The Compaction of Mortar and Concrete

—(Part 2) Effects of Compaction on the Properties of hardened Concrete of different Mixes—

H. Takahashi
S. Nakane

Summary

It is the aim of this report to present the result of experiments in the effect of compaction on the properties of hardened concrete for precast members. Four concrete mixes used in the tests were crushed stone concrete of dry consistency, artificial lightweight aggregate (ALA short for) concrete of dry consistency, crushed stone concrete of medium consistency and ALA concrete of medium consistency. The effects of compaction were estimated from the strength and specific gravity of hardened concrete.

Main subjects of the investigation were given as follows.

1). *Influence of frequency, acceleration and amplitude on the properties of compacted hardened concrete.*
2). *Effect of compacting time.*
3). *Effect of compaction methods.*
4). *Difference of compaction effect between concrete of dry consistency and medium consistency.*
5). *Difference of compaction effect between heavy concrete and lightweight concrete.*

In consequence we obtained following result. Namely, when acceleration was allowed to increase gradually, effect of compaction changed little untill acceleration came up to a certain point where compaction grew suddenly. But at greater acceleration compaction effect differed little from that point.

This phenomenon was considered to relate to liquefaction of fresh concrete. The criterion to liquefy the concrete mixture varied with its consistency, but had small concern with specific gravity of concrete.

As for frequency, it had not so much correlation to compaction effect as to viscosity described in (Part 1). This indicated that strength and specific gravity were less sensitive for frequency than viscosity. However, on concrete of medium consistency it was observed that extreme decrease of viscosity lead to decrease of strength by segregation.

As for other subjects, it was confirmed that compacting time more than 3 minutes contributed little to the growth of compaction, and that Shock Method was profitable for compaction of concrete from the point of economy.

1. INTRODUCTION

Empirically we have taken recognition of the benefit of concrete compaction, and recently the range of its application has been increasing in compliance with such new phenomena as the use of high-frequency vibrator, appearance of new compaction method, compaction of super-dry consistency concrete for precast members and compaction of high-density or lightweight concrete.

On the other hand, accurate specifications for the optimum compaction under those various circumstances have not always been established. So here in this report we tried to study the optimum compacting conditions of various concrete mixes which are used in manufacturing precast concrete members.

As Mori refered to the properties of vibrated fresh mixture in his report (Part 1), we dealt with the effect of compaction on the quality of hardened concrete in this report (Part 2).

2. APPARATUS AND EXPERIMENTAL PROCEDURE

The outline of experiments were as follows.

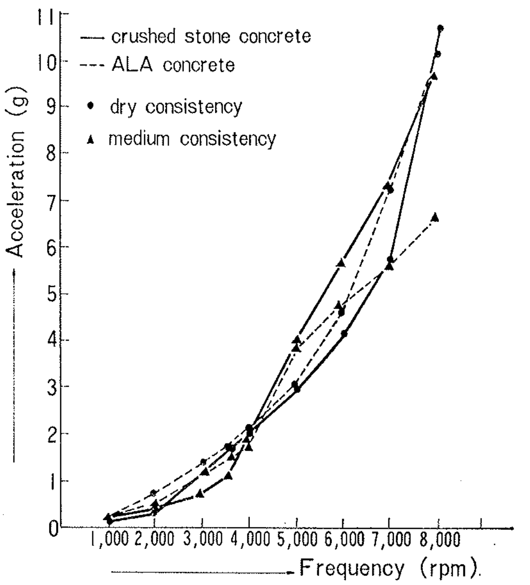

Fig-1. Performance curve of vibration table in compacting various concrete mixes

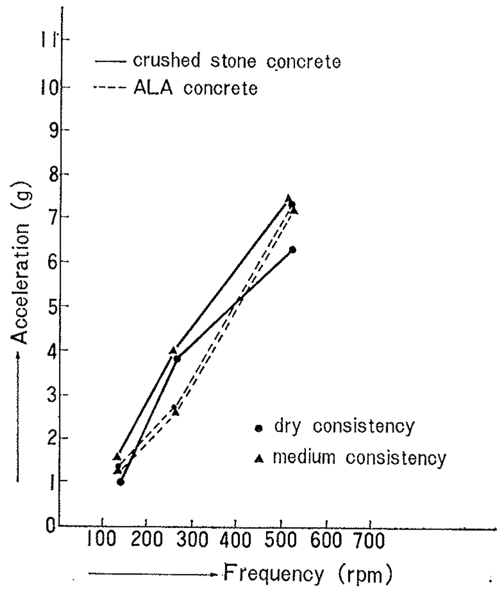

Fig-2. Performance curve of shock table in compacting various concrete mixes

Factors		Levels
Compaction method		Vibration, Shock
Compacting time (minute)		1, 3, 10
Frequency (rpm)	Vibration	1000, 2000, 2500, 3000, 4000, 6000, 8000
	Shock	130, 260, 520

Table-1. Experimental conditions in compacting concrete of dry consistency

Factors		Levels
Compaction method		Vibration, Shock
Compacting time (minute)		3, 10
Frequency (rpm)	Vibration	1000, 2000, 3000, 3600, 4000, 5000, 6000
	Shock	130, 260, 520

Table-2. Experimental conditions in compacting concrete of medium consistency

2.1. Compacting Apparatus

Compaction were carried out by Vibration Table and Shock Table. The former was manufactured for trial by YAMADA KIKAI KOGYO CO., LTD., and has the performance of changing frequency from 1000 r.p.m. to 9000 r.p.m. continuously (changing acceleration from 0.2G to 12G). The latter was also manufactured in particular for the test and its frequency is able to be selected at the option from 130, 260 and 520 r.p.m. step by step.

