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STATUS REPORT ON ROLLER COMPACTED CONCRETE PAVEMENTS

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SYNOPSIS

Although the history of international application of roller compacted concrete pavement (RCCP) for roads can be traced back to the early 1970's, actual studies in Japan were not begun until 1987. In October, 1990, the Pavement Committee of the Japan Road Association published technical standards related to RCCP. This paper describes the investigations and studies of RCCP which formed the basis for those standards and explains the actual past and present situation in relation to RCCP design and construction in Japan. Examined in this paper are the concept and characteristics of RCCP construction; the background of development of RCCP technology; the present situation of RCCP in Japan; and the present problems and future of RCCP.

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1. INTRODUCTION

The aim of roller compacted concrete pavement (hereafter "RCCP") construction is a high-strength concrete slab using cement concrete having a much lower water/cement ratio than conventional cement concrete; RCCP is spread using an asphalt paver and compacted with vibratory roller(s). The advantages of RCCP are: initial construction costs are lower; no special equipment is required; and the road may be opened to traffic earlier than roads paved using conventional methods. RCCP has recently been highlighted because: 1) renewed interest in concrete pavement following the oil shock in 1973, which resulted in a shortage of asphalt and a sharp increase in price, has made use of RCCP increasingly attractive; 2) more effective equipment such as the large vibratory roller and high compaction type paver have been developed; and 3) roller compacted dams (RCD) are being constructed in increasing numbers. Among these reasons, 2), the development of equipment, which made possible the construction of a more reliable slab, had the greatest effect.

Many countries around the world, including Spain, France, Norway, Sweden, the U.S.A., Canada and Australia have a record of trials and actual use of RCCP. As of 1986, it is estimated that the total area covered by RCCP exceeded 8 million m^2. In Japan, too, there has been increasing use of RCCP and the Pavement Committee of the Japan Road Association has established technical standards for RCCP based on these collected data. This paper briefly describes the present situation regarding RCCP in Europe and the U.S.A., and projects the future of RCCP in Japan.

2. THE CONCEPT AND CHARACTERISTICS OF RCCP CONSTRUCTION

2.1 The Concept of RCCP Construction

Fig. 1[1] shows the relationship of unit water content and degree of compaction to the quality of concrete. As can be seen, RCCP uses concrete (hereafter "RCC") having a low unit water content and compacts it under high compaction energy to produce a high-quality (high-strength, high-density) concrete slab. RCC is found among various types of concrete as shown in Fig. 2[2]. Its design mix includes a high coarse aggregate content, which provides high stability due to interlocking action, and low unit water content, making the RCC slab surface stable enough to support workers or water sprinkling vehicles after compaction. Moreover, RCC is classified as a cement-stabilized mixture from the view point of unit water content, and as a conventional concrete from the view point of cement content. Although it is shown as a surface layer in Fig. 3[3], it can also be used as a base layer under another surface layer.

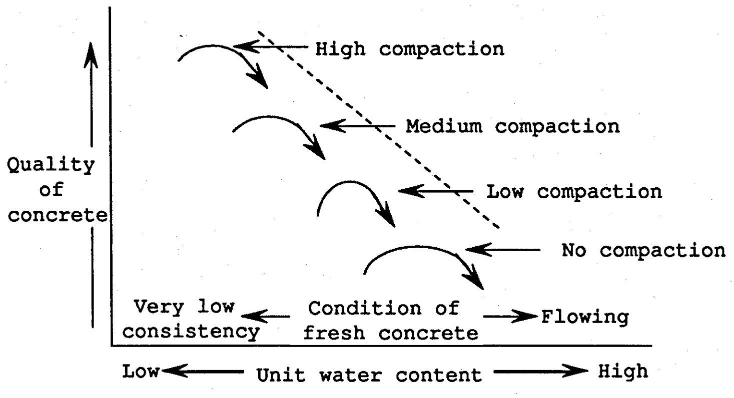


Fig. 1 Concrete quality in relation to unit water content and compaction

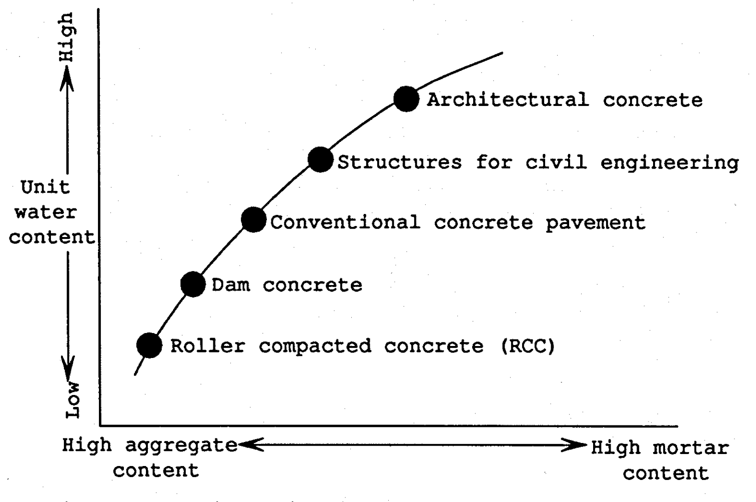


Fig. 2 Proportions for various kinds of concrete

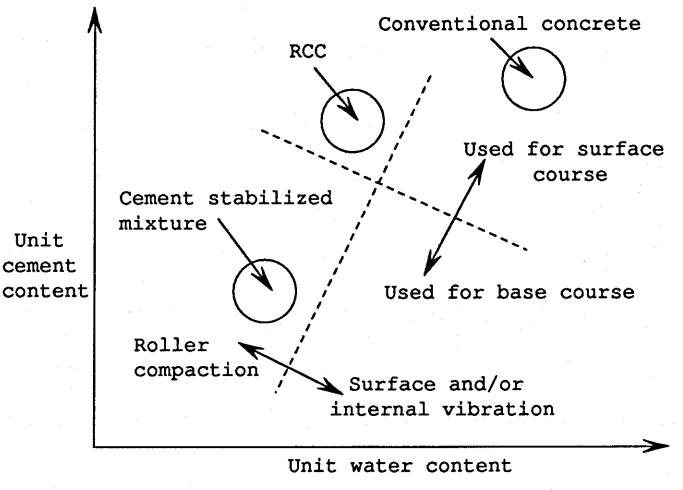


Fig. 3 Position of RCCP among cement mixtures

Based on the above, RCCP appears to lie somewhere between stabilized cement and conventional cement concrete; the relationship is shown in Table 1.

