L10

# 港湾技研資料

TECHNICAL NOTE OF
PORT AND HARBOUR RESEARCH INSTITUTE
MINISTRY OF TRANSPORT, JAPAN

No. 26 September, 1966

## プレパックドコンクリートの型わくに作用する圧力について

**赤塚 雄三**

## PRESSURE ON FORMS OF PREPACKED CONCRETE

**By Yuzo Akatsuka**

昭和41年9月

運輸省港湾技術研究所

国土技術政策総合研究所
図書室
蔵書

TECHNICAL NOTE OF PORT AND HARBOUR RESEARCH INSTITUTE,
MINISTRY OF TRANSPORT

# No. 26, "PRESSURE ON FORMS OF PREPACKED CONCRETE"

By Yuzo Akatsuka

## ERRATA

| Page | Line* | To be corrected | Correct |
|---|---|---|---|
| 3 | 18 T | 1: | P: |
| 3 | 15 B | whtich | which |
| 3 | 12 B | conriderably | considerably |
| 3 | 11 B | coefficiont | coefficient |
| 7 | 3 T | suɪface | surface |
| 7 | 3 B | movment | movement |
| 9 | 5 B | Pressured | Pressure |
| 10 | 2 T | 0,56 kg/ɔm$^2$ | 0,56 kg/cm$^2$ |
| 10 | 7 T | velue | value |
| 11 | 7 T | increace | increase |
| 11 | 12 T | pressures | pressures were |
| 11 | 6 B | spricific | specific |
| 11 | 4 B | spacific | specific |
| 12 | 11 T | volues | values |
| 12 | 19 T | Pressure No. 3 | Pressure Gage No. 3 |
| 12 | 15 B | vicinty | vicinity |
| 12 | 4 B | Pressre | Pressure |
| 13 | 14 T | neglible | negligible |
| 13 | 17 B | sid | side |
| 13 | 10 B | pressre | pressure |
| 14 | 13 T | $p \quad r_p\, h' + \cdots\cdots$ | $p = r_p\, h' + \cdots\cdots$ |
| 14 | 2 B | inadequae | inadequate |
| 15 | 7 — 6 B | "Basic Studies of Control of Practices in Prepacked Concrete for Harbour Works," | "Basic Studies on Quality Control of Prepacked Concrete for Harbour Construction Works," |

---

*T and B indicate the line number from top and bottom, respectively.

# PRESSURE ON FORMS OF PREPACKED CONCRETE

By Yuzo Akatsuka*

## 1. Foreword

Of the cost elements in concrete construction, the proportion occupied by formwork will depend on the type of structure and conditions in the field. For ordinary reinforced concrete this proportion is said to be 20 to 30 percent. In comparison, with prepacked concrete, for structures of massive plain concrete such as breakwaters, the cost is 10 to 20 percent, for breakwaters with smaller cross-section 20 to 30 percent and for reinforced concrete structures such as caissons and L-blocks about 30 to 40 percent [1] so that the cost of formwork is relatively higher than for conventional concrete. Another feature about prepacked concrete is that bulging of forms or separation at joints often comprise causes of damaging leakage of mortar. Therefore, it is believed a proper evaluation of pressure acting on forms is an important factor governing the success and economy of the construction project.

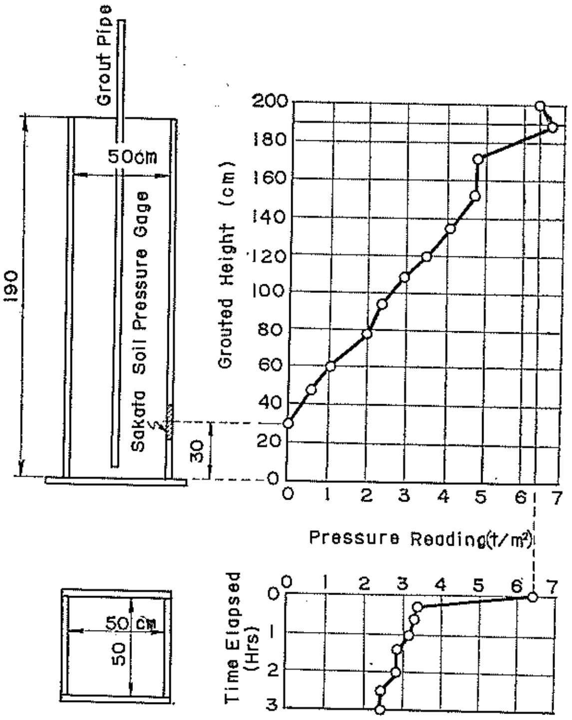
## 2. Past Data and Limits of Application

There have been only a very little number of studies of pressure acting on forms except for a few cases of actual observations and publication of estimating formulae.