Fig. 1 and Fig. 2 show the performance curves of apparatus mounting test pieces of various concrete mixes. (cf. Photo 1 and 2)

2.2. Experimental Conditions in Compaction

Factors in compacting concrete were compaction method, compacting time and frequency as shown in Table 1 and 2. Acceleration and amplitude in compaction were to be decided homologously relate to the frequency. (cf. Fig. 1 and 2)

2.3. Materials

Gravels used in the tests were crushed gray-wacke sandstone from Chichibu (specific gravity 2.6) and a pelletized artificial lightweight aggregate on the market (apparent specific gravity in saturated surface dry condition 1.35). Crushed stone was used as a combination of 20–10mm size and 10–5mm size. Sand from the river Fuji (specific gravity 2.63 and fineness modulus 3.18) were used as fine aggregate. As cement and admixture, high-early-strength portland cement manufactured by ONODA CEMENT CO., LTD. and Pozolis 100N were used.

2.4. Concrete Mix

As the result of trial mixing, four concrete mixes shown in Table 3 were selected. Since the slump value of dry consistency concrete was zero cm, we represented its consistency by Vee-bee con-

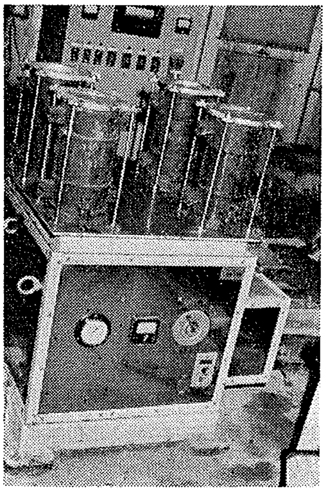

Photo-1. Vibration table

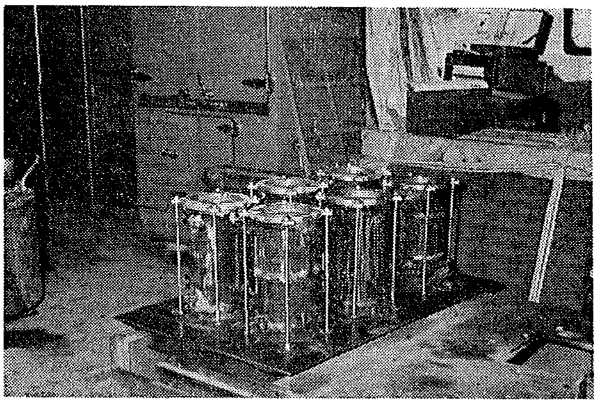

Photo-2. Shock table

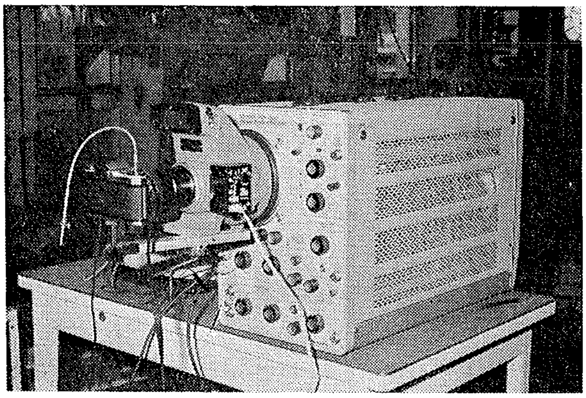

Photo-3. Synchroscope

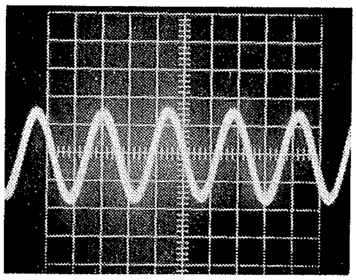

Photo-4. Wave shape of displacement in vibration method

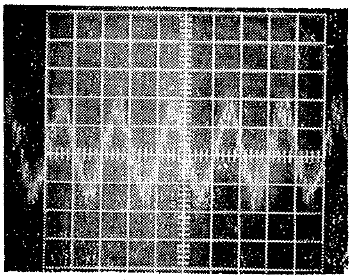

Photo-5. Wave shape of acceleration in vibration method

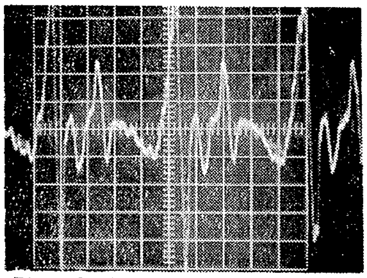

Photo-6. Wave shape of displacement in shock method

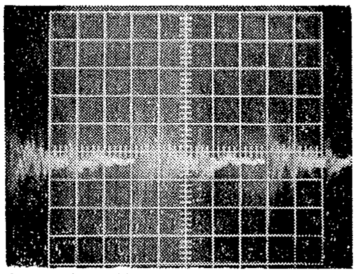

Photo-7. Wave shape of acceleration in shock method

	W/C	S/A	Water	Cement	Sand	Gravel (kg)		Admixture
	(%)	(%)	(kg)	(kg)	(kg)	20−10mm	10−5mm	Pozolis 100N(g)
• Crushed stone concrete of dry consistency	50	45	149	297	876	661	444	—
• Crushed stone concrete of medium consistency	50	43	185	370	766	630	423	—
• ALA concrete of dry consistency	44	39	140	320	782	666		640
• ALA concrete of medium consistency	44	41	168	383	743	587		770