Table 1 The relationship between RCCP and other concretes

Item		Conventional concrete pavement	Cement-treated base
Mix proportions	Water content	X	O
	Cement content	O	X
Construction	Speed	X	O
	Compaction	X	O
Performance	Strength, durability	O	X
	Surface quality	O	X

Note: O = Similar; X = Dissimilar

2.2 Characteristics of RCCP

The characteristics of RCCP in comparison to conventional cement concrete as described above are: 1) intervals between joints can be larger or, in some cases, eliminated because there is less shrinkage due to low unit water and cement content; 2) road can be opened to traffic earlier because of high load-bearing capacity at an early age; 3) higher construction speed can be obtained with conventional asphalt paving equipment, thus reducing construction costs; and 4) there are no restrictions on slab thickness because construction without the use of forms is possible. The following problems, however, still require further research and study in the future: 1) methods of obtaining the required surface texture and evenness; and 2) whether artificial joints made with a joint cutter (hereafter "cutter joints") should be used to prevent shrinkage cracks.

3. BACKGROUND OF TECHNICAL DEVELOPMENT OF RCCP

3.1 Worldwide Situation

Due to its many advantages, construction using RCCP began many years ago in European countries and North America. Records as of 1986 indicate that RCCP covered areas of: 4.3 million m^2 in Spain; 2.4 million m^2 in France; 0.8

million m^2 in Canada; and 0.4 million m^2 in the U.S.A. The author visited Europe, North America and Australia in 1987 and 1988 on a survey undertaken by The Cement Association of Japan. A summary of the results follows[4].

3.1.1 The first trial in the world was carried out in Spain in the early 1970's. In the mid-1980's trials were carried out, not only on roads with light traffic, but on roads with heavy traffic as well.

3.1.2 Following the oil crisis of 1973, RCCP began to see increasing use in Europe and North America. Since the mid-1980's, when technical and economical evaluations based on slow-speed heavy-vehicle industrial trials were made, RCCP has been used for public roads.

3.1.3 The use of RCCP is based on its advantages: a) high construction speed; b) early opening to traffic; and c) low cost. However, the problem of the best way of controlling shrinkage cracks and maintaining surface evenness remain to be faced. Concentrated efforts to solve these problems will result in increasing use of RCCP in future.

3.1.4 Judging from the study results, Japan would benefit from introduction of RCCP technology, with modification to meet local conditions.

3.2 Related Technology in Japan

Technical development started in Japan in 1987, backed up by past experience. Related technology is described below.

3.2.1 Sapporo-Chitose road[5]

The first large-scale RCCP project was carried out in 1953 on a 7,027-m section of the Sapporo-Chitose road. A cross-section is shown in Fig. 4. As can be seen, the 4-cm asphalt concrete surface was laid on an 18-cm RCCP slab which formed a white base. This type of pavement is called a composite structure. Although all work was done manually with a 6-ton roller, the same specifications can be applied without major changes for work today in which various equipment is used.

3.2.2 Cement-stabilized base

The cement-stabilized base has been in use for many years. Technical standards were established in 1961 and are set out in the "Asphalt Pavement Manual," published by the Japan Road Association. The cement content of the design mix used in this method is 2-4% by weight (10% by weight in RCCP), with a compressive strength of 20-30 kg/cm^2 at 7 days, and is normally finished to a layer thickness of 15-30 cm. For construction, the mixture is normally spread with a base paver and compacted with a vibratory and/or pneumatic-tire roller; this is followed immediately by the spraying of an asphalt emulsion for curing. Past results show the high durability of this base layer; in addition, the same techniques and almost the same equipment can be applied for RCCP construction.

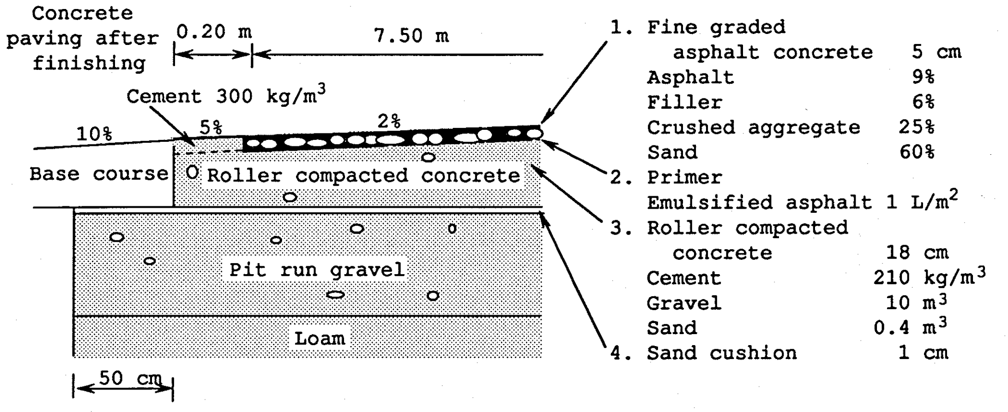


Fig. 4 Cross-section of Sapporo-Chitose RCCP road

3.2.3 Cement-Macadamix method

In this type of RCCP, a single-size aggregate (60/40 or 40/20 mm) is well mixed with cement mortar having a water/cement ratio of 40%. The mixture is spread and roller compacted. This method relies on the interlocking action of the single-size aggregate and the cementation reaction of the cement paste, and is generally applicable for base courses; unfortunately, it has not been applied nation-wide.