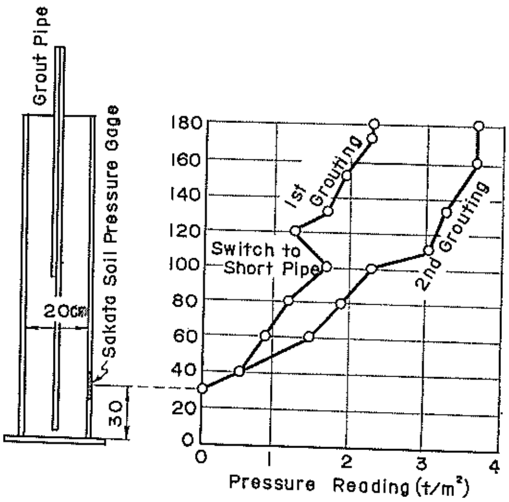
Fig. 1 (a), (b) is one of the cases, showing results of tests conducted by N. Kubo. [2] In these tests, only the pressures at the time of grouting with mortar were measured and apparently readings of pressure gages were adjusted to zero after placing of aggregate. In the test of Fig. 1 (a) the object to be grouted was a columnal object of small cross-section. Also, as the pressure gage was installed near the outlet of the grouting pipe, the result was that both dynamic and static pressures were measured simultaneously so that the pressure at the time of grouting was comparatively great. However, inmediately after completion of grouting, the pressure was reduced to approximately

---

* Dr. Eng., Chief Research Engineer, Materials Laboratory, Structure Division



(a) 0.5 x 0.5 = 0.25m²



(b) 0.2 x 1.9 = 0.38m²

Fig. 1 Example of Actual Measurements of Pressure Borne by Forms when Grouting with Mortar

Pump pressure = 2 kg/cm², Grouting speed = 14 liters/min, Coarse Aggregate = 15~40 mm, Flow-out time =18~22 sec one-half, so that there remained a pressure amounting to the following:

Static pressure of mortar $= 2.0 \times (1.9 - 0.3) = 3.2$ t/m$^2$

In the test of Fig. 1 (b) there is considerable difference between the two measurements, but the average is roughly equal to the static pressure of the mortar. In comparison with the test of Fig. 1 (a) the grouting pressure is generally small, but this is presumed to be due to the decrease in dynamic pressure caused by increase in the grouted area and the increase in distance between outlets and pressure gages due to switching of grout pipes.

R. Sugiki and K. Horimatsu 3) have proposed the following equation for estimating the maximum dynamic pressure acting against forms:

$$P = \frac{0.1\ rh}{d} + 3.6 \frac{v}{Vd^2} \cdots\cdots\cdots\cdots (1)$$

where r: weight of mortar per unit volume (t/m$^3$)
h: height of grout from outlet (m)
d: shortest distance from outlet to nearest form surface (m)
v: velocity of grout from outlet (m$^3$/min)
V: volume of concrete within range grouted from outlet with mortar (m$^3$)
l: maximum dynamic pressure acting against forms (t/m$^2$)

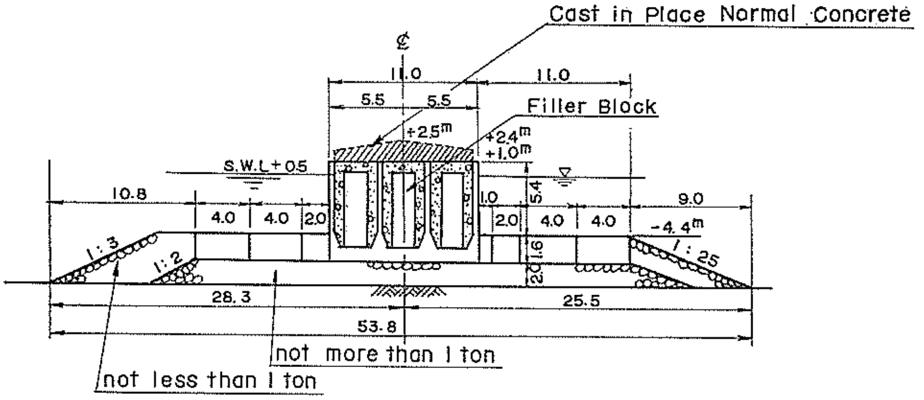
There are examples of the estimated dynamic pressure calculuted from this equation having agreed with actual observed values 4), but the shortcoming of of this equation is that P will vary greatly depending on the values at whtich d and V are determined (when $d = o$ then $p = \infty$ ).

