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EXPERIMENTAL STUDY ON AN IMPROVED ZONE IN CONCRETE BY A PERMEABLE FORM

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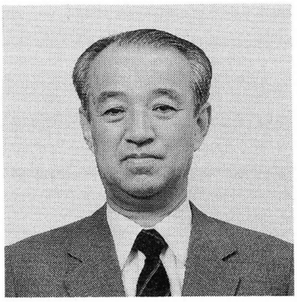

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SYNOPSIS

Recently there has been increasing social interest in the deterioration of concrete structures and many studies by various organisations have been carried out on improvement of concrete durability. The permeable form described in this paper was developed on the basis of a concept that the improvement of the quality at the surface layer of concrete contributes to improving the concrete's durability as a whole. Most experimental studies done to date have been concerned with the evaluation of the quality of the concrete's surface layer. This paper examines, rather, a zone of improved concrete quality by carrying out experiments on the zone of dewatering in the concrete resulting from the use of the permeable form. It considers the mechanism of discharge of surplus water and the influence on bleed water. Within the scope of these experiments, the improved zone can be considered to be from the form surface to around 10 to 20 cm inwards. Accordingly this permeable form can be expected to contribute to the avoidance of rust of the reinforcing bars and to improve the adhesion strength between the horizontal bars and concrete in such portions.

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1. INTRODUCTION

Because of advantages such as high resistance to external forces, high durability and the ability to offer considerable discretion in the selection of the forms of structures, concrete is at present widely used, being the most represented material in the building of structures.

However, in recent years, with the issue of accelerated deterioration caused by corrosion of reinforcement by salt air, alkali aggregate reaction and so on, appearing in the press, concern over the durability of concrete has come to the fore.

Though to date a great deal of research has been carried out regarding concrete durability, this public concern has given the opportunity for vigorous research into improved durability of concrete structures to progress with close co-operation between government, academia and industry.

The authors expect that the Permeable Form Method, which is continuing to be developed and brought by them to the stage of practical use, will make a considerable contribution to the improvement of concrete durability. With the concept that the method improves the quality of the concrete surface from the point of view of durability, it was originally devised as a solution to the problem of honeycombing on concrete surfaces which has long been troublesome for concrete construction technologists [1].

The effect on the improvement of concrete durability by the use of permeable forms has been verified by previous experimental research [2,3] and has been evaluated by public agency programs [4].

These studies provide comparative examination based on various surface layer quality indices, for concrete made using permeable forms and conventional forms

The improvement in concrete durability when permeable forms are used is accessed by concrete technologists to be caused by the reduction of honeycombing on the surface and the formation of a fine dense layer at the concrete surface. However, there have been few examples of studies into the dewatered zone or the improved concrete zone resulting form permeable form usage.

This study attempts to identify the dewatered zone and the improved concrete zone arising from that dewatering, when using permeable forms.

2. OUTLINE OF PERMEABLE FORMWORK

The permeable forms used in this experimental research are referred to by the title of Textile Form. 3-5mm holes at a 5-10cm spacing are drilled in conventional form plywood and then a special textile, developed for use on concrete formwork, is spread over and attached to the form.

The special textile, as shown in Figure 1, is of a double layered fabric. The surface which contacts the concrete functions as a filter, being permeable to air and water but with the great majority of cement particles unable to pass through it. The other side of the fabric acts as a drain, guiding the air and water to the holes in the formwork sheathing boards. The fabric is made from polyester and polypropylene fibres of approximately 0.7mm thickness.

The fixing of the fabric to the sheathing boards is achieved by stapling the fabric around the edges of the form panel on its back surface, in the case of plywood forms, or attaching it to the backside of the form panel with double-sided adhesive tape, in the case of metal forms.

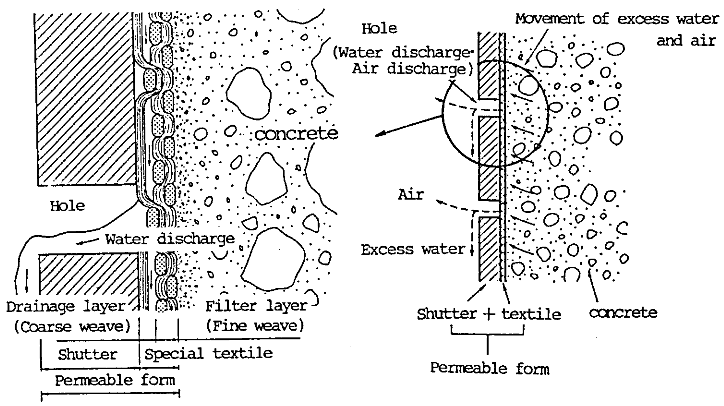


Fig.1 Outline of Permeable Form

3. IDENTIFICATION OF THE DEWATERED ZONE WITH PERMEABLE FORMS

3.1 Aim of Experiment

In the case of using permeable forms it is known that the quality of the concrete surface layer is improved due to the reduction of the water/cement ratio in the surface layer by the drainage of excess water and the formation of a fine dense paste layer at the surface of the concrete. However studies quantitatively examining to what depth from the surface the water is discharged by permeable forms and to what degree the water/cement ratio is decreased as a result, are few.

This study carried out experiments to identify the dewatered zone resulting from permeable forms and to determine the decrease in water/cement ratio in that zone.