3.2.4 Roller Compacted Dams (RCD)

Roller Compacted Dams have been used in Japan since 1974 because they can be constructed quickly and inexpensively, and basic RCD technology has established itself. RCD concrete contains larger-size aggregate than RCCP does, and the unit cement content is limited to 120-130 kg/m^3 to control heat of hydration. Know-how gained through RCD construction will be applied to RCCP construction.

4. PRESENT SITUATION OF RCCP IN JAPAN

4.1 Surveys and Research

In Japan, RCCP has been used in the public sector by such organizations as the Ministry of Construction and the Japan Highway Public Corporation; it has also been used by private firms. Technical studies have been carried out by governmental agencies and by technical committees of the Japan Road Association, The Cement Association of Japan and the Japan Road Contractors' Association in accordance with their various specialties. For example, The Cement Association of Japan, in cooperation with the Kanto Regional Construction Bureau of the Ministry of Construction, spent three years working on the development of technology for application of low-shrinkage cement to permit larger joint spacing and on repeated trials aimed at shortening the time required before the road can be opened to traffic.

In August, 1988, the Pavement Committee of the Japan Road Association published "Guidelines for Roller Compacted Concrete Pavement Trials"[6] to standardize surveying and research in design and construction of RCCP. Based on these guidelines, nation-wide trials have been carried out, many by private firms. In April, 1988, the RCCP Technical Committee of the Japan Road Contractors'

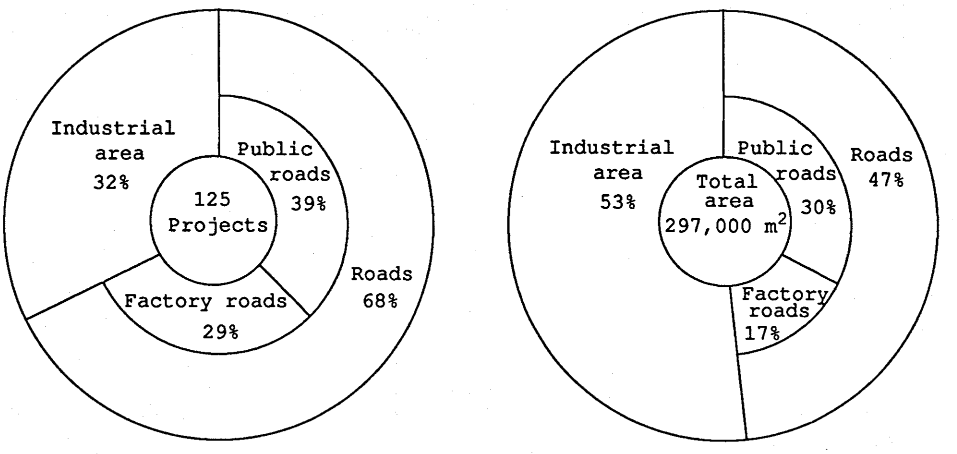
Association also began a study of the main problems occurring during construction. As a result of the cooperation between these agencies and committees, a considerable amount of effective data was collected. The Japan Road Association used these data to establish technical standards for RCCP appropriate for conditions in Japan.

4.2 Present Situation of RCCP in Japan

Stimulated by the progressive use of RCCP abroad, The Cement Association of Japan carried out its first trial at a factory belonging to Osaka Cement Co., Ltd.; road officials and private road engineers were invited. Many other trials followed immediately in the wake of this one. Only 35 years had passed since RCCP was first tried in the Sapporo-Chitose road project. Construction records as of 1990, indicate that RCCP trials covering a total area of 297,000 m^2 were carried out at 125 locations in Hokkaido, Tohoku, Kanto, Hokuriku, Chubu, Kinki, Chugoku, Shikoku and Kyushu[7]. Almost all trials were open to road officials and engineers for study.

4.2.1 Applicable locations

As can be seen in Fig. 5, industrial construction area was comparatively large, partly in an attempt to confirm workability and performance before application to public roads. In addition, the use of RCCP for construction of multi-lane roads without the use of forms made it particularly suitable for industrial areas. Further, many pilot projects and tests of RCCP for use in construction of public roads were carried out by regional construction bureaus of the Ministry of Construction. In 1988 and 1989, government-backed trials of RCCP suitability for L and A traffic roads (see Table 2 for chart of road-traffic classifications) were carried out, based on the guidelines previously mentioned. The data collected from these trials have been applied in our establishment of technical standards.



(a) Percentage by number of projects (b) Percentage by area

Fig. 5 Locations of RCCP projects

Table 2 Road classification by traffic volume

Classification	One-way daily traffic volume of heavy vehicles
L	100 or fewer
A	101 to 250
B	251 to 1,000
C	1,001 to 3,000
D	Over 3,000

Note 1: Vehicles having a number plate with one of the following numbers in the first position are regarded as heavy vehicles in Japan:
0-Construction machines and other large-sized special motor vehicles
1-Cargo trucks
2-Buses (passenger capacity, 11 or more)
8-Small or ordinary motor vehicles for special use
9-Special large-sized motor vehicles (excluding construction machines and others)
Load limit: 5 tons for wheel load, 10 tons for axle load and 20 tons for gross weight of a vehicle.

Note 2: If a road has more than two traffic lanes in one direction, about 80% of the traffic volume may be used for the distribution of traffic loads among the lanes.