According to experiments made by the author 5), the range reached by mortar from one outlet will vary conriderably depending on fluidity of mortar, grouting speed, intrusion coefficiont of coarse aggregate and dimensions of formwork section, but under normal conditions it can be considered to be 2 to 3 m. As the dynamic pressure at the edge of the range reached is zero, the area in which the pressure works effectively will be considerably limited. Therefore, although it may be important to estimate the maximum pressure, it is not necessarily appropriate to use this as basic data for design of formwork.

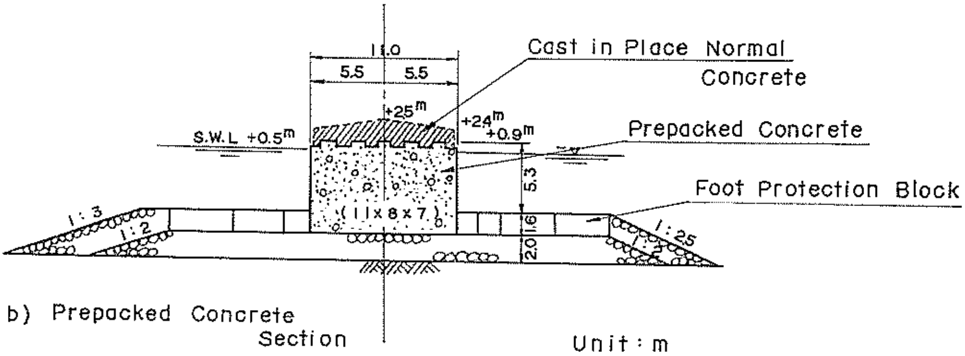
The foregoing are representative samples of published information regarding pressure acting on formwork. Each contains elements subject to influence of conditions of measurement or application so that they are inadequate for obtaining data by which pressure can be accurately evaluated. Furthermore, when it comes to pressure from dumping of coarse aggregate, there are not even actual measurement data which have been reported. In this paper, the test results of the prepacked concrete work for the Port of Akita South Breakwater Project[6] will be introduced and a study made of the pressures acting on formwork at time of placing aggregate and of grouting of mortar.

## 3. Conditions of Pressure Measurement and Results of Measurements

The grouted objects which were observed were blocks of prepacked concrete connecting caissons ( 8 × 11 × 7m ) spaced one caisson length apart. The standard cross-section is shown in Fig. 2. The shape and dimensions of the steel forms used and the locations of pressure gages (Unyu-Gijutsu-Kenkyujo, Kowan-Shisetsubu, Type No. 5 automatic recording soil pressure gage) are as shown in Fig. 3. Fig. 4 indicates the method by which pressure gages were mounted. The grouted blocks were 9 m long, 11 m wide and 7 m high.



(a) Caisson Section



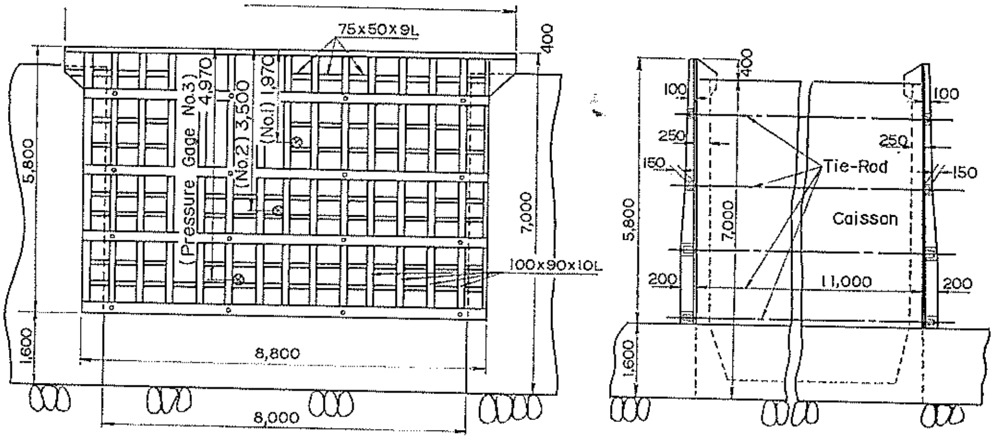
(b) Prepacked Concrete Section

Unit : m

Fig. 2 Standard Section of Port of Akita South Breakwater

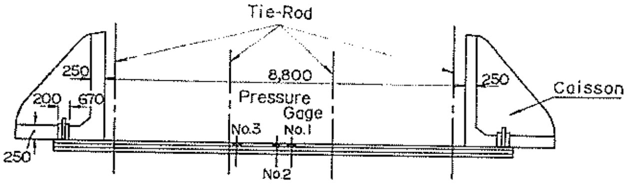
On the sides at the bottom were placed foot protection blocks 1.6 m high as shown in Fig. 2 so that these were used as parts of the forms. Therefore, the height of forms on which pressure gages were mounted was 5.8 m including 0.4 m superfluous at the top. Grouting of mortar was started at 8:00 hours on October 10, 1959 and was continued for 25 hours when it was stopped due to stormy weather. Fig. 5 shows the locations of grout pipes and the change in the free surface of the mortar according to time.