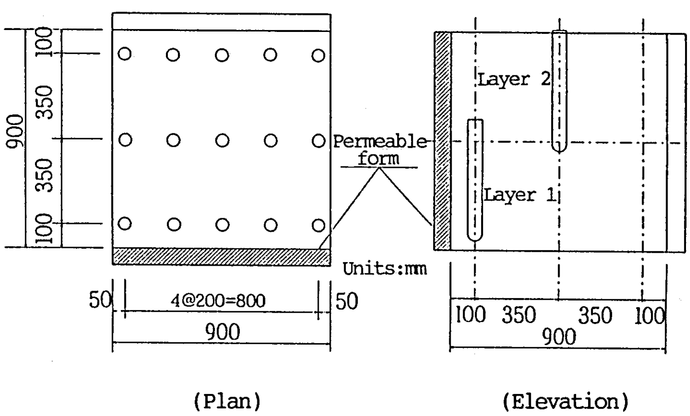


Fig.2 Concrete Placement and Compaction

3.2 Outline of Experiment

In order to determine the degree of depth from the formwork surface from which dewatering occurs when using permeable forms, it is necessary to investigate the movement of water in the fresh concrete placed within those forms. While various methods can be considered for investigating the movement of water in fresh concrete, in this study the method used involved the recording of water level movements with time as measured by water level recorders which were installed at various depths from the form surface within the concrete body under investigation.

With this method it was expected that, according to the differences in water level between the various water level recorders, it would be possible to differentiate between the zone in which horizontal water movement towards the form occurred (the dewatered zone) and the zone where no such movement took place.

The experimental concrete body was a 90cm sided cube made up with a permeable form on one vertical surface and a conventional form used on the opposing side. The placing of concrete was carried out in two layers of 45cm thickness as shown in Figure 2, while compaction was performed using a 32mm cylindrical concrete vibrator. Vibration time was at a rate of 200 seconds per cubic metre (200s/m^3). At each point, as shown in Figure 2, the vibration time was 5 seconds. For the concrete mixture used refer to Table 1.

The experiment was carried out with the following objectives:

(1) Measurement of the amount of water discharged from the forms.

(2) Measurement of the levels in the water level recorders installed within the body of the concrete.

Table 1 Concrete Materials and Mixture

Cement : Normal portland cement
Fine aggregate : From TENRYU and SETO areas, fineness modulus 2.70
Coarse aggregate : From ISHIMAKI areas, fineness modulus 6.64
Admixture : AE water reducing agent

Nominal strength (kgf/cm^2)	Slump range (cm)	Amount of air range (%)	Water cement ratio W/C (%)	Sand percentage s/a (%)	Unit content (kg/m^3)				
					Water W	Cement C	Fine aggregate S	Coarse aggregate G	Admixture
180	12± 2.5	4± 1	65	47.7	176	271	859	1,099	0.271

3.3 Experimental Method

(1) Measurement of the Amount of Water Discharged from the Forms

The amount of water discharged from the forms was recorded from immediately after concrete compaction was concluded until discharge ceased.

(2) Measurement of the Levels in the Water Level Recorders

The specification of the simple water level recorders used for measuring the movement of water through the concrete with permeable forms was as follows:

The recorder is made of PVC pipe (VP 25, l=1m) with holes drilled circumferentially in 4 locations and at 20mm spacings longitudinally. In order to prevent blockage the pipes were wrapped in fabric. A scale was placed within the pipe so that the water level could be measured by reading of the height of the water surface. The period of measurement was for about 8 hours after the completion of concrete placement. The arrangement of the recorders was as shown in Figure 3.

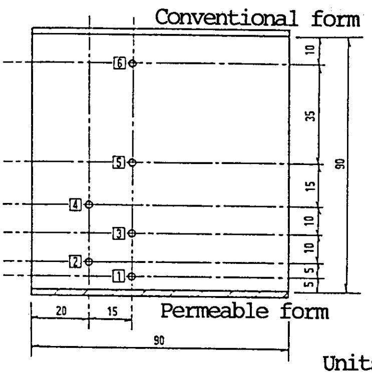


Fig.3 Location of Water Level Recorders (Plan)

3.4 Experimental Results and Discussion

Figure 4 shows the results of the amount of water discharged from the surface with the permeable form. The discharge of water lasted for a period of about 2 hours after the completion of concrete placement. The total amount discharged per unit area in the time period was 2.51 l/ m^2. By the time of completion of concrete placing the discharge amounted to about 40% of the total and the remaining 60% discharged steadily after placing was finished. Figure 5 shows the results of the water level measurements. It is considered possible that water level recorders number 2 (located at 10cm) and number 4 (located at 30cm) could be effected by the proximity of the side form. Consequently, in the main, the remaining recorders only are considered here.

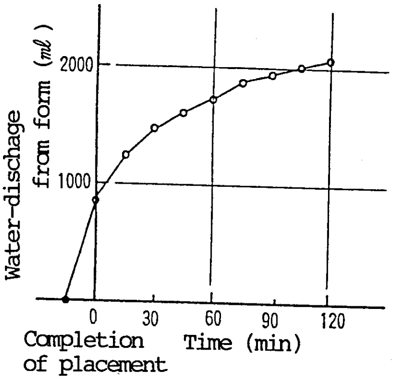


Fig.4 Amount of Water Dischaged

For each recorder the water level rose along with the concrete placement and progressed reaching a peak about 1 hour after completion of concrete placement. After that the level started to decline being restored to the level at the time placement finished and then continued to decline further.

