of above mentioned four factors during compaction can be understood. If the vertical distribution of the factor CF in pattern IV is obtained in advance, the compaction condition can

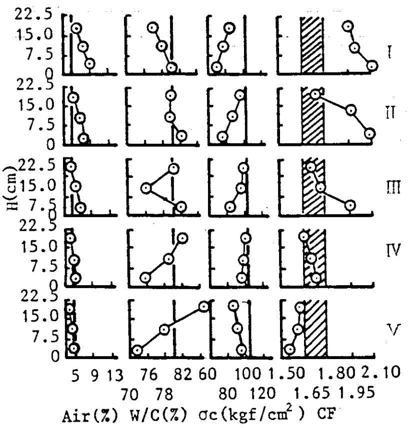


Fig.12 Vertical Distribution Patterns of Air Content, Water Cement Ratio W/C, Compressive Strength σc and Compaction Factor CF at Each Compaction Factor CF.

be controlled by measuring the factor in upperlayer.

5. RELATIONSHIP BETWEEN COMPACTION CONDITION AND COMPACTION DEGREE

In this chapter, the relationships between compaction degree and vibration characters such as vibrator weight, frequency and amplitude are investigated. Then, the influence of layer thickness on the compaction degree is clarified using different height specimens. Furthermore, the degree in large size specimen is compared with that in small one concerning the flowing condition of concrete during compaction.

(1) Relationship Between Vibration Character and Compaction Degree

The vibrator weight, frequency and amplitude are taken as vibration characters and the effects of these characters on compaction degree are investigated. Fig.13 shows the relationship between the factor CF and the weight, frequency and amplitude in each layer. The concrete Mix No.2 is compacted under the conditions of II , III and IV . The shaded portions in this figure are the range of sufficient compaction judged from the factor CF. The factor decreases with the increase in each character. The decrement rate of the factor with increase in frequency is the largest, and it is thought that sufficient compaction can be carried out by the proper selection of this character.

The vibration energy equation (4) [3] has been used to evaluate the effects of above three characters on compaction work all inclusively.

$$E = 2A(W + F/2)N \cdot t \cdot 1/S \qquad (4)$$

where E = vibration energy (kgf cm/cm^2), 2A = amplitude (cm), W = weightof vibrator (kgf), F = centrifugal force (kgf), N = frequency (Hz), t = vibrating time and S = surface area of compaction plate (cm^2). The centrifugal force F included in equation (4) is shown as following equation (5).

$$F = (2\pi N)^2 RM \qquad (5)$$

where M = mass of eccentric (kg), and R = eccentricity (cm). The energy E in equation (4) is theoretical energy transmitted on the unit surface area of concrete and the acceleration in equation (5) is proportional to the square of frequency and amplitude. The reduction of amplitude and frequency cannot be avoided by increase in the weight practically. In this case, the energy

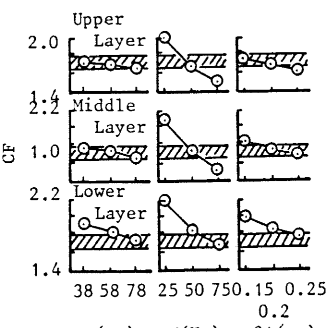


Fig.13 Effects of Vibrator Weight W, Vibrating Frequency N and Amplitude 2A on Compaction Factor CF.

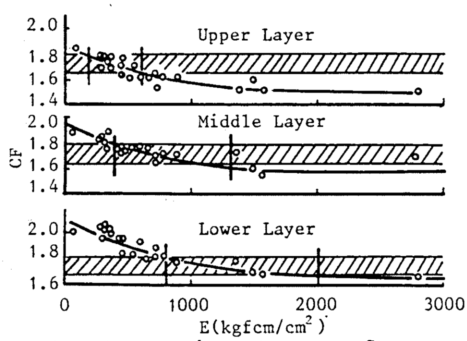


Fig.14 Relations between Compaction Energy E and Compaction Factor CF.

calculated by equation (4) gives a overestimated value. Then the centrifugal force F is not calculated by setting frequency and amplitude but by the measured acceleration α' (g) in order to obtain the correct energy possibly.

$$F = \alpha' M \qquad (5')$$

Fig.14 shows the relationship between the energy and the factor CF in each layer. The concrete Mix No.2 is compacted under the conditions I ~ IV . The energy is calculated from equations (4) and (5'). The shaded portions in this figure are the range of sufficient compaction. The energies within this range in upper, middle and lower layer are about 200~600, 400~1300 and 800~2000 $kgf \cdot cm/cm^2$ respectively. Thus, the minimum energy to obtain the sufficient compaction all over the placing height is about 800 $kgf\ cm/cm^2$. The energy can be obtained by combinations of vibration characters and vibrating time from equation (4). The best efficient combination should be chosen considering economics, field conditions and so on.