When measuring pressure working on forms, deformation of the forms must be considered. In other words, forms will be deformed by placing of aggregate and grouting of mortar as shown in Fig. 6 (a), but there will be a restorative force which will work to press the bearing surface of the pressure gage against the concrete so that the pressure of the concrete is recorded. This condition is continued after hardening so that after the pressure is removed a reading of the pressure gage can be obtained and a pressure approximately equal to that before hardening is recorded. In these tests a device was



(a) Side Elevation (b) Cross Section

(Unit: mm)



(c) Plan

Fig. 3 Shapes and Dimensions of Forms and Locations of Pressure Gages

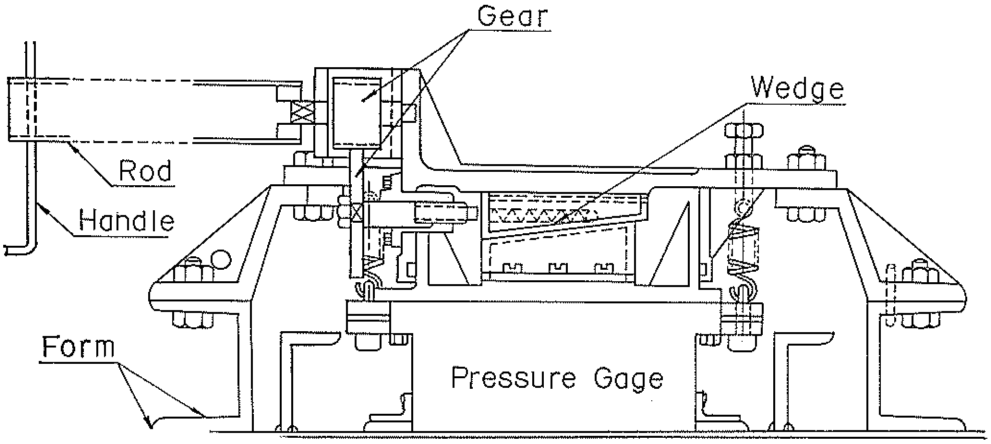


Fig. 4 Unyu-Gijutsu-Kenkyujo, Kowan-Shisetsubu, Type No. 5 Soil Pressure Gage and Method of Mounting

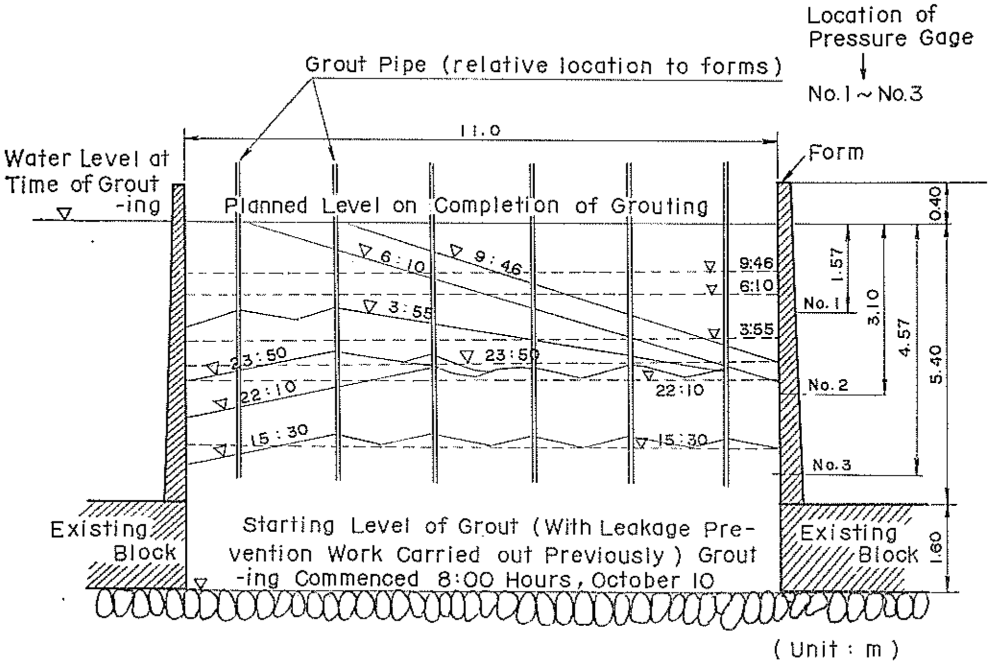


Fig. 5 Time of Measurement of Mortar Surface and Estimated Level

| | |
|---|---|
| Solid line : | Mortar surface estimated from assumption of average grade of slope to be approximately 1 : 6 and from height of grouted mortar observed using grout pipe as depth gage. |
| Broken line : | Average level of mortar assumed from quantity of mortar grouted and estimated mortar surface. Grouting discontinued at 9 : 46 hours, October 11 due to stormy weather. |