With regard to the peak levels at each recorder, it can be seen that recorder number 1, the closest to the permeable form (at 5cm), had the lowest level, there being a trend then for the peak level to increase up to recorder number 5 (at 45cm). Also, while recorders number 4 and 6 had peak water levels reaching about the level of the concrete surface, recorders up to number 3 showed levels lower than the concrete surface.

From this it can be conjectured that, for this concrete mixture, the extent of the dewatered zone resulting from the permeable form is about 10 to 20cm from the form surface and that pore water pressure within the concrete reduces with proximity to the permeable form.

With the total discharge amount, 2.1 litres, and the dewatered zone taken at 20cm, the decrease in water/cement ratio due to the discharge from the form surface can be determined as follows:

$Wa = 0.9 \times 0.9 \times 0.2 = 0.162$ (m^3)
$\Delta W = 2.1$ (l) / 0.162(m^3) $= 13.0$ (l/m^3)
$W' = W - \Delta W = 176 - 13.0 = 163.0$ (l/m^3)
$W'/C = 163.0 / 271 \times 100 = 60.1$ (%)
$\Delta W/C = 65 - 60.1 = 4.9$ (%)

Where Wa : Volume of dewatered zone (m^3)
ΔW : Discharge from the dewatered zone (l/m^3)
W' : Amount of unit water content after dewatering (l/m^3)
W : Water content per unit volume of concrete (kg/m^3)
C : Cement content per unit volume of concrete (kg/m^3)

In the same way, the fall in the water/cement ratio for a 10cm wide dewatered zone was calculated to be 9.6%.

From the results above it can be concluded that for the concrete mixture used and with the dewatered zone taken as 10 to 20cm thick, the decrease in water cement ratio is of the order of 5% to 10%.

It is considered that the improvement in the quality of the concrete surface layer (10 to 20cm) is a consequence of this reduction in water/cement ratio.

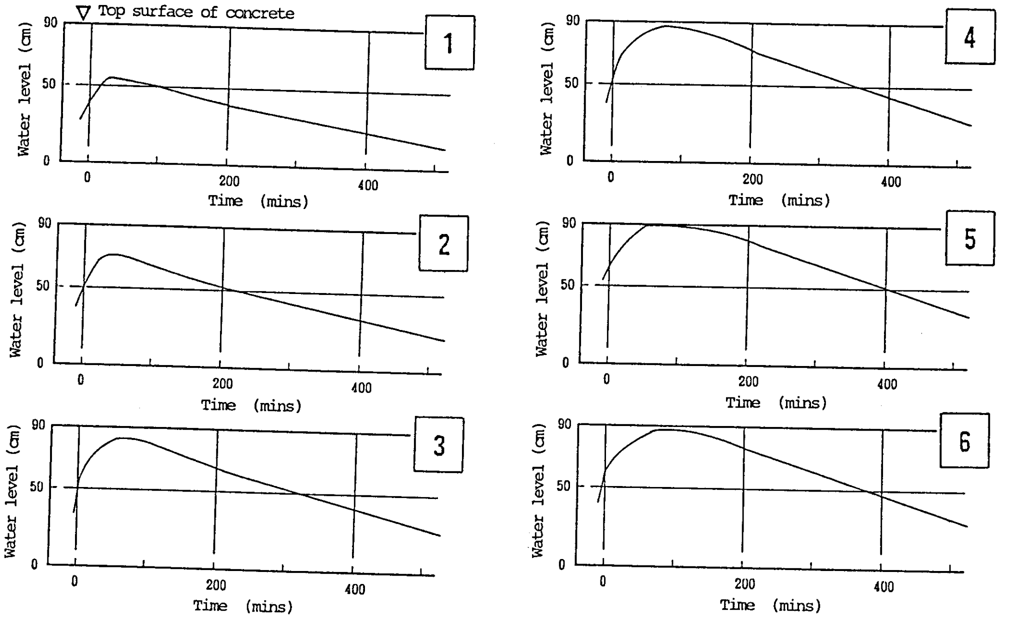


Fig.5 Change in Water Level in the Recorders

4. THE EFFECT ON BLEEDING OF THE DEWATERING WHEN USING PERMEABLE FORMS

4.1 Aim of Experiment

As concrete is a mixture composed of materials with different specific gravities (cement, aggregates and water), concrete in the fresh state displays a phenomenon called "bleeding" whereby the materials with the higher specific gravities (aggregates and cement powder) settle, while on the other hand, water, with a lower specific gravity, rises. Consequently, in the case of conventional forms from which no water is discharged, the phenomenon of the existence of voids forming directly under fixed items in the concrete, such as reinforcing steel, can be observed. In the case of permeable forms, as some of the surplus water discharges from the form surface, it is anticipated that, overall, the amount of bleeding of water is reduced and, consequently, the occurrence of voids under fixed items in the concrete is also reduced.

In this study, in order to evaluate the effect of water discharge from the permeable forms on bleeding, experiments were undertaken with the aim to examine quantitatively the voids formed directly under fixtures within the body of the concrete for both permeable and conventional form cases.

4.2 Outline of Experiment

Within a concrete structure various fixtures such as reinforcement and pipes are found. In this experiment steel pipes were used. Steel pipes were placed into concrete bodies which used permeable forms and conventional forms. Two concrete mixtes were used. They had identical amounts of water per unit of concrete volume but had different water/cement ratios. Observations were made of the relationship between the location of the steel pipes and the amount of voids developed under the pipes, and also their diameter and the amount of voids. The amount of voids was defined as the greatest value of the length of the void measured perpendicularly under the steel pipe.