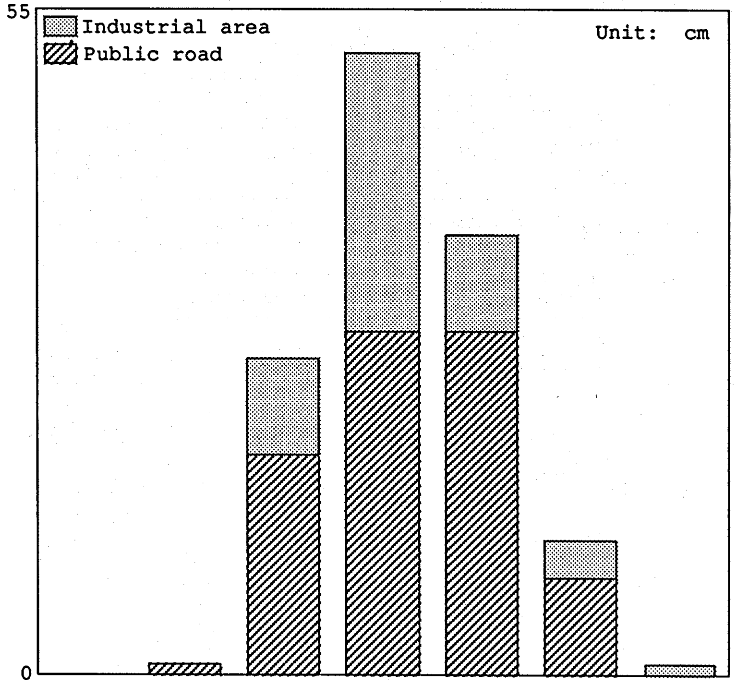
4.2.2 Pavement structure

4.2.2.1 RCC slab design thickness

RCC slab thickness range is shown in Fig. 6; most slabs are 25 cm or less in thickness. Although the Japan Road Association's "Cement Concrete Pavement Manual" stipulates that slab thickness be 15 cm for L traffic roads, 20 cm for A traffic roads, 25 cm for B traffic roads, 28 cm for C traffic roads and 30 cm for D traffic roads, 25 cm is considered to be the maximum RCCP slab thickness; the base course is strengthened to withstand heavier traffic conditions. The base course layer is required to have a standard load-bearing capacity of $K_{30} \geq 20$ kgf/cm^3, regardless of traffic classification. At present RCCP slab is considered to be the equivalent of conventional cement concrete slab based on their similar physical properties, flexural strength and fatigue resistance[8],[9]. Trials are being planned for slab thicknesses exceeding 25 cm, despite the problems which remain to be studied.

4.2.2.2 Joint structure and spacing

In Japan, the usual cement concrete pavement contains slip- and tie-bars to transfer loads at joints, and wire mesh to control crack propagation. However, the setting of bars and mesh in RCC slab is rather complex, making it difficult to obtain reliable paving. For this reason, RCCP joints are not reinforced. As shrinkage cracks always appear at certain spacing intervals, a study on whether or not cutter joints are required, and if they are required, what the proper spacing should be, remains to be carried out. Cutter joints are usually used with conventional concrete slab, and many trials have been carried out with various joint spacing intervals. Based on experience, joint intervals should be 10-15 m for slabs less than 25 cm thick and 15-20 m for 25-cm-thick slabs.



	5	10	15	20	25	30	38
▨		1	19	29	29	8	
░			8	24	7	3	1

Fig. 6 Range of RCCP slab thickness

4.2.3 Mix design

4.2.3.1 Method of determining design mix

The method of determining RCC design mix, based on the results of our research, is shown in Fig. 7. First, optimum moisture or unit water content is determined to obtain RCC of the proper consistency. Then, test prisms (10 X 10 X 40 cm) having this unit water content, but various unit cement contents, are subjected to bending strength tests to find out the optimum cement content which meets the requirements for 28-day bending strength. The three test methods shown in Table 3 are presently used to evaluate consistency. The best one of these will be selected in the future.

