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STUDIES ON APPLICATION OF REGULATED SET CEMENT CONCRETE TO EMERGENCY WORKS

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SYNOPSIS

The thing most demanded in emergency works is to accurately grasp the strength at early age after concrete is placed. The strength of regulated set cement cocrete is affected by the cement content, temperature of placing concrete, atmospheric temperature, the quantity of concrete to be placed and so on, accordingly so far, it has been difficult to accurately estimate the strength at early age.

Therefore in this study, the method of accurately estimating the strength at early age of the regulated set cement concrete for emergency works was devised. Besides, it was clarified by using a statistical method what extent of reliability this estimating method has.

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1. Preface

Regulated set cement has become widely known, and as it's recognition is understood more and more, it has become used in many fields, recently it is used many times in emergency works.

Especially in recent years, the remarkable increase of traffic has quicken the wear of the road, and increased the frequency of repairs, moreover it isn't often possible to close the road for a long period of time, so to use regulated set cement for emergency paving works has become common. The other usages are, for expansion joints for bridges, for railroad crossings that needs emergency spot repairs, and for others like flooring system for factory, and foundation of machinery, to shorten the construction period and reduce the loss from non-operation period.

Researches carried out in the past, that placed the regulated set cement's application to emergency work as the main object, are below.

Research by Kamao[1] et al., is when using the regulated set cement concrete, in low temperature condition, than water reducing agents are effective in generating strength, in short period of time. Researches by Uchikawa[2,3] et al.'s groups, are when using the regulated set cement concrete for emergency works, to generate early strength in low to high temperature conditions, 3~5 hours are enough to be in practical strength; also for temperature stress, it is no problem for the flooring system's temperature rises quite high but the temperature differences inside the flooring system are relatively small: and by adding a suitable amount of steel fiber to the regulated set cement concrete, the increase of early bending strength is especially outstanding. These researches are very useful when using the regulated set cement for emergency works. However, what is needed most while emergency works, are to grasp the strength of concrete, after placing it, in early age.

It has been difficult to estimate the strength, in early age, accurately for it was effected by the amount of regulated set cement concrete, the placing temperature, the outside air temperature, and the amount of concrete for placing.

Therefore, this research's aim is to estimate the strength of the regulated set cement concrete for emergency works in early age accurately.

When in emergency works, generally high-range water-reducing agent is used as rich mixture to generate strength in short period of time (For instance, in pavement work, about 250kgf/cm^2 of compressive strength in 3~4 hours of aging.) Therefore, the concrete used in this research are all object to concrete with high-range water-reducing agent added.

The research is outlined as follow:

1) It is to prove the practicability of application of the relationship, of the cumulative temperature and the strength, to the concrete at the site. The concrete that was applicated in the site, was cylindrical specimen (ϕ 10×20cm) made during a replacing of flooring system work of a bridge, cured in three methods near the flooring.

2) It is estimation of the adiabatic temperature-rise curve. To calculate the temperature of the member section, first must estimate the adiabatic temperature-rise curve. Here the author performed an analysis, of the experimental data from the research carried out by Oshio[4] et al., about the exothermic character of regulated set cement concrete; and to practical factors, it was shown into drawings and charts.

3) It is estimation of the temperature-rise after concrete is placed by the Schmidt method[5], which is said the estimation to be quite accurate; and calculate by the adiabatic temperature-rise attained in research 2), and considering the temperature cooling down by heat radiation. The model assuming here is the width of flooring system's repairing work.

4) Is to search the strength of the concrete in optional ages, using standard cumulative temperature (when amount of cement 400kg/m^3, placing temperature 20℃, placing height 10cm.) When the estimated temperature curve of the concrete is attained, by Schmidt method, than by this attain cumulative

temperature. The strength in optional ages are estimated from combining the relation of cumulative temperature and strength attained in research 1).

5) Is to be able to attain the strength of the concrete, when amount of cement, placing temperature, and placing amount are optional. A method to multiply the compensation factor to the standard cumulative temperature, is developed.

6) It is to prove the effect of the strength, when the model is different. In this research, the models to estimate the strength of the concrete are heat isolated in four surface and heat radiating in two, for these are assumed as the flooring system, of the highway bridge's repairing work. Further more we prepared rather larger member models with five surface heat isolated and one surface heat radiating, to compare with the two surface heat radiating model, and to perform comparison and examination of the difference in strength.

7) It is to prove the limit of reliability, of the strength estimating method, proposed by this research, by using statistical method. Also the regulated set cement concrete's stiffness is effected by amount of cement, temperature (placing temperature, outside air temperature), amount of placing and other factors, but it is effected largely by the temperature. So we proved how the temperature effect upon the strength, using the strength estimating method.

2. The application of cumulative temperature and strength's formula for the concrete at the site.

(1) The calculation of conditions and cumulative temperature of the concrete at the site.

In December of 1983, the company Onoda performed the Owari Bridge's flooring replacement work as emergency paving work. On that occasion, the company placed cylindrical specimens, $\phi 10\times 20$cm in size, near the site of flooring system, and performed three types of curing as below.

a. Outer air curing; specimen, $\phi 10\times 20$cm in size, cured in outer air.

b. Insulated curing; specimen, $\phi 10\times 20$cm in size, cured inside a carton filled with glass wool.

c. Heated curing; specimen, $\phi 10\times 20$cm in size, cured on a insulation mat and by heat wave, as same as the flooring system.

Further more, placed thermocouple to each specimen's center and measured the temperature hysteresis by thermograph.

Fig.-1 show the temperature of the specimen's center and the age strength of time of all curing method.

The mix proportion of concrete this time was, slump 12 ± 2.5cm, W/C=37%, s/a=38%, C=400kg/m^3, S=707kg/m^3, G=1177kg/m^3, water reducing agent: MT−150 (C×2.0%), retarder: C×0.1%.