The experimental concrete bodies were of the same type as used in the experiments verifying the dewatered zone. Steel piping placed inside the concrete was of length 400mm and of diameters 50, 34, 27 and 13mm. So that the pipes would not move during concrete placement, each pipe was fixed with 9mm reinforcement. The arrangement of the pipes is shown in Photo 1 and Figure 6. Concrete was placed in two separate layers. The first layer was placed up to the underside of those pipes located at the mid depth of the concrete bodies. Compaction was carried out as for the dewatered zone experiment and the second layer was placed following compaction of the first layer. The two concrete mixes used in this experiment are shown in Table 2.

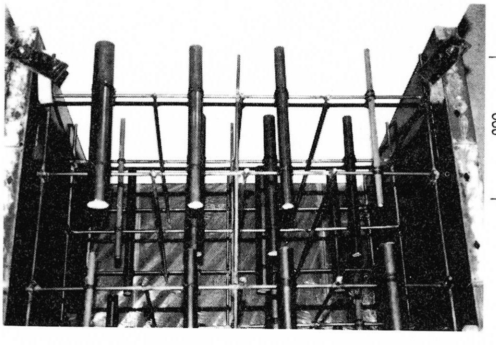


Photo-1 Location of Steel Pipes

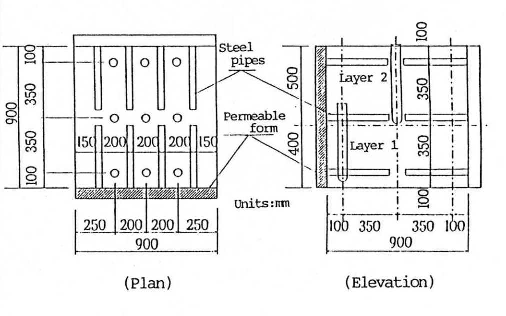


Fig.6 Location of Steel Pipes

Table 2 Mixture Proportion of Concrete

(a) Mix A

Nominal strength (kgf/cm²)	Slump range (cm)	Amount of air range (%)	Water cement ratio W/C (%)	Sand percentage s/a (%)	Unit content (kg/m³)				
					Water W	Cement C	Fine aggregate S	Coarse aggregate G	Admixture
300	12± 2.5	4± 1	47	42.9	175	373	738	1,147	0.373

(b) Mix B

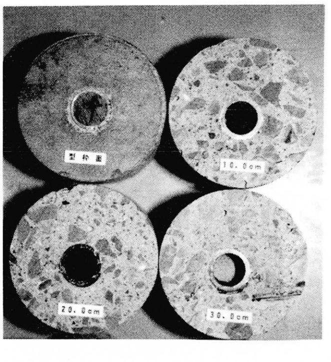
Nominal strength (kgf/cm²)	Slump range (cm)	Amount of air range (%)	Water cement ratio W/C (%)	Sand percentage s/a (%)	Unit content (kg/m³)				
					Water W	Cement C	Fine aggregate S	Coarse aggregate G	Admixture
180	12± 2.5	4± 1	65	47.7	176	271	859	1,099	0.271

4.3 Method of Experiment

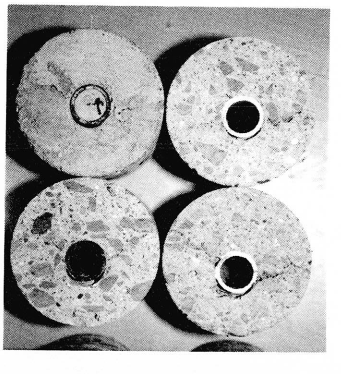
With the steel pipes at their centre, cores (l=450mm) were taken from the faces of the concrete bodies which used the permeable forms and those which used the conventional forms. Following this, the cores were cut into 10cm thick sections beginning from the surface nearest the form. The void under the steel pipe were then measured for each face of the sections for each core.

4.4 Experimental Results and Discussion

Photo 2 shows the condition of the sections for the 27mm diameter pipes which were located at the upper level for both permeable and conventional form cases for concrete mix B, which has the lesser amount of cement. As can be seen in Photo 2, for the permeable form case, from the form surface to a depth of 10cm there was no void under the pipe but for the conventional form voids were observed in all sections.



Permeable Form



Conventional Form

Photo-2 Condition of the Sections for the Pipes Installed in the Upper Level

Figures 7 and 8 show the relationship between the voids under the pipe and the depth along the pipe for mix A and B respectively.

The following points can be read from Figures 7 and 8:

For the relationship between pipe location and amount of voids:

(1) It was observed that, irrespective of the mixture and for both the permeable and conventional forms, the voids below the pipe increased with increasing distance from the form surface.

(2) For the permeable form and irrespective of the mixture, from the face adjacent to the form to 10cm into the concrete, along the pipe, there was no void under the pipes located at mid-depth and less than 1mm deep voids under the pipes located in the upper section. Similarly for the conventional forms the central depth voids measured 0 to 0.5mm and for the upper section 1 to 2mm. However, for mix A from a depth 20cm from the form and for mix B from 10cm depth along the pipe, the difference between the permeable and the conventional forms is not clear.

(3) With both permeable and conventional forms, for the pipes located in the upper layer and the mid-depth layer, the voids were greater for mix B than mix A. That is to say, with the amount of water per unit of concrete about the same, voids below the pipes developed more easily in the mixture with the lower amount of cement per unit of concrete.