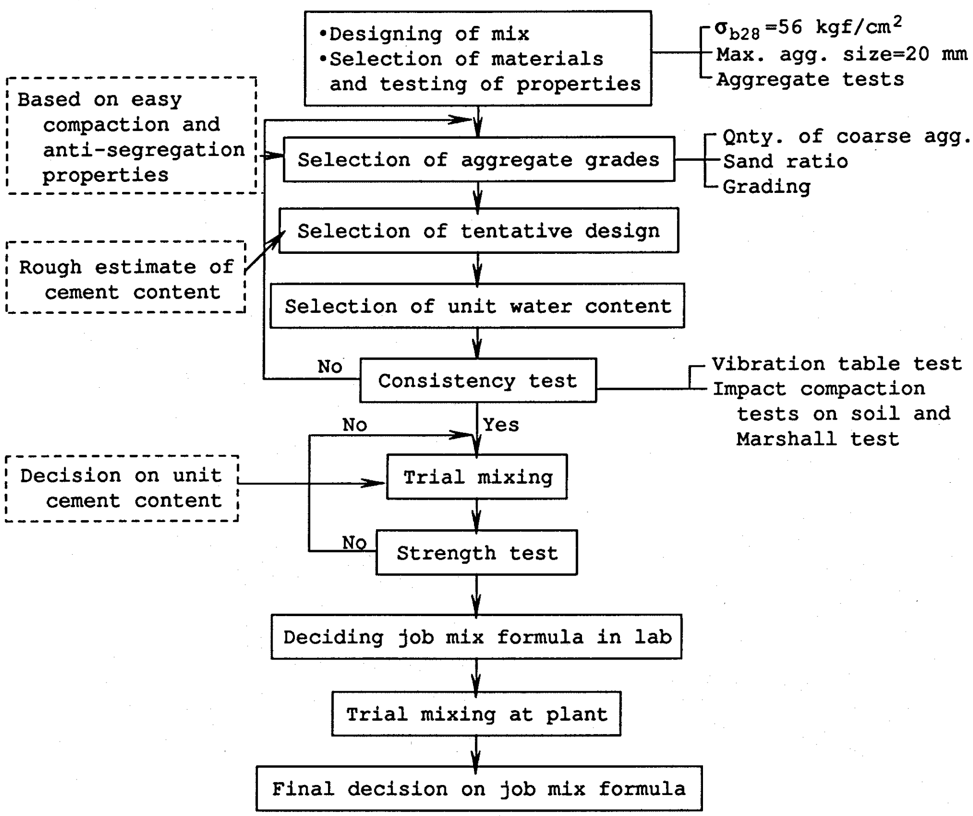


Fig. 7 Mix design flow of RCC

Table 3 Evaluation of RCC consistency

a) Evaluation using a vibrating table

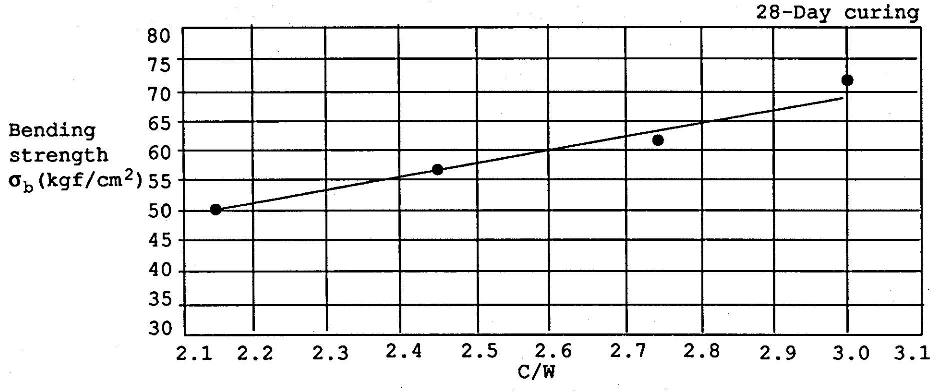
Apparatus	Vibration (VPM)	Amplitude (mm)	Acceleration (g)	Pressure (kg)	Evaluation
VC Tester	3,000	1.0	10.0	20	Modified VC; voids filled

b) Evaluation using the impact-compaction test

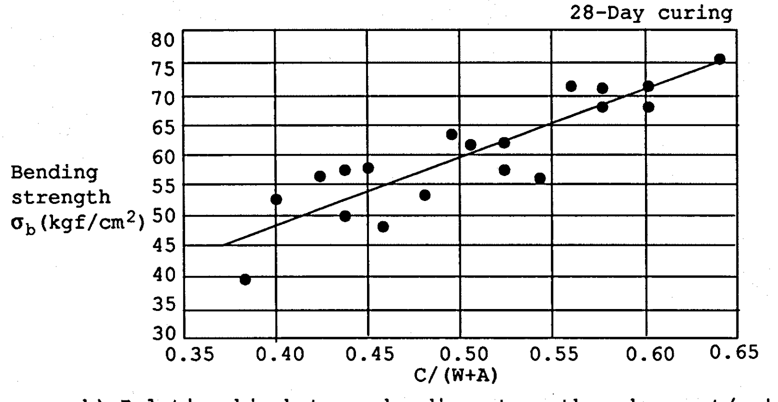
Method	Mass (kg)	Drop height (cm)	Layer No.	Times	Evaluation
JIS A1210	Rammer 4.5	45.0	3	65	Optimum water content
Marshall compaction	Hammer 4.5	45.0	1	50	Degree of compaction

Sample bending strength results are shown in Fig. 8[10]. Fig. 8 b) shows results obtained by the Japan Highway Public Corporation where combinations of test-prism cement/water ratio (C/W) and void content (A) are considered as c/(W+A). A 28-day design bending strength of 45 kgf/cm^2, the same as that for conventional concrete, is applied. Therefore, a design mix target strength of

56 kgf/cm^2 (Construction Manual) or 60 kgf/cm^2 (Japan Highway Public Corporation) is presently being used. This is somewhat higher than the 52 kgf/cm^2 target value for conventional concrete, because the amount of data regarding strength is not considered sufficient to form a basis for technical judgement.



a) Relationship between bending strength and cement/water ratio

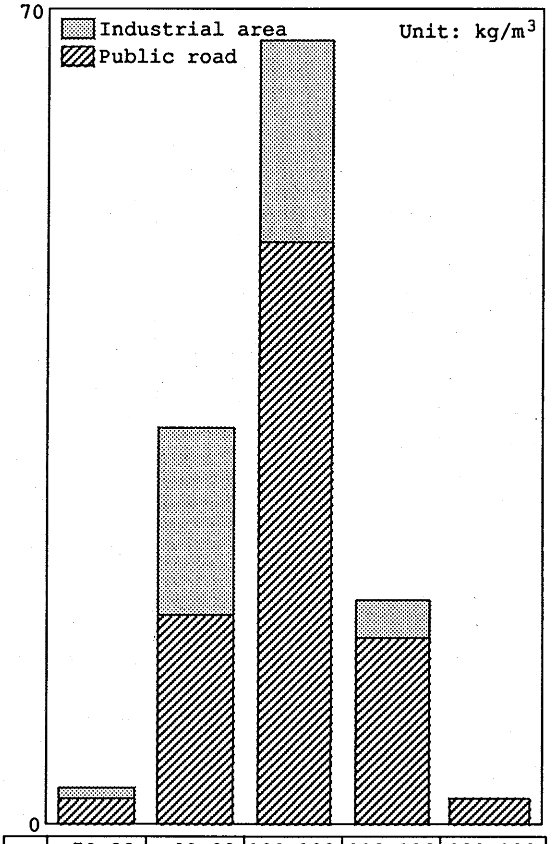


b) Relationship between bending strength and cement/void ratio

Fig. 8 Sample results of bending strength tests

4.2.3.2 RCC design mix

Although 40 mm is the maximum size of coarse aggregate generally used for conventional concrete, 20-25 mm is generally used for RCC to maintain good workability and uniform slab quality. As shown in Fig. 9, unit water content for RCC is about 30 kg/m^3 less than that for conventional concrete, which usually requires 120-140 kg/m^3.