attached as shown in Fig. 4 so that the bearing surface of a pressure gage could be moved slightly parallel either towards the concrete or in the opposite direction (the sea side), and by occasionally moving the bearing surface it was attempted to remove the influence of the hardening of concrete. While the mortar possessed fluidity, the space formed by movement of the bearing surface would be filled by the movement of the mortar as shown in Fig. 6 (b) and it was thought the pressure borne by the bearing surface would be restored. The movement of the bearing surface was accomplished by turning of the handle shown in Fig. 4, arranged so that 1/8 of a turn would produce a movement of 0.025mm.

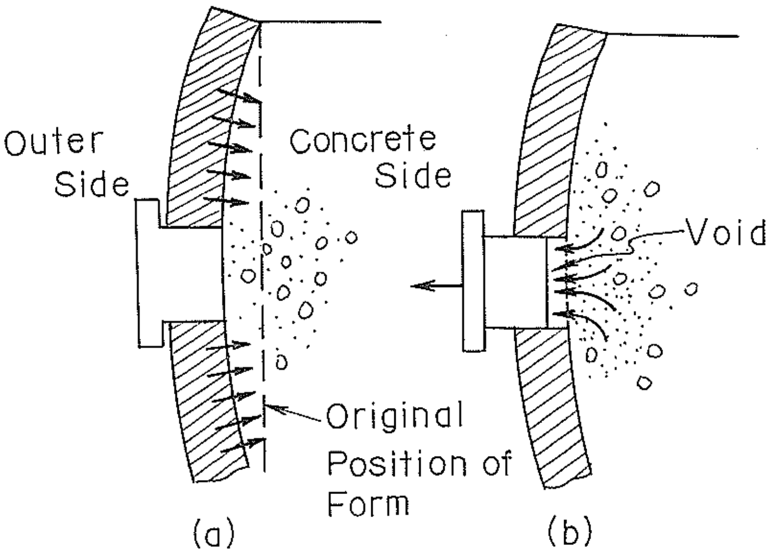


Fig. 6 Deformation of Forms and Location of Pressure Gage

The results of the measurements are as shown in Fig. 7. The circle and triangle symbols in the graph indicate movment by 0.25 mm of the pressure gage bearing surface to the sea side and the concrete side, respectively. In Table 1, the conditions for proportioning of mortar are given.

## Table 1 Proportioning Conditions of Mortar

| Mix proportions of grouted mortar | Materials for mortar |
|---|---|
| F/ (C+F) = 37.5 %<br>S/ (C+F) = 93.8 %<br>W/(C+F) = 53 %<br>Aid/(C+F) = 1.0 % | C : Tohoku Kaihatsu normal portland cement<br>F : Joban fly ash<br>Aid : Intrusion Aid<br>W : Sea water<br>S : Ohama beach sand, Sp. Gr. = 2.59, F.M. = 2.33<br>Oiwake bcach sand, Sp. Gr. = 2.65, F.M. = 1.95 |

| | | Sp. Gr. | Void Ratio % | F. M. | Max. size mm | Min. size mm |
|---|---|---|---|---|---|---|
| Coarse Aggregate | Iwami River gravel | 2.54 | 37.9 | 9.37 | 80 | 25 |
| | Asahi River gravel | 2.67 | 39.9 | 9.50 | 100 | 25 |

| | | |
|---|---|---|
| Preliminary test results | Grout setting time | Initial, 7 hrs 1 min ; Final, 8 hrs 47 min |
| | Grout mix proportions | F/ (C+F) = 33.3 %, W/ (C+F) = 42.5 %,<br>Aid/ (C+F) = 1.0 % |
| | Test conditions | Flow test of grout = 15 sec, Temperature = 19.5°C |
| | Expansion ratio of morta | Expansion at 4 hours = 10.0 %, Bleeding = 1.0 % |
| | Test conditions | Flow test of grout = 20.6 sec,<br>Storage temperature = 20.0°C |