Voids were not observed under the pipes of lower layer.

No definite trend was observed for the relationship between pipe diameter and the amount of voids.

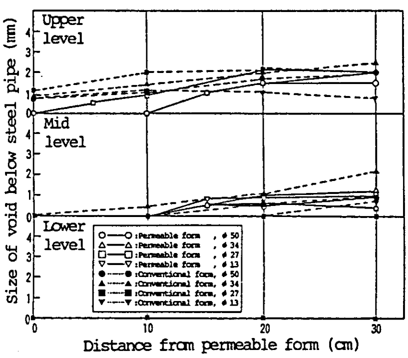


Fig.7 Relationship between Distance from the Form and Size of Voids below Steel Pipes (Mix A)

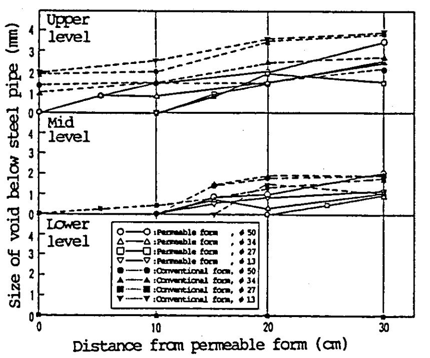


Fig.8 Relationship between Distance from the Form and Size of Voids below Steel Pipes (Mix B)

According to the results obtained above, for the two concrete mixes used in this experiment, it can be concluded that within 10cm of the form surface the concrete made using the permeable form has less tendency to develop voids under the pipes than with conventional forms. It is supposed that this phenonmenon is caused by the following two factors:

(1) In the case of permeable forms being used, as part of the water in the concrete is discharged from the form, the amount of bleeding in the concrete is reduced. The phenomenon observed during the experiment of the reduction in the amount of bleed water rising to the top surface of the concrete in the vicinity of the permeable form also corroborates this supposition.

(2) As a result of the discharge of water at the form surface, horizontal movement of water occurs adjacent to the form and the cement and fine aggregate particles in the concrete, which are carried by this flow of water, fill up the voids. It would be thought that the extent of this filling of the voids would have bounds and according to the results of this experiment this bound was of the order of 10cm depth from the form surface.

5. THE STRENGTH CHARACTERISTICS OF CONCRETE MADE USING PERMEABLE FORMS

5.1 Aim of Experiment

To investigate the extent of the depth from the form surface of the concrete of improved quality and the degree of quality improvement resulting from the dewatering by use of permeable forms. Taking strength as an index to assess concrete quality, this experiment was carried out with aim of determining quantitatively the effect on concrete strength of the reduction in water/cement ratio resulting from the use of permeable forms.

5.2 Outline of Experiment

For concrete made with permeable forms and conventional forms, which involves no dewatering from the form, comparative tests were undertaken of hardness using a Schmidt hammer and of compressive strength.

For the measurement of hardness, reading were taken using a P-type Schmidt Hammer (pendulum type for low strength concrete). For compressive strength, cores were taken from the experimental concrete body and the improved zone of concrete strength resulting from dewatering was studied by examining the relationship between depth from the surface and compressive strength of the cores in the same manner as carried out for the experiment determining the extent of the dewatered zone.

In this experiment the experimental concrete body and the method of placement and compaction of the concrete were the same as for the two experiments already discussed.

The concrete mixture used is shown in Table 3.

Table 3 Mix Proportion of Concrete

Nominal strength (kgf/cm²)	Slump range (cm)	Amount of air range (%)	Water cement ratio W/C (%)	Sand percentage s/a (%)	Unit content (kg/m³)				
					Water W	Cement C	Fine aggregate S	Coarse aggregate G	Admixture
210	8± 2.5	4± 1	60	46.1	163	272	846	1,153	0.272

5.3 Method of Experiment

(1) Measurement of the Amount of Water Discharged

The water discharge from the permeable forms was measured for the upper, middle and lower sections of the form, from completion of concrete compaction until the cessation of discharge, at 15 minute intervals.

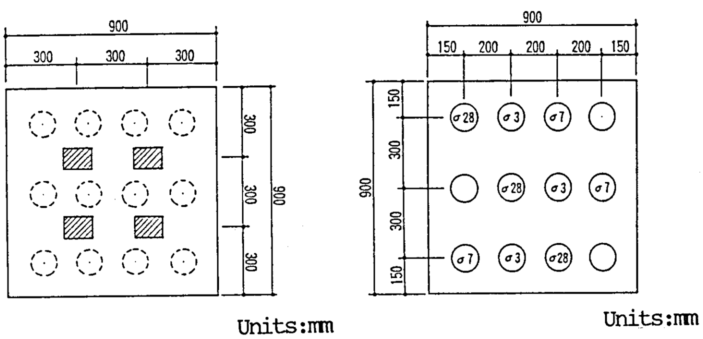
(2) Measurement of Surface Rebound Hardness Using Schmidt Hammer

Rebound hardness was measured using a P-type Schmidt Hammer for low strength concrete. Figure 9 shows the locations where readings were taken. The age of the concrete at the time of the readings was 3 days and 28 days.