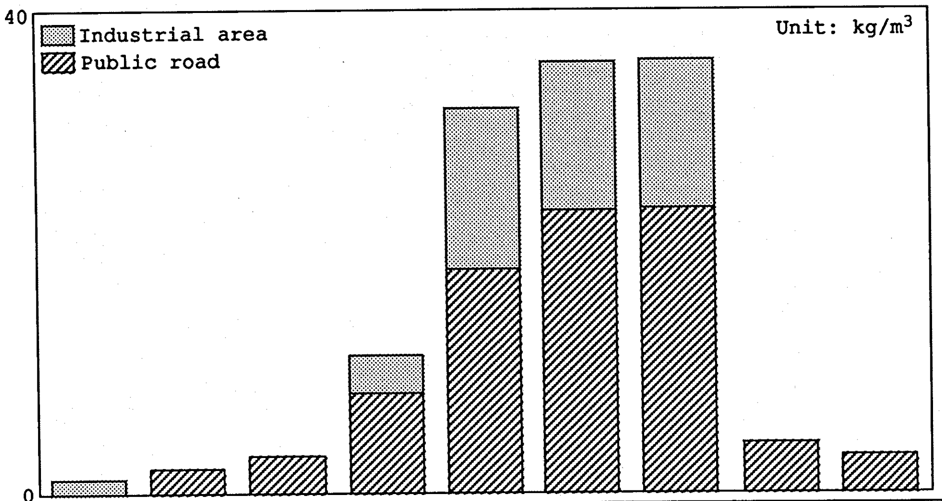


	70-89	90-99	100-109	110-119	120-129
Public road (hatched)	2	18	47	15	2
Industrial area (dotted)	1	16	21	3	

Fig. 9 Range of unit water content in RCC

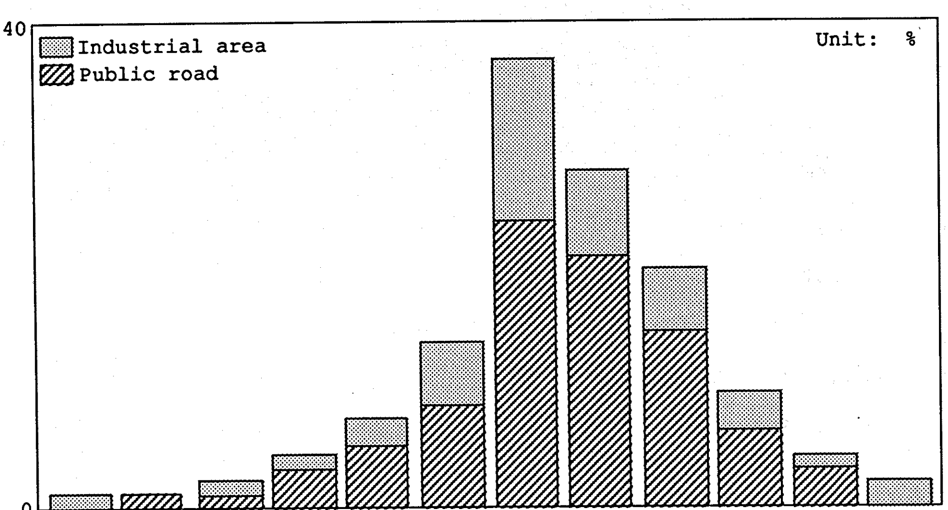
The range of unit cement content is shown in Fig. 10. As can be seen, RCC requires about 20 kg/m^3 less than the conventional cement content of 300 kg/m^3 or more. An admixture is used in most cases, and a standard air-entraining or retardant type is often the admixture of choice.

The sand ratio (s/a) and quantity of coarse aggregate per unit weight of concrete are shown in Figs. 11 and 12, respectively. The broad range of s/a is due to the necessity of maintaining a dense surface texture and avoiding segregation, as well as the need to obtain the high density required for application of RCCP as a surface course. The quantity of coarse aggregate per unit weight of concrete is 100-200 kg/m^3 larger than that for conventional concrete, which usually requires 1,100 kg/m^3. Thus, the design mix for RCC for use in Japan requires lower unit water and cement contents, and a higher aggregate content than does the design mix for conventional concrete. However, the range of s/a ratios required to maintain good surface texture, avoid segregation and obtain high density at the bottom of slab is quite broad.



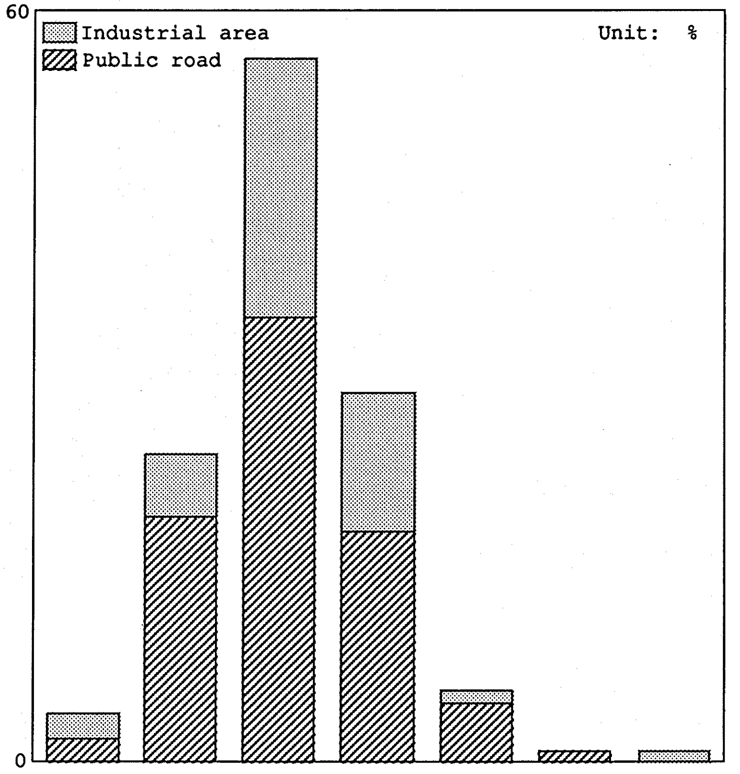
	160	200-219	220-239	240-259	260-279	280-299	300-319	320-339	340-359
Public road		2	3	8	18	23	23	4	3
Industrial area	1			3	13	12	12		