(2) Effect of Specimen Size on Compaction Degree

Above discussion is concerned with the case using specimen P-1. In this section the effects of the specimen height with the same sectional area and place area with the same specimen height on the compaction degree are investigated. Fig.15 shows the relationship between specimen height and the factor CF in upper and lower layer. The concrete Mix No.2 is placed into the mould to manufacture specimen P-1, 2 and 3 and compacted under the conditions V . The higher the specimen height, the higher the factor CF in each vibrating time and the rate of increment with the increase in height in lower layer is more than in upper layer. From this figure it is recognized that propagation of compaction effect to lower part is difficult with increase in height, but is easy in upper part comparatively. The almost of the factors in upper layer are smaller than the required value, but some of the factors in lower layer are higher than the value. It is thought that this disproportioned distribution of the compaction degree in the vertical direction is caused by inadequate combination of vibration characters.

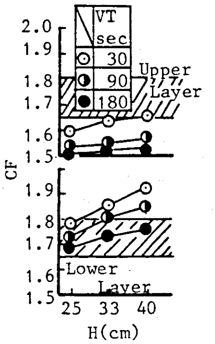


Fig.15 Relations between Specimen Height H and Compaction Factor CF.

The effect of placing area with constant height on compaction degree is investigated. The concrete Mix No.3 is placed into the mould to manufacture specimen P-2 and L and compacted under the condition. The compaction method of specimen L is shown in Fig.2.

Fig.16 shows the relationship between the compressive strengths of specimen P-2 and those of specimen L. The strengths in each layer of center portion and wall side portion in the specimen L are corresponded to those in the specimen P-2 and vibrating time and sampling portion are shown

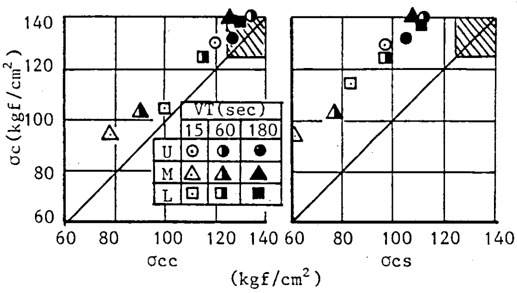


Fig.16 Comparisons between Compressive Strengths of Specimen P-2 and those of Specimen L(σc:P-2, σcc :Central Portion of L, σcs:Side Wall Portion of L).

by the symbol in the figure. The clearance between center of core section sampled from wall side portion and side sheathing is about 10 cm. The strengths of center and wall side portion in specimen L are about 10kgf/cm^2 and 30kgf/cm^2 lower than those in specimen P-2 respectively. These are resulted from the fact that in specimen P-2 mobility of the concrete due to compaction is restricted by both the mould wall and vibrator plate but in specimen L the compaction effect escapes from the concrete surface on which vibrator plate is not situated. From the mix analysis test result, the variation trends of internal composition during compaction are the same in both cases. However, the vibrating time when the cement paste moved downward turns to upward in specimen L is slightly longer than that in specimen P-2. Therefore, it is necessary to prolong the vibrating time to attain the sufficient compaction state in specimen L. The strength reduction in the wall side portion of specimen L is caused from uncomplete filling up of the voids by cement paste or mortar due to the shortening of the vibrating time.

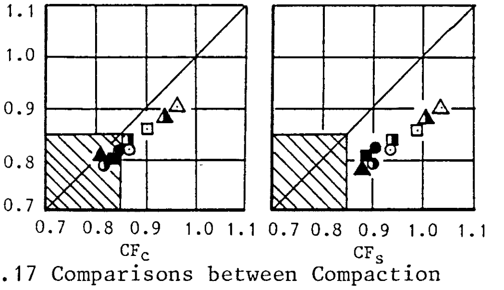


Fig.17 Comparisons between Compaction Factors of Specimen P-2 and those of Specimen L(CF:P-2, CFc:Central Portion of L, Cfs:Side Wall Portion of L).

Substituting the results of mix analysis and compressive strength test into equation(2), the following equation is obtained.

$$\log\sigma_c = 3.366-1.515(W/C+0.054a) \quad (6)$$

Fig.17 shows the relationship between the factors CF of specimen P-2 and those of specimen L calculated from the term $(W/C + 0.054a)$ in equation(6). The symbols are the same as Fig.16. The factor in specimen L are higher than those in specimen P-2. This trend is considerable in the wall side portion. These correspondences are similar to the results showed in Fig.16. From these results, it is necessary to prolong the vibrating time in specimen L to obtain the same compaction degree as that in specimen P-2.

As the specimen L compacted excessively is not manufactured, the lower limit value of 2σ control limit cannot be calculated. However, the lower limit strength of 2σ control limit measured in standard specimen, 122kgf/cm^2 is assumed to be target strength. Substituting this value into equation(6), the upper limit of the factor CF, 0.85 is obtained. The satisfied ranges of these values are shown in Fig.16 and 17.