Measured the area from Fig.-1 by planimeter and, set 10℃ as the standard and calculated the cumulative temperature. Each cumulative temperatures are, 3h outer air curing: 53℃·h, 3h insulated curing: 80℃·h, 5h outer air curing: 91℃·h, 5h heated curing: 100℃·h, 5h insulated curing: 145℃·h.

(2) Applying cumulative temperature and strength to the formula.

When plotting, on cumulative temperature and compressive strength's graph, it is shown as the Fig.-2. The mixture author used in the laboratory (C=400kg/m^3, W/C=37%) is different from the concrete mixture (C=400kg/m^3, W/C=37%) used at the work site, but it shows that cumulative temperature and strength's graph is quite effective in estimating the strength of the concrete at the site.

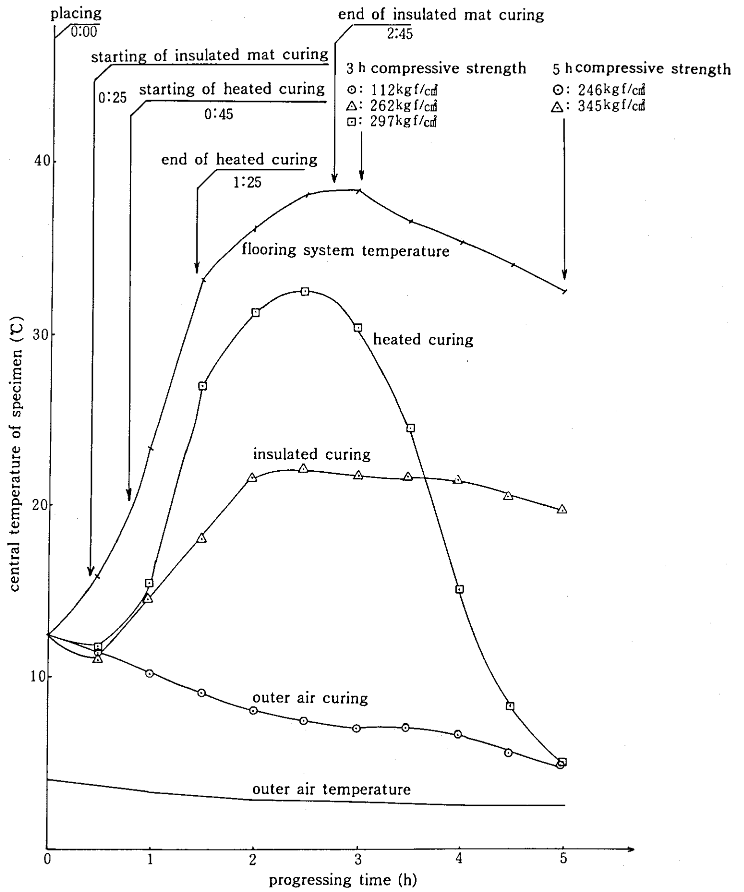


Fig.-1 Specimen's central temperature and strength of time aging in various curing method

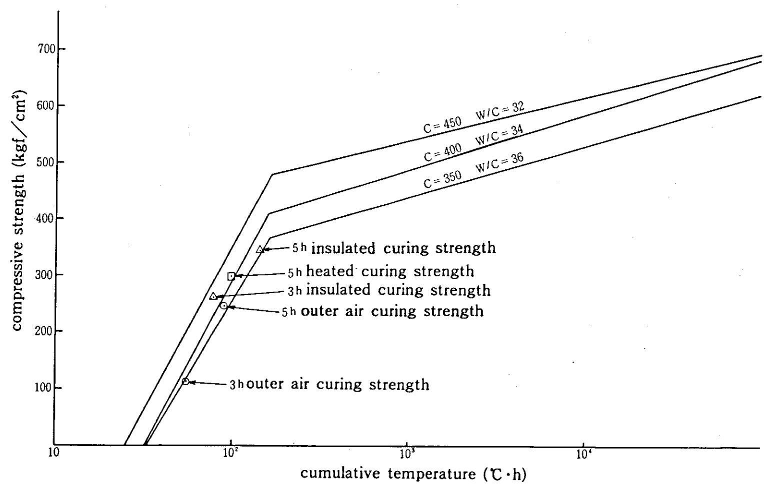


Fig.-2 Cumulative temperature and compressive strength of concrete at site

3. The estimating method of the adiabatic temperature-rise curve

To calculate the temperature-rise of the measure section, after placing the concrete, first must estimate the adiabatic temperature-rise curve. To estimate the adiabatic temperature-rise curve, we used the measured values, resulted from adiabatic temperature-rise experiment performed by Ohshio[4] et al. We used same analysis method as Ohshio to analyse. From Ohshio's research, the regulated set cement concrete's adiabatic temperature-rise curve is difficult to denote, by using one of the usual exponent functional formula; it is better to perform regression, by exponent functional formula [(1) and (3)] shown in following formula, and line formula (2) connected by inflection point A, B, as shown in Fig.-3.

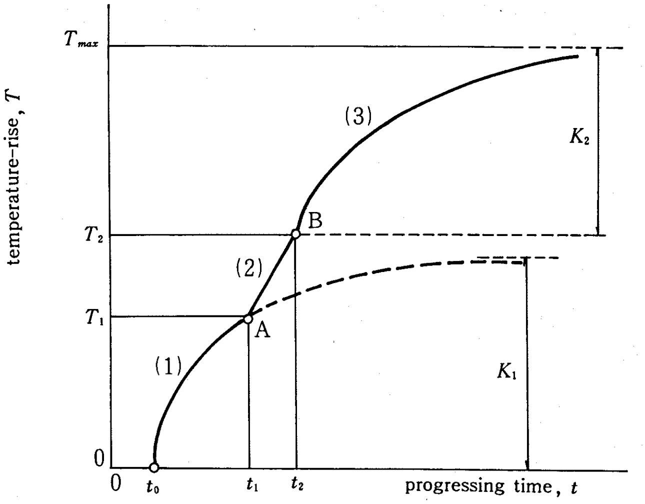


Fig.-3 Model drawing of regression formula for adiabatic temperature-rise[4]