Fig. 10 Range of unit cement content in RCC



	21	-31.9	-33.9	-35.9	-37.9	-39.9	-41.9	-43.9	-45.9	-47.9	-49.9	-51.9
Public road		1	1	3	5	8	23	20	14	6	3	
Industrial area	1		1	1	2	5	13	7	5	3	1	2

Fig. 11 Range of RCC sand ratio (s/a)



	1000-1009	1100-1199	1200-1299	1300-1399	1400-1499	1500-1599	1910
	2	20	37	19	5	1	
	2	5	21	11	1		1

Fig. 12 Range of quantity of coarse aggregate per unit weight of RCC

4.2.4 Construction

Fig. 13 shows a flow-chart for RCCP construction.

4.2.4.1 Mixing and haulage of RCC

In most cases, RCC is mixed at an existing ready-mixed concrete plant. As the mixture is concrete with an extra-stiff consistency, a pan-type or pugmill-type mixer is generally used for mixing, and the capacity per batch is reduced to 2/3 of nominal capacity in most cases. For haulage to site, dump trucks are used. The most important factor in the mixing process is strict control of unit water content. When the water content is excessive, the surface of the mixture forms waves and the final slab surface is uneven. On the other hand, if not enough water is used, the resulting density is insufficient and the mixture tends to segregate. Therefore, careful unit water content control is the key to obtaining a satisfactory mixture. During haulage, the mixture should be covered with a plastic sheet to prevent evaporation of water. Generally, the allowable time between mixing and completion of compaction is less than one hour, but this depends on the season.

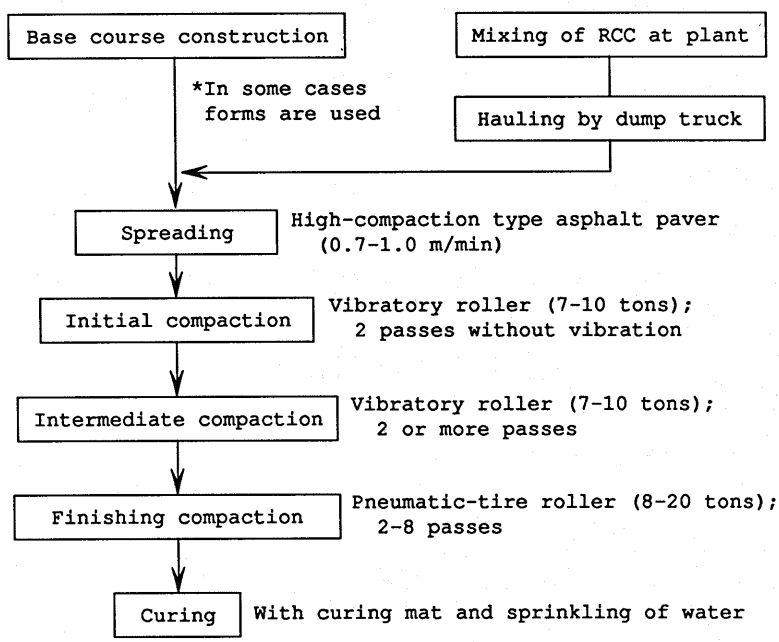


Fig. 13 Flow-chart for RCCP construction

4.2.4.2 Spreading of mixture

As RCCP is spread in one 15-30 cm-thick layer, an asphalt paver is usually used to spread the mixture uniformly and prevent segregation. A high-compaction paver is often selected to meet the requirements of road construction (evenness, etc.) because when initial paver screed compaction is insufficient, surface unevenness occurs during roller compaction.

4.2.4.3 Compaction

To obtain sufficient density throughout the slab thickness, a 7-10-ton vibratory roller is usually used. A combination of two passes without vibration and two to four passes with vibration is the usual method. After vibratory compaction, an 8-20-ton pneumatic-tire roller is used to finish the surface to maintain density and prevent peeling of cement mortar. In some cases, an oscillating roller is used to avoid hairline cracks during compaction.

4.2.4.4 Curing

In most cases, the finished RCC slab surface is covered with a curing mat for three days. One of RCCP's important characteristics is that it can be opened to traffic very soon after construction. This is particularly important when RCCP is used in rehabilitation works. In some trials, water was sprinkled on the slab for one day during the curing period in an attempt to achieve even sooner opening of the road to traffic; however, further study is required if a good surface texture is to be obtained. For this purpose, trials involving the use of a membrane curing agent and surface treatment with polymer cement milk or cement mortar are currently being carried out.

5. PRESENT PROBLEMS AND THE FUTURE OF RCCP

With the rapid increase in number and area of RCCP projects, total area will soon reach 300,000 m^2. Based on the data obtained from these projects, the Japan Road Association has established technical standards for the use of RCCP in Japan.

5.1 Present Problems Related to Structure

5.1.1 Pavement structure

As the physical properties of RCC after hardening are similar to those of conventional concrete, conventional design methods can be applied. However, long-term performance data must be collected for future analysis. Moreover, to make the best use of RCCP's superior physical properties, thinking regarding future applications must be flexible; for example, the possibility of combining RCCP with a cement-stabilized base layer or the combination of a cement or asphalt surface layer with a RCCP base, or even the use of RCCP as an alternative to conventional concrete slabs.