Table-3. Mixing proportions per 1 m^3 (by weight) sistometer. The Vee-bee value of crushed stone concrete of dry consistency was 19.5 seconds and that of ALA concrete was 21.5 seconds.

The slump value of medium consistency was 5–8cm both in crushed stone concrete and in ALA concrete.

Mixing were carried out for just 3 minutes after three minutes dry mixing.

2.5. Test Piece

Test pieces were moulded in cylindrical shape of 15×30cm. Four pieces in Vibration method and six pieces in Shock method were compacted at the same time. Difference of position of location on the table surface was negligible on the effect of compaction.

Pouring of concrete milk into the cylinder was divided into halves. Each Pouring was followed by expedient compaction for 30 seconds and then compacting time was measured.

Tests on hardened concrete were carried out out after standard curing in water for 1, 7 and 28 days.

2.6. Measurement of Segregation

Since concrete of medium consistency had a tendency to be segregated by large acceleration, average segregation depth was measured with a special rule.

2.7. Estimation of Compaction

Though there are many methods for estimating compaction effect such as by ultrasonic test, by water permeability test, and by measurement of density (or specific gravity) and strength of concrete, we here in this tests took the method by measuring compressive strength and specific gravity. Well compacted high density concrete are considered to be related to high compressive strength concrete.

3. TEST RESULT

Prior to mentioning test result, it is necessary to confirm following matters.

That is, among factors taken up in the test, compaction method and compacting time are able to be treated as independent factors, but frequency is not formally to be treated as independent variable because it is confounded with the effect of acceleration and amplitude.

In this vibration apparatus acceleration and amplitude vary in accordance with its frequency as is so in case of any such apparatus. So, acceleration and amplitude also must not be treated as independent variables.

In Shock method, though maximum amplitude was fixed to 3 mm, the effect of frequency and acceleration were also confounded with each other.

In spite of this situation, as it is troublesome to present the results in graph or table, we dared treat them as if independent variables in this paragraph taking into consideration of the abovementioned.

The followings are the test result in respective concrete mix.

3.1. Compaction of crushed Stone Concrete of dry Consistency

Fig. 3 shows the effect of frequency on the compressive strength and specific gravity of hardened concrete.

In vibration method the strength and specific gravity increased suddenly at around 2500–3000 r.p.m. when frequency was allowed to increase gradually. At higher frequency, though there was a certain point decreasing compaction effect, as a whole, the compaction increased gradually until it attained maximum value at 8000 r.p.m.

In Shock method also the strength and the specific gravity increased gradually in accordance with increase of the frequency and they attained maximum value at 520 r.p.m.

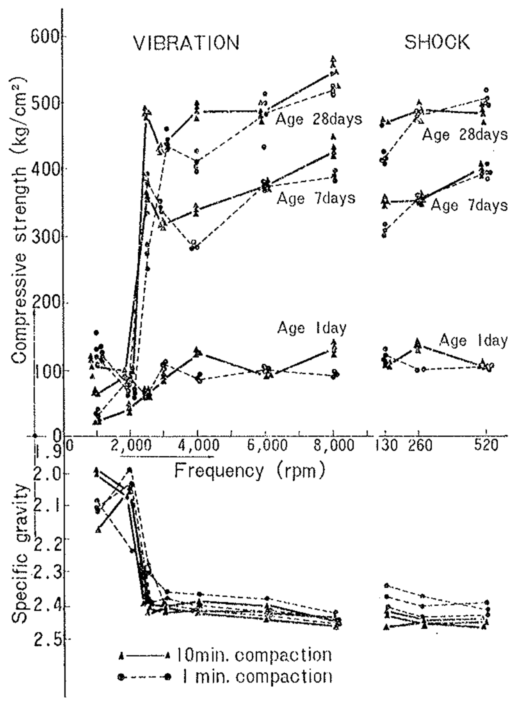

Fig-3. Assumed effect of frequency on the compressive strength and specific gravity of dry consistency crushed stone concrete