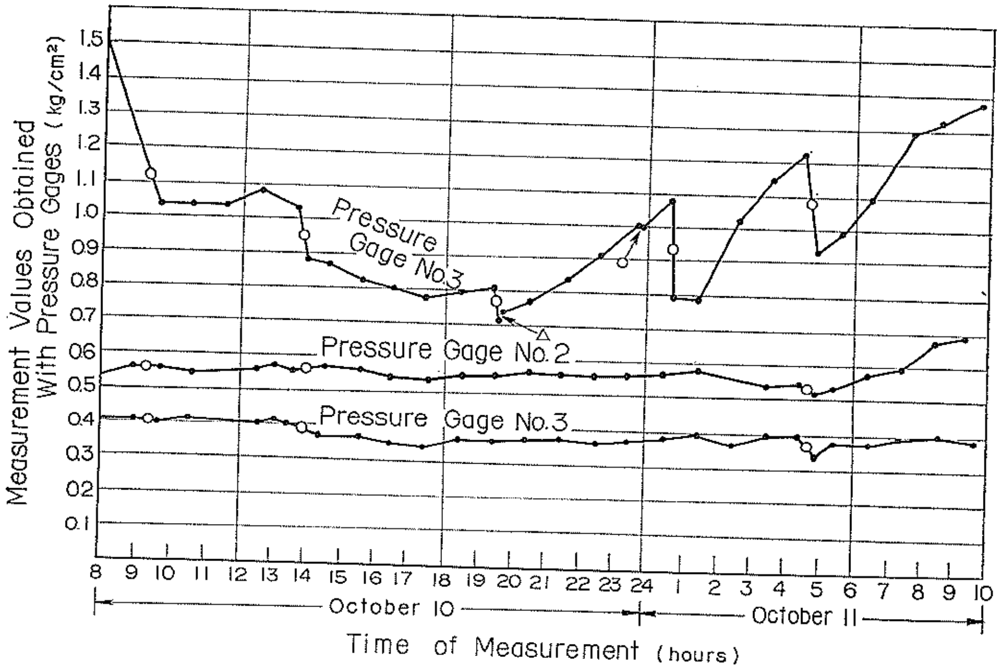


Fig. 7 Time of Measurement of Pressure Acting on Forms and Measurement values Obtained with Pressure Gages

○ indicates movement of pressure gage bearing surface by 0.025 mm in direction opposite to concrete (to sea side)

△ indicates movement of pressure gage bearing surface by 0.025 mm in direction of concrete

## 4. Pressure at Time of Placing Aggregate

Judging from the change with time of the mortar surface, it is estimated the mortar reached the levels of Pressure Gages No. 3 and No. 2 between 14:00 and 15:00 hours on October 10th and 4:00 and 5:00 hours on Octcber 11th respectively. Also, it is thought the mortar did not reach the level of Pressure Gage No. 1. Therefore, the gage reading obtained previously indicates the pressure to which the form was subjected when coarse aggregate was dumped. A study of the values measured shown in Fig. 7 would be as follows:

(1) Pressured Gage No. 1

The influence of wave pressure is included in the readings of Pressure Gage No. 1 so that the mean value is taken to cancel this influence and leave only the pressure at the time of placing of coarse aggregate, which is 0.39 kg/cm$^2$.

(2) Pressure Gage No. 2

Taking the mean value 0.56 kg/ɔm$^2$ of readings for 8:00 hours to 11:05 hours on October 10th, the pressure at time of placing of coarse aggrate is obtained.

(3) Pressure Gage No. 3

Pressure Gage No. 3 was situated at the lowest point of the three pressure gages and at the beginning showed an extremely high velue of 1.5 kg/cm$^2$. This was thought to be due to the packing of coarse aggregate from impact of repeated dumping which caused the type of deformation shown in Fig. 6 (a). The fact that the pressure was reduced drastically by movement of the pressure gage to the sea side by 0.025 mm at a time and that this reduction was as much as 0.89 kg/cm$^2$ for two movements makes this clear. It was estimated that the pressure at the time of placing of coarse aggregate was of this order.

(4) Summary

Pressure working on forms are due to coarse aggregate and sea water. Assuming distribution of hydrostatic pressure of a fluid with a density corresponding to the unit volumetric weight of the coarse aggregate with interstices filled by sea water ($r_a = 2.0$ g/cm$^3$), the pressures at the locations of Pressure Gages No. 1 to No. 3 are calculated.