(3) Compressive Strength Test of Cores

Figure 9 shows the locations from which the 100mm diameter, 450mm long cores were taken. Each core was cut into 10cm thick sections commencing from the surface adjacent to the form. After cutting, and using those core sections, the variation of compressive strength with depth from the surface adjacent to the form was examined. The experiment was carried out in accordance with JIS A 1108 "The Method of Concrete Compressive Strength Testing" and the calculation of core strengths with JIS 1107 "Method of Cutting from Concrete and Method of Concrete Compressive Strength Testing for Cores and Blocks".

The concrete was tested at ages 3, 7 and 28 days.



(a) Rebound hardness (b) Compressive strength

Fig.9 Location of Reboud Hardness and Compressive Strength Measurment Locations (Plan)

5.4 Experimental Results and Discussion

(1) Amount of Discharge

The results of the measurement of discharge from the permeable form are shown in Figure 10 while the results for discharge from the three regions (upper, middle and lower) are shown in Figure 11. Discharge from the form continued for about 2 hours following completion of concrete placement and the total discharge per unit area of form surface was 1.8 l/m². Comparing the amount of discharge from different locations (Figure 11), the discharge was seen to increase directly with the lowering of the location of the discharge.

Assuming that water discharge is only from concrete of thickness of 10 or 20cm from the form, reduction in water/cemet ratios, calculated in the same way as previously detailed, gives figures of 6.7% and 3.4% respectively.

Compared with the results from the experiment to identify the dewatered zone this experiment gave somewhat smaller values. It is thought that this is due to the differences in the concrete mixtures.

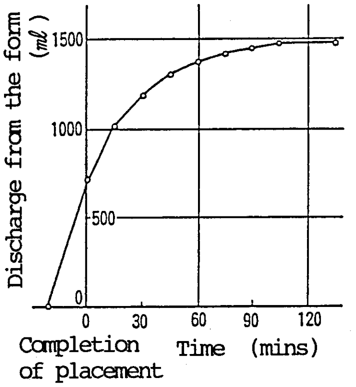


Fig.10 Water Dischage Results (Total dischage)

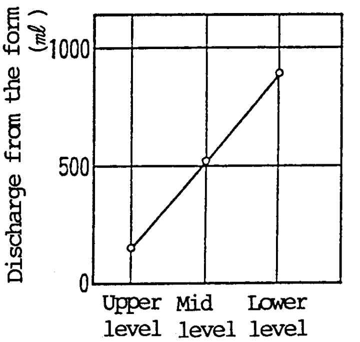


Fig.11 Water Dischage Results (By level)

(2) Rebound Hardness Using Schmidt Hammer

The results of measurement of the rebound hardness using a Low Strength P-type Schmidt Hammer are shown in Table 4. As shown in the Table the hardness of the concrete which used permeable form was 70% higher at 3 days and 40% higher at 28 days than for the conventioanl form case. From this result it can be judged that the improvement in hardness for concrete dewatered by the permeable forms is greater the younger is the concrete. It is thought that the cause of the increased rebound hardness of concrete made with the permeable forms is that with the discharge of water from the form there is an accumulation of cement and very fine aggregate at the concrete surface forming a dense layer.

Table 4 Surface Rebound Hardness Results

Tipe of form	Level	Rebound hardness			
		At 3 days		At 28 days	
Permeable	Upper	57.0	Average	62.5	Average
	Lower	56.5	56.8	63.3	62.9
Conventional	Upper	34.0	Average	44.3	Average
	Lower	34.4	34.2	47.0	45.7

(3) Compressive Strength

The ratio of the compressive strength of permeable form concrete to that of conventional form concrete at varying depths into the cores is shown in Table 5. Each value shown in the Table 5 represents the compressive strength of the permeable form concrete divided by that for the conventional form concrete. In general, and for all ages of concrete, the compressive strength for the permeable form case is increased. This trend is particularly evident in the surface layer from the concrete surface to a depth of 20cm. It is seen that the extent of the zone of increased compressive strength is consistent with the zone determined in the experiment to identify the dewatered zone. Also, for the concrete mixture used in this experiment, the compressive strength of the surface layer (up to about 20cm from the form) on which the permeable form had been used proved to be about 5% greater than for the conventional form case which had no dewatering.

Figure 12 shows the variation of compressive strength with depth from the form surface for the permeable form and conventional form cases. From the point of view of the location from which cores were taken, while some exceptions can be identified, there was a trend for the value of the compressive strength to be greater with the lowering of the location from which cores were taken for both permeable form and conventional form. The cause of this is a combination of factors including:

a) At the time concrete is setting the lower levels of concrete are consolidated by the dead load of the concrete above and the structure becomes more dense.

b) At the lower level the remaining bleed water is low and the bond strength between the aggregate and the cement is greater.

Considering the variation of strength with the depth of the section into the core, in the permeable form case, for cores taken from the lowest level a clear trend was recognised that the closer to the surface the stronger was the concrete, for all ages.

According to the above result, for concrete made using the permeable form, the improved strength zone is seen to be similar to the dewatered zone, that is, of the order of 10 to 20cm thick.