$t_0 \leqq t < t_1$

$$T = K_1(1 - e^{-B_1(t-t_0)}) \quad \cdots\cdots (1)$$

$t_1 \leqq t < t_2$

$$T = \frac{T_2 - T_1}{t_2 - t_1}(t - t_1) + T_1 \quad \cdots\cdots (2)$$

$t \geqq t_2$

$$T = K_2(1 - e^{-B_2(t-t_2)}) + T_2 \quad \cdots\cdots (3)$$

Insert;
T: Temperature-rise (℃)
t_0: Starting time delay of exothermic (h)
t_1, t_2: Time difference of inflection point A, B (h)
T_1,T_2: Temperature difference of inflection point A, B (℃)
K_1,K_2: Convergence value of exponent formula (1), (3) (℃)
B_1, B_2: Exponent section of exponent formula (1), (3)
T_{max}: Ending value of adiabatic temperature-rise (℃$=T_2+K_2$)[4]

Regression was done in following procedure, by the least square multiplication. That is, the condition of formula (1), and formula (2) that makes formula (4) the least are;

$$S = \frac{1}{n}\sum_{i=1}^{n}[T_i - K(1 - e^{-Bt_i})]^2 \quad \cdots\cdots (4)$$

T_1, and T_2, as shown in Fig.-3, are the temperature of exponent functional formula's ending and starting point, so there is no need to find it for K and B. So it is not included in formula (4). Also $(t-t_0)$, and $(t-t_2)$ are replaced as t_i in formula (1) and formula (2).

When finding K as $\frac{\partial S}{\partial K}=0$, than becomes formula (5).

$$K=\frac{\sum_{i=1}^{n} T_i(1-e^{-Bt_i})}{\sum_{i=1}^{n}(1-e^{-Bt_i})^2} \quad \cdots\cdots (5)$$

On the other hand, substituting the formula obtained by $\frac{\partial S}{\partial B}=0$ into formula (4), formula (6) is obtained.

Insert data T_i, and t_i into formula (5), and (6), and find B and K[4),6)]. This time the number of data n was 16.

$$\sum_{i=1}^{n}(1-e^{-Bt_i})^2\cdot\sum_{i=1}^{n} T_i\cdot t_i e^{-Bt_i}-\sum_{i=1}^{n} T_i(1-e^{-Bt_i}) \cdot\sum_{i=1}^{n} t_i e^{-Bt_i}\cdot(1-e^{-Bt_i})=0 \quad \cdots\cdots (6)$$

Fig.-4 is the value of t_1, t_2, and T_2, obtained by dividing adiabatic temperature-rise curve when placing temperature is 20℃ into formula (1), formula (2), and formula (3) parts, like in Fig.-3. From experiment t_0 was zero, and the value of T_1 is obtained by inserting t_1 to formula (1), to estimate the adiabatic temperature-rise formula of regulated set cement concrete, so they were not shown in Fig.-4. Fig.-5 in the value of, K_1, K_2, B_1, and B_2, which was found by values of Fig.-4 in the regression formula. Fig.-6 and Fig.-7 shows the graph of calculation of X_i/X_{0i}, in each placing temperature, substituting X_{0i} as the factors in placing temperature, and X_i as the factors in each placing temperature. Therefore, it can be estimated, when the adiabatic temperature-rise formula of regulated set cement concrete of fixed amount of unit cement and placing temperature, is within unit cements 300～500kg/m³, and placing temperature 5～30℃, when multiplying the factors of Fig.-4 and Fig.-5 to the percentage of Fig.-6 and Fig.-7 and compensated.