The comparison with measured values are shown in Table 2. It is seen that the measured values at points near the surface are larger than the calculated values assumed to represent distribution of hydrostatic pressure, while on the other hand at lower points the measured values are smaller than calculated values and indicate pressure distribution similar to distribution of soil pressure. However, there is only a slight difference between measured and calculated values so that it can be said the distribution of pressure to which forms are subjected

**Table 2**

| | Calculated value (C) | Measured velue (M) | $\frac{(M-C)}{C}$ (%) |
|---|---|---|---|
| No. 1 | 0.314 kg/cm$^2$ | 0.39 kg/cm$^2$ | + 24.2 |
| No. 2 | 0.620 〃 | 0.56 〃 | − 9.7 |
| No. 3 (Static) | 0.914 〃 | 0.89 〃 | − 2.6 |
| No. 3 (Impact) | (0.914) 〃 | 1.50 〃 | + 64.1 |

when coarse aggregate is placed may be considered approximately as the distribution of hydrostatic pressure of a fluid with a density corresponding to the unit volumetric weight of coarse aggregate (in water, the value corresponding to the aggregate with voids filled with water). For the pressure occurring when aggregate is compacted by the impact of dumping, it can be considered suitable to include an increace of about 60 to 70 percent of the calculated values obtained from the above described hydrostatic pressure distribution.

## 5. Pressures when Grouting with Mortar

Regarding pressures acting at time of grouting, there are the hydrostatic, dynamic and expansion pressures of mortars. As the mortar did not reach Pressure Gage No. 1, this will be excluded and the pressures considered for Pressure Gage No. 2 and No. 3.

(1) Pressure Gage No. 2

From the reduction of pressure by movement of the bearing surface at 4:30 hours on October 11 and the condition of recovery thereafter, it can be considered that the mortar reached Pressure Gage No. 2 between 4:00 and 5:00 hours on the 11th. The pressure rise from 4:30 hours is approximately linear, the maximum pressure being 0.7 kg/cm$^2$. Calculating the pressure at the location of Pressure Gage No. 2 assuming the mortar surface to be near Pressure Gage No. 1 at this time and that the pressure of unhardened prepacked concrete is hydrostatically distributed, a value of 0.674 kg/cm$^2$ is obtained and the difference with the observed vslue is +3.90 % of the calculated value.

Pressure from prepacked concrete

$= 2.36 \times (310 - 160) = 354$ g/cm$^2$

Pressure from saturated coarse aggregate

$= 2.00 \times 160 = 320$ g/cm$^2$

where unit volumetric weights 2.36 and 2.00 are based on the calculation below

(i) Average sprcific gravity of coarse aggregate

$= (2.67 + 2.54) \div 2 = 2.60$

Average spacific gravity of mortar $= 2.00$

Void ratio of coarse aggregate $= 40$ %

Unit volumetric weight of prepacked concrete

$= 2.60 \times 0.6 + 2.00 \times 0.4 = 2.36$ (g/cm$^3$)

(ii) Average specific gravity of coarse aggregate = 2.60
Average specific gravity of sea water = 1.04
Unit volumetric weight of saturated coarse
aggregate = $2.60 \times 0.6 + 1.04 \times 0.4 = 2.00$ (g/cm$^3$)

The period of time required from the mortar first reached the bearing surface until maximum pressure was attained was about 6 hours. However, although it is thought setting and expansion had progressed to some degree, the above calculations would include the several percent of error due to assumption that pessure of saturated coarse aggregate is hydrostatically distributed and it cannot be judged that the difference with the actual measured volues was due to the expansion pressure.

(2) Pressure Gage No. 3

It was around 14:00 to 15:00 hours on October 10 when mortar reached Pressure Gage No. 3, but it can be considered the mortar started to rise from 19:30 hours. Assuming the mortar rose smoothly after this, it is estimated the level of the mortar surface was about 2 m above the pressure gage. Calculating the pressure due to hydrostasic pressure distribution at the location of Pressure No. 3 in the same manner as in the case of Gage No. 2, a value of 0.986 kg/cm$^2$ is obtained and the difference with the observed value 1.046 kg/cm$^2$ is + 6.1 % of the calculated value. The sudden drop (0.3 kg/cm$^2$) in pressure from movement of the bearing surface to the sea side at 0:30 hours, the time required for recovery and the time elapsed after the mortar reached the vicinty of the pressure gage (approximately 10 hours) indicate that the mortar in this vicinity had lost quite a bid of its fluidity, and it is thought the above mentioned differnce with the actual measured values includes the influence of expansion pressure. Therefore, the readings of the prssure gage after this can be estimated to be the sum of the hydrostatic pressure and the expansion pressure. The pressure which was recovered at 3:00 hours on October 11 rose smoothly after this, but was reduced again by movement towards the sea side at 4:30 hours. From the fact that it required 3 hours for recovery, it can be judged that setting had progressed considerably. Assuming the location of the mortar surface at 9:46 hours of the 11th to be near Pressre Gage No. 1 and calculating the pressure at Gage No. 3 a value of 1.020 kg/cm$^2$ is obtained and the difference with the observed value 1.400 kg/cm$^2$ is 37.2 %. However, in the measured values, the pressure from residual deflection, (0.07 + 0.15) = 0.22 kg/cm², due to movements toward the sea side at 0:30 hours and 4:30 hours on the 11th are added as apparent pressure and when this is deducted from the measured values the actual pressure becomes 1.18 kg/cm². The difference with the calculated values is then 0.16 kg/cm², roughly corresponding to the expansion pressure of the mortar.