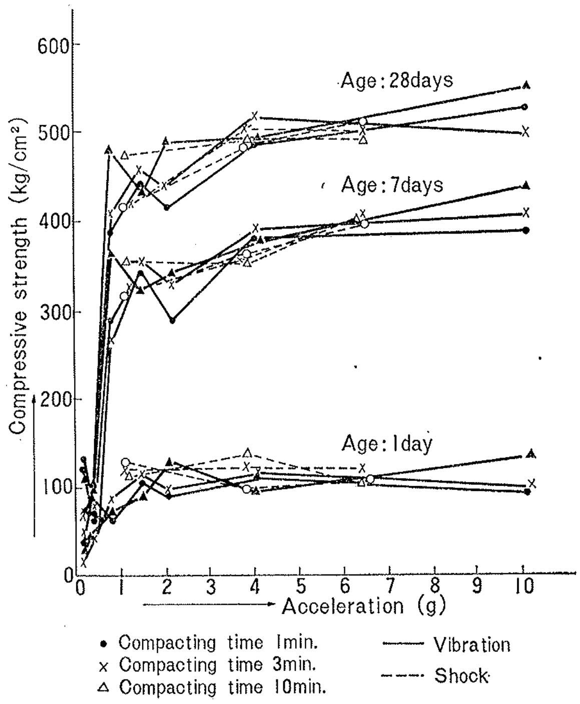

Fig-4. Relation between acceleration and strength on crushed stone concrete of dry consistency

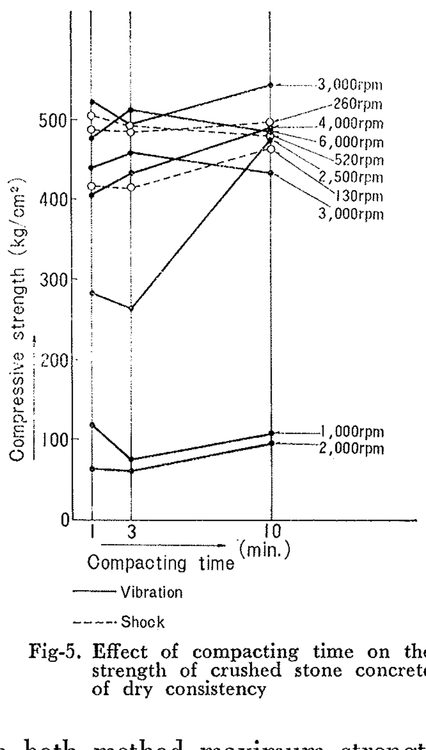

Fig-5. Effect of compacting time on the strength of crushed stone concrete of dry consistency

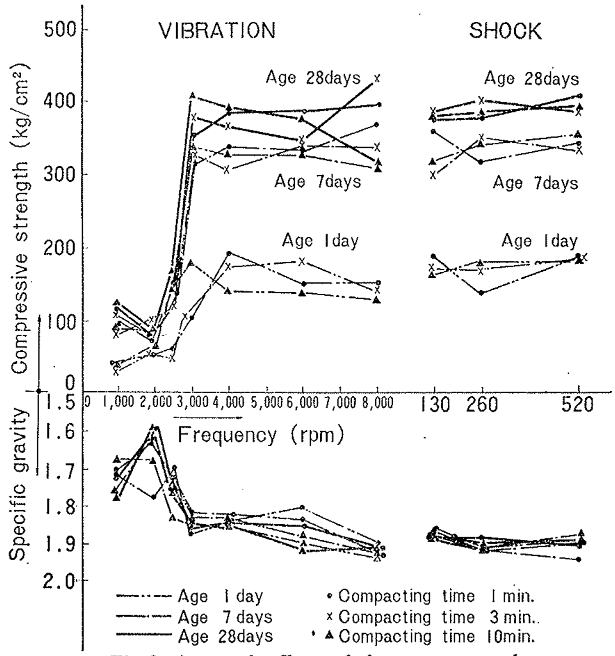

Fig-6. Assumed effect of frequency on the compressive strength and specific gravity of ALA concrete of dry consistency

In both method maximum strength and maximum specific gravity showed almost the same value. Maximum specific gravity 2.45 deserved that of most filled up concrete of air content zero percent.

It was the rough conclusion of the result that compacting conditions of more than 3000 r.p.m. in vibration (more than 1G) and more than 130 r.p.m. in Shock method (more than 1G) would lead to satisfactory compaction. But too large frequency and too large acceleration gave slight contribution to the increase of the compaction.

Maximum strength obtained was extremely larger than calculated strength (450 kg/cm^2 Non

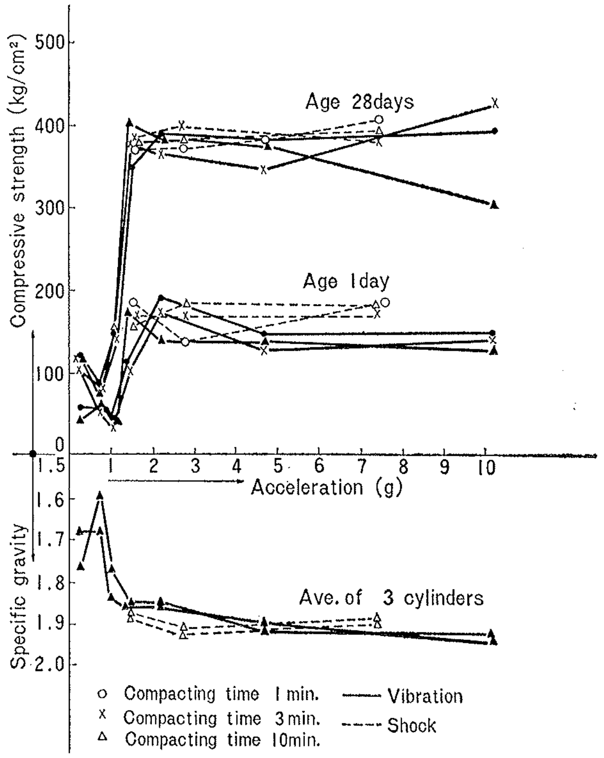

Fig-7. Relationship between acceleration and strength of ALA concrete of dry consistency