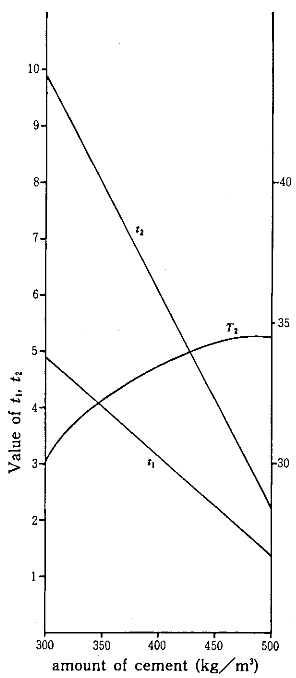


Fig.-4 Value of t_1, t_2, and T_2

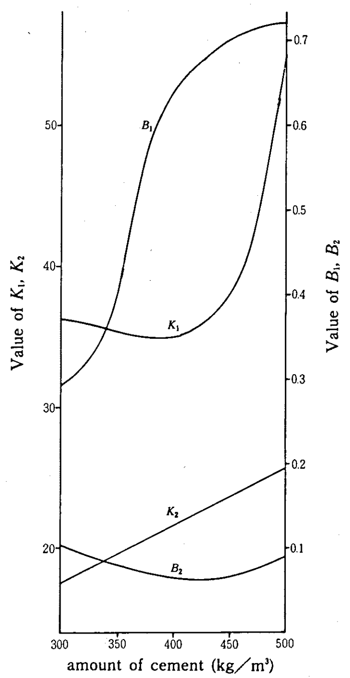


Fig.-5 Value of K_1, K_2, and B_1, B_2

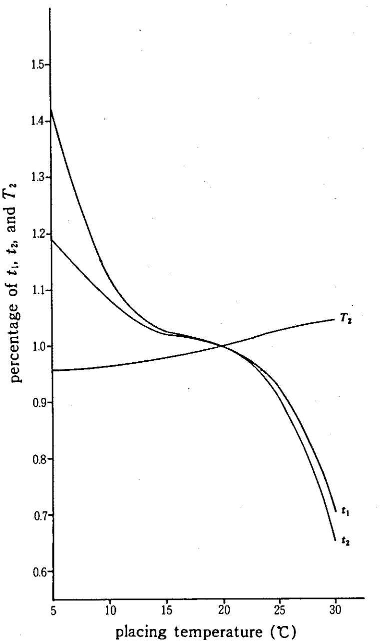


Fig.-6 Correction of t_1, t_2, and T_2

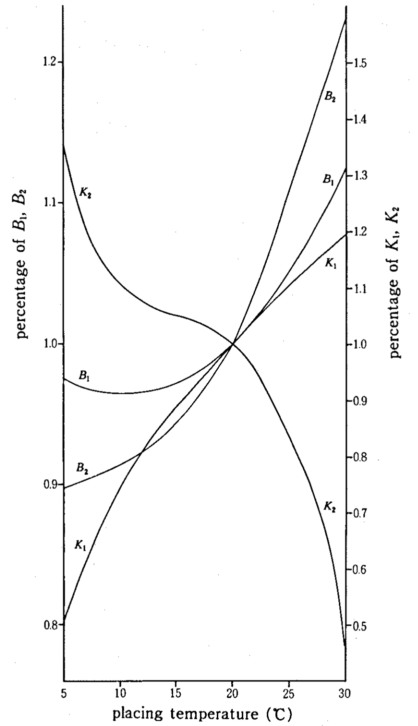


Fig.-7 Correction of K_1, K_2, and B_1, B_2

4. Temperature estimating method of concrete's inner side using Schmidt method

There are many ways in estimating the temperature of measure, but we will use Schmidt method, for it is quite accurate and it is normally used in practical usage.

Schmidt method can be used in 3-dimensional flow of heat, but here a brief interpretation of the principal in 1-dimension will be introduced. For real structures, it equivalent to slub structure that releases heat only from top and bottom surfaces, and walls that releases heat only from inner side and outer surfaces.

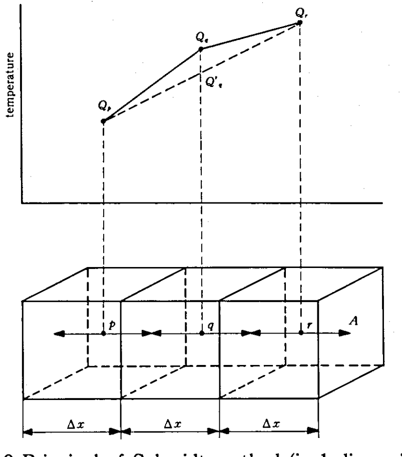


Fig.-8 Principal of Schmidt method (in 1 dimension)[5]

Now, considering a long thin concrete bar (surface area A) as show in Fig.-8 and that heat only flows into axle direction. Dividing the bar into length of Δx, and consuming the three blocks as p, q, r, and the temperature as Q_p, Q_q, Q_r, then temperature-rise of q after Δt time; the ΔQ_q are shown as formula (7).

$$\Delta Q_q=\frac{a\cdot\Delta t}{(\Delta x)^2}(Q_p+Q_r-2Q_q) \cdots\cdots (7)$$

Insert;
a: Heat diffusion coefficient (m^2/day)
Δt: Time of next step (day)
Δx: Space between measures (m)

Therefore, temperature Q'_q, of point q after Δt time, is as shown in formula (8), adding Q_q to ΔQ_q.

$$Q'_q=Q_q+\Delta Q_q=Q_q+\frac{a\cdot\Delta t}{(\Delta x)^2}(Q_p+Q_r-2Q_q) \cdots\cdots (8)$$

If, Δx, Δt (a is constant) that satisfies the formula (9) are selected than formula (8) will be shown as formula (10).

$$\frac{a\cdot\Delta t}{(\Delta x)^2}=\frac{1}{2} \cdots\cdots (9)$$

$$Q'_q=Q_q+\frac{1}{2}(Q_p+Q_r-2Q_q)=\frac{1}{2}(Q_p+Q_r) \cdots\cdots (10)$$

That is, for formula (10), the average value of the two point's temperature is equal, to the midpoint of the temperature after Δt time (but $\Delta t=(\Delta x)^2/2a$).

Therefore, to obtain the temperature-rise of concrete measure, after placing the concrete is to, fix the initial conditions and boundary conditions, find formula (10)'s Q'_q, then add adiabatic temperature-rise increment in Δt time, and heat distributions of passing time's sequential numeric calculation can be obtained. This is the Schmidt method[5),7)].

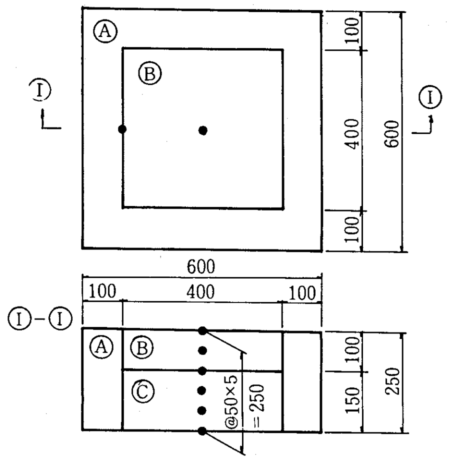
5. Temperature estimation method of inner concrete of the model exercise

When adiabatic temperature-rise curve is obtained by 3. than perform the estimation of the concrete's inner temperature, supposing the emergency repair work.

Models are heat isolated in four surfaces, 10cm in width of regulated set cement concrete construction joint added, and to radiate the heat from top and bottom surface, supposing to perform repair work for addition of width, to an already built flooring system of a highway bridge, as Fig.-9 shows.