(3) Summary

Summarizing the above, in regard to the maximum pressure acting in forms at the time of grouting mortar, it would be permissible to think of it as about the sum of the hydrostatic pressure of a fluid with a density corresponding to the unit volumetric weight of the prepacked concrete and the expansion pressure of about 0.14 kg/cm². The influence of dynamic pressure is limited to a very small range as described in 2. and in these tests also it is found to be neglible.

## 6. Effective Pressure Acting on Forms and Estimating Formula

In the experiment described in 3.~5. the pressure acting on the bearing surface of the pressure gage is the measured value. When water or other matter does not exist on the outside of the forms, pressure corresponding to the measured value will be working, but as in the case of this experiment, when there is sea water or the like on the opposite sid of the bearing surface, the hydrostatic pressure due to this will work on the forms in the opposite direction and it is clear that this equalizes part of the pressure recorded by the pressure gage. Therefore, the effective pressure working in the form is equal to the difference between the pressure described in 3.~5. and the equivalent of the hydrostatic pressure of sea water.

However, when building formwork in sea water, the sea water level is not always the same and the hydrostatic pressre working from the outside will become lower than the average water pressure due to the influence of waves so that it will be safer to provide a structure which can withstand the pressure described in 3.~5., From this viewpoint and based on the results of the considerations in 4.~5.. formulae for estimating pressure working on forms would be as given below.

Pressure at time of placing coarse aggregate

$p = (1 + i)\, r_a h$ ·································· (2)

p : pressure acting on forms at time of placing coarse aggregate (t/m²) i : impact coefficient at time of placing coarse aggregate $0.6 \sim 0.7$

h : height filled with coarse aggregate (m)

$r_a$ : saturated unit volumetric weight of coarse aggregate ($t/m^3$)

$$\text{in air} : \left(\frac{100-e}{100}\right) \rho_a$$

$$\text{in water} : \left(\frac{100-e}{100}\right) \rho_a + \frac{e}{100} \rho_w$$

e : void ratio of coarce aggregate (%) , in ordinary cases this may be taken as 40 %

$\rho_a$ : specific gravity of coarse aggregate

$\rho_w$ : specific gravity of water

Pressure at time of grouting with mortar

$$p \quad r_p h' + r_a (h - h') + 1.4 \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

p : pressure acting on forms when grouting with mortar ($t/m^2$)

$r_p$: unit volumetric weight of prepacked concrete ($t/m^3$)

$$= \frac{e}{100}\rho_m + \frac{100-e}{100}\rho_a$$

h' : height grouted with mortar (m)

$\rho_m$ : unit volumetric weight of mortar, in ordinary cases this may be taken as 2.0 ($t/m^3$)

1.4 : constant corresponding to expansion pressure of mortar

## 7. Closure

With a view to deriving a practical method of estimating the pressure acting on prepacked concrete forms, the author has made a study of data presented in the past, following which Equations (2) and (3) are suggested based on results of experiments at Port Akita. However, since there are few examples of actual measurements of the pressure of prepacked concrete, ascertainment of the suitability of these equations is inadequae. Suggestions of readers in regard to this problem would be greatly appreciated.

## References

1) Port and Harbor Research Institute : "Selected Works of Prepacked Concrete in Japan," Japan Society of Civil Engineers, Concrete Library, No. 13, 312 pp, March, 1965.

2) Naoshi Kubo and Jiro Saito : "Theory and Practice of Prepacked Concrete," Kindai Tosho, pp 55—53, July, 1964.

3) Rokuro Sugiki and Kazuo Horimatsu : "Methods of Concreting," Sankaido, p. 185, April, 1959.

4) Shin Kudo : "Remodeling of Tunnel by Lining with Grouted Concrete," Morioka Construction Bureau, Japanese National Railways.

5) Yuzo Akatsuka : "Basic Studies of Control of Practices in Prepacked Concrete for Harbor Works, " Report of Port and Harbor Research Institute, Vol. 4, No. 6, 93pp., December, 1965.

6) "Report on Construction of Port of Akita South Breakwater Prepacked Concrete," Ministry of Transport, Akita Port Construction Office, Project Data (unpublished) 35 pp, March, 1960.

(Received by the Institute, August 15, '66.)