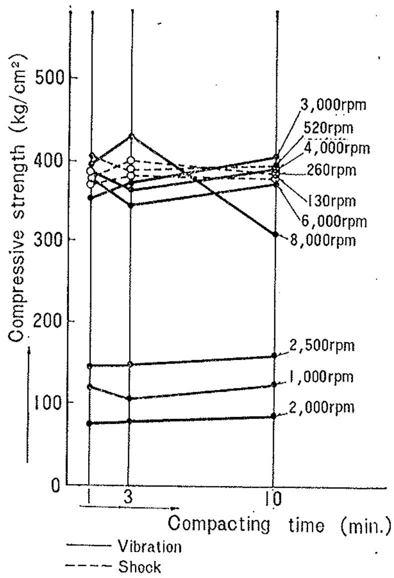

Fig-8. Effect of compacting time on ALA concrete of dry consistency

AE concrete) by the proposed formula of the Cement Association of Japan and the strength calculated by JASS 5 formula (350 kg/cm^2) according to the same water cement ratio 50%.

Fig. 4 shows the relation between acceleration and strength of hardened concrete. It is noticeable that both in vibration and shock method strength was identical at the same acceleration.

As Shock method is accompanied with free vibration, large compacting effect can be brought from small frequency.

As for compacting time there was a tendency as shown in Fig. 5, that the longer compacting time brought a little development of compaction.

Standard deviation of strength among test pieces compacted under the same compacting condition was very small.

Effect of compaction revealed little on the concrete of younger age, while it was excellent on the concrete of elder age.

3.2. Compaction of ALA Concrete of dry Consistency

Effect of frequency upon the properties of ALA concrete of dry consistency closely resembled that of crushed stone concrete of dry consistency as shown in Fig. 6, and compaction developed suddenly at around 3000 r.p.m. in vibration method. In Shock method still 130 r.p.m. was satisfactory frequency for compaction, and at larger frequency development of compaction was not recognized at all.

From the point of simple consideration, compacting condition of more than 3000 r.p.m. in vibration and more than 130 r.p.m. in shock method seemed satisfactory, but it is difficult to give the quantitative meaning to these numenical values as these frequencies involved the effect of acceleration and amplitude. Its meaning must be treated within the limits of qualitative one.

Calculating in accordance with JASS 5 at the same water cement ratio 44%, compressive strength of ALA concrete was presumed to be 305 kg/cm^2, and test result was far larger than it.

Effect of acceleration on the compressive strength and specific gravity of hardened concrete was shown in Fig. 7. Compaction behaviour of crushed stone concrete of dry consistency and ALA

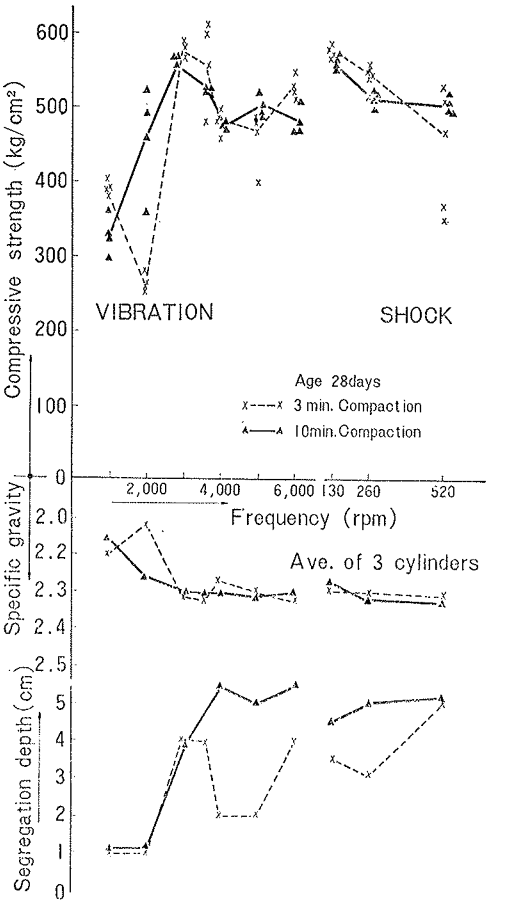

Fig-9. Assumed effect of frequency on the strength, specific gravity and segregation depth (crushed stone concrete of medium consistency)

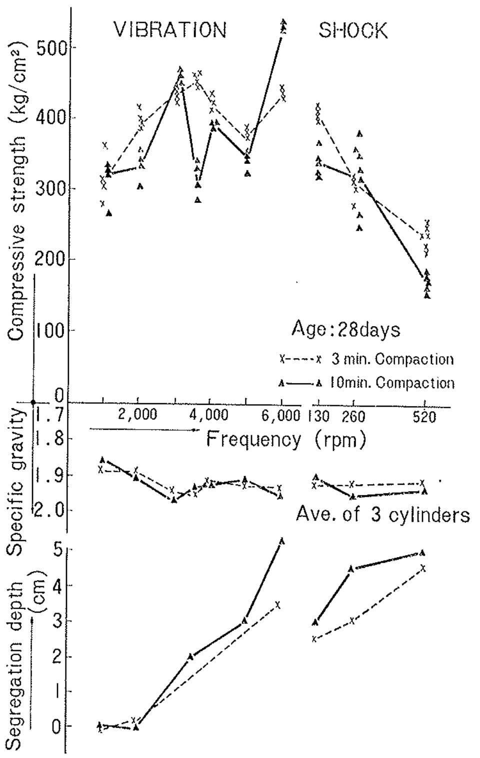

Fig-11. Assumed effect of frequency on the strength, specific gravity and segregation depth (ALA concrete of medium consistency)