For temperature estimation of the measure, analyse by Schmidt method using the following conditions.
(i) Initial condition
time=0, concrete temperature=placing temperature
(ii) Boundary condition
(I) Outer air temperature and placing temperature are equal.
(II) Considering the surface temperature being higher than outer air, obtain the surface temperature, as the width H, found by the following formula, is added[7)].

$$H=\frac{\lambda_c}{\alpha}=0.2\ \mathrm{m}$$



Ⓐ; insulation (styrene foam)
Ⓑ ; regulated set cement concrete
Ⓒ ; ordinary cement concrete
● ; termocouple

Fig.-9 Sizes and from of specimens used in model experiment (two surface radiation type)

Insert; λ_c: Heat conductivity of concrete (2.0kcal／m·h·℃)
α: Heat conductivity of air (10kcal／m^2·h·℃)

(III) The adiabatic temperature-rise of the construction joint is half of the placing parts.
(IV) There is no adiabatic temperature-rise at the surface.
(V) Heat conductivity of regulated set cement concrete and ordinary cement concrete are both 0.083m^2／day.

The result of these analysis are the Fig.-10.

Fig.-10 is the temperature hysteresis after placing the concrete, amount of unit cement 400kg／m^3, and placing temperature about 20℃. Full lines are the observation temperature from the surface of concrete, and broken lines illustrates the value estimated by calculating the Schmidt method.

From this, temperature hysteresis of new concrete's center (5cm from the top surface) reaching the maximum temperature, is just about the estimated value. But, the temperature of observation value declining after the maximum temperature was conformed much faster. Also, there seem to be a difference in temperature hysteresis, when reaching the maximum temperature, at the boundary surface of the old concrete, but it is confirmed that after reaching the maximum temperature, it fits the estimated value.

The time it takes for observation value to reach the maximum temperature is faster in both concrete center and boundary surface. From this, the exothermic of regulated set cement concrete, is a phenomenon, of very short period of time.

When performing the Schmidt method, the adiabatic temperature-rise curve differs a little by choosing, boundary condition Δx or virtual width.

For models this time, chose the value closest to the observation value as possible, so Δx=2.5cm and virtual width H=0.2m.

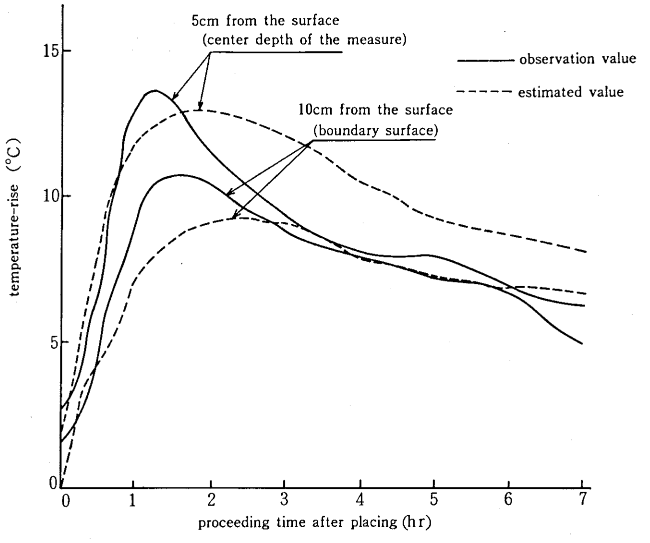


Fig.-10 Time changing of inner measure

6. Strength estimating method using temperature estimating curve

(1) Strength estimation of placing concrete's center depth

To obtain the average strength of the placing concrete, here we will use the temperature estimating curve of center depth. Using Schmidt method in 5., have obtained temperature estimating curve, placing temperature 20℃, amount of cement 400kg/m³, in the center depth (5cm from the surface) as standard to calculate the cumulative temperature in each time age. And when placing the approximate line, of regulated set cement concrete's cumulative temperature and strength's relationship together, it becomes Fig.-11. From this figure, the estimating of strength of arbitrary measure when placing temperature is 20℃ and amount of cement is 400kg/m³.

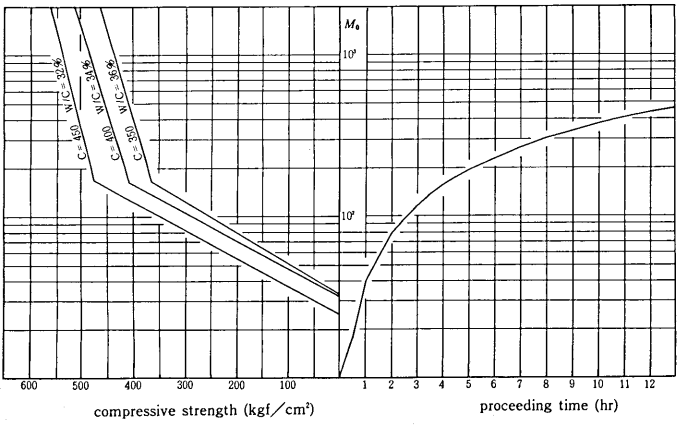


Fig.-11 Strength estimation in arbitrary ages

(2) Corrections when amount of cement, placing temperature, and placing height, differs

When the amount of cement and placing temperature differs from above (standard), perform corrections to Fig.-4 and Fig.-7, and obtain the adiabatic temperature-rise curve, and from using Schmidt method, draw out temperature estimating curve, and find cumulative temperature M. When cumulative temperature M is found set M_0 as standard cumulative temperature (amount of cement 400kg/m³, placing temperature 20℃, placing height 10cm), calculate $M/M_0=\alpha$ for every placing temperature's each time age. Fig.-12 illustrates the calculation when amount of cement was 450kg/m³.