6. CONCLUSIONS

As above mentioned, vibrating compaction mechanism, evaluation method of compaction degree and effects of compaction conditions on compaction degree of extremely stiff consistency and lean mixed concrete have been discussed. These are summarized as follows.

1) The compaction effect by surface vibrator is transmitted downward from surface layer. During this compaction process, the movements of water and cement paste can be observed conspicuously. That is to say, the cement paste moves downward quickly at initial stage and turns to move upward after a certain time and then gradual upward movement continues.

2) Fine aggregate particles are carried by upward or downward flow stated in 1). The degree of fine aggregate movement is less than that of water and cement.

3) Coarse aggregate movement during compaction process is a little and the movement direction is reverse to those of water, cement and fine aggregate. This means that the coarse aggregate moves and is replaced by water, cement paste or mortar.

4) From the results of 1),2) and 3), it is understood that water, cement, fine aggregate and coarse aggregate move with influencing on one another during compaction process and a certain compaction level is obtained. On the other hand, air bubbles move upward independently of these movements.

5) The close correlation between cement water ratio, cement void ratio and unit weight, and compressive strength can not be obtained. Both water cement ratio W/C and air content are pointed out as the important internal composition factors influencing on compressive strength and the strength equation formed by the parameter($W/C + k\alpha$) is shown.

6) The compaction degree can be evaluated by above mentioned parameter and the compaction control procedure using the parameter is shown.

7) The most efficient combination of vibration characters such as weight, frequency and amplitude should be chosen. The disproportioned distribution of compaction degree in the vertical direction often occurs in higher placing thickness provided among others unapt frequency is set.

8) Compaction of small sized specimen is easier than that of large sized specimen for the same vibrating time. Because in the former specimen mobility of concrete is restricted by the mould wall and vibrator plate but in the latter one compaction effect escapes from the concrete surface. The correspondence of the compaction degree between both specimens is shown.

ACKNOWLEDGMENTS

In carring out this research and producing the surface vibrator by way of trial, the authors received the guidance and assistance from K.Torii of The Tohoku Regional Construction Bureau, Ministry of Construction and Hayashi Vibrator Co, LTD. The authors would like to express our grateful thanks to their kind assistance. This research was supported by scientific research fund from the Ministry of Education.

REFERENCES

[1] T.Uesaka, K.Shioiri, " Progress of Compaction Method for Dam Concrete", Concrete Journal, Vol.23, No.7 1985

[2] Y.Nakahara, et al., " Studies on Roller Compacted Concrete (Part 1 5),Kajima Technical Research Report, No.26 29, 1978 1980

[3] Technology Research Centre for National Land Development : "Dam Construction by RCD Construction Method", 1981

[4] Technology Research Centre for National Land Development : "Technical Guide for RCD Construction Method", 1981

[5] A.Yamazumi, S.Kobayashi, "Extremely Stiff Consistency Concrete-Application for RCD Construction Method-", Construction Technique, Vol.36, No.12, 1981

[6] T.Fujisawa, "Quality Control of Concrete in Dam Construction", Concrete Journal, Vol.21, No.7, 1983

[7] T.Hirose, S.Shimizu, K.Takemura, "Research of The Dam Construction by Roller Compacted Dam Concrete", Proc. of JSCE, No.303, 1980

[8] Y.Negami, H.Shimada, T.Okumura, "RCD Concrete with 150mm of Maximum Size-Construction of Energy Dissipater Section in Shin Nakano Water Control Dam-", Cement and Concrete, No.420, 1982

[9] E.K.Schrader, "The First Concrete Gravity Dam Designed and Built for Roller Compacted Construction Methods", Concrete International, Vol.4 No.10, 1982

[10] T.Hirose, T.Yanagida, "Dam Construction in Japan, Burst of Growth Demands Speed, Economy", Concrete International, May 1984

[11] J.Harada, "Construction of Tamagawa Dam by RCD Construction Method", Cement and Concrete, No.457,1985

[12] Y.Aoyagi, "The Present Technique Developments and Future Problems of Roller Compacted Concrete", Civil Engineering for Electric Power, No.188, 1984

[13] A.Shimazu, et al. "Experiment on Compaction of RCD Concrete", Public Works Research Institute Ministry of Construction Report, No.1980, 1983

[14] H.Nakauchi, Y.Nakagawa, A.Shono, "Experimental Study on Compaction of RCD Concrete (Report No.1)", Technical Research Report of Hazama-Gumi, LTD. ,1981

[15] M.Kagaya, H.Tokuda, M.Kawakami, "Segregation Phenomena of Concrete with Various Chemical Admixtures due to Vibrating Compaction", Journal of the JSMS, Vol.32, No.353, 1983

[16] S.Popovics, "New Formulas for The Prediction of The Effect of Porosity on Concrete Strength", ACI Journal, Vol.82, No.2, 1985