Table 5 Comparative Compressive Strength with Section Location

Level	Concrete age		
(Depth from form)	3 days	7 days	28 days
① 0～10cm	1.07	1.06	1.06
② 10～20cm	1.03	1.07	1.05
③ 20～30cm	1.03	1.08	1.02
④ 30～40cm	0.99	1.04	1.00
Average	1.03	1.06	1.03

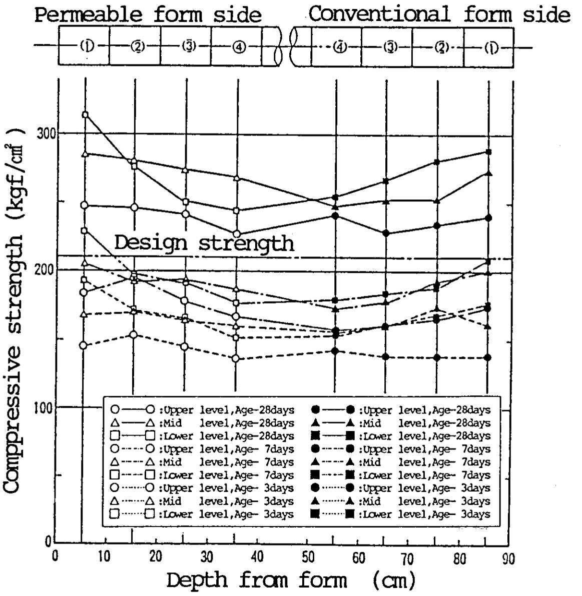


Fig.12 Results of Compressive Strength Test

6. CONSIDERATION OF THE DEWATERING MECHANISM WITH PERMEABLE FORMS

The following points can be read from the results of experiments carried out in this study in relation to the movement of pore water in concrete made using permeable forms.

(1) In addition to the vertical movement of water with bleeding, discharge from the form induces horizontal water movement.

(2) Following the completion of placement, discharge also occurs without disturbance of the concrete.

(3) The horizontal movement of water occurs predominately within an extent of 10 to 20cm from the form.

Also, considering the relationship between elapsed time and discharge amount, about one half of the total discharge volume occurs in a short time during placement and compaction, while the remaining amount discharges continuously over a long period. In other words, about the same amount of water is discharged in two greatly different time periods, during placement and after placement, and it is postulated that the mechanism of dewatering in these two phases is distinctly different (refer to Figure 13).

Firstly, for the dewatering mechanism during placement it is thougth that when concrete is placed inside the forms and compacted, paste collects along the form due to the sheathing effect [5] in the same way as for conventional forms and restrains the discharge. However when this is followed by vibration, a " forced dewatering" occurs due to the vibration pressure. With this forced dewatering, the paste again collects and with the formation of a dense paste layer the resistance to discharge gradually increases and the speed of discharge (the volume of discharge per unit time) is reduced. As a result, in the main, this first stage dewatering can be characterised as Forced Dewatering.

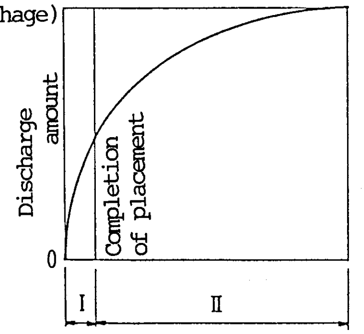


Fig.13 Relationship between Elpased Time and Amount of Water Discharge

The next stage of dewatering, not involving a forced discharge of water, can be termed "spontaneous dewatering". The mechanism of Spontaneous Dewatering is clearly attributable to the void water pressure in the fresh concrete.

Even during the Forced Dewatering stage the pore water pressure distribution is expected to be that of hydrostatic water pressure for the depth of concrete placed. However, with the action of the vibrators during the placement of concrete, it is supposed that the distribution of pore water pressure becomes very complex due to the development of excess pore pressures.

For the static situation of concrete undisturbed by vibrators, it can be inferred from the previous discussion of the results of the water level recorders installed within the concrete (Figure 5), that the pore water pressure distribution in the vertical direction in the early stages of setting is similar to a hydrostatic water pressure distribution. Further, in the case of the permeable form, the pore water pressure in the horizontal direction at the form surface is theoretically zero. Accordingly during the Spontaneous Dewaterig stage the pore water pressure is zero at the form surface and increases with distance from the form and finally it becomes constant. This distribution can be represented as a parabolic distribution. With the horizontal distribution of pore pressure with distance from the form face assumed as parabolic ($y=x^{1/2}$) and the vertical distribution with depth from the in-situ concrete surface taken as triangular (i.e. increasing linearly from zero at the surface), the resultant vector of the difference of pore water pressure can be determined.

Figure 14 is a representation of any four contiguous squares taken from a square mesh diagram such as Figure 15. The resultant vector at each intersection point of such a square mesh diagram, as in Figure 15, can be calculated as shown in Figure 14. For example, the vertical component of the resultant vector for point k is shown as the difference in vertical pore pressure between points k and i (V = Vk - Vi) and the horizontal component as the difference in horizontal pore water pressure between points k and j (H = Hk - Hj).

The diagram of resultant vectors is constructed using axes scaled in whole numbers with the intersection point between the top surface (horizontal) and the form surface (vertical) of the in-situ concrete assigned as the origin. The resultant vector of the pore water pressure at each point is shown in Figure 15 as an arrow at each point of intersection. The magnitude of the resultant vector is obtained using the scale at the bottom of Figure 15.