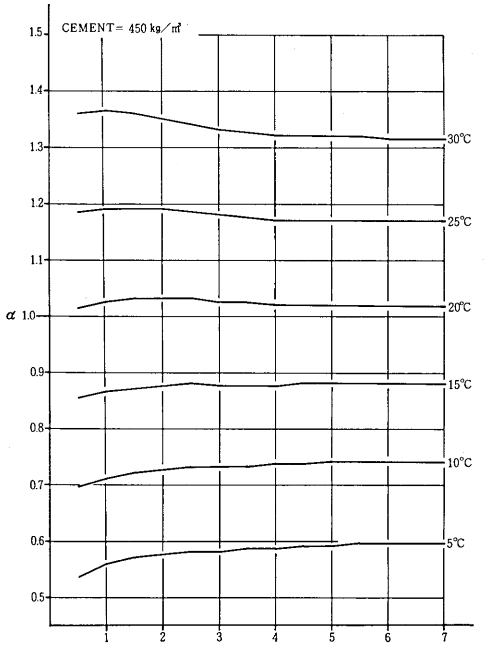


Fig.-12 Corrected factor α for cement amount and placing temperature (M/M_0)

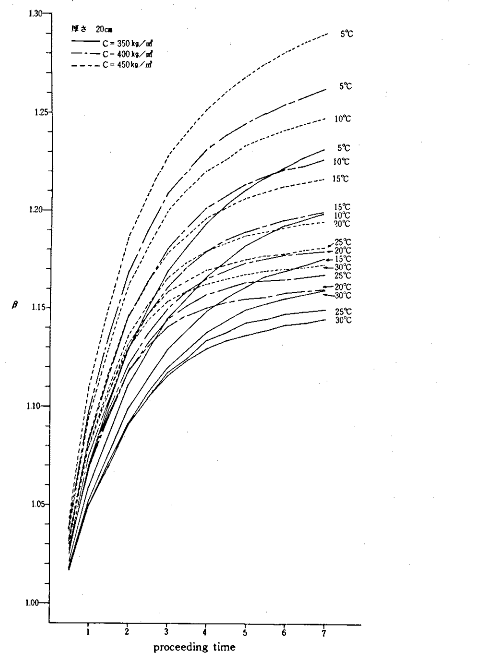


Fig.-13 Corrected factor β for placing height (M_p/M_q)

Also, when the placing height differs, obtain the temperature estimating curve of 5cm, 10cm, 15cm, and 20cm, using Schmidt method.

When estimating curve is obtained, than calculate the cumulative temperature for each time age and substitute the value attained to M_p. Next, substitute the cumulative temperature of the above calculation value's placing height 10cm to M_q and $M_p/M_q=\beta$ illustrated as placing height 20cm is Fig.-13.

Therefore, when α and β is multiplied to standard cumulative temperature M_0, it is possible to correct the arbituary amount of cement and height of placing, and obtain the strength of concrete in arbituary ages by Fig.-11.

(3) The relation of temperature (placing temperature and outer air temperature), and strength

When it is two surface heat radiating, and the placing height is 10cm, illustrate the relation of temperature and compressive strength on Fig.-14. It is the compressive strength of each temperature, when cement amount is 350kg/m³, 400kg/m³, and 450kg/m³ the ages are 3 hour, and 5 hour.

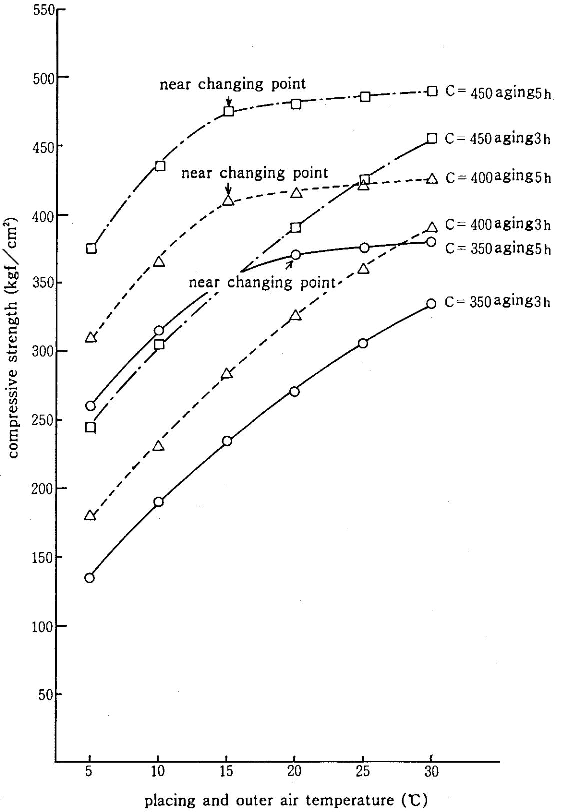


Fig.-14 Relation of temperature and compressive strength when two surface radiation and placing height is 10cm

The changing point of Fig.-14 is, as illustrated in Fig.-2, the regulated set cement concrete in relation to cumulative temperature and compressive strength, and when changing the cumulative temperature to logarithm, near cumulative temperature point 150℃·h, a point that changes the strength appearing slope was recognized and this is called the changing point. This occurs, when during the time of the formation of the hydration material, in regulated set cement.

From Fig.-14 we can see, that effect of the temperature to the strength is quite large. Till the changing point, strength increases rapidly with temperature, and after the changing point, the level of strength increase to temperature increase is in slow moving.

By the way, in a case when cement amount is 400kg/m^3 and aging for 5 hours, the strength difference of 100kgf/cm^2 to temperature difference of 10℃ in 5℃～15℃ (near changing point, cumulative temperature 165℃·h, to the strength of only 15kgf/cm^2 to temperature difference of 15℃ in 15℃～30℃.

Understanding from this, is the regulated set cement concrete receives great effect from the temperature before reaching the changing point, so when aiming for early strength at 3 to 5 hours of aging, than temperature management becomes very important.