5.1.2 Joints

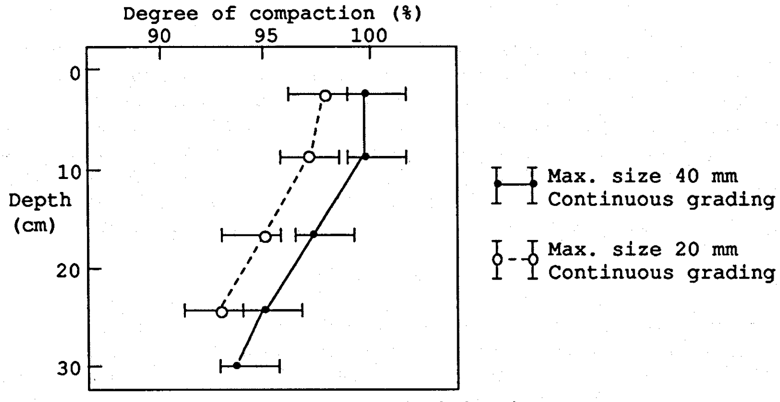
Cutter joints (depth = 1/4 slab thickness) are required to prevent the occurrence of shrinkage cracks in RCC slabs in Japan. However, the many examples of use of RCC slabs without artificial joints in foreign countries indicate that further study is needed on the behavior of cracks in RCC slabs. In the future, joint spacing will be determined in accordance with the purpose of application and pavement structure.

5.1.3 Slab thickness

For roads handling heavy traffic (C or D traffic classification), there are two construction methods: 1) increasing the slab thickness; and 2) maintaining a constant slab thickness.

5.1.3.1 Increasing slab thickness

Normally, design thicknesses for C and D traffic are 28 and 30 cm, respectively. For airport runways or taxiways, a thickness exceeding 30 cm is required. In these cases, the thick RCC slab must be compacted uniformly from the bottom to the surface because actual data shows a lower degree of compaction at the bottom, as shown in Fig. 14[11]. Moreover, bending strength decreases when voids increase, as shown in Fig. 8. Therefore, a study of design and construction methods, including the possibility of adopting multi-layer construction, needs to be carried out.



$$\text{Degree of compaction} = \frac{\text{Measured density}}{\text{Theoretical density}}$$

Fig. 14 Sample densities of RCCP throughout its depth

5.1.3.2 Maintaining a constant slab thickness

When slab thickness is kept constant at 25 cm, the items shown in Table 4 should be considered.

Table 4 Points for consideration in RCCP pavement structure

Item / Effect	(1) Increased design bending strength	(2) Strengthening of subbase	(3) Use of RCC slab as white base
Load-bearing capacity of base of RCC slab	O	O	O
Evenness	Δ	Δ	O
Surface texture, durability	Δ		Δ

Notes: O = Direct effect; Δ = Secondary effect

(1) According to trial calculations, design bending strength should be increased to 50 kgf/m^2 for C traffic and to 52 kgf/m^2 for D traffic when slab thickness is constant at 25 cm.

(2) To increase load-bearing capacity of base course, a cement-stabilized layer or lean-mix RCC should be used. According to trial calculations, a K_{30} value of 60 kgf/cm^3 for C traffic and 100 kgf/cm^3 for D traffic is required when the design method described in the "Cement Concrete Pavement Manual" is adopted. When a combination of RCC slab and lean-mix RCC or a cement-stabilized base is applied, a base thickness of 20-25 cm is required.

(3) An asphalt overlay on RCC slab is effective in reducing traffic-load and thermal stresses. According to trial calculations, a 5-cm-thick overlay can reduce traffic load stress by 10%, and a 10-cm-thick overlay can reduce stress by 20%; an overlay can also reduce thermal stress at the rate of about 1 kgf/cm^2 per °C of temperature difference.

5.2 Problems Related to Design Mix

Further study of design mix is required to determine the best method of evaluating the consistency and grade of aggregate most suitable for the amount of compaction energy applied. It goes without saying that the workability of RCC depends mainly on unit water and unit cement contents. In addition, the locations of shrinkage cracks, whose appearance should be minimized, can be guided by the placement of cutter joints. Joint design and design mix should be determined on the basis of suitability for RCC. To improve workability, the possibility of addition of a retarder or fly ash should be studied.

5.3 Problems related to surface evenness

5.3.1 Data from seven projects carried out under the auspices of the Japan Road Association show that surface evenness of RCCP is inferior to that of conventional concrete (σ = 2.4-3.0 mm for 25-cm-thick slab, 1.4-2.9 mm for 20-cm, and 1.4-1.6 mm for 15 cm; normally $\sigma \leq$ 2,0 mm for conventional concrete slab). This may be because this type of construction is still in the trial stage and total area is small. In order to improve evenness, stable RCC consistency, continuous construction without stopping of the finisher and supply of concrete sufficient for the type of equipment used are important factors.

5.3.2 Due to the high aggregate content and extra-stiff consistency, there is a tendency toward segregation at the surface and bottom of the layer when RCC is spread. Segregation can lead to disintegration at the surface and structural weakness of slab at the bottom. Therefore, measures to prevent segregation during construction and in the mix itself require further study. In addition, a study of surface finishing methods using cement slurry or cement mortar should be planned.

5.3.3 At present, a curing mat and sprinkling for at least one to three days is the method used for curing. To hasten the curing process and permit earlier opening of the road to traffic, the development of a membrane curing agent or material which can be used as a surface treatment is required.

5.4 The Future of RCCP

In the past, cement concrete pavement accounted for a large share of road paving, until it was replaced by asphalt pavement in the 1960's. At present, asphalt pavement is facing the problems of rutting due to plastic flow and wear by traffic. To overcome these problems, further studies of cement concrete pavement should be carried out. However, this still leaves the problems of high cost due to the amount of equipment required and the long curing period. Against this background, RCCP is being highlighted as a possible solution to these problems. Proposed technical standards related to RCCP were issued by the Japan Road Association in October, 1990.

To promote and advance the use of RCCP throughout Japan, the following are required: 1) a stable supply of good-quality RCC; 2) publication of the RCC production manual; 3) use of RCCP in large-scale projects; and 4) flexibility in RCCP design concepts. The author sincerely hopes that RCCP's superior characteristics will lead it to be used nation-wide in any project whose requirements it fills and wherever it is economically feasible.

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