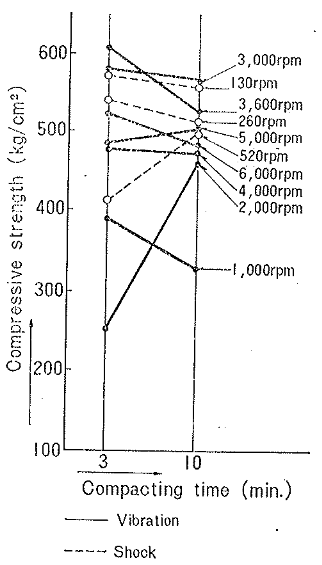

Fig-10. Effect of compacting time on crushed stone concrete of medium consistency

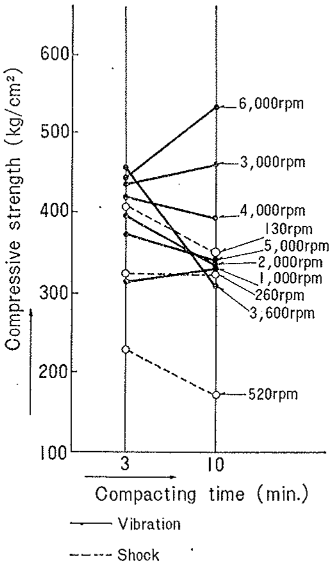

Fig-12. Effect of compacting time on ALA concrete of medium consistency

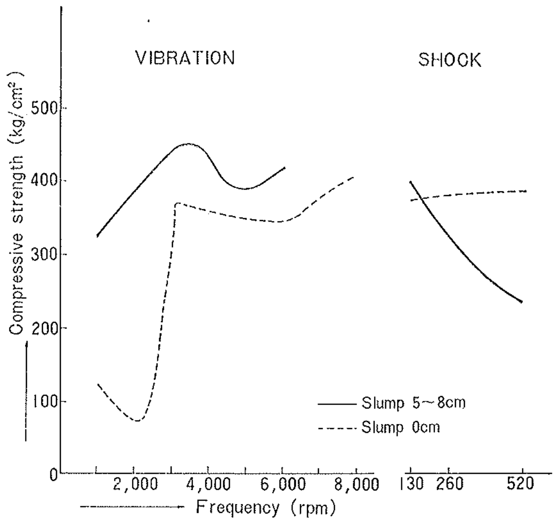

Fig-13. Compaction behaviour of ALA concrete of different consistency (water cement ratio 44%)

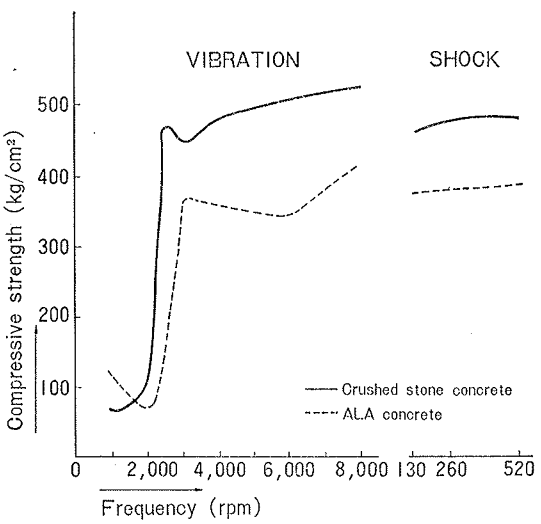

Fig-14. Compaction behaviour of concrete of the same dry consistency concrete of the same consistency seemed similar to each other, while those absolute value of strength differed owing to the difference of gravels.

This relates that compacting behaviour of concrete is affected so much by the consistency of mixed concrete. Almost the same compaction effect was made from the same acceleration without distinction of compaction method.

As shown in Fig. 8, it made little difference on the compaction effect whether compacting time was longer or not. Exceptionally in case of vibrating condition of 8000 r.p.m., 10 minutes vibration resulted in slight decrease of the compressive strength because segregation occurred as the result of overvibrating in low viscosity.

3.3. Compaction of crushed Stone Concrete of medium Consistency.

Fig. 9 shows the influence of frequency upon the compressive strength, specific gravity and segregation depth of compacted concrete.

In vibration method fairly well compaction was done still in 1000 r.p.m., and the more frequency increased the more strength and specific gravity developed until frequency came up to 3000 r.p.m. where compaction was best accomplished. At larger frequency than 3000 r.p.m. strength had a tendency to be on the decrease, and as a whole the curve formed a mountain shape having a peak at 3000 r.p.m.

In Shock method best compaction was done at 130 r.p.m. and at larger frequency strength decreased.