(4) In comparison with the different model (one surface heat radiating type)

As illustrated in Fig.-15, the model is supposing relatively bigger measure, heat isolated in five surface, and radiating heat only from one surface, of 40cm thick regulated set cement concrete. analysis of temperature estimating curve is as show in Fig.-16. Full lines are the values Ohshio et al. observation by thermocouple, and broken lines are the estimated values calculated by the author using the Schmidt method. You can see that the observation values and estimations value is more approximate in this model to two surface radiating type.

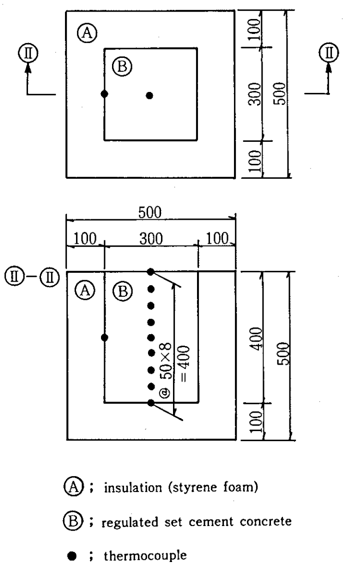


Fig.-15 Sizes and form of specimens used in model experiment (one surface radiation type)[5]

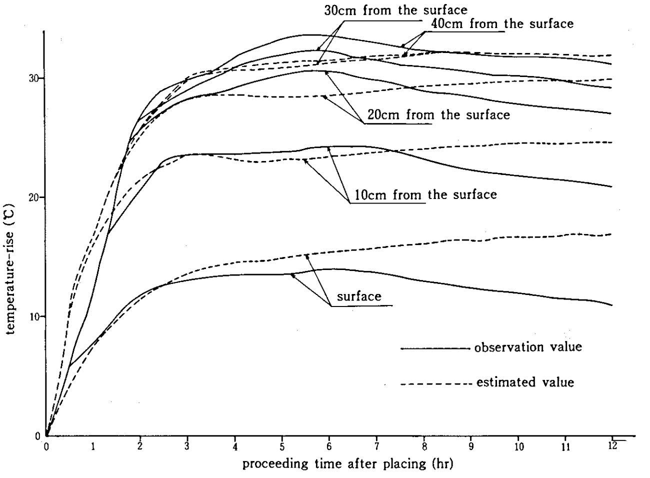


Fig.-16 Time changing of inner measure (one surface radiation type)

Here we would like to analyse the effect of one and two surface radiating to the strength. When calculating the cumulative temperature 5cm from the surface, in every time age, and done like in two surface radiation, the placing temperature 20℃ and the cement amount 400kg／m³, it will be like Fig.-17. Then, after 3 hours (before changing point) and after 5 hours (after changing point), check the strength according to the Fig.-17. Compared to the one surface radiation type's strength 380kgf／cm², after aging for 3 hours, to two surface type, 320kgf／cm²; the difference is 60kgf／cm². For 5 hour aging, after the changing point, one surface radiation type's strength is 430kgf／cm² to two surface type which is 415kgf／cm², and difference is 15kgf／cm².

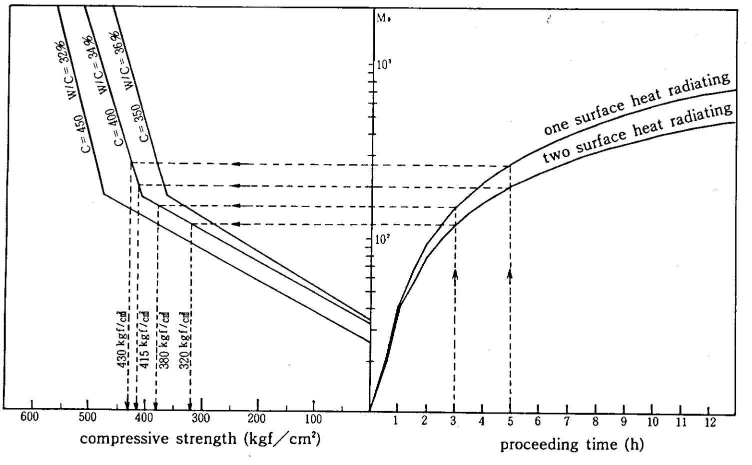


Fig.-17 Comparison of strength of one surfaced radiation type and two surfaced type

Therefore, one surface radiation type is higher in strength than two surface radiation type by about 20% in 3 hours aging, and about 5% in 5 hours aging.

(5) Reliability of strength estimating method

The reliability of strength estimating method of the two surface radiated model type will be analysed.

Cumulative temperature is obtained by the temperature estimating curve founded by a Schmidt method. So it might differ a little from the cumulative temperature obtained by the inner temperature of the concrete. We researched how this difference shows up on the strength.

Fig.-18 is the value of compressive strength obtained by cumulative temperature of the observation value and estimation value of two surface radiation type aforesaid (look up Fig.-10). Significant from Fig.-18, there are almost no difference between the observation value and the estimation value of two surface radiating model type.

From this, it has been confirmed that obtaining cumulative temperature from estimation value is quite accurate. Next we would like to write about the effect, by the difference of the depth direction, 5cm from the surface (center depth of the measure), and 10cm from the surface (boundary surface to the old concrete), on the strength. Different initials of temperature hysteresis, that is to say, the strength of the boundary surface drops about 20kgf／cm²～25kgf／cm² after one or two hours of the placing, but as the time passes difference to the center section cannot be recognized, and after 7 hours it is almost equal.