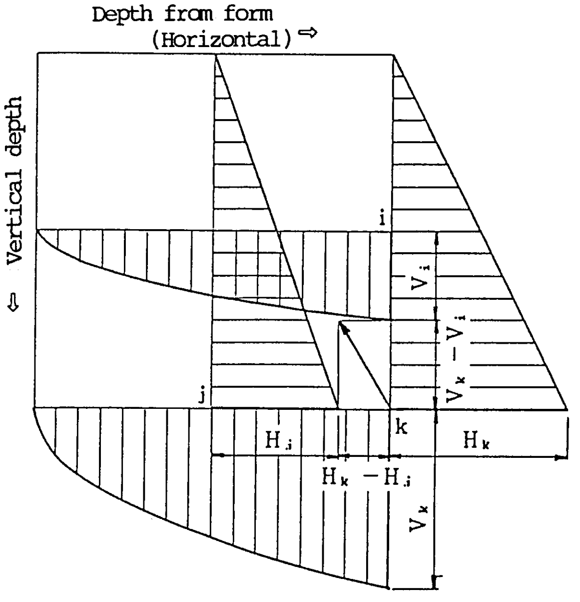


Fig.14 Idealization of Pore Water Pressure Difference

From the model of resultant vectors of pore water pressure differences shown in Figure 15, the following points can be concluded:

(1) With the permeable form, the resultant vector increases with vertical depth into the placed concrete. This indicates that the discharge of water occurs more readily with depth.

(2) The horizontal component of the resultant vector increases with proximity to the form. This indicates that the discharge occurs more readily with proximity to the form.

(3) There are zones where the vertical component of the resultant vector is greater than the horizontal component. This indicates that horizontal movement of pore water is limited.

As these results conform with the results of the previously mentioned experiments it is concluded that the Spontaneous Dewatering that occurs with the permeable form is due to the difference in pore water pressures in the direction perpendicular to the form (i.e. horizontal, in this case).

The contribution of this Spontaneous Dewatering to the formation of the dense paste layer was not evaluated but it is thought there is movement of the solid fine particles (i.e. cement, very fine aggregate and initial hydration products and so on) resulting from the horizontal movement of pore water. It is thought that these very fine particles further densify the dense surface layer created during the Forced Dewatering stage.

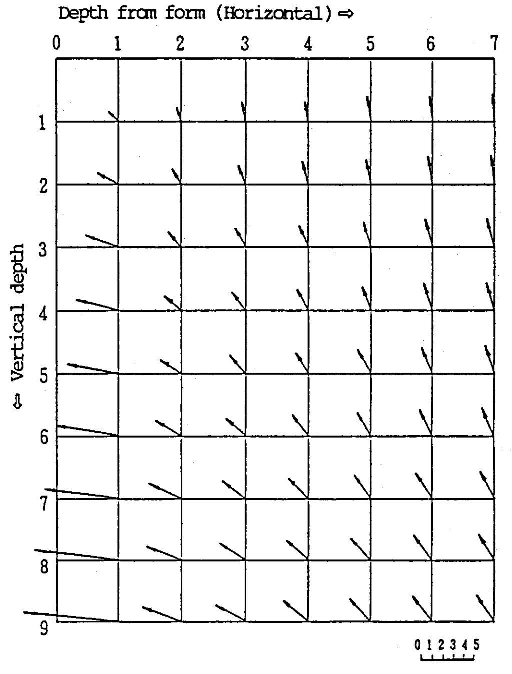


Fig.15 Resultant Vectors of Pore Water Pressure Difference

7. CONCLUSION

This study investigated the improved quality zone in concrete and considered the mechanism of discharge of excess water by conducting:

(1) An experiment on the zone of excess water discharge from within the concrete when using permeable forms.

(2) An experiment to identify the effect of the dewatering on bleeding.

(3) An experiment investigating the strength characteristics of concrete made using permeable forms.

The results of the experimental research undertaken in this study may be summarised as follows:

(1) With the use of the permeable forms, in addition to the vertical movement of water by bleeding, horizontal movement is induced by the dewatering from the forms. The bulk of this horizontal water movement was limited to an area of within about 10 to 20cm from the form surface.

(2) With the use of permeable forms, the voids occurring under steel pipe fixtures within the concrete occurred to a lesser degree than for

conventional forms. This phenomenon was observed in an area to about 10cm depth from the form.

(3) With the case of the permeable forms, rebound hardness as measured by a Schmidt Hammer was increased by about 70% at 3 days and 40% at 28 days when compared with the conventional form case.

(4) With the use of permeable forms, compressive strength of the surface layer (10-20cm) was increased as compared to the conventional form case. In particular, at the lower level where the amount of water discharged was high, the tendency that, the closer to the form surface the higher would be the compressive strength, was clearly identified.

Consequently the zone of improved concrete quality can be considered to be from the surface to about 10 to 20cm depth. From that, for reinforced concrete structures, it can be expected that the permeable forms will contribute to the suppression of development of rust in the cover area and the improvement of bond strength between horizontal reinforcement and concrete.

Further, based on these results, the considerations in relation to the mechanism of the discharge of excess water from within the concrete can be summarised as follows:

(1) The mechanism of dewatering by the permeable forms at the time of concrete placement is different to that after placement is completed. The former can be called Forced Dewatering and the latter Spontaneous Dewatering.

(2) Spontaneous Dewatering results from pore water pressure differences in the concrete with distance from the face of the form. With Forced Dewatering and later Spontaneous Dewatering a fine paste layer develops at the surface of the concrete. However the contribution of each type of dewatering to the formation of the paste layer is not quantitatively known. This point will have to be further elucidated to evaluate the effect of Spontaneous Dewatering which is characteristic of permeable forms.

In the future we intend to continue research and development of the characteristics of concrete made with permeable forms and to develop formwork that has wider application than possible with current types of formwork (Intelligent Form).

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