Maximum compressive strength in both method were almost identical and close to 600 kg/cm^2.

When frequency highly increased (acceleration also increased), viscosity of concrete decreased so excessively that gravel was inclined to precipitate having larger specific gravity in concrete matrix, and therefore depth of precipitation from the surface of cylinder was measured.

As the result, more than 4 cm of 30 cm height of cylinder was composed merely of mortar by compaction at higher frequency than 3000 r.p.m. in vibration and 130 r.p.m. in Shock method. Therefore, preceding decrease of strength seemed to be caused by precipitation of gravel.

Acceleration for optimum compaction of medium consistency concrete was within the limits of 1.0–1.5G and at larger acceleration segregation of concrete mix occurred.

Liquefaction happened at the acceleration of 0.5G on concrete of medium consistency.

As for compacting time, the longer it was at large frequency or acceleration, the more decrease of strength happened as shown in Fig. 10. As a whole it seemed better to limit the compaction time within 3 minutes.

Even if strength was decreasing owing to segregation of mix, specific gravity of concrete did not change at all. This indicated that the estimation of compaction should not be done merely from the point of density.

Compared with the strength of dry consistency concrete, the strength of crushed stone concrete of medium consistency was slightly larger in spite of the same water cement ratio 50%, because the amount of cement used was much more in medium consistency.

3.4. Compaction of ALA Concrete of medium Consistency

Fig. 11 shows the influence of frequency on the properties of compacted ALA concrete of medium consistency.

The outline of result in vibration method much resembled that of crushed stone concrete of medium consistency. The relationship between frequency and compressive strength drew a mountain-shape curve with its peak at 3000 r.p.m.. The curve was unstable compared with those of crushed stone concrete, and standard deviation of strength was larger.

In Shock method maximum strength was obtained at 130 r.p.m., but it was smaller than that obtained in vibration method. At higher frequency than 130 r.p.m. strength decreased to an extreme. This seemed to be caused by over-vibrating as described below.

Putting all these results together, compacting condition of 3000 r.p.m. in vibration method and of less frequency than 130 r.p.m. in Shock method seemed to be appropriate on compaction of the ALA concrete of medium consistency.

It was noteworthy that the range of optimum compacting condition became narrower than the other case because of excessive decrease of strength at higher frequency or acceleration.

When viscosity of concrete matrix became lower, artificial lightweight aggregate had an inclination to rise toward the surface of cylinder. As the thickness of segregation could not be determined from the surface, so segregation measured from broken face of cylinders after splitting test. At the frequency of 3000 r.p.m. in vibration method or 130 r.p.m. in Shock method the layer of mortar without gravel in the bottom of cylinder became 5 cm thick.

The upper layer which contained lots of lightweight aggregate in the result of segregation became weak in strength, because lightweight aggregate itself had comparatively small strength, and therefore concrete revealed large decrease of strength.

This inclination came into existence especially in Shock method. That phenomenon seemed to be caused by setting too excessive compacting condition in Shock method and did not indicate at all unsuitableness of the method itself. The high power of Shock method should rather be estimated from it.

The effect of compacting time was shown in Fig. 12. Strength of 10 minutes compaction was smaller than that of 3 minutes in the compaction of ALA concrete of medium consistency.

Compared with ALA concrete of dry consistency, maximum strength of ALA concrete of medium consistency was a little larger, but inferior strength also abounded among medium consistency concrete.

4. DISCUSSION

Comments on the test result were shown as follows in every investigated subject.

4.1. Effect of Frequency

Compacting behaviour in the function of frequency differed considerably between the concrete of dry consistency and medium consistency. Fig. 13–14 show the proto-type of the inclination.

But it was a question to what extent this inclination was caused by frequency alone. Mori referred to in Part 1 that with fixed acceleration, frequency did not affect much the compaction effect, and with frequency fixed, the viscosity of concrete decreased like an exponential function according to the increase of acceleration, and that with increase of frequency, viscosity of concrete had some extreme value considered to be caused by resonance.

Considering Mori's result and also the fact that frequency in this test was confounded with the effect of acceleration and amplitude, we inferred that the greater part of abovementioned inclination which had been treated as the effect of frequency was really caused by the effect of acceleration.

As the corroboration of the inference, it was addueed that regardless of frequency the same compaction effect was obtained from the same acceleration, and that on the material of large decrement like concrete, resonance did not occurred so remarkably as in case of rigid material.

The fact that compaction after liquefaction did not change with the increase of frequency in dry consistency concrete, made it difficult to explain compaction behaviour in connection with resonance.

However it seemed to be caused by frequency alone that compaction behaviour in vibrating method changed sharply at 3000 r.p.m. regardless of consistency and kinds of concrete. This phenomenon, corresponded to extreme value of viscosity as Mori mentioned. But it indicated the resonance of 15×30 cm cylinder and not the resonance of plain concrete. It was not concerned in consistency and specific gravity of interior concrete. Therefore it was difficult to give general meaning to 3000 r.p.m.

In practical vibration the utilization of resonance in vibration system containing weight of formwork and table is usually impossible because of the difference of the member size in each case. Without utilization of resonance it is possible to obtain equal compaction effect by large acceleration and so acceleration is rather convenient to explain compaction behaviour than frequency.

4.2. Influence of Acceleration

The effect of acceleration was presumed in the rough as follows.

That is, concrete had a plastic property when it was not compacted, but it liquefied rapidly when acceleration became up to a certain value and internal friction of concrete matrix decreased remarkably. The minimum acceleration to liquefy concrete differed with the consistency of concrete. In the range of our test it was 1.0G on dry consistency concrete of slump 0 cm and 0.5G on the medium consistency concrete of slump 5–8 cm.

Concrete once liquefied made little change of strength and specific gravity for a certain while even though acceleration were increasing.

Mori mentioned that viscosity decreased like an exponential function with increase of acceleration, but in our test strength and specific gravity of hardened concrete did not seemed to be sensitive enough to reflect the delicate change of viscosity.

This can be explained as follows. Namely, the bubbles in concrete were slipping out with the decrease of viscosity until viscosity came up to a certain point and escaping of bubbles was completed. Then the density of concrete did not change, while viscosity decreased with the increase of acceleration.

Segregation of concrete was promoted by the difference of specific gravity in the concrete matrix when viscosity decreased excessively at too large acceleration, and so strength decreased in spite of high density.

From the above-mentioned it is important to set up enough compacting condition both to liquefy and not to segregate concrete matrix.

In case of compacting large member the compacting condition will not uniform in every part of member because of damping characteristic, and so preceding condition must be satisfied in the part of the worst condition.

4.3. Influence of Amplitude

There are some papers to report that amplitude effects much on the compaction of medium consistency concrete. However, in our test correlation between amplitude and compaction effect was not distinct.

4.4. Influence of Compacting Time

Influence of compacting time had different inclination with the concrete of different consistency. That is, on various concrete of dry consistency, strength and specific gravity were slightly on the increase in longer compaction. On medium consistency concrete of slump 5–8 cm, the longer compacting time was the more segregation was promoted and compressive strength decreased.

In case of larger acceleration than 1.0G it is probably proper to compact for 3–10 minutes on concrete of slump 0 cm and for less than 3 minutes on concrete of slump 5–8 cm.

4.5. Influence of Compacting Method

Almost the same compaction effect was brought out from the same acceleration both in Shock method and Vibration method.

In Shock method the same acceleration was obtained at smaller frequency by adjusting the fall depth.

The impact force of dead load and compaction at natural frequency of the system by following free vibration were utilized in Shock method.

4.6. Influence of Concrete Mix

Optimum compacting condition was much affected by the consistency of concrete. This indicated that concrete of medium consistency was liquefied at small acceleration, but large acceleration was necessary to liquefy concrete of dry consistency.

If the consistency of concrete is identical, compaction behaviour differed little independently of the kind of gravel. In compaction of medium consistency concrete the extent of optimum condition was limited narrowly to prevent segregation.

Especially on ALA concrete deterioration of quality by segregation was remarkable, and so it seemed better to treat it in dry consistency.

5. CONCLUSION

Conclusion through the test was itemized as follows.

1). Compaction was much influenced by acceleration and it was convenient to explain the compaction behaviour in relation with acceleration rather than frequency.

2). With the increase of acceleration liquefaction of concrete occurred at a certain acceleration. In front and in the rear of liquefaction compaction effect changed rapidly. The limits to liquefy concrete was 1G on concrete of slump 0 cm and 0.5G on concrete of slump 5–8 cm.

3). Compacting behaviour of concrete differed with its consistency.

4). Segregation of concrete mix occurred when acceleration was too large against the consistency of concrete and compressive strength of concrete decreased gradually.

5). Especially on ALA concrete decrease of the strength by segregation was so remarkable that it seemed better to treat it in dry consistency.

6). In case of segregation tre estimation of compaction should not be done only from density of concrete.

7). If consistency of concrete is fixed, specific gravity of gravel affected little compacting behaviour.

8). Influence of compacting time differed with consistency and provided acceleration of concrete. It was proper to compact for 3–10 minutes on concrete of slump 0 cm and for less than 3 minutes on concrete of slump 5–8 cm.

9). In Shock method large compaction effect was brought out by small frequency because it was accompanied by free vibration.

10). Almost the same compaction was obtained from the same acceleration even if frequency differed.

ACKNOWLEDGEMENTS

The author gratefully acknowledges Mr. S. Morohashi (Chief research officer in Shock Beton Japan Co. Ltd.,) for his assistance in the tests.

REFERENCES

1. H. Takahashi, S. Nakane and A. Komatsu: Study on Compaction of Concrete (I)—Compaction of crushed Stone Concrete of dry Consistency. Summaries of technical Papers at annual Meeting of A. I. J., 1969, pp. 103–104.

2. H. Takahashi, S. Nakane and A. Komatsu: Study on Compaction of Concrete (II)—Compaction of medium Consistency Concrete. Summaries of technical Papers at annual Meeting of A. I. J., 1969, pp. 105–106.
3. H. Mori: Study on Compaction of Concrete (III)—Properties of vibrated Cement Mixture. Summaries of technical Papers at annual Meeting of A. I. J., 1969, pp. 107–108.
4. H. Takahashi, S. Nakane and A. Komatsu: Study on Compaction of Concrete (IV)—Compaction of artificial lightweight Aggregate Concrete of dry Consistency. Report of annual Convension of A. I. J. KANTO Branch, 1969, pp. 393–396.