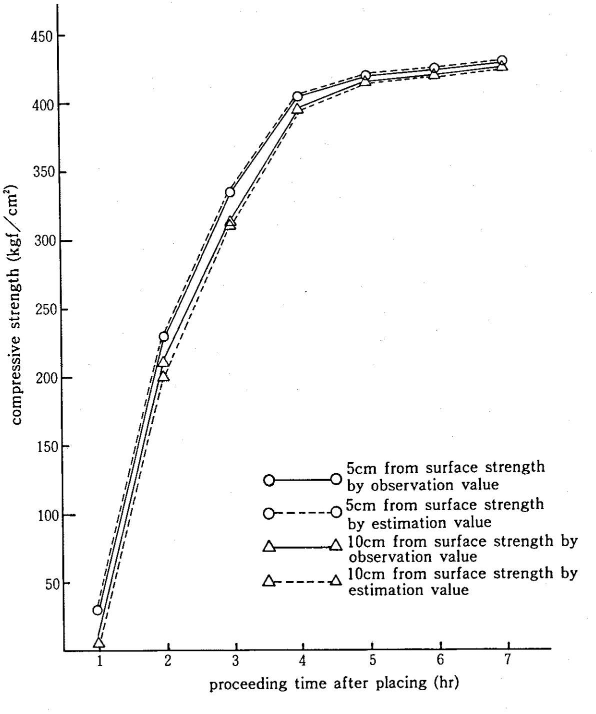


Fig.-18 Compressive strength obtained by observation and estimation value of cumulative temperature

Also, in Fig.-11, when estimating strength from cumulative temperature, there are needs to in clarifying this regression line's level of reliability. Here we obtained 90% of reliable section of the regression line using statistic method[8]. In Table-1, 90% of reliable section of average cumulative temperature $\overline{M}$ is obtained. Before the changing point ($0<M<150$℃·h), and after the changing point (150℃·h$<M<$20, 160℃·h), have been divided and calculated. From this chart, the error of the upper and lower end, of the 90% reliable section, are only 10% so this is considered quite reliable.

Table-1 Reliable section of average cumulative temperature $\overline{M}$

types of concrete	section	average cumulative temperature $\overline{M}$ (℃·h)	reliable section (kgf/cm²)	* error (%)
C=350	0<M< 150	68.8	σ=170.1±17.2	10.1
	150<M<20160	4208.5	σ=495.6±11.9	2.4
C=400	0<M< 150	67.8	σ=190.8±16.3	8.5
	150<M<20160	3842.1	σ=547.0± 7.4	1.4
C=450	0<M< 150	67.9	σ=254.0±24.3	9.6
	150<M<20160	4580.7	σ=593.1±12.1	2.0

*The error of the upper and lower end, of the 90% reliable section

(6) One example of strength estimating method for regulated set cement concrete

Will explain by strength estimating method of measure centering, as an example two surface radiator type with cement amount, placing temperature, and placing height different from the standard.

Conditions of the example are as follows.
cement amount 450kgf/m^3
placing temperature 10℃
placing width 20cm
estimation of the strength 5 hours after placing

First, read out standard cumulative temperature M_0 of 5 hours from placing in Fig.-11. For this M_0 is read 190℃·h.

Next, find the corrected factors α of cement 450kg/m^3, and placing temperature 10℃, from Fig.-12. For this α is 0.74. For last, find the corrected factor β of placing height from Fig.-13 which is $\beta = 1.23$. So the cumulative temperature M is

$$M = M_0 \cdot \alpha \cdot \beta = 190 \times 0.74 \times 1.23 = 172.9 \ (°C \cdot h)$$

When the cumulative temperature $(M) = 172.9$ (℃·h) of after 5 hours has been found, than from Fig-11, the compressive strength is estimated as 470kgf/cm^2, by the intersection of $M = 172.9$ (℃·h) and strength estimating curve of cement amount 450kg/cm^3.

7. Conclusion

What is demanded, when using regulated set cement concrete for emergency work, is to know the strength, in short aging, accurately after concrete is placed. To do so, we conceived strength estimating method, using exothermic character of regulated set cement concrete, and cleared the following matters.
matters.

(1) When using, the formula of cumulative temperature and strength to concrete at the site, it is very approximate, even though curing is different, like insulating and performing outer air curing at the site, so to estimate the site strength, using cumulative temperature and strength's relation is quite effective.

(2) When simulating a thickening of built flooring system, at highway bridge's emergency repair work. The inner temperature of the concrete was estimated by Schmidt method, in model experiment. From the result there was a difference to the observation value. But, calculating the cumulative temperature of the concrete's center, using the estimated value, the error to the observation value only 3.7%, 7 hours after placing. So finding the cumulative temperature by temperature estimating curve obtained by Schmidt method, is quite accurate.

(3) When performing thickening of built flooring system, like in (2), we have conceived a method to estimate the compressive strength of arbitrary age when placing new concrete. The proceedure are 1) find the standard cumulative temperature M_0 of the arbitrary age, 2) find the corrected factor α of cement amount and placing temperature, 3) find the corrected factor β of placing height, 4) multiply α and β to M_0 and calculate the cumulative temperature of arbitrary age, and obtain the estimate compressive strength. Performing in this way, the compressive strength of arbitrary age can be easily obtained. To make this more practical, we made graphs of 1)~4) and made it possible to read out of it.

(4) The effect of temperature (placing temperature, outer air temperature) to the strength of regulated set cement concrete, is large till the changing point, and small after it. So, when aiming for early aging at like 3 hours aging and 5 hours, the management of the temperature become very important.

(5) We performed a comparison of two surface radiating type and one surface radiating type's strength when the cement amount is 400kg/m^3, and the placing and outer air temperature are 20℃. Result was that, one surfaced type was 20% higher in 3 hours aging (before changing point) and 5% higher in 5 hours aging (after changing point) than two surfaced type.

(6) We analysed the reliability of the strength estimating method we conceived by statistic method. From this result when estimating the strength by cumulative temperature, as shown in Table-1; the error of the upper and lower end, of the 90% of the reliable section, by the average cumulative temperature $\overline{M}$, before and after the changing point is 10% so, it could be said quite reliable.

This research paper, is a part of academic dissertation[9], of one of the author Kiyomi Nakashima, when he received the doctor's degree in engineering from Tokyo Univ., January 16, 